SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation

UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes

VOLUME I: SOURCES

UNITED NATIONS
New York, 2000

NOTE

The report of the Committee without its annexes appears as Official Records of the General Assembly, Fifty-fifth Session, Supplement No. 46 (A/55/46).

The designation employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The country names used in this document are, in most cases, those that were in use at the time the data were collected or the text prepared. In other cases, however, the names have been updated, where this was possible and appropriate, to reflect political changes.

UNITED NATIONS PUBLICATION
Sales No. E.00.IX.3
ISBN 92-1-142238-8

ANNEX D

Medical radiation exposures

CONTENTS

Page

INTRODUCTION

1. Over the last 100 years, ionizing radiation has been increasingly applied in medicine and is now firmly established as an essential tool for diagnosis and therapy. The overwhelming benefits accruing to patients from properly conducted procedures have fostered the widespread practice of medical radiology [A22], with the result that medical radiation exposures have become an important component of the total radiation exposure of populations.

2. Since beginning its work in 1955, the Committee has regularly monitored the medical uses of radiation as part of its continuing review of sources of exposure. The most recent analysis, included in the UNSCEAR 1993 Report [U3], covered the period 1985–1990, but information available since 1970 was cited in order to investigate trends in usage and doses. The Committee concluded that medical applications are the largest man-made source of radiation exposure for the world's population, although there was still a far from equitable distribution of medical radiation services in different countries with different levels of health care; whereas the 1993 worldwide estimate for the annual per caput dose from diagnostic examinations was 0.3 mSv, corresponding average values for countries of the upper and lower health-care levels were 1.1 mSv and 0.05 mSv, respectively. A century after Röntgen's seminal discovery of x rays, some two thirds of the world's population still lacks adequate diagnostic imaging and radiation therapy services [W12].

3. The Committee also concluded that population exposures from the diagnostic and therapeutic uses of ionizing radiation were likely to be increasing worldwide, particularly in countries where medical services are in the earlier stages of development [U3]. However, further and more comprehensive analyses would be required in order to refine global estimates and establish important trends.

4. The need for such analysis is heightened by a number of underlying factors that could affect the practice of radiology, in terms of both the type and frequency of procedures carried out and the associated levels of dose to individual patients [S60]. For example, population growth, urbanization, and longer lifespans can be expected to result in growing demands for medical radiology [U3]. Conversely, as a general trend some reductions in dose can be expected to arise from continuing advances in the technology for ionizing radiation and its substitution by non-ionizing radiations, more widespread and formalized implementation of quality assurance procedures in radiology departments, better training of staff involved in medical radiology [I2], and more rigorous standards for patient protection [I3, I5, I17].

5. Accordingly, this Annex presents the results of an updated, broad review of medical radiation exposures. Its purpose is to provide new qualitative and quantitative information on the frequencies and doses for diagnostic and therapeutic procedures, to assess medical radiation exposures worldwide, to make comparisons with data from previous reviews, and to explore temporal or regional trends in the practice of medical radiology. Although the review is not intended as a means to optimize procedures or as a guideline for radiation protection, it will nevertheless provide the background for such work.

I. SCOPE AND BASIS FOR THE ANALYSIS

A. MEDICAL RADIATION PROCEDURES

6. This Annex is principally concerned with exposures received by patients from the use of radiation generators or radionuclides as part of their diagnosis or treatment (Chapters II–V). Medical exposures are also conducted for medico-legal reasons and on volunteers (patients or healthy persons) for the purposes of research; this latter category of exposures is considered in Chapter VI. The information on patient exposures reported for different types of procedure in various countries is assumed to reflect routine practice, although a brief discussion of radiation incidents in medicine is included in Chapter VII for the purpose of illustration. Exposures received by medical staff from medical radiology are discussed elsewhere, in Annex E, "*Occupational radiation exposures*". Exposures of the general public arising from contact with patients undergoing therapy with sealed or unsealed radio-nuclides, the disposal of radioactive waste from hospitals, and the production of radionuclides for medicine are considered in Annex C, "*Exposures to the public from man-made sources of radiation*".

7. Diagnostic procedures, in particular the widespread use of x rays, are the most common application of radiation in medicine. The range of x-ray techniques used, such as radiography, fluoroscopy, computed tomography, interventional radiology, and bone densitometry, are discussed in Chapter II. There is also significant practice in imaging and other functional studies involving administrations to patients of unsealed radionuclides; these uses are described in Chapter III. Such nuclear medicine and x-ray procedures are intended to provide doctors with diagnostic information and in principle are conducted with the lowest practicable levels of patient dose to meet clinical objectives [M39, S54].

8. In contrast, therapeutic exposures are less frequent and the levels of dose are very much higher in view of the quite different purpose. Radiotherapy is used mainly for the treatment of cancer, where the intention is to deliver a lethal dose to malignant tissue within a well-defined target volume, while minimizing the irradiation of surrounding healthy tissue. Many patients receiving radiotherapy have a limited life expectancy owing to their age or disease. Treatments are most often carried out using radiation generators and sealed radionuclide sources. Teletherapy and brachytherapy techniques are considered in Chapter IV. A small amount of therapy practice involves the administration of unsealed radionuclides, and this technique is discussed in Chapter V.

9. In addition to diagnostic imaging or therapy, there are also some other applications of ionizing radiation for tissue analysis in the clinical assessment of health or disease, mostly in the course of research projects. For example, *in vivo* neutron activation analysis, based on the detection of characteristic gamma rays produced by the interaction of neutrons within the body, has been used to measure calcium, nitrogen, and cadmium, with whole-body doses up to 10 mSv [C12, S28]. Also, x-ray fluorescence techniques have been used for *in vivo* measurements of iodine, lead, and cadmium [C12]. However, such exposures are not a widespread practice and are not considered further in this review.

B. SOURCES OF DATA

10. The broad characterization of practice in medical radiology requires a knowledge of the frequency of each type of procedure and the associated levels of patient dose. To be able to provide as complete an assessment as possible of global practice in medical radiology, the Committee conducted a worldwide survey of medical radiation usage and exposures by means of a widely distributed questionnaire soliciting systematic information for the years 1991–1996. This Annex summarizes all data submitted to the Committee up to the end of 1999. The questionnaire was similar to that employed for the previous review [U3], although the format was revised to improve the quality and utility of the data collected. Information was sought on national facilities for radiological examinations and treatments, together with specific data for important types of procedure: annual numbers of procedures, age and sex distributions of patients, and representative doses. Respondents to the UNSCEAR Survey of Medical Radiation Usage and Exposures are listed in the References, Part A.

11. The availability of detailed national data on medical radiology practice varies considerably even in developed countries. For example, periodic surveys of national practice are conducted in some countries (see, *inter alia*, [O6, S61, S62, S63, T16, Z17]). The information on, say, frequency and dose provided to the Committee in the present survey was therefore often based on limited data from a particular region or even an individual hospital; these data were then assumed, with appropriate scaling, to be representative of the entire country. When known, such instances of extrapolation are generally identified in the footnotes to the tables. The interpretation of non-standard or incomplete dosimetric information provided in the questionnaires is discussed in detail in the appropriate Sections below.

12. The valuable information provided by responses to the UNSCEAR Survey of Medical Radiation Usage and Exposures has been supplemented by selected data from publications following an extensive review of the literature. These are used in particular when discussing specific practices and illustrating trends.

C. DOSIMETRIC ASPECTS

13. Medical exposures to individual patients are summarized most completely in terms of the absorbed dose to each organ or tissue of the body, although this approach is often difficult to realize in practice, particularly for any large-scale dose survey. Weighted-organ dose quantities, such as effective dose equivalent [I7] and effective dose [I3], represent convenient indicators of overall exposure in the assessment of diagnostic practice (see, for example, [M33, O6]). They broadly reflect in a qualitative manner the risks to health of the stochastic (though not deterministic) effects associated with exposure to ionizing radiation. The Committee has previously used such quantities to evaluate patient doses [U3, U4, U6], with the express purpose of allowing a robust comparison of practice between, *inter alia*, types of procedure, countries, health-care levels, time periods, and sources of radiation.

14. However, the Committee has always indicated most strongly that these effective doses should not be used directly for estimating detriment (to individuals or populations) from medical exposures by application, for example, of the nominal fatality probability coefficients given by ICRP [I3]. Such assessments would be inappropriate and serve no purpose in view of the uncertainties arising from potential demographic differences (in terms of health status, age, and sex) between particular populations of patients and those general populations for whom the ICRP derived the risk coefficients. It has been suggested, for example, that effective dose could broadly underestimate the detriment from diagnostic exposures of young patients by a factor of about 2 and, conversely, could overestimate the detriment from the exposure of old patients by a factor of at least 5 [N1]. The analysis of radiation risk from diagnostic medical exposures requires detailed knowledge of organ doses and the age and sex of patients. Such analyses have been carried out (see, for example, [H18 , K12, K13, M23]), although this important topic is beyond the scope of this review and is not considered further.

15. Notwithstanding the above caveat, practice in diagnostic radiology is summarized in this Annex, for comparative purposes, principally in terms of effective

doses to exposed individuals undergoing each type of procedure and, taking into account numbers of procedures, collective effective doses over exposed populations. Other more practical dose descriptors are also used, as appropriate, in analysing diagnostic exposures. These are discussed more fully below for examinations with x rays (Section II.B) and radiopharmaceuticals (Section III.B). The typical dose values quoted for specific examinations are generally arithmetic mean values, summarizing distributions of measurements over groups of patients or hospitals that are often wide and highly skewed.

16. Diagnostic practices may also be characterized in terms of per caput doses, by averaging collective effective doses over entire populations (including non-exposed individuals). Although such doses provide a broad indication of practice, they tend to conceal significant variations in the patterns of exposure received by individuals; some individuals might have a considerable number of x-ray examinations in their lifetime and others might have none at all. For example, it was estimated in 1992 that about 1% of the population of the United Kingdom received a lifetime dose of more than 100 mSv from medical x rays, yet the annual per caput effective dose was about 0.4 mSv [H9]. It has also been observed that radiological examinations are performed somewhat more frequently in terminally ill patients [M50], with about 5% of all the diagnostic x-ray and nuclear medicine procedures at one institution in the United States involving patients in their last six months of life, who collectively represented about 2% of the total number of patients examined [M19]. A study in Germany found that of the 60% of patients admitted into two large hospitals who underwent diagnostic x-ray procedures, about 6% received only 1 exposure, although the proportions receiving more than 12, 50 and 100 exposures were 24%, 6% and 1%, respectively [M73].

17. Although effective dose is used in this Annex, with some caution as discussed above, in the evaluation of patient doses from diagnostic exposures, this quantity is inappropriate for characterizing therapeutic exposures, in which levels of irradiation are by intent high enough to cause deterministic effects in the target volume. After due consideration of the complex issues involved, the Committee previously included broad estimates of collective effective dose for therapeutic exposures, computed on the basis of scattered radiation outside the target volumes. This was done to provide a robust assessment of practice for the purposes of comparison within a comprehensive review [U3]. The present analysis, by contrast, summarizes therapy largely in terms of frequency of practice, together with some information on prescribed doses. It is recognized, however, that assessing risk from the irradiation of non-target organs may be of particular importance for young patients who are successfully cured by radiotherapy for, say, Hodgkin's disease (see, for example [V27]), or for patients undergoing radiotherapy for inflammatory disease.

D. ASSESSMENT OF GLOBAL PRACTICE

18. The availability, complexity, and utilization of radiological equipment for imaging and therapy varies widely from country to country. In the inevitable absence of comprehensive information on national practice from all countries, particularly those in the least developed regions of the world, the assessment of global activities in medical radiology requires extrapolation from the limited data available from the questionnaires or the published literature. Models for doing this were developed in the UNSCEAR 1988 and 1993 Reports [U3, U4] on the basis of observed broad correlations between the number of x-ray examinations per unit of population and the number of physicians per unit of population. Accordingly, information on the number of physicians per million popula-tion, which is in general a more widely available statistic, can be used to scale diagnostic x-ray frequencies from a few countries to all regions of the world. As part of this global model, countries are categorized into four levels of health care according to broad ranges for the number of physicians per unit of population: health-care level I (at least 1 physician per 1,000 population), health-care level II (1 physician for 1,000–3,000 population), health-care level III (1 physician for 3,000–10,000 population), and health-care level IV (1 physician for more than 10,000 population). It should be emphasized that this classification of countries is used solely for the purposes of modeling and does not imply any judgements on the quality of health care.

19. Since diagnostic x-ray examinations represent the main source of exposure for populations, stratifying countries according to health-care level provides a robust model for assessing general worldwide frequencies and collective doses from practice in medical radiology. For the present analysis, information on the number of physicians per unit of population has been taken principally from data provided to the Committee in the questionnaires or from survey data published by WHO on human resources for health in the years 1988–1991 [W20]. The annual numbers of diagnostic medical x-ray examinations reported by different countries span several orders of magnitude. Figure I illustrates correlations between these annual totals in countries of different health-care levels and either the population or the total number of physicians in those countries. In general, annual numbers of examinations appear broadly to correlate better with national totals of physicians (Figure Ib) than with populations (Figure Ia), this being in general agreement with the model. For completeness, Figure II presents the relationship between dental x-ray examinations and either the population (Figure IIa) or the number of dentists (Figure IIb). However, there could be confusion as to whether the reported national totals for dental x rays refer to numbers of examinations or numbers of films. Also, it is likely in developing countries that significant numbers of dental x-ray examinations are conducted in hospitals rather than in dental practices.

20. There are clearly limitations to this broad classification system. For example, there will be differences in how different countries define a "physician", and these

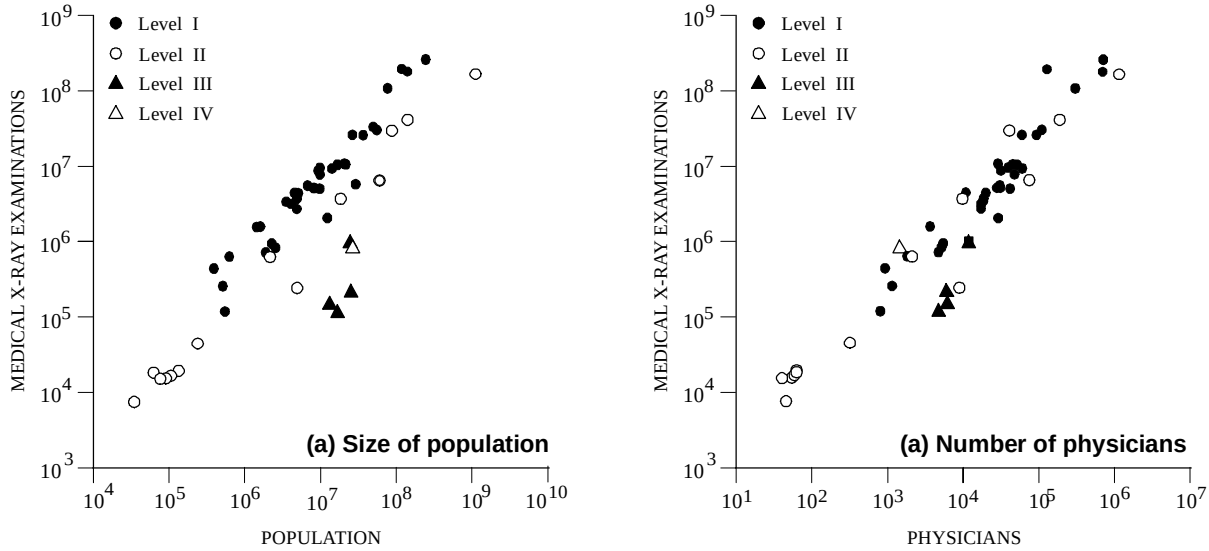

Figure I. Annual number of diagnostic medical x-ray examinations in relation to (a) size of population and (b) number of physicians.

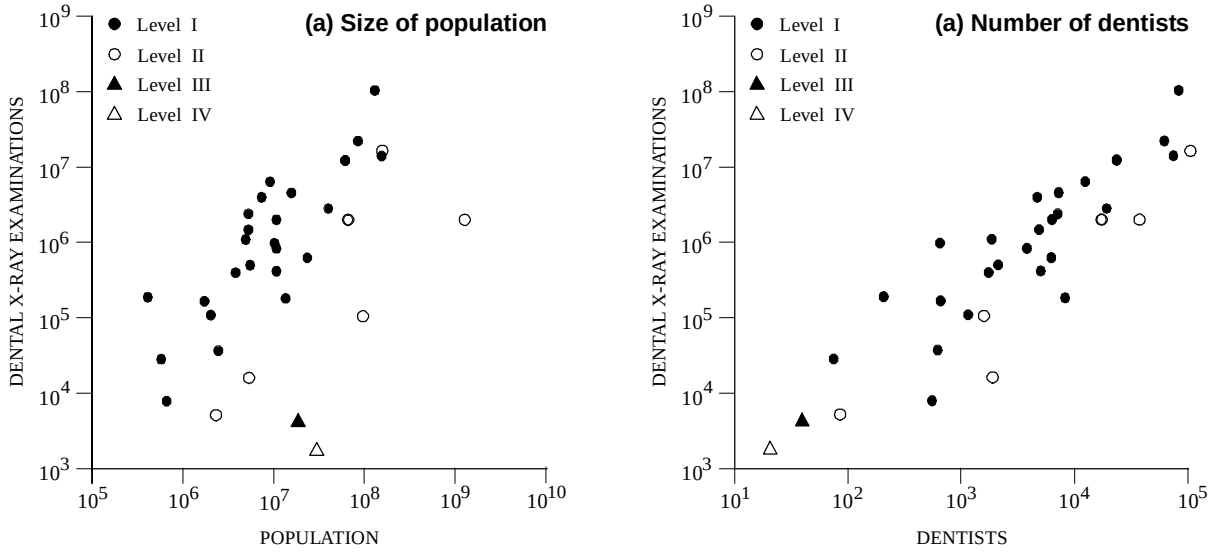

Figure II. Annual number of diagnostic dental x-ray examinations in relation to (a) size of population and (b) number of dentists.

lead to uncertainties in the data on numbers of physicians. Also, assigning countries to health-care levels on the basis of average national data will hide possibly significant regional variations within countries, particularly for large ones [U3]. Some examples can be given below in relation to Latin America [B33]. In Argentina, Brazil, Colombia, Costa Rica, Mexico, and Venezuela, the numbers and variety of radiological studies performed in university and regional hospitals are comparable to those performed in similar centres in more developed countries. In those large countries with high levels of urbanization, the main hospitals often tend to be private, and these establishments have relatively modern and sophisticated imaging services. In those countries with intermediate-sized populations, the range of diagnostic equipment and services available is usually not as great, with resources concentrated in capital cities and regional centres.

21. The global model can be expected to provide only a very broad characterization of overall national practice in medical radiology. For example, South Africa is assumed in the present analysis to fall in health-care level I, although significant variations are reported in the frequency of x-ray examinations between race groups, ranging from 67 per 1,000 blacks to 460 per 1,000 whites [H29, M22]. Ecuador is classified in health-care level I, although the indicators of national radiology practice are rather less than the average levels for this category. Some countries have been classified in levels different from those to which they would have been assigned based strictly on the number of physicians. Examples are Jordan, Libyan Arab Jamahiriya, Mexico and Turkey (level II rather than level I) and Sudan (level III rather than level II). The provision of health-care is broadly influenced by national economic status, and WHO has, for analytical purposes, also classified countries according to the following

scheme [W21]: least developed countries (LDCs); developing countries (excluding LDCs); economies in transition; and developed market economies. The Committee might wish to explore this approach for potential application in future assessments of global medical exposures.

22. Continued use of the same global model in this Annex as that adopted by the Committee for its previous analyses [U3, U4] ensures consistency of approach and allows the comparing of practice between different levels of health care and periods of time. The total population of the world in 1996 was estimated to be 5,800 million [W21]. Table 1 presents a breakdown of this present total by health-care level according to the global model, together with similar data reported for analyses in previous years. Ideally, this model should have access to additional national data on medical radiation usage. For example, information on the frequency of medical x-ray examinations is presently available from 36 countries in health-care level I, which collectively represent 67% of the total population of that health-care level; for other health-care levels, data are available from 14 countries in level II (representing 50% of the total population in the level), 4 countries in level III (representing 13% of the total population in the level), and only 1 country in level IV (representing 5% of total population in the level). Overall, information on x-ray usage is available for 46% of the world population. Such relatively small sample sizes necessarily demand that some caution is exercised when interpreting the results of the present analyses.

23. Medical radiology is practiced under widely differing circumstances, even in well-developed countries in the upper levels of health care, in terms of the size and nature of the facilities where the procedures are conducted, whether they are in the public or private domain, and the specialist training of the medical doctors and support staff. Basic data on medical radiation resources for 1991–1996, acquired from responses to the questionnaire and other sources, are tabulated in Tables 2–8: numbers of physicians and dentists (Table 2), diagnostic imaging equipment (Table 3), diagnostic imaging equipment per million population (Table 4), radiotherapy equipment (Table 5), radiotherapy equipment per million population (Table 6), temporal trends in average provision for medical radiology per million population by health-care level (Table 7), and annual numbers of medical radiation examinations and treatments (Table 8). The global use of medical radiology is summarized in Table 9. The symbol «-» is used in these and subsequent tables to indicate where data were not available, whereas zeros indicate the complete absence of a practice or type of equipment.

24. In general, there are broad trends for lower mean levels of resources and practice when comparing values derived for health-care level I with those derived for the lower levels (II to IV). However, significant differences are often apparent between individual countries within the same health-care level. Also, the amounts of data available in particular for the lower health-care levels (III and IV) are limited. The results of such reviews should always be used with some caution and interpreted only in the full knowledge of uncertainties in the reliability and representativeness of the national data presented [R21]. These data will have been derived using a variety of different methods and designs of survey and there may, for example, be significant bias in national estimates extrapolated from data for a single region or institution because of the wide variations in practice that inevitably exist within countries [A15, A21, K18, P16, S38, W33]. There will also be differences in interpretation between countries in relation to categories of staff (for example physician), equipment (for example brachytherapy units) and procedure (for example, the potential confusion between x-ray film or examination). In addition, the detailed data on frequency and dose subsequently reported in this review are subject to uncertainties arising from the exact scope of the examination groupings used (in relation, for example, to the broad x-ray categories of "Abdomen" or "Head") and the methods (including calibration) employed for dose assessments. Furthermore, it should be noted that the averaging of data within health-care levels has often been carried out over different populations and this could be important when comparisons of mean values are being made, particularly in relation to temporal trends utilizing data for the different periods of time from previous reviews.

E. SUMMARY

25. The exposure of patients to ionizing radiations for medical diagnosis and therapy has been assessed on a global scale utilizing survey data on national practice provided by a questionnaire on the resources for medical radiology and the frequencies and doses for different types of procedure, supplemented by a review of the published literature. Available data have been scaled up to provide estimates for the world population on the basis of a global model in which countries are categorized into four health-care levels according to the commonly-available metric of number of physicians per unit of population. Notwithstanding some differences in the quality and reliability of the national data and the broad method of extrapolation, the model provides a robust assessment of global practice in medical radiology for the purposes of comparison with previous data and the assessment of trends.

II. DIAGNOSTIC RADIOLOGY

26. Diagnostic examinations with x rays have been used in medicine for over a century, although with increasing sophistication; key technical advances are summarized in Table 10. During the last 20 years in particular, medical imaging has experienced a technological revolution, and it now allows the improved imaging of anatomy, physiology, and metabolism [H1]. Steady advances in the quality of x-ray images and in patient protection have ensured a continuing role for diagnostic x rays in health care, although alternative modalities for diagnosis are becoming increasingly available, such as ultrasound, endoscopy, and, particularly in developed countries, MRI. Nevertheless, because x-ray examinations remain the most frequent use of ionizing radiation in medicine, they are the most significant source of medical exposure for the world population. An increasingly wide range of equipment and techniques is employed to meet a diversity of diagnostic clinical purposes.

A. TECHNIQUES OF EXAMINATION

27. Traditional x-ray examinations involve static imaging, which uses film in cassettes with intensifying screens (radiography), and dynamic imaging, which uses (electronic) image intensifiers (fluoroscopy). Cine film (35 mm) is also used in radiological studies of the heart. Radiographic exposures are commonly performed during fluoroscopy, often using a 100 mm film camera linked to the intensifier (photofluorography), although digital radiographic techniques are increasingly being introduced. The visibility of particular tissues can be enhanced by the introduction of contrast media into the patient, such as barium for the gastrointestinal (GI) tract and iodine for the blood vessels (angiography), the urinary system (urography) or the biliary system (cholecystography). In addition to fixed installations in hospital departments and practices, mobile equipment for radiography or fluoroscopy allows imaging in the wards or operating theatres. Radiography is occasionally conducted in the homes of patients by visiting radiographers using portable x-ray units.

28. Digital methods for the processing and display of x-ray images were first introduced into clinical practice with the advent of CT in 1972. This revolutionary technology was able to provide high-quality images of isolated slices of the patient using a thin rotating beam of x rays, albeit with relatively high patient doses. The subsequent development of helical CT has lead to further scanning techniques such as CT endoscopy and CT fluoroscopy. Continuing advances in computer technology have also promoted the general development of digital radiography, where images are acquired in digital form, most commonly from an image intensifier (digital fluorography) or from a storage phosphor plate (computed radiography) [H1]. Other detector systems for indirect (with an intermediate phosphor) or direct digital radiography, utilizing for example amorphous selenium and amorphous silicon, are under development [R22, Y4]. The technique of digital subtraction angiography (DSA) is based on digital image processing with logarithmic subtraction and edge enhancement; it is used increasingly for the visualization of blood vessels throughout the body. Such improvements in imaging and innovations in other equipment, such as needles, guidewires, catheters, stents, and contrast media, have facilitated the development of interventional radiological techniques, in which imaging helps to guide therapeutic procedures and to deliver therapeutic agents [A19]. Digital technology also provides for the storage and transfer of images within and between hospitals and their transmission for remote consultation (teleradiology) using digital networks known as picture archive and communications systems (PACS).

29. In addition to examinations on symptomatic patients with specific clinical indications, diagnostic x-ray examinations are also undertaken in connection with mass screening programmes of sections of the population. These may be for the purposes of, for example, diagnosing tuberculosis, breast cancer or, particularly in Japan, stomach cancer, and managing occupational health [N1]. Furthermore, some examinations are conducted for medico-legal reasons and others on volunteers participating in medical research.

B. DOSIMETRY

30. The levels of dose to patients undergoing diagnostic examinations with x rays are in principle determined by the quality of images required and the extent of investigation necessary to meet specific clinical objectives. In practice, numerous factors relating to both the radiological equipment and the procedures in use have an influence on the imaging process. Some of the more important aspects of practice that have a broad impact on patient dose are summarized in Table 11; this information represents an updated version of a similar list given in the UNSCEAR 1993 Report [U3]. Patient size is, of course, an additional determinant of dose for individual examinations [S58], although this factor cannot be used generally to improve practice. Accordingly, comparisons of dose to assess relative performance are made in terms of mean values observed over groups of patients or in relation to standard-sized patients.

31. Because x-ray procedures characteristically involve a series of partial-body exposures, they produce complex patterns of energy deposition within the patient and various dose measurement strategies are necessarily employed [F17, N27]. Organ doses are in general difficult to assess, and in practice routine patient monitoring is usually based on directly measurable dose quantities, such as entrance surface dose (with backscatter [P17]) per radiograph and, particularly for complex procedures involving fluoroscopy, dose-area product per examination [B46, K25, L14, L27,

N9]. Dose-area product meters are increasingly being fitted to x-ray equipment and their development has continued so as to allow also the display in real-time of dose rate and cumulative dose [G14, R23]. The quantities entrance surface dose and dose-area product are often measured as part of quality assurance programmes or in other surveys of practice [B55, M41, P27]. Dose assessments reported in this manner are widely used in this Annex and assumed to be reliable, although essential details of dosemeter calibration [D30, G27, G52, N9] are often unknown. From a radiation protection point of view, the types of dose measurement discussed above have also formed the practical basis, both nationally [L16, N1, Z17] and internationally [C6, I5, N24, S57], for specifying reference values (diagnostic reference levels) for common diagnostic x-ray examinations, as a way of promoting improvements in practice [I17, O11, W38]. In addition to measurements on patients, assessments of dose performance at x-ray facilities are also conducted by calculation [B50] and by using patient-equivalent phantoms to provide indications of dose and dose rates under standard conditions of exposure [M28, M40, R15, S44, W39].

32. Organ dose and effective dose [B45] are generally estimated from routine dose measurements using conversion factors appropriate to the conditions of exposure; coefficients that have been used in various dose studies are reviewed elsewhere [R11]. These coefficients may be derived experimentally on the basis of physical anthropomorphic phantoms (see, for example, [M21, M44, R11]) or calculated using Monte Carlo simulation techniques with mathematical phantoms (see, for example, [S56, T9, Z15, Z16]). Theoretical normalized organ dose data are available *inter alia* in relation to routine examinations of adults (see, for example, [D7, H15, R9, S11]), paediatric patients (see, for example, [H16, R10]), and cardiac [S9] and angiographic [K27] examinations, although care is needed when applying such coefficients to clinical practice [P19, W35]. The comparison of organ and effective doses derived from measurements and calculations under similar conditions of exposure indicates reasonable agreement between the methods and highlights the limitations and uncertainties in both approaches [M48]. Computational methods of dosimetry in particular are advancing steadily, with the development of more realistic (voxel) phantoms based on digital images of humans [D5, J6, V24, X1, Z24]. Differences in the results from calculations for different anthropomorphic phantoms under similar conditions of exposure underline the uncertainties in such computed dose coefficients, which should not be applied to examinations of individual patients [Z25].

33. Assessment of the weighted dose quantity of effective dose is particularly problematic for the very localized and low levels of exposure involved in dental radiology, in which doses to the so-called "remainder organs" are dominant [L37]. For example, for given sets of organ dose data from dental exposures, the values of effective dose [I3] have been reported to be less than the corresponding values of effective dose equivalent [I7] by factors of 2–10 [K42, U3]. Such differences in interpretation represent an additional source of uncertainty that should be borne in mind when comparing reported effective dose data.

34. For the intensive imaging procedures used in interventional radiology, a knowledge of the localized dose to skin is also important with respect to the potential for deterministic effects of irradiation [C2, G34]. Such cumulative skin doses can be assessed by calculation (see, for example, [G17]) or measured directly on the patient using film (see, for example, [F14, K21, L25, V10]) or thermoluminescent dosemeters (TLDs) (see, for example, [G18]) or solid-state detectors (see, for example, [P18]), or by portal monitoring [W43]. It is also possible to make simultaneous measurements of cumulative dose and dose-area product during fluoroscopic examinations using a single transmission ionization chamber [G14].

35. Special dosimetric techniques are often employed in the case of mammography and CT in view of the peculiar conditions of irradiation for these examinations [D40, J13, Y13, Z19]. Practice in mammography is generally assessed in terms of the mean dose to glandular tissue, derived in relation to a standard breast thickness using coefficients normalized to measurements of air kerma made free-in-air (see, for example, [B67, F20, H17, H49, K44, L15, N37, S83, Y2, Z2, Z20]), although direct measurements of entrance surface dose on patients have also been employed [G11, Z2]. Effective doses from mammography are included in the present analysis for completeness, although this quantity is not an appropriate indicator of risk for such exposures of female patients. Estimates of risk should be based on the mean dose to glandular tissue and age-specific risk factors.

36. CT generally involves the irradiation of thin slices of the patient in rotational geometry by a fan beam of x rays. The principal dosimetric quantity in CT is the computed tomography dose index (CTDI), in which the dose profile along the axis of rotation for a single slice is averaged over the nominal slice thickness [S7]. The CTDI can be measured free-in-air [S8] or in homogeneous CT dosimetry phantoms for the head and body [C36, K11, L20], although such reported values can reflect subtle differences in the definition of CTDI [E3]. A related quantity, the multiple scan average dose (MSAD), provides an indication of the dose in a phantom for a series of multiple scans with a constant separation [S7]. Organ doses and effective doses to patients for particular scanning protocols can be estimated [K41, S30] using dose coefficients provided by mathematical modeling, which are normalized to a free-in-air axial dose [B64, C37, H43, J3, J12, W49, Z5, Z6], or by dose measurements with TLDs in phantoms [N16]. Other dosimetric quantities of interest that are under development for characterizing practice in CT include dose-area product [P5] and dose-length product [E4, S40] in relation to CTDI measurements in standard phantoms; these quantities in turn allow the broad estimation of effective dose to patients [H42, J13].

37. Whereas organ doses and effective doses generally provide the most complete assessment of x-ray exposures, an alternative dosimetric method focuses on the energy imparted as a practical measure of patient dose [A7, A24, G13, P6]. Such values of energy imparted allow estimates of effective dose to be derived for the exposure of both adult and paediatric patients [A1, A3, H5, H38]. Biological dosimetry, based on an analysis of chromosome aberrations in human lymphocytes, has also been reported for patients who received extensive exposure to diagnostic x rays [W17]. However, this technique is of limited importance in routine practice.

C. ANALYSIS OF EXPOSURES

1. Frequency of examinations

38. The annual numbers of diagnostic medical x-ray examinations reported by different countries for 1991–1996 span several orders of magnitude. The annual frequencies (numbers of examinations per 1,000 population) are summarized by type of procedure in Table 12, with countries grouped according to health-care level. Part A includes information for some common types of examination and Part B for some special procedures and also the total of all medical x-ray examinations. The percentage contributions of each type of examination to total frequency are given in Table 13. Mean values of frequencies have been derived for each health-care level by dividing the total numbers of procedures by the total population.

39. There are significant differences in the patterns of practice from one country to another, even within the same health-care level. Many of the reported data were obtained from surveys or registrations that were complete enough to give representative results. In other cases, however, figures have been estimated from smaller or more localized samples that might not adequately reflect national practice. There may also be some differences in the examination categories used in national surveys. Some particular qualifications noted for the present data are given in footnotes to Tables 12 and 13. National annual frequencies for the total of all medical x-ray examinations vary by a factor of nearly 10 within the sample of 36 countries listed in health-care level I (151–1,477 examinations per 1,000 population); smaller variations exist in the samples of 14 countries in level II (98–306 examinations per 1,000 population), and 4 countries in level III (7–37 examinations per 1,000 population). Information was available from only one country in health-care level IV (the United Republic of Tanzania: 29 examinations per 1,000 population). The average total frequencies for levels II and III are factors of 6 and 50, respectively, smaller than the average for level I, 920 examinations per 1,000 population.

40. The relative use of fluoroscopy and photofluorography also varies between countries. For example, the percentage contribution from fluoroscopic procedures to the annual total of all medical x-ray examinations is about 4% in Russia, 9% in Ukraine [K18], 10% in Germany (with many of these examinations involving long exposure times) and 28% in Romania [D28]. In China [Z13], chest fluoroscopy accounts for 62% of all x-ray examinations. Photofluorography accounts for about 16% and 32% of all x-ray examinations in Romania [D28] and Russia, respectively, and for 55% of all chest radiography in Poland [S49].

41. In general, examinations of the chest are the single most important type of procedure; the relatively low frequencies reported for Sudan and the United Republic of Tanzania, for example, are apparently due to incomplete survey data. Significant contributions to practice in all health-care levels are made by examinations of the limbs and joints and the spine. The more complex procedures summarized in Part B of Tables 12 and 13 are in general performed less frequently in the countries of lower health-care levels. The decreased use of CT in levels II–IV relative to level I can, however, be viewed against a relative increase in conventional examinations of the head. Temporal trends in the frequency of examinations are discussed Section II.E.

2. Exposed populations

42. The distributions by age and sex of patients undergoing various diagnostic x-ray examinations in 1991–1996 are presented in Table 14 for selected countries of the four health-care levels; some known limitations in the reported data are given in the footnotes. The analysis uses the same three broad ranges of patient age as the UNSCEAR 1993 Report [U3]. It has already been noted that the populations of patients undergoing diagnostic examinations with x rays are in general older than the corresponding whole populations, although significant numbers of procedures are conducted on children [U3]. Some differences in patient age distribution are apparent from country to country for a particular type of examination, even when considering a single health-care level. However, the population-weighted mean values for each level suggest some general trends in the age/type of examination and age/health-care level relationships. For example, older patients predominate for examinations of the gastrointestinal tract, urography, and cholecystography, whereas children form a substantial fraction of the patients undergoing examinations of the limbs and joints, head, and pelvis and hip. In general, greater proportions of examinations are conducted on patients in the two younger age groups for countries in levels II–IV than for level I countries. This finding is broadly consistent with the observation that there is a bias towards younger ages in the general population for many developing countries [U3].

43. Notwithstanding specific examinations such as mammography and pelvimetry, the male vs. female distributions of diagnostic x-ray examinations do not deviate greatly from the underlying patterns for whole populations. There are, however, some variations between countries in the data reported for each particular type of procedure.

3. Doses from specific types of examination

44. The typical effective doses to patients from medical x rays reported by different countries for 1991–1996 are presented in Table 15. Part A includes mean values of effective dose for some common types of examination and Part B for some special procedures and also the annual total of all medical x-ray examinations. Representative values of other dosimetric quantities used to characterize patient doses from x-ray examinations are summarized for different countries in Table 16. Part A includes mean values of entrance surface dose for some common types of radiograph and Part B mean values of dose-area product for some specific, more complex diagnostic x-ray examinations involving fluoroscopy. Further patient dose data have been published in connection, for example, with examinations of the cervical spine [M22, N15, O3, R11], extremities [H21, M22, O3], hysterosalpingography [C29, F16, G28, S51], barium studies of the gastrointestinal tract [C30, D29, G29, G30, L29, L49, M38, S52, W37, Y10, Z14] and extracorporeal shock wave lithotripsy (ESWL) [M47]. Studies have also been conducted of the dose rates during fluoroscopy (see, for example [B51, B52, S53]). Dose rates have been reported in relation to some different organs of patients undergoing x-ray examinations in Bangladesh [B44]. X rays are also used in chiropractic [B29, E12] and podiatry [A23]. The dosimetric aspects of some specific procedures are discussed further below.

(a) Angiographic and interventional procedures

45. Advances in technology for imaging and ancillary equipment have facilitated the development of increasingly complex radiological procedures for angiography and interventional radiology [B49, C25] and specific methods are required for assessing and monitoring the resultant patient doses [B57, F18, G34, G35, G36]. Angiographic examinations involve complex patterns of imaging [K28] and are often complementary to interventional procedures, providing evaluations before and after treatment. Some reported dose data for different types of angiographic procedure are given in Table 17. Doses to patients from interventional radiology procedures are summarized in Table 18.

46. A survey of practice in five European countries identified over 400 different types of interventional procedures involving a range of medical imaging specialities, such as neuroradiology, vascular radiology, and cardioangiography [M8]; typical data from Germany for 1990 indicated that nearly 60% of such procedures fall within the broad category of angioplasty (dilatation), with significant applications also in biopsy/drainage (11%), pain therapy (11%), embolization (7%), and genitourinary (7%) and biliary (5%) interventions. Such interventional procedures are generally complex and can involve significant periods of patient exposure, although these types of therapy often represent alternatives to more hazardous surgery or are the sole method of treatment. Interventional radiology is already an established part of mainstream medicine and is likely to expand further with the continuing development and adoption of new procedures [B1], particularly in countries with well-developed health-care systems [J9, L11]. In Europe, the average rate of percutaneous transluminal coronary angioplasty (PTCA) procedures in 1993 was 343 per million population, an annual increase of 12% over previous data for 1992, but with considerable variation among national practices, from Romania (1 per million) to Iceland (876 per million) [U15]. Information on interventional cardiology in Spain (practiced at 81 hospitals) indicated a total of 90,915 procedures in 1997 (a rate of 2,270 per million population), with 72,370 (80%) being diagnostic (increase of 13% relative to 1996) and 18,545 (20%) being therapeutic (increase of 24% relative to 1996).

47. Dose rates during such sophisticated procedures can be relatively high, for example up to a regulatory maximum of 180 mGy min^{-1} at the patient surface during high-level-mode fluoroscopy in the United States [C4]. Lower dose rates are technically possible, however, when using new techniques such as pulsed progressive fluoroscopy [H26]. The combination in interventional radiology of prolonged localized fluoroscopy, multiple radiographic exposures, and repeated procedures on particular patients can cause patient doses to reach levels associated with acute radiation injury of skin [C2, C14, W31]. Procedures of particular concern in this respect include radiofrequency cardiac catheter ablation, percutaneous transluminal angioplasty, vascular embolization, stent and filter replacement, thrombolytic and fibrinolytic procedures, percutaneous transhepatic cholangiography, endoscopic retrograde cholangiopancreatography, transjugular intrahepatic portosystemic shunt, percutaneous nephrostomy, and biliary drainage or urinary/biliary stone removal [F9]. However, there may in general be some under-reporting of skin injuries in view of the time delay between exposure and manifestation of damage. In the United States from 1992 to 1995, there were 26 reports to the Food and Drug Administration (FDA) of radiation-induced skin injuries from fluoroscopy [S46]. By 1999, the FDA had documented some 50 cases of radiation-induced burns, many involving cardiological procedures [A25]. Details have been published, for example, of occurrences of epilation [H23, K29], dermatitis [C21, D31, K22, P13, R24, S65, S66, V11], and erythematous lesions [S46, V11]. In one study of arrhythmia ablation procedures, about 6% of 500 patients were found to have received enough radiation exposure to reach the threshold dose (2 Gy) for early transient erythema, although no clinical manifestations of acute radiation-induced skin injury were observed [P14]. Another analysis of neurological procedures on 426 patients has suggested that long-term erythema may be encountered in 1%–2% of embolizations, with there being a potential for temporary erythema in 11% of both carotid procedures and cerebral angiograms, 3% of nerve block procedures, 7% of lumbar procedures, and 23% of embolization procedures [O7].

48. Dose data for different types of interventional procedure are summarized in Table 18: fluoroscopy time and, with due account of exposures from radiography, localized surface dose (measured or estimated assuming static beam), dose-area product, and effective dose. In general, fluoroscopy times are appreciable, and skin doses may approach or exceed the thresholds for deterministic effects [U3]. Some examples reported for particular patients can be given: a fluoroscopic exposure of 190 minutes and a localized dose of 8.4 Gy during radiofrequency ablation [C3]; an estimated maximum skin dose of 6.6 Gy from 110 minutes of fluoroscopy and 46 DSA acquisitions in the course of neurological embolization [H23]; an accumulated skin dose of 11–16 Gy from an estimated 90–120 minutes of fluoroscopy during cardiac radiofrequency ablation [V11]; and estimated maxima of 20 Gy and 3.5 Gy for skin exposure from fluoroscopy and DSA acquisitions, respectively, for a patient undergoing a series of biliary procedures over a four-week period [S46]. Doses may be significantly underestimated if contributions from cine exposures are not fully taken into account; the potential for skin injury will be underestimated if only fluoroscopy time is monitored, but overestimated when doses from different beam projections are combined [O14]. Notwithstanding significant variations between individual patients, values of dose-area product and effective dose for interventional procedures are typically larger than those for common diagnostic x-ray examinations; for example, dose-area product values of up to 918 Gy cm^2 have been reported during embolization procedures [B9]. One study comparing the use of conventional and digital systems for a range of interventional vascular procedures found mean values of dose-area product to be higher for the digital equipment in 13 out of 15 patient groups [R12]. Guidance concerning efficacy and radiation safety in interventional radiology is being prepared by WHO [B30, W9].

(b) Computed tomography

49. Technological developments to improve the quality and speed with which images are obtained have fostered the growth of CT practice throughout the world over the last two decades, allowing the routine performance of more and more extensive and elaborate examinations with relatively high levels of patient dose. The expanding use of CT in the diagnosis and assessment of cancer and other pathological conditions [D37, N35, R31] has made a substantial impact on both patient care and population exposure from medical x rays. In the United Kingdom, for example, the number of CT scanners in clinical use increased steadily following introduction of the technique in 1972 before finally reaching a plateau in 1995, as illustrated in Figure III. Whereas CT was estimated in 1989 to account for about 2% of the national total of all x-ray examinations and about 20% of the resultant collective dose, a further analysis for 1997 suggests that the latter figure may have risen to about 40% [S30]. Data from national surveys in eight other countries have confirmed as a general pattern the increasing importance of CT as a source of exposure for populations [S5]. In Germany during the years 1990–1992, CT accounted for, on average, about 3.5% of all x-ray examinations and about 35% of the associated collective effective dose, and further increases are foreseen [B31]. A similar analysis for Norway in 1993 indicated contributions from CT to x-ray frequency and collective dose of 7% and 30%, respectively [O12].

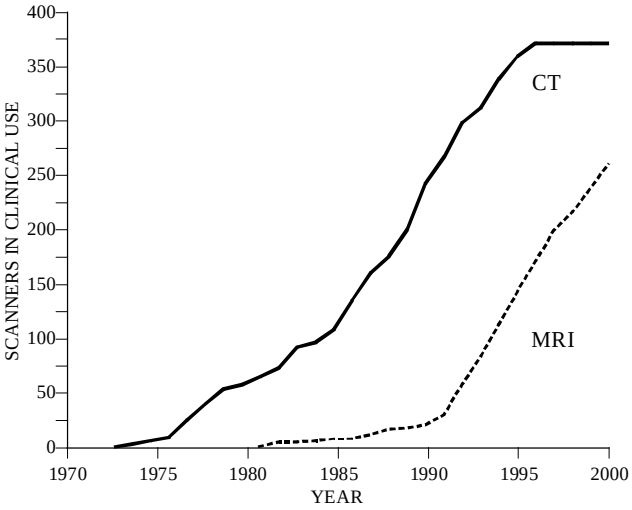

Figure III. CT and MRI equipment in the United Kingdom.

50. Mean values of effective dose reported by some surveys of CT practice are summarized in Table 19 for common types of procedure. In addition to apparent differences between such mean national data, there are also significant variations, for a given general type of procedure, in the typical doses at individual CT centres [O12, S40, S69, V15] and in the particular doses for individual patients [S70, W44]. Organ doses for CT procedures have been estimated in various studies on the basis of measurements [D32, E9, L31, M50, M51, N16, N30, N31, N32, P21] or calculations [H33, H34, O12, P22, T17]. In general, comparisons between sets of organ doses derived from measurements and calculations for a given examination technique demonstrate reasonable agreement when due account is taken of any differences in the exposure conditions being modeled [C31, G38, S71]. Absorbed dose to the lens of the eye may be above 50 mGy for certain CT procedures on the head [M52, M53, M54, M55, W45]. Doses to the thyroid, breast and testes from scattered radiation are significantly reduced when lead shielding is used [B59, H35, P23]. Reductions in breast dose during direct scanning have also been reported using an overlying bismuth filter [H36]. Lower levels of patient dose are often possible in CT with attention to choice of scanning technique [G39, K30], particularly with regard to lower settings [K32, M56, P24, R26, S72] or dynamic modulation [G40, H37, K31] of tube current. With the use of standard techniques, the energy imparted to the patient has been shown to increase with patient size, although the calculated effective dose is higher in children than adults [W46]: 6.0 mSv (newborn) and 1.5 mSv (adult) during head examinations, and 5.3 mSv (newborn) and 3.1 mSv (adult) during abdomen examinations [H38]. Significant

dose reductions have been reported in paediatric CT by the appropriate lowering of exposure settings [C32, S73, W47].

51. Clinical practice in CT has been stimulated in particular by the notable technical development in 1989 of helical (spiral) scanning [K33, K34]. This technique provides significant clinical advantages by allowing the rapid acquisition of image data over large volumes of the patient during a single breath hold [D33, H39]. Although image quality and patient dose in helical CT are broadly similar to those for conventional slice-by-slice imaging when equal or equivalent scan parameters are chosen, the speed and convenience of helical scanning is likely to promote increases in both the frequency of CT procedures and the levels of patient effective dose from procedures of increasing complexity [D34, M57, S10, T18, Z18]. However, the use of an increased pitch (>1) in helical scanning leads to a reduction in patient dose [M58] and such techniques have been successfully applied to clinical examinations to achieve lower doses for adults [C33, D35, H40, K35, P21, S74, S75, V16, W48] and children [R27]. The advent of the technology for helical CT has also facilitated the development of new techniques such as CT angiography [K36, K37, R28, R29], virtual CT endoscopy [P25], lung cancer screening CT [I26, N30, N33], and CT fluoroscopy [D36, K38, K39, S75]. This latter technique provides real-time reconstruction and display of CT images, with the potential for significantly high patient (and staff) exposure; preliminary studies have indicated, for example, patient skin dose rates of 190–830 mGy per minute during interventional CT fluoroscopy [N34] and an effective dose rate of 3.6 mSv per minute for abdominal scanning [A26]. The most recent innovation in CT has been the development of multidetector-array scanners that allow, for example, two [S93] or four [B60, H41, K40, O13] slices to be acquired in a single rotation in order to reduce scanning times for volume acquisition of data and improve longitudinal resolution. However, the radiation slice profiles and doses may be larger at all scan width settings for multi-slice scanners in comparison with single-slice systems under similar conditions of exposure [M59]. Such multislice scanning may also facilitate the further development of complex examinations with increased imaging of the patient and so potentially lead to increases in patient dose from CT.

52. Ultra-fast (sub-100ms) CT was proposed in the 1970's [I27] and developed in the 1980s using electron beam (EB) technology [B61, M60]. Such EBCT scanners have found particular application in the investigation of coronary artery disease [B62, L32, R30, T19], although their total number has remained relatively small: about 73 worldwide in 1997, with installations in the United States and Japan accounting for 47% and 26%, respectively [M61]. Doses from EBCT have been shown to be comparable to those from conventional CT scanning [M62, M63, S76], but higher than those from helical scanning [B63]. Analysis of EBCT practice at one institution indicates the following typical effective doses by type of procedure: 6.0 mSv for chest (25% of all EBCT), 7.2 mSv for abdomen (20%), 6.8 mSv for pelvis (10%), 2.4 mSv for head (3%), 2.0 mSv for cardiac function (multi-slice mode) (7%), 0.5 mSv for coronary artery calcification (single-slice mode) (30%), and 2.0 mSv for pulmonary emboli (5%) [M61].

53. In the longer term, CT may be partially replaced by MRI. This is already the imaging modality of choice for the central nervous and musculoskeletal systems, and applications are being refined for the chest and abdomen and in angiography [Z1]. The pace of change will be governed by the high cost and availability of MRI equipment [C34]. The provision for CT and MRI varies widely from country to country, even within the same health-care level; numbers of scanners per million population are summarized in Table 4. Whereas the number of CT scanners has probably reached a plateau in the United States, for example, increases can be expected elsewhere for some time. Further refinements in CT technology are likely [C35, D38, M64].

(c) Chest examinations

54. X-ray examinations of the chest are worthy of special mention in view of their high frequency. The thorax is one of the most technically challenging anatomic regions to image radiographically due to the large differences in tissue density and thickness present in the chest [R32]. The conventional chest radiograph, utilizing a film-screen detector, has proved a robust diagnostic aid over the last century [H44]. However, technological innovations have continued over the last decade in the quest for optimal imaging [L35, W50]; such advances include changes in applied potential [A27, S80], improvements in films and screens [H45, M66, V17], asymmetric [M67] and twin [M65] screen-film combinations, beam equalization systems [V18], and digital techniques such as storage phosphor (computed) radiography [H46, I29], image intensifier radiography [B65] and selenium drum detectors [C39, H47, L36]. Mobile x-ray units are used in hospitals for radiography on patients who cannot be moved from their beds. Such examinations are routinely performed in intensive therapy units [L34] and frequently in other wards; collectively, they may account for nearly one half of all chest radiographs in large hospitals [W7]. Reported doses from some different techniques in chest radiography are summarized in Table 20. Gonad doses are low (<0.03 mGy per exposure) when there is adequate beam collimation [L34, N36].

55. Fluoroscopy is widely used in some countries for conducting radiological examinations of the chest (see Table 12). Reported patient doses are summarized in Table 15. In general, the effective doses when using fluoroscopy are larger than those from radiographic or photofluorographic imaging of the chest.

(d) Dental radiography

56. Dental radiography is one of the most frequent types of radiological procedure, although the exposures to individual patients are low. The most common techniques involve intraoral non-screen films either to provide an image of the upper and lower teeth together (bitewing radiography) [C19] or to demonstrate full tooth structure, including pulp, root, and gum anatomy (periapical radiography). Digital subtraction radiography techniques are also used in longitudinal studies [R14]. Alternatively, narrow-beam rotational tomography is used to view the teeth and jaw bones in a single image; such panoramic radiography uses an external film in a cassette with intensifying screens and an x-ray tube that rotates around the head to provide a tomographic image of the whole mouth [G26]. Data on frequencies and effective doses in dental radiology reported for various countries are presented in Table 21. Entrance surface doses are summarized in Table 22.

57. Notwithstanding the relatively low levels of individual exposure from dental radiology, the dose to the patient can be significantly influenced by the equipment and technique used and the quality assurance measures in place [C13, N3]. Some typical values of effective dose per dental x-ray examination for a range of exposure conditions are shown in Table 23; these data indicate broad variations by factors of 8 and 2 for changes in technique for intraoral and panoral procedures, respectively. The effective dose from intraoral radiography is less dependent on the radiation quality of the x-ray beam than is the case for general radiography [K42]. Optimized techniques of periapical radiography have been shown from measurements in an anthropomorphic phantom to result in entrance doses of 0.5–1.3 mGy and effective doses of 1.1–3.3 μSv per exposure [L17]. In contrast, the mean entrance surface dose for conventional dental x-ray examinations in Romania apparently rose by about 250% between 1980 (10.7 mGy) and 1990 (27.5 mGy), with a concomitant tenfold increase in effective dose (0.01 mSv to 0.11 mSv); this trend was attributed largely to shortcomings in x-ray technology [D9].

58. The planning of dental implant surgery often requires tomographic imaging to evaluate the dimensions of the potential implant sites and the location of anatomical structures. Both conventional tomography and CT are routinely employed in dento-maxillofacial radiography [E9]. Using hypocycloidal or spiral conventional tomography, the absorbed doses to radiosensitive organs are below 0.2 mGy. Doses from CT can be considerably higher, with, for example, maximum doses of 38 mGy and 31 mGy being measured at the skin surface and the parotid gland, respectively [E9], although methods for reduced doses from helical CT have also been demonstrated [D32, D39]. The dose from a new volumetric CT scanner, developed specifically for dental imaging, is reported to be approximately one sixth of that from traditional spiral CT [M27]. The use of a dedicated multimodal dental imaging system has also been shown to involve lower doses than alternative CT techniques [L26]. On the basis of measurements in a human phantom, estimates of effective dose for such complex film tomography range from <1 μSv to 30 μSv, depending on the anatomical location of the imaging plane and the collimation option used [F13]; similar measurements for panoramic radiography gave an effective dose of 26 μSv.

59. Orthodontic analysis in the diagnosis and treatment of malocclusion disorders uses the standard imaging technique of cephalometry to generate reproducible images of the skull, dentition, and facial profile soft tissues. Such cephalometric radiographs involve lateral views of the skull from a fixed distance. The doses produced at particular anatomical sites in the head by different experimental techniques have been shown to vary by up to an order of magnitude [T14].

60. Direct digital imaging systems, which can provide adequate image quality at significantly reduced doses in comparison to conventional techniques, are becoming increasingly available for both intraoral [B28] and panoral [N4] radiography. Doses associated with charge coupled devices (CCDs) and computed radiography systems (photo-stimulable phosphor luminescence technology) have been reported to be up to approximately 50% and 80% lower, respectively, than those associated with conventional techniques.

(e) Mammography

61. The number of countries with mammography screening programmes has been increasing, and this trend is likely to continue [U3]. Initially, routine screening was generally not carried out for women under the age of 50 [B68, D8], although younger women have now been included in some countries. National screening programmes are broadly characterized by good quality control and standardization of practice. The doses to patients from mammography reported for various countries are summarized in Table 24. Periodic surveys in some countries have demonstrated reductions in dose over the last decade due to improvements in quality control and changes in technique (see, for example, [C5, C40, F10, M7]); in other countries [L38, S82], doses have increased due to trends for higher film optical densities and the use of grids for improved image quality [R34, W51]. There is no general consensus in Europe concerning the best way for balancing dose and image quality [V19, Z21].

62. Mammography is generally carried out using dedicated, special x-ray equipment that employs relatively low applied potentials (25–30 kV) and tubes with molybdenum anode/filter combinations; such equipment is sometimes mounted in vehicles to provide mobile units for screening programmes [D41]. The mean dose to the glandular tissue is affected by the size and composition of the breast, with the former varying both within and between populations and the latter throughout a woman's life [E13]. Standard phantoms and models of the breast are generally adopted to facilitate comparisons of practice, although surveys of doses to individual patients are increasingly also being conducted (see Table 24). Recent

innovations in equipment that allow a choice of different anode/filter materials (such as rhodium) and automatic selection of applied potential offer advantages in dose and image quality, particularly for women with relatively thick breasts on compression [T20, Y14, Y15].

63. Digital imaging techniques are being developed that potentially could provide lower doses than at present, while also allowing improvements in image quality, although their improper application could result in higher doses [A28, C41, C42, G16, K6, K45, K46, K48, N38, P1]. Other developments include the use of niobium filtration [C43], equalization techniques [P29, S84], phase contrast imaging [A36, I32, K51], a laser-based micro-focused x-ray source [K47], and synchrotron radiation [A29, B13, J5]. MRI is also being developed for mammography [K1, W52]. However, in the short term at least, conventional film-screen mammography is likely to be the primary breast imaging modality, supplemented by ultrasound techniques [S18].

(f) *In utero* exposures

64. X-ray examinations on pregnant patients may also expose the fetus [D42]. For this reason, many such types of procedure are not carried out routinely without there being overriding clinical indications, although there may also be inadvertent fetal exposure from examinations conducted in the very early stages of pregnancy [E14, S85]. Precise estimates of fetal dose may require special techniques, although uterus dose is often assumed as a surrogate [A30, M68, O16, O17]. Typical doses to the uterus from common types of x-ray procedure are summarized in Table 25 [W30] (see also various other sources of data, including, for example [O15, S85]). The wide range of doses reported is due to differences in equipment and technique. For example, one study of maximum absorbed dose to an embryo from intravenous urography demonstrated a range between hospitals of 5.8 to 35 mGy [D25].

65. X rays have also been used for more than 50 years to assess the dimensions of the maternal pelvis in pregnancy. Such pelvimetry is usually performed in the late stages of pregnancy if cephalopelvic disproportion or breech presentation is suspected. In the United Kingdom, for example, pelvimetry is typically performed in connection with 1%–4% of all deliveries in an obstetric department, with over two thirds of the centres in a national survey reporting its use as being either static or decreasing [M29]. A range of techniques are employed, including conventional plain film radiography using a grid or air-gap technique (generally involving a single erect lateral projection, but with up to three films for postnatal investigations), CT (generally a single lateral scan projection radiograph, but with antero-posterior (AP) projection and axial slices also being used), and digital radiography; MRI pelvimetry is also under investigation. Differences in x-ray technique lead to wide variations in the resulting dose to the fetus [T21]. Measurements at 20 centres in the United Kingdom with an anthropomorphic phantom of a pregnant woman at full term revealed mean fetal doses varying by a factor of up to about 40 [B47]. Those from conventional pelvimetry were in the range 0.15–0.75 mGy, with doses from CT pelvimetry spanning 0.05–0.35 mGy. Conventional pelvimetry (erect lateral projection) gave, on average, four times the dose from CT pelvimetry (lateral scan projection radiographs), although the use of an air gap technique resulted in doses that were comparable to those with CT. Digital pelvimetry using storage phosphor plate technology (computed radiography) can be conducted with doses that are about 50% of those from high sensitivity screen-film systems [H50, K52]. Digital fluorography has also successfully been utilized in pelvimetry, where it allows a tenfold reduction in entrance surface dose compared with conventional techniques [W10], although the potential for lower fetal doses with this technique depends on the ease of patient positioning [B47].

(g) Bone densitometry

66. Assessment of the mineral content of bones by densitometry is used in the diagnosis and management of patients with metabolic bone disease. Over the last 30 years, a number of non-invasive radiological techniques have been developed for performing quantitative measurements on bone [G8, G41, G42, S23, S28, S87, W13]. Notwithstanding the early use of quantitative measurements based on conventional radiography [J14], the first commercially available specialist technique was that of single-photon absorptiometry (SPA), in which transmission through the patient of a scanning pencil beam from a radionuclide source is measured with a detector. Such measurements on bones in the arm or heel typically involve surface doses of 50 μGy and effective doses of <1 μSv [G5]. Truscott et al. [T3] have developed a portable system for measuring bone mineral density in the pre-term neonatal forearm, with an absorbed dose to the skin of 6 μGy.

67. Broadly similar levels of dose are achieved when the radionuclide source used in SPA is replaced by an x-ray tube, as in the technique of single photon x-ray absorptiometry (SXA). Measurements at more clinically relevant sites were made possible with the development of dual photon absorptiometry (DPA), although since 1988 this technique has largely been superseded by dual photon x-ray absorptiometry (DXA). Depending on the manufacturer, the dual energy x-ray beam required for DXA is generated either by rapidly switching the applied potential between 70 kV and 140 kV or by using an energy-selective rare earth filter [B4]; flash pulses from a portable, field emission x-ray tube have also been investigated [S86]. First-generation DXA scanners used a pencil beam, but the subsequent introduction of fan beams has allowed more rapid scanning. The dose to the patient depends on the precision of the measurement, as well as the site of investigation, which is commonly the spine, femur, hip, or whole body. Effective doses are typically 0.1–8 μSv per examination, with an entrance dose of 2–1,400 μGy [B69, G5, H12, K7, L9, N11, N12, N39]. The latest DXA scanners with fan beams provide improved images with a near diagnostic radiographic quality, although the patient dose is somewhat increased (entrance surface dose of about 900 μGy

and effective dose of 7–75 μSv [N12, N39]). Doses have also been reported for DXA measurements on a 5 year old child: an entrance surface dose of 6.0 μGy and an effective dose of 0.28 μSv for PA scans of the spine, and an entrance surface dose of 0.12 μGy and an effective dose of 0.03 μSv for total body scans [N40].

68. Experimental devices for bone densitometry have also been developed that are based on radiation scattering (Compton or Rayleigh) techniques, although such equipment is not in widespread use [M69, W53]. The absorbed dose over the volume of measurement is typically below 2 mGy with radionuclide sources [D12] and 0.1 mGy with a polychromatic x-ray source [S23].

69. A differential measurement of cortical and cancellous bone can be obtained from digital images provided by CT scanners using the techniques of quantitative computed tomography (QCT) [G5, P30]. Patient doses are relatively high, although they are critically dependent on the details of the method used. For measurements on the spine with a single energy technique, reported effective doses are 0.05–2.2 mSv and the surface doses between 10.4 mGy and 33.8 mGy; corresponding effective dose data with a dual energy technique range from 0.1 to 1 mSv [G5, H12, K7, N11, N39]. QCT measurements are also performed on the peripheral skeleton (pQCT) [L39], with an effective dose typically of about 3 μSv [G5].

70. Bone densitometry has an important role in the diagnosis of osteoporosis in high-risk groups and in the monitoring of treatment in particular patients, although the technique is not at present widely used in population-based screening for, say, low bone mass in perimenopausal women [C10]. DXA has become the most widely used technique. Variations in the levels of provision for DXA in different countries are indicated in Table 26. It has been estimated that clinical practice in the United Kingdom would ideally entail about 175 bone scans per 100,000 population per year. The annual collective dose from this enhanced level of examinations would typically be around 1 man Sv; by comparison, the total from all diagnostic examinations with x rays in the United Kingdom is about 20,000 man Sv.

71. DXA could become a tool for population screening. The estimated worldwide total of axial DXA scanners has increased steadily from over 6,000 in 1995 [L5] to 12,500 in 1998 [L40]; there are also over 9,000 peripheral x-ray systems [L40]. Notwithstanding such worldwide growth in the practice of bone densitometry, patient doses per examination are at the lower end of the exposure range normally encountered in diagnostic radiology. Accordingly, the contribution to collective dose from increased numbers of these procedures is still likely to remain insignificant.

(h) Paediatric radiology

72. Over the last decade, paediatric radiology has become internationally recognized as a subspeciality within diagnostic radiology, with increasing numbers of specialized radiologists, departments, and imaging equipment. Examinations of children (aged 0–15 years) merit special consideration in view of the increased radiation risk [R35]; the increased risk for thyroid, skin, brain, and breast cancer arising from the exposure of children is discussed further in Annex I, "*Epidemiological evaluation of radiation-induced cancer*". Specific techniques are required for assessing organ and effective doses to paediatric patients (see Section II.B and, for example, [A31, A32, H16, H38, H51, H52, P32, V20, V21, Z22]). There is, however, a relative lack of information on the typical levels of dose for such examinations. A preliminary analysis based mainly on data from the United Kingdom suggests that effective doses to children from conventional (not digital) radiographic x-ray examinations are, in general, lower than those from conventional examinations of adults by factors of between 2 and 10, depending on the age group [W11]. For examinations of the chest, which are by far the most frequent procedure for children, doses are generally no less than about one half of those for adults, whereas doses for examinations of the head appear broadly independent of age. For complex examinations involving many radiographs and fluoroscopy, such as barium meals, effective doses to children are generally about 30%–60% of those for adults. However, doses to paediatric patients from CT may be similar, or even higher, than the relatively high levels observed for adults [H38]. Age-specific dose data for x-ray examinations in Poland indicate patterns similar to those described above [L7].

73. As part of the development of quality criteria for diagnostic radiographic images in paediatrics [P31], three surveys of entrance surface dose measurements were carried out in Europe between 1989 and 1995 for frequent x-ray examinations [K4]. The results of over 1,500 such measurements are summarized in Table 27. For chest and skull examinations, there is a remarkable similarity between the median values for the three age groups, with no distinct increase with age. In all cases, the distributions of dose were very wide. Other local surveys have demonstrated variations in practice [B70, C44, L41, O3] and reduced levels of dose attributable to the careful choice of equipment and technique [C45, K19, M30, M31, M32, S88]. The main factors influencing dose for radiographic procedures are the speed of the film-screen combination and the use of an antiscatter grid. The main factors for fluoroscopy are the use of a grid and the operating characteristics (dose rate level) of the image intensifier [T22]. Differences in practice have been reported between non-specialist and specialist paediatric imaging centres. The latter often delivered higher doses to younger children as a result of the widespread use of a grid; doses in fluoroscopy were significantly lower, however [K19]. Some examples of the doses achievable with best practice [C20] are given in Table 28.

74. Reduced doses have also been reported from the use of digital imaging techniques in paediatric radiography. Computed radiography has been used successfully at speeds (using the analogy of speed classification for film-

screen systems) corresponding to 600 for chests and 1,000 for other examinations on children [H22]. Since few departments in the United Kingdom appear to employ film-screen systems with speeds greater than 400, such practice with computed radiography is equivalent, on average, to dose reductions of at least 60% (or 30% for chests). Initial results with a novel digital x-ray device incorporating a multiwire chamber show that it could significantly reduce doses in paediatric imaging [K20]. The mean values of entrance surface dose measured on samples of children undergoing different types of radiograph were 0.08 mGy (AP spine), 0.07 mGy (PA spine), 0.13 mGy (LAT spine), and 0.06 mGy (pelvis); entrance surface doses for a conventional imaging system were higher by a factor of between 12 and 19.

75. Reductions have been reported in the frequency of x-ray examinations of the urinary system and skeletal surveys for malignant disease when radionuclide studies are integrated into strategies for paediatric imaging [G2]. For older children, the effective dose from intravenous urography (IVU) may be double the dose of about 1 mSv from the alternative diagnostic technique for renal investigation, ^{99m}Tc DMSA scintigraphy [S45].

D. ASSESSMENT OF GLOBAL PRACTICE

76. Table 29 shows some reported national average annual individual doses (per patient and per caput) and collective effective doses from diagnostic medical x-ray examinations. The assessment of global practice according to the model described in Section I.D, however, requires knowledge of the mean values, by health-care level, of the frequency and the dose for each type of diagnostic x-ray examination. Although the data in Table 12 provide robust estimates of the total numbers of examinations per 1,000 population within health-care levels I and II, the values for the individual types of examination have had to be averaged over different populations due to the lack of comprehensive information for all countries listed and so do not represent a self-consistent set of data. Estimates of the relative frequencies by type of examination have therefore been made using selected national data for each health-care level. When appropriately scaled and combined with typical values of effective dose per examination, these frequencies lead to the estimates of annual collective doses for 1991–1996 shown in Table 30; the limited data available for health-care levels III and IV have been pooled so as to provide more reliable estimates for a combined population. Analyses are presented separately for both medical and dental x-ray examinations. The rounded values of effective dose for each examination category are either based on the data in Table 15 or, particularly in the case of health-care levels III–IV, are estimates in the absence of more specific data. Derived average effective doses per examination and per caput are also shown. The percentage contributions to annual frequency and collective dose due to the various types of diagnostic medical x-ray examination are analysed by health-care level in Table 31. The uncertainties inherent in the estimates of mean frequencies and doses 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.

77. According to the model developed, the global annual frequencies and doses assessed for 1991–1996 are dominated by the national practices in health-care level I; about 80% of the estimated global collective dose from medical x rays arises from examinations conducted in these particular countries, which together account for about one-quarter of the world population. The most important examinations in terms of the overall frequency of medical x rays are those of the chest and the limbs and joints, whereas the global collective dose is dominated by the more complex, but less frequent, procedures such as CT and examinations of the gastrointestinal tract. Significant differences are also apparent between the mean frequencies and doses for the different health-care levels. For example, the contributions from CT are markedly less for health-care levels II–IV relative to level I, and chest fluoroscopy appears particularly important for health-care level II due to its very high utilization for the large population of China. Practice with dental x rays has been assessed to be considerably smaller than that from medical x rays; the global frequency and collective dose are less than the corresponding values for medical x rays by factors of more than 3 and 100, respectively.

E. TRENDS IN DIAGNOSTIC RADIOLOGY

78. Trends in the global use of medical x rays are summarized in Figure IV in terms of increases, relative to the previous assessment for 1985–1990 [U3], in some key indicators of annual practice; small changes are unlikely to be significant in view of sampling differences and uncertainties in the estimated values. Whereas there has been an increase in global population by about 10% between studies, the estimated global total number of examinations has grown by about 20% and therefore the frequency per 1,000 population has increased by about 10%. The overall mean effective dose per examination has risen by about 20% and the annual collective effective dose by nearly 50%. Differences in the patterns of practice between the assessments for 1985–1990 and 1991–1996 are highlighted in Figure V, which illustrates the relative contributions by examination type to the global collective dose from medical x rays. Most notably, increases in contributions are apparent from CT, angiography and interventional procedures, with there being decreased contributions for examinations of the gastrointestinal tract and chest photofluorography. The global annual collective effective dose from dental x-ray examinations estimated for 1991–1996 is about 20% lower than the collective effective dose equivalent estimated for the previous assessment [U3]; the inherent differences in magnitude between these two dose quantities expected for dental exposures have already been

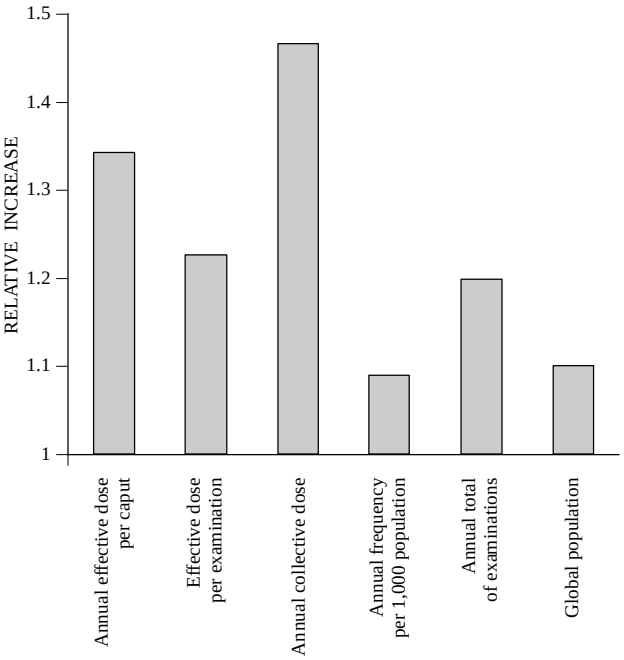

Figure IV. Temporal trends in global practice with medical x-ray examinations: average frequencies and doses for 1991-1996 relative to previous estimates for 1985-1990.

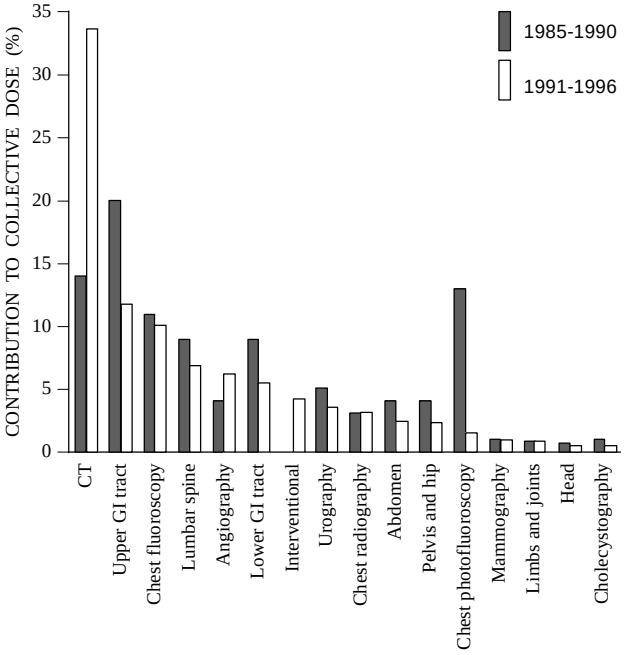

Figure V. Percentage contributions by examination type to global collective dose from medical x-ray examinations: comparison of data for 1955-1990 and 1991-1996.

noted (Section II.B). The present estimate of effective dose per caput is about 30% lower than the figure assessed previously for dental x rays. In light of the considerable variations in the reported national data concerning the distributions by age and sex of patients undergoing various types of diagnostic x-ray examination (Table 14), it is difficult to discern any specific trends in the mean values relative to previous data. The average levels of x-ray equipment per million population estimated for the various health-care levels and time periods are summarized in Table 7, although the significant differences that exist between individual countries of the same health-care level and the limited sample sizes should also be noted (Table 4). However, the analysis suggests a broad trend for reducing numbers of medical x-ray generators per million population in health-care level I and hence also in the world. There is an apparent increase in the average number of medical x-ray examinations per medical x-ray generator, with estimates of 2,500 for 1991–1996 and 2,100 for 1985–1990.

79. Overall trends in radiation exposures from diagnostic examinations with x rays are due to two kinds of change: changes in both the type and frequency of the procedures carried out, as determined by the prevailing patterns of disease and clinical practice; and changes in the associated levels of dose to individual patients for given procedures. Doses are influenced by the continuing advances in techniques for the production, detection, and control of radiation, including the development of alternative modalities for diagnosis, as well as by initiatives in quality assurance and patient protection [A34, H54, H55, R36, R37]. Trends in the frequencies of examinations and doses per examination are discussed further in the two Sections following.

1. Frequencies of examinations

80. Temporal trends in the annual frequencies of all diagnostic medical x-ray examinations per 1,000 population are summarized in Table 32. The present estimates of average total frequency for health-care levels I (920 per 1,000) and II (154 per 1,000) are larger than the previous values for 1985–1990 (890 and 120 per 1,000, respectively), although the averages for each time period have been made over different populations; any comparisons of data for health-care levels III and IV are less reliable owing to the limited sample sizes involved. Notwithstanding these overall trends in average frequency for the different health-care levels of the global model, national frequencies have increased in some countries and decreased in others between 1985–1990 and 1991–1996; some specific examples are given below. Temporal trends in the average annual numbers of different types of diagnostic medical x-ray examination per 1,000 population by health-care level are summarized in Table 33. The annual frequencies of diagnostic dental x-ray examinations per 1,000 population for different countries and time periods are summarized in Table 34, together with the average values for each health-care level.

81. Increases in the annual total numbers of examinations and frequencies per 1,000 population have been reported for some countries, accompanied also by significant changes in the patterns of practice for individual types of procedure. For example, in the Czech Republic, the annual number of medical x-ray examinations rose from 8,100,000 in 1990 to 9,150,000 in 1994, with particularly large increases observed for CT and mammography due to the installation of new equipment and also some changes in the system of health

insurance. In Cyprus, the annual frequency of medical x-ray examinations rose steadily from 794 per 1,000 population in 1990 to 1,021 per 1,000 in 1995. In Poland, the annual number of x-ray examinations per 1,000 population rose from 572 to 715 between 1986 and 1996 [S49]. Increases were observed for examinations of the spine, CT, photofluorography and mammography, with there being decreases for urography and examinations of the upper gastrointestinal tract due probably to an increased use of ultrasound. In Norway, the total frequency of radiological examinations increased from 641 to 710 per 1,000 inhabitants between 1983 and 1993, with the most significant trends being for increased numbers of CT examinations and, owing to the introduction of alternative procedures, reduced numbers of examinations of the gastrointestinal tract [O6]. In Malaysia, almost all examinations experienced increasing frequency from 1990 to 1994, with the exceptions of barium studies, cholecystography and urography owing to an increasing use of ultrasound and fibre-optic endoscopy [N26]. The most notable increases were observed for CT, cardiac procedures and mammography. Data for the United States indicate an estimated increase of between 30% and 60% in the numbers of radiological examinations in hospitals between 1980 and 1990, with CT being an important influence [M1].

82. Elsewhere, practice has remained more static or has shown some decreases. In Bulgaria, the annual frequency of medical x-ray examinations rose from 220 per 1,000 population in 1950 to a peak of 1,170 per 1,000 in 1980, before falling to a level of 560 per 1,000 in 1992; corresponding values of effective dose per caput were 0.4 mSv, 1.79 mSv and 0.72 mSv, respectively for these particular years. In Russia, the annual frequency of medical x-ray examinations rose from 1,340 per 1,000 population in 1980 to a rate of 1,560 per 1,000 in 1985, since when it has fallen to a level of 1,230 per 1,000 in 1997; corresponding values of effective dose per caput for these particular years were 1.26 mSv, 1.32 mSv and 0.80 mSv, respectively. However, the frequency of dental x-ray examinations in Russia rose steadily from 74 per 1,000 population in 1985 to 96 per 1,000 in 1997. In the Ukraine, the frequency of x-ray examinations has decreased from 948 per 1,000 population in 1987 to 600 per 1,000 population in 1994, with the effective dose per caput decreasing correspondingly by about a factor 2 [K18]; these reductions were due in particular to decreases in the numbers of examinations being performed in the regions contaminated by the accident at Chernobyl and in the utilization of the higher-dose fluoroscopic procedures. In Ghana, estimates of the annual frequency of x-ray examinations during the period 1990 to 1996 ranged from 6 to 11 per 1,000 population, with there being no simple pattern [S38]. In Germany, the increase in the annual frequency of x-ray procedures between 1988 and 1992 has been slight overall, with increasing practice in CT, angiography, and interventional radiology offsetting a marked decrease in examinations of the gastrointestinal, biliary, and urinary tracts [A2]. The frequency of medical x-ray examinations has also remained fairly constant in the United Kingdom between 1983 and 1993, although the frequency of dental x-ray examinations has increased by over 30% [T15]. Large increases were also reported for CT, mammography, angiography and interventional procedures, with substantial decreases apparent for examinations that have been partially replaced by endoscopy (barium meals) and ultrasound (biliary and urinary systems). In contrast, the overall frequency of medical (excluding dental) x-ray examinations in Romania decreased by about 20% between 1980 and 1990, with the somewhat larger decreases (over 30%) for fluoroscopy and photofluorography being offset by an increase of over 20% for radiography [D1]; a subsequent analysis of all types of x-ray examination during 1990–1995 has suggested a fairly static total annual frequency (495 versus 511 per 1,000 population), although there have been further reductions in collective dose [D28]. In South Africa, the overall annual frequency of x-ray examinations (excluding mass miniature and dental) in 1990 was reported to be 180 per 1,000 population, although marked differences were observed between race groups, with rates of 67 per 1,000 for blacks, 110 for coloureds, 230 for Asians, and 460 for whites [M22]. In Canada, variations in the frequency of medical x-ray examinations between the different provinces ranged from 708 per 1,000 population to 1,043 per 1,000, with the national mean value being 892 per 1,000 [A15].

83. Developments in imaging technology, particularly those involving non-ionizing radiation, will have a significant influence on the practice of radiology and on the medical exposure of populations. Transfer of technology is likely to be most rapid in developed countries, categorized as health-care level I. MRI is becoming the imaging modality of choice for many areas of anatomical examination, although its wide-scale adoption was initially hampered by relatively long imaging times and high equipment cost [Z1]. The number of

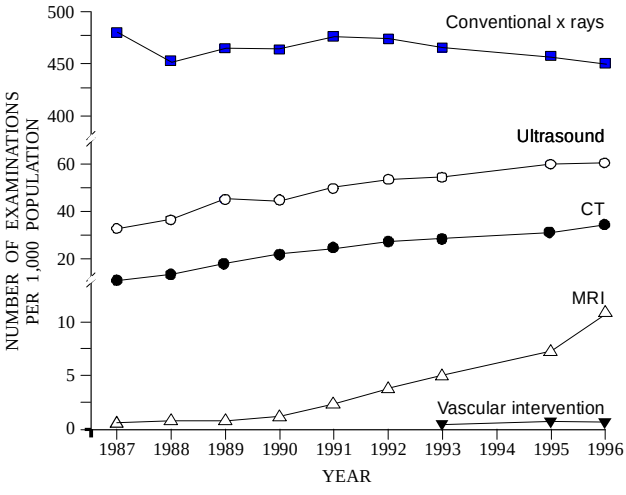

Figure VI. Trends in diagnostic radiology practice in the Netherlands [B89].

MRI studies worldwide grew from 6 million in 1989 to 18 million in 1995, with the total number of installed MRI systems having risen from 2,800 to 9,400 over this period [D23]. In contrast to MRI, ultrasound represents a relatively cheap, portable, and increasingly sophisticated form of imaging [W1]. Fibre-optic endoscopes allow direct visualiza-

tion of the gastrointestinal tract and not only complement but also replace some x-ray examinations [W2]. For example, surveys in the United Kingdom for one particular region (population 4.7 million) from 1986 to 1992 showed a steady increase in the annual frequency of endoscopies (upper gastrointestinal endoscopies and colonoscopies), from 8.4 to 10.0 procedures per 1,000 population, whereas there was a corresponding decline in barium studies (meals and enemas), from 12.9 to 10.1 procedures per 1,000 population [S36]. The trends in diagnostic radiology practice in the Netherlands between 1987 and 1996 are summarized in Figure VI [B89]; although the number of conventional x-ray examinations per 1,000 population has remained fairly constant, there have been increases in practice with CT, MRI and ultrasound.

84. Economic growth in South-East Asia is allowing significant improvements in general health care, and basic x-ray services are becoming available in most rural areas [M2]. Disease patterns in urban centres are becoming similar to those in Europe and North America, although a shortage of staff and a lack of standardization in training remain areas of concern in this part of the world.

2. Doses per examination

85. The average values of effective dose per examination derived from surveys by UNSCEAR are summarized in Table 35 by type of examination, health-care level and time period. Any analysis for trends is hampered by the averaging of doses over different populations and the uncertainties in the data. However, there are perhaps broad suggestions for reductions in typical dose with time for some radiographic examinations, such as pelvis and hip, and head, and for an increase in the dose per CT procedure between 1980–90 and 1991–1996. Overall, the estimate of 1.2 mSv for the global mean effective dose per medical x-ray examination during 1991–1996 (Table 30) is larger than the corresponding value of 1.0 mSv estimated for 1985–1990. This trend is likely to be due to the increasing use of complex and higher dose imaging procedures, particularly CT, in developed countries.

86. There are continuing developments in equipment and techniques for imaging [S90]. Film technology continues to advance, focusing on grain and emulsion structure in both the film and intensifying screen and on better spectral matching of the screen-film combination [F22, S1]. Conventional film images of high quality can be obtained with comparatively low patient doses, although there are still large differences in image quality for similar speed systems, depending on the manufacturer and on the screen-film combination [G1]. Digital radiological techniques offer the potential for improved image quality, although this is in general at the expense of higher patient doses. The impact of introducing such equipment depends somewhat on the choice of exposure settings and the techniques in use [K55]. For example, digital fluoroscopic systems were shown in one particular analysis to result in significantly lower levels of dose-area product during barium studies compared with non-digital systems: 7.8 Gy cm^2 and 24.2 Gy cm^2, respectively, for meals, and 13.9 Gy cm^2 and 25.3 Gy cm^2, respectively, for enemas [B14]. A second study, however, reported similar or even higher levels of dose from digital compared with conventional equipment (4.9 Gy cm^2 and 3.8 Gy cm^2, respectively, for meals and 16.7 Gy cm^2 and 20 Gy cm^2 for enemas), owing to increased levels of exposure during the fluoroscopic part of such examinations [H10].

87. For digital radiography systems, exposure can be preselected in a broad range so that patient dose can be adapted to the diagnostic problem and the image quality necessary. Photostimulable phosphor computed radiography offers the important advantages of high imaging efficiency over a wide exposure range and the presentation of images at consistent display levels independent of exposure levels [B71, F21]. The greater reliability of the image reproduction can lead to a reduction in the numbers of repeat films needed because of incorrect exposure [C1, P33, W55]. Reduction of patient dose per image is in general limited by considerations of image quality (signal to noise ratio), although lower doses have been reported for particular applications of computed radiography compared with doses from conventional techniques [J15, S89,W8].

88. For digital fluorography, spatial resolution is comparable to that with the 100 mm film technique, although lower than that for full-size, film-screen radiography. Image-intensifier-TV-based digital systems were shown in one study to reduce patient effective dose during examination of the abdomen by factors of at least 5 for a given projection when compared with conventional medium-fast film-screen combinations [M3]. In digital subtraction vascular imaging, the input dose to the image intensifier can vary significantly (typically 5–20 μGy per frame) depending on the particular settings selected [S3]; this dose is considerably higher than for modern digital fluorography (typically 0.5–1.5 μGy per frame) or for standard radiography with a fast (400 speed) film-screen combination (typically less than 5 μGy per radiograph). Accordingly, there is a potential for high patient doses in DSA as a result of the capability for rapid acquisition of images and the frequent use of long series of images for subtraction.

89. The introduction of digital imaging leads to significant changes in operational practices in radiology departments [C46, D43, K53, L42, V22]. The use of improper technique could result in higher patient doses. The increasing adoption of digital technology provides opportunities for advances in the post-processing of images, computer-aided diagnosis, and medical image management within and between hospitals using PACS systems [S91]. Such systems will allow better monitoring of radiology practice and help reduce patient exposures from the loss of films [H1, W56]. Initial developments came in the United States and Japan, but both large- and small-scale projects are now under way in European radiology departments [S4]. The transmission of digital radiographic images for remote consultation (teleradiology) promises to enhance practice in radiology, particularly for facilities at which services are otherwise deficient [L12,

W54]. However, the increasing utilization of digital imaging technology in developed countries, particularly CT and advances such as helical and dynamic CT scanning, is likely to result in further increases in the global average dose per examination.

90. Notwithstanding the proliferation of increasingly complex x-ray technology in developed countries, WHO has since the 1970s concentrated on developing design criteria for equipment to provide basic radiography, so as to lessen the inequity in imaging services around the world. The most recent version is known as the WHO Imaging System-Radiography (WHIS-RAD) [W12]. WHO-specified equipment is currently produced by several leading manufacturers, and by 1995 about 1,000 units had been installed in 60 countries. However, health services have failed to adopt the system to the degree that had been expected, despite its ease of use; there were, for example, only 39 units operating in nine countries of the Americas in 1997 [B33].

91. Novel digital x-ray imaging systems that employ improved detector technology and offer potential reductions in patient dose by up to two orders of magnitude in comparison with film-screen systems are under development [A35, L43, Y4]. These devices employ various approaches based on phosphor x-ray converters, where light quanta are produced as an intermediate stage, as well as direct x-ray-to-charge conversion materials such as gases and, using thin-film transistor and charge-coupled device (CCD) technologies, zinc cadmium telluride, amorphous selenium, and amorphous silicon [A33, C47, H53, M70, R38]. Self-scanned flat-panel detectors could in principle provide high-quality radiographic, fluoroscopic, or fluorographic images [S92, Z23]. In addition to such large-area devices, trials are in progress of a prototype low-dose imaging system based on a scanning beam geometry [S2].

92. More speculative developments in imaging are under investigation, including the use of synchrotron radiation [C48, K56, L44, M5], phase-contrast imaging using polychromatic hard x rays [W6], time-gated imaging using x rays from a laser-produced plasma [G44], and a compact radiological source based on electron cyclotron resonance magnetic mirror discharge [B2]. Also, the recent availability of large-array biomagnetometer systems is facilitating the development of techniques of magnetic source imaging, in which magnetoencephalography is combined with MRI to map brain activity for the purposes of guiding neurosurgical interventional procedures [G15]. It has been argued, however, that radiology practice is on balance likely to be more affected in the medium term by the maturing of existing technologies than by the innovative modalities under development [Y1].

3. Quality assurance and patient protection initiatives

93. Measures that facilitate the achievement and maintenance of good practice in diagnostic radiology will have some influence on the frequency of examinations and levels of patient dose [T16]. In general, such initiatives can be expected to decrease doses per examination and per caput doses worldwide, owing to reductions in repeated and unnecessary exposures [D44, K54, M71]. Among the topics of relevance will be the implementation of quality assurance measures in radiology departments, including accreditation under formal quality systems [I1] and audits of practice [G43, M72, V23, W58, W59]; the training and education of persons involved with medical radiation, including clinicians, technicians, physicists, and administrators [I2]; the promulgation of basic recommendations on patient protection [I3, I5, I17]; and guidance on the rational and effective use of imaging [H30, W3, W4, W5].

94. Several studies have highlighted the problem of unnecessary exposures. An analysis in the United Kingdom, for example, suggested that at least 20% of examinations were clinically unhelpful to patient management and, without any clear justification, should not have been performed [N2]. Guidelines [C49, R1] for the appropriate use of diagnostic radiology have been found to reduce selectively the rates of referral by primary care physicians (general practitioners) [R2]. Clinical audit, which is a retrospective analysis of performance that is closely linked to the mainly prospective process of quality assurance, is likely to play an increasingly important role in the control of radiology. In Romania, a study of radiology practice at a sample of 130 hospitals in 1995 observed that about 23% of the radiographs produced were of no diagnostic utility; this rate equates, on a national scale, to a total of 2 million such radiographs [D6]. Over 50% of darkrooms in the study were found to have excessive illumination.

95. Dose reductions attributable to the influence of patient protection measures have been reported in several large studies. A review in 1995 of national dose data in the United Kingdom revealed an average 30% reduction over a 10-year period in the mean levels of entrance surface dose and dose-area product for common types of radiograph and x-ray examination [H11, W57]. The main identifiable reason for this dose reduction was the more extensive use of faster film-screen combinations, facilitated by the coherent combination of a national protocol for patient dose measurements and systematic advice on patient protection, including national reference dose levels [N41, S6]. Fewer than 10% of hospitals exceeded the national reference doses in 1995, compared with 25% in 1985. Such reductions in the collective dose from conventional x-ray examinations in the United Kingdom will, however, have been offset by the much increased use of CT [S10]. Practice in CT can be expected to be influenced in due course by the development of quality criteria for CT examinations, which include reference dose levels [E4]. The applicability of similar European quality criteria to radiographic images of adult patients has been assessed widely in surveys involving some 3,000 dose and image quality measurements in about 100 hospitals [C6].

Even as these surveys show the persistence of wide variations in performance, they provide clear evidence that higher doses prevailed when there was little or no compliance with recommended techniques [M11].

96. Significant dose reductions have also been demonstrated over a 5-year period at a large teaching hospital in Madrid as the result of a systematic programme for the optimization of patient protection, which included implementation of patient dosimetry and quality control [V1]; in particular, between 1986 and 1990 effective doses for studies of the gastrointestinal tract were reduced by about 50% as a result of replacing deficient fluoroscopic equipment (from 10.7 mSv to 4.9 mSv for barium meals and from 9.4 mSv to 6.8 mSv for barium enemas), while doses from examinations of the spine fell by about 40% owing to changes in film cassettes and tube filtration (from 0.31 mSv to 0.18 mSv for cervical spine and from 2.2 mSv to 1.4 mSv for lumbar spine). In contrast, there were increases over this period in the mean doses per examination from CT (from 5.7 mSv to 6.5 mSv) and angiography (from 12 mSv to 13 mSv) and increases by a factor of 2 in the contributions from these procedures to total collective dose (with 25% due to CT and 17% from angiography in 1990).

97. A pilot international programme on radiation doses in diagnostic radiology, which involved two series of measurements in seven countries on three continents, achieved considerable reductions in dose, without deterioration of diagnostic information, by the application of simple and inexpensive methods [I4, O8, O18]. Average reductions of about 50% in entrance surface dose were reported following increases in tube filtration, applied potential and film-screen speed. These methods led to significant improvements between surveys in the percentage of x-ray rooms complying with reference dose values suggested by the European Commission [C6]: initial and final levels of compliance were 20% and 75% for lumbar spine (PA), 29% and 36% for chest (PA), 75% and 100% for abdomen, and 0% and 100% for breast.

98. Dose reductions from changes in equipment or technique, without any significant effect on the diagnostic efficacy of examinations, have also been reported by numerous individual studies. These include, for example, the use of rare earth intensifying screens for radiography [G33, J4, S55], lower tube currents during fluoroscopy [S21], pulsed fluoroscopy [V12], review of grid usage in fluoroscopy [L30, S52], additional filtration [G30], and region-of-interest (ROI) radiologic imaging [G32, K25, M43, S59]. The latter involves placement, between the x-ray source and the patient, of a filter which attenuates the beam peripheral to the ROI. Reported dose reductions associated with the introduction of such filters are as follows: 70% in dose-area product during fluoroscopy [L1] and factors of 3–10 in skin dose during imaging in neurointerventional radiology [R5].

F. SUMMARY

99. The utilization of x rays for diagnosis in medicine varies significantly between countries (Tables 4, 8 and 12). Information on national practices that has been provided to the Committee by a sample of countries has been extrapolated to allow a broad assessment of global practice, although inevitably there may be significant uncertainties in many of the calculated results. On the basis of a global model in which countries are stratified into four health-care levels depending on the number of physicians relative to the size of population, the world annual total number of medical x-ray examinations for 1991–1996 is estimated to be about 1,900 million, corresponding to a frequency of 330 per 1,000 world population (Table 9); previous estimates of these quantities for 1985–1990 were 1,600 million and 300 per 1,000 population, respectively. The present global total of examinations is distributed amongst the different health-care levels of the model 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–IV (20 per 1,000 population). In addition to such medical x rays, there is also an estimated global annual total of about 520 million dental x-ray examinations, corresponding to a frequency of 90 per 1,000 world population; the assumed distribution between health-care levels is for over 90% to occur in level I and <0.1% in levels III–IV. 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 (Tables 32 and 34).

100. The estimated doses to the world population from diagnostic medical and dental x-ray examinations are summarized in Table 36. The global annual collective effective dose from medical x rays for 1991–1996 is estimated to be about 2,330,000 man Sv, equating to an average dose per caput of 0.4 mSv; previous estimates of these quantities for 1985–1990 were 1,600,000 man Sv and 0.3 mSv, respectively. The distribution of collective dose among the different health-care levels of the global model is presently as follows: 80% in countries of level I (giving a mean dose of 1.2 mSv per caput), 18% in countries of level II (corresponding to 0.14 mSv per caput) and 2% in countries of health-care levels III–IV (corresponding to 0.02 mSv per caput). Diagnostic dental x-ray examinations are 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 are less than the corresponding estimates for 1985–1990 of 18,000 man Sv and 0.003 mSv per caput, although uncertainties in all these estimates are considerable and this apparent trend may not be real. Approximately 68% of the present global collective dose from dental x rays arises from countries in health-care level I, with contributions of about 31% and <1% from health-care levels II and III–IV, respectively.

101. The numbers of x-ray generators (excluding dental units) available for diagnostic radiology vary considerably between countries and the health-care levels of the global model (Table 4), with estimated averages per million population of 0.5, 0.2 and 0.02 for levels I, II and III–IV, respectively (Table 9). The estimated average annual number of medical x-ray examinations per medical x-ray generator is lower for countries of health-care levels III–IV (value of 1,100) than for those of level II (2,300) or level I (2,700). The estimated average values of annual collective dose per medical x-ray generator follow a similar global pattern: 1.2 man Sv per unit in levels III–IV, 2.0 man Sv per unit in level II, and 3.6 man Sv per unit in level I.

102. The estimated global mean effective dose per medical x-ray examination for 1991–1996 is 1.2 mSv (Table 30), which may be compared with the level of 1.0 mSv estimated for 1985–1990. However, the levels of dose to individual patients vary significantly between the different types of examination and also countries (Tables 15 and 16). The contributions to collective dose provided by the different categories of examination are summarized in Table 31 by health-care level. On a global scale, population exposure from medical x rays is now dominated by CT (which provides 34% of the annual collective dose), rather than examinations of the upper gastrointestinal tract (12%) which was estimated to be the most important procedure for 1985–1990 (Figure V). This new pattern also applies for countries of health-care level I, where the mean contribution from CT is presently 41%, although the dominant practices elsewhere are chest fluoroscopy in health-care level II (50% of collective dose) and examinations of the lower gastrointestinal tract in levels III–IV (34%), with CT providing contributions of only 5% and 2%, respectively.

III. DIAGNOSTIC ADMINISTRATIONS OF RADIOPHARMACEUTICALS

103. Administration of radionuclide preparations (radiopharmaceuticals) to patients, broadly referred to as nuclear medicine, is widely practiced throughout the world. The procedures are primarily intended for diagnostic purposes. Many of the diagnostic applications of radionuclides are conducted *in vitro* rather than *in vivo*. For example, about 100 million procedures with such material were performed in the United States in 1989, although only 10% of these involved the administration of radiopharmaceuticals directly to patients [N13]. The remaining 90% of practice comprised radioimmunoassay procedures, which use small amounts of radioactive material in the analysis of biological specimens such as blood and urine and do not give rise to the exposure of patients; these uses are not considered further in this review. Diagnostic *in vivo* examinations are discussed in this Section, and less-frequent therapeutic nuclear medicine procedures are considered in Chapter V.

A. TECHNIQUES

104. Whereas the broad aim in diagnostic radiology is the imaging of anatomy, the practice of nuclear medicine is more closely linked to the investigation of patho-physiological processes. In essence, radionuclides are used as a biological tracer by incorporating them into a pharmaceutical appropriate to the nature of an investigation; key technical advances are summarized in Table 37. Following administration of the radiopharmaceutical to the patient, the resulting biodistribution and localization is dictated by the pharmaceutical preparation used, with the radionuclide label providing the means of detection. Most procedures involve some type of measurement concerning the retention or excretion of the tracer so as to quantify organ or tissue function. Probe detectors can be used to measure uptake in particular organs such as the thyroid, whereas imaging is carried out using rectilinear scanners with single or double detectors or, more commonly, with a large field of view gamma camera.

105. Diagnostic techniques with radiopharmaceuticals are widely utilized in medicine; clinical applications include oncology [B80, M83, M84, R41, V26], cardiology [B81, P40, P41, Z26, Z27], neurology and psychiatry [E17], and endocrinology, as well as the investigation of infection and inflammation [N47, P38, P39] and various biological systems (musculo-skeletal, respiratory, gastrointestinal and genito-urinary) [M25, P8]. In oncology, for example, important roles for nuclear medicine include detecting unknown primary sites of cancer, differentiating between benign and malignant disease, staging the extent of disease (local, nodes and metastases), planning and assessing the response to therapy, and detecting recurrence [C18]. Alternatively, dilution techniques, based on the measurement of activity in samples of body fluids, can be used, for example, in haematology to assess plasma volume, red cell mass, total body water, extracellular fluid, and exchangeable electrolytes [P8]. The activities administered are determined by the diagnostic information required within the chosen period of the procedure [M86]. International [E10, E16, G48, I5] and national (for example, [A20, F25, M85]) guidance is available concerning the techniques and typical activities for common procedures.

106. In practice, a range of radionuclides are used in diagnostic nuclear medicine that meet the necessary requirements for effective and efficient imaging. All are produced artificially, using four principal routes of manufacture: cyclotron bombardment (producing, for example, ^{67}Ga, ^{111}In, ^{201}Tl, ^{57}Co, ^{123}I, ^{11}C, ^{15}O, ^{13}N, and ^{18}F); reactor irradiation (^{51}Cr, ^{75}Se, ^{59}Fe, ^{58}Co, ^{125}I, and ^{131}I, for example); fission products (yielding, for example, ^{131}I, ^{133}Xe and ^{90}Sr); and generators that provide secondary

decay products from longer-lived parent radionuclides. The most common example of the latter is the column generator incorporating ^{99}Mo for the provision of ^{99m}Tc which, because of its highly suitable physical characteristics for a wide range of applications, forms the basis for over 80% of the radiopharmaceuticals used in nuclear medicine. Most ^{99m}Tc generators utilize fission-produced ^{99}Mo, although techniques of neutron irradiation could provide a viable alternative source of this important parent radionuclide [B82, K61]. Other examples of generators include those incorporating ^{113}Sn (for the provision of ^{113m}In), ^{81}Rb (for ^{81m}Kr), and ^{68}Ge (for ^{68}Ga).

107. In addition to conventional planar imaging, techniques have also been developed to allow emission tomography which, like x-ray CT, can demonstrate internal structures or functional information from cross-sectional slices of the patient [I24]. Two basic modalities have evolved. The most common is that of single-photon emission computed tomography (SPECT). This utilizes conventional gamma-emitting radiopharmaceuticals and is often performed in combination with planar imaging. SPECT imaging requires a scanning system incorporating a circular array of detectors or, more often, a rotating gamma camera system with up to four detector heads. The second modality is the more specialized technique of positron emission tomography (PET). This is based on the simultaneous detection of the pairs of photons (511 keV) arising from positron annihilation and mostly uses the short-lived biologically active radionuclides ^{15}O, ^{11}C, ^{18}F, and ^{13}N. Dedicated PET scanners comprise a circular array of detectors, although PET imaging can also be performed using coincidence-adapted gamma camera systems [B83, J8, L50]. Quantitative functional tomographic imaging requires correction for the attenuation of photons by the patient, and this can be accomplished by transmission measurements made before, after, or during the emission scan, using an external radionuclide source [B39]. Such transmission measurements add little to the typical dose routinely received in clinical SPECT or PET; the additional dose is typically <0.1 mSv [A40, T12].

108. Radionuclides are also used for the intraoperative localization of tumours and lymph nodes using surgical nuclear probes and a range of radiopharmaceuticals [C53, P9, R13, S104, T13, W62]. Such practice has, for example, increased steadily in the United Kingdom since 1980, with a total of 68 surgical procedures being undertaken at 35 hospitals over a 15–year period [P10]. Probe detectors and mobile gamma cameras also allow bedside nuclear medicine investigation in the intensive-care unit [P11].

B. DOSIMETRY

109. The radiation doses to patients resulting from administrations of radiopharmaceuticals are determined by a range of physical and biological factors which include the amount and form of the radioactive material administered, the route of administration, the biokinetics and physiological fate of the radiopharmaceutical, and the decay scheme of the radionuclide [I35, M87, R42]. Absorbed doses to the various organs and tissues are generally estimated using the dosimetric formalism developed by the Medical Internal Radiation Dose Committee of the United States Society of Nuclear Medicine (MIRD) [L51, S105]. Broadly, this approach involves knowledge of the cumulative activities in each source organ, together with estimates and summation of the absorbed fractions of energy in every target organ from each source organ. Cumulative activities are derived on the basis of quantification of organ uptake in human studies using, for example, SPECT and PET imaging, or extrapolation from animal models [D47, L52, M87, S105]. Specific absorbed fractions are estimated by Monte Carlo calculations [L53, Z28] using anthropomorphic mathematical phantoms; values are available for standardized phantoms representing typical adult, paediatric and pregnant patients [S105, S106]; more realistic voxel phantoms are also being developed for use in internal dosimetry [J19, P42, Y18].

110. Coefficients derived using this methodology have been published that allow the estimation of organ and effective doses to adults and children from administered activities for a wide range of commonly used radiopharmaceuticals [I19, I37, I39]. Data are also available for some new radiopharmaceuticals (see, for example, [A41]) and for other computational techniques [J20, J21]. The administration of radiopharmaceuticals to patients also gives rise to the exposure of other population groups, such as breast-feeding infants [M88, M89], although these doses are not considered further in this review. The average doses to specific organs provided by conventional macroscopic dosimetry can grossly underestimate radiation exposures to individual cells [A42]. New methods of cellular dosimetry are being developed for assessing the risks associated with new pharmaceuticals that target specific cells and cellular components with short-range radiations, such as Auger electrons [B84, F24, H63].

111. Patient doses for common types of procedure are summarized principally in this review in terms of the administered activities for each radiopharmaceutical, although some typical values of effective dose are included and estimates of collective effective dose are used broadly to characterize overall practice.

C. ANALYSIS OF EXPOSURES

1. Frequency of examinations

112. The use of radiopharmaceuticals in medical diagnosis is less widespread than the use of x rays. There are large variations in practice from country to country, with nuclear medicine examinations not being performed at all in some smaller countries or LDCs. Annual numbers of diagnostic administrations of radiopharmaceuticals reported by different

countries for the years 1991–1996 are summarized in Table 38 by type of procedure and for all diagnostic practice. Data are presented in terms of numbers of administrations per 1,000 population, with some analysis by radionuclide and with countries grouped according to health-care level. These national figures were often estimated in quite different ways, and some particular qualifications to the data are given in the footnotes. The percentage contributions of each type of examination to total frequency are given in Table 39. Mean values of frequencies have been derived for each health-care level by averaging total numbers of procedures over total populations.

113. There are significant differences in the patterns of practice between countries, even for those within the same health-care level. National annual total frequencies vary by a factor of over 100 in the 36 countries in health-care level I utilizing nuclear medicine (0.5–65 examinations per 1,000 population); disregarding countries with zero practice, smaller variations exist in level II (0.6–2.1 examinations per 1,000 population in a sample of nine countries), level III (0.05–0.6 examinations per 1,000 population in a sample of three countries), and level IV (0.01–0.02 examinations per 1,000 population in a sample of two countries). The average total frequencies for levels II, III, and IV are smaller than the average for level I (about 19 examinations per 1,000 population) by factors of about 17, 70, and 1,000, respectively. These averages are less (by at least a factor of 50 in the case of level I) than the corresponding average use of x rays for diagnostic examinations at each level.

114. Notwithstanding differences between the individual countries, some general differences are apparent in the patterns of use between the broad health-care levels. For countries in level I, practice is dominated by bone scans, with significant contributions also from thyroid scans, cardiovascular studies, liver/spleen scans, and lung studies. In the United States, for example, 90% of practice in 1991 was accounted for by just 10 *in vivo* diagnostic procedures, although over 150 different types of nuclear medicine procedure were in use [N13]. For countries in levels II–IV, thyroid studies are the most important type of procedure. Temporal trends in the frequency of examinations are discussed in Section III.E.

2. Exposed populations

115. The distributions by age and sex of patients undergoing various types of diagnostic nuclear medicine procedure in 1991–1996 are presented in Table 40 for selected countries of the four health-care levels; additional information about some of these data is included in the footnotes. This analysis uses the same three broad ranges of patient age as were used for x-ray examinations, above, and in the UNSCEAR 1993 Report [U3]. Some country-to-country differences in age distribution are evident for each particular type of examination, even within the same health-care level. Previous analyses have suggested that diagnostic nuclear medicine is largely conducted on populations of patients who are in general older than those undergoing x-ray examinations and thus also older in comparison with whole populations [U3]. This conclusion is broadly supported by the present survey, although significant numbers of procedures, particularly renal and brain scans, are conducted on children. As for broad differences in practice between the health-care levels, there is for most types of procedure a shift towards the two younger age ranges for countries in levels II–IV compared with countries in level I. This is likely to reflect the known differences in national population age structures [U3].

116. Notwithstanding the preponderance of cardiovascular studies on males and thyroid studies on females, the distributions of nuclear medicine examinations between the sexes do not deviate greatly from the underlying patterns for whole populations, although some national variations are apparent in the data reported for particular types of procedure.

3. Doses

117. The typical activities administered in different countries for different types of diagnostic procedure in 1991–1996 are presented in Table 41. The average activities shown for key radiopharmaceuticals within each health-care level include weightings for the numbers of such administrations in each country. Some reported values of effective dose for common procedures, calculated from administered activities using standard dosimetric methods [I19, I37], are shown in Table 42. Typical effective doses from PET imaging are presented in Table 43, together with estimates of the corresponding mean doses to the uterus. Further data are given elsewhere concerning uterine doses for other nuclear medicine procedures (for example, [A20]) and doses to the embryo/fetus of pregnant patients [M90, R43, R44, S107]. In general, the typical effective doses from diagnostic nuclear medicine procedures span a similar range to those from diagnostic x-ray examinations.

118. Diagnostic procedures on children are conducted using levels of administered activity that are lower than the corresponding values for adult patients [E16, S41]. The administered activities are generally scaled according to body surface area or weight [A20]. When following the latter scheme, the resultant effective doses to children will in general be roughly the same as those to an adult. Examples of the effective doses to paediatric patients undergoing some common procedures are given in Table 44 [G47].

119. Abnormally high local tissue doses may result when there is partial or complete extravasation of the activity intended for intravenous administration [K64, P8]. For example, maximum local doses of 128 Gy (from 740 MBq ^{99m}Tc extravasated into 0.5 ml) and 378 Gy (74 MBq of ^{201}Tl) have been estimated on the assumption of no biological clearance, although doses in practice are likely to be substantially lower and no deterministic effects have been observed [B85, T24]. The absorbed doses to particular organs can be reduced through modifications to practice during some nuclear medicine procedures [I38].

D. ASSESSMENT OF GLOBAL PRACTICE

120. Table 45 shows some reported national average annual individual doses (per patient and per caput) and collective effective doses from diagnostic nuclear medicine procedures. In order to provide a systematic assessment of practice worldwide, national data from the UNSCEAR Survey of Medical Radiation Usage and Exposures have been combined on the basis of the global model of population described in Section I.D. The resulting annual frequencies estimated for common types of diagnostic nuclear medicine procedures are summarized in Table 46. These data have been derived with rounding by scaling the average relative frequencies observed for each health-care level (Table 39) by the average total frequencies per 1,000 population (Table 38); the mean procedure-specific frequencies in Table 38 can not be used directly since averaging has been carried out over different populations as a result of the incomplete sets of national data available. Table 46 also includes final estimates of collective dose on the basis of the doses per procedure shown, which are assumed broadly to be representative of practices for the different health-care levels. Derived average effective doses per procedure and per caput are also shown. The percentage contributions to annual frequency and collective dose due to the various types of diagnostic nuclear medicine procedure are analysed by health-care level in Table 47. The uncertainties inherent in the estimates of mean frequencies and doses 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. In particular, uncertainties are likely in the frequencies of thyroid studies, where uptake scans will sometimes have been included in the national frequencies reported for thyroid scans, and in the effective doses from such studies, which can depend critically on the level of uptake in the thyroid. In general, the present analysis of patient exposures has been hampered by the variety of different radiopharmaceuticals in use for each type of procedure and the often incomplete data provided on national practices.

121. The present analysis suggests that the global annual frequencies and doses for diagnostic nuclear medicine in 1991–1996 are dominated by the national practices in health-care level I, with about 80% of the estimated global collective dose arising from procedures conducted in these particular countries. This finding is similar to that for diagnostic x-ray examinations, although the magnitudes of the two practices are quite different; the annual numbers of nuclear medicine procedures and their collective dose are less than the corresponding figures for medical x rays by factors of about 60 and 15, respectively. However, the overall mean dose per nuclear medicine procedure (4.6 mSv) is larger than that per medical x-ray examination (1.2 mSv).

122. The most important procedures in terms of both the overall frequency of nuclear medicine procedures and the global collective dose are bone scans, cardiovascular studies and thyroid studies, although significant differences are apparent between the practices assessed for the different health-care levels. In particular, thyroid studies are dominant in the lower health-care levels (III and IV).

E. TRENDS IN DIAGNOSTIC PRACTICE WITH RADIOPHARMACEUTICALS

1. Frequencies of examinations

123. Temporal trends in the annual frequencies of all diagnostic nuclear medicine procedures per 1,000 population are summarized in Table 48. The present estimates of average total frequency for health-care levels I (19 per 1,000) and II (1.1 per 1,000) are larger than the previous values for 1985–1990 (16 and 0.5 per 1,000, respectively), although the averages for each time period have been made over different populations; comparisons of data for health-care levels III and IV are less reliable owing to the limited sample sizes involved. Notwithstanding these overall trends in average frequency for the different health-care levels of the global model, national frequencies for individual countries have increased in some and decreased in others between 1985–1990 and 1991–1996; some specific examples are given below. Temporal trends in the average annual numbers of different types of diagnostic nuclear medicine procedures per 1,000 population by health-care level are summarized in Table 49.

124. The annual number of *in vivo* nuclear medicine examinations performed in hospitals in the United States increased by about 16%, from approximately 6.4 million to 7.4 million (30 per 1,000 population) between 1980 and 1990, slower than the projected growth rate of 8% per year for this period [M1]. This was mainly the result of the virtual disappearance of ^{99m}Tc pertechnetate brain scintigraphy and ^{99m}Tc sulphur colloid liver imaging, which have been replaced by other modalities such as CT and MRI, although cardiac and pulmonary procedures doubled their share of total studies. This pattern reflects different underlying trends. On the one hand there has been increasing use of alternative techniques providing high-contrast, high-resolution imaging as replacements for poorer-resolution nuclear medicine procedures for the detection and definition of pathological anatomy. On the other hand, pathophysiologically oriented nuclear medicine studies made significant progress as new radiopharmaceuticals (such as myocardial perfusion and cerebral blood flow agents), instrumentation (such as SPECT and PET), and computers and hardware (allowing, for example, renal function evaluation) became available [N13]. A further analysis of procedure volume in the United States showed virtually no increase on a national scale between 1992 and 1993 [T2]. The frequency of procedures in Canada is also likely to have remained fairly static between 1989 and 1993 [A15].

125. Similar trends for increases in overall practice have been observed elsewhere. For example, in the Slovak Republic, annual numbers of diagnostic procedures increased by an average of 2.5% per year between 1985 (4.7 per 1,000 population) and 1992 (5.6 per 1,000) [F8]. Comparison of

national data for the United Kingdom in 1982 and 1990 indicates an overall increase of 14% (to a level of 8 per 1,000 population) in the annual number of administrations (corresponding to an average of about 2% per year); a rise of 22% in imaging studies was, however, offset by a 30% decrease in the number of non-imaging investigations [E1]. There was less frequent use of radionuclides for brain and liver investigations owing to the greater availability of CT and ultrasound, whereas bone, lung, renal, and cardiac nuclear medicine studies increased in frequency. The estimated collective dose of 1,400 man Sv for 1990 represents an increase of about 50% over the estimate for 1982 [H3]. Practice in the United Kingdom increased by a further 15% between 1990 and 1993, probably due to a greater usage of myocardial perfusion and lung ventilation/ perfusion studies [E11, W63]. The trends observed in Germany for the different types of procedure have been broadly similar to those in the United Kingdom described above [K12]. In New Zealand, the frequency of diagnostic administrations rose by 12% between 1983 (7.5 per 1,000 population) and 1993 (8.4 per 1,000), with a large increase in bone scans offsetting reduced numbers of brain scans and liver/ spleen studies [L28]. Analyses of practices in Romania for 1990 and 1995 have shown a 12% increase in examination frequency and a 15% decrease in collective dose [I36]. A reduction in collective dose has also been observed in Finland between 1994 (220 man Sv) and 1997 (207 man Sv) as a result of reduced usage of ^{131}I and essentially constant total numbers of procedures [K59]. In Denmark, total numbers of diagnostic procedures rose from 76,433 in 1993 to 77,483 in 1995. Numbers of procedures have also risen in the Czech Republic, with totals of 236,819 in 1990 and 292,927 in 1994.

126. Somewhat greater increases in practice have been reported elsewhere. For example, in Australia there was a 50% increase in the frequency of nuclear medicine procedures between 1980 (8 per 1,000 population) and 1991 (12 per 1,000), corresponding to an average of 4.5% per year [C7]; the annual per caput effective dose from diagnostic procedures doubled, however, over this period (to 64 μSv). The number of radiopharmaceuticals in use grew to approximately 60, with ^{99m}Tc-, ^{201}Tl-, ^{67}Ga-, and ^{131}I-based materials dominating. In Cyprus, diagnostic practice rose from a total frequency of 2.7 procedures per 1,000 population in 1990 to 6.4 per 1,000 in 1996. In the Islamic Republic of Iran, the annual number of diagnostic nuclear medicine procedures increased by 42% over the years 1985–1989 (average annual rate of about 10.5% per year), to 1.9 per 1,000 population [M10]. In Russia, however, the frequency of nuclear medicine procedures fell from 15 per 1,000 population in 1990 to 13 per 1,000 in 1997.

2. Diagnostic practices

127. The role of nuclear medicine in patient care is being enhanced through advances in physics, computer sciences, medicinal chemistry, molecular biology and clinical care [B87, G50]. Important developments in radiopharmaceuticals are changing nuclear medicine practices [M91, P2]. The general trend is from diagnosis to prognosis, with the focus of research in pharmaceuticals moving from organs to cells, extracellular to intracellular processes, chemistry to biology and diagnosis to therapy [G49, I34]. In particular, there is increasing interest in the labelling of bioconjugates, such as antibodies, peptides and receptor-specific molecules, since these bioactive molecules offer the promise of selectively carrying radionuclides to specific sites for effective imaging (and therapy) [B86, P44]. Over 80% of the radiopharmaceuticals presently used in diagnostic nuclear medicine are based on ^{99m}Tc; this dominance is likely to continue through the development of new complexes for functional imaging. New ^{99m}Tc-labelled agents are able to replace a number of established agents on the basis of improved convenience, imaging, and dosimetry. There is, for example, increasing interest in ^{99m}Tc-based agents for myocardial perfusion imaging, brain perfusion, renal function, infection and inflammation, and tumour imaging [C54, D2]. Advances in cell labelling and the formulation of complex biological agents, such as monoclonal antibodies, are providing novel imaging applications using radioimmunoscintigraphy [K2]. However, ^{131}I is still widely used in many countries and has been the main reason for the observed higher effective doses per examination in developing countries compared with industrialized countries [U3]. The contribution of ^{131}I to the collective dose from diagnostic nuclear medicine practice varies considerably between countries: for example, about 90% for Romania [I6], 59% for the Islamic Republic of Iran [M10], 39% for the Slovak Republic [F8], 17% for Taiwan Province of China [L6], 10% for Finland [K59], 3% for the United Kingdom [H3], and 0.1% for Australia [C7].

128. Continuing developments in physics and instrumentation are improving the utility of nuclear medicine and are likely to influence patterns of practice, particularly in developed countries [K65, L54, S90]. The SPECT technique is becoming increasingly important in three-dimensional imaging, facilitated by the use of multiheaded camera systems, digital circuitry, and increased computer power [G3, T25]. Hybrid systems have also been developed to allow both SPECT and PET imaging (so-called coincidence-adapted cameras). The development of new compounds for labelling with short-lived positron-emitting radionuclides, such as ^{15}O, ^{11}C, ^{13}N, and ^{18}F, is creating an enormous potential for metabolic tracer imaging and physiological studies through the use of PET [G51, H64, J22, L55, L56, M92, S42, U16, W64]. Over 1,000 compounds have been labelled to study specific biochemical processes and physiologic function by PET [I34]. One estimate for the extent of PET in 1997 suggested a total of about 70 centres worldwide conducting studies at a rate of 4–6 patients per working day [A15]. There are now over 60 scanners installed in Germany and 30 in Japan; elsewhere the availability of PET is more limited, with, for example, Russia having 2 functioning scanners (with a further 2 in planning) [K16] and Argentina having the only PET scanner in Latin America [B88]. The expansion of PET on a larger scale will depend on the

availability in hospitals of cheaper equipment, appropriate radionuclides, and approved radiopharmaceuticals [F26, J23, W65]; technical developments can be expected to provide solutions to some of these problems [C8].

129. Significant reductions in patient dose during cardiac clinical investigations have been reported from the use of a novel camera employing a gas-filled multiwire chamber detector in combination with the short-lived radionuclide ^{178}Ta [L2]. This equipment is now commercially available and, in comparison with a conventional gamma camera, is claimed to involve dose levels that are 20 times lower than those for ^{99m}Tc and 200 times lower than those for ^{201}Tl.

F. SUMMARY

130. A wide variety of radiopharmaceuticals are administered diagnostically to patients to study tissue physiology and organ function. The utilization of diagnostic nuclear medicine varies significantly between countries (Tables 4, 8 and 38) and broad estimates of worldwide practice have been made from the limited national survey data available using a global model, although the uncertainties in this approach are likely to be significant. The world annual total number of procedures for 1991–1996 is estimated to be about 32.5 million, corresponding to a frequency of 5.6 per 1,000 world population (Table 9); previous estimates of these quantities for 1985–1990 were 24 million and 4.5 per 1,000 population, respectively. The present global total of procedures is distributed amongst the different health-care levels of the model as follows: 89% in countries of level I (at a mean rate of 19 per 1,000 population), 11% in countries of level II (1.1 per 1,000 population), and <1% collectively in countries of health-care levels III (0.3 per 1,000 population) and IV (0.02 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 48).

131. The estimated doses to the world population from diagnostic nuclear medicine procedures are summarized in Table 50. The global annual collective effective dose for 1991–1996 is estimated to be about 150,000 man Sv, equating to an average dose per caput of 0.03 mSv; these estimates are similar to previous figures for 1985–1990 (160,000 man Sv and 0.03 mSv, respectively), despite the increase (by over 20%) in the frequency of procedures. The distribution of collective dose amongst the different health-care levels of the global model is presently as follows: 82% in countries of level I (giving a mean dose of 0.08 mSv per caput), 15% in countries of level II (corresponding to 0.008 mSv per caput), 2% in countries of health-care level III (corresponding to 0.006 mSv per caput), and 0.1% in countries of health-care level IV (corresponding to <0.001 mSv per caput). The contributions to collective dose from the different categories of procedure are summarized in Table 37. Globally, practice is dominated by bone scans, cardiovascular studies and thyroid studies, with the latter being particularly important in countries of the lower health-care levels (III and IV).

132. Overall, diagnostic practices with radiopharmaceuticals remain small in comparison with the use of x rays; the annual numbers of nuclear medicine procedures and their collective dose are only 2% and 6%, respectively, of the corresponding values for medical x rays. However, the mean dose per procedure is larger for nuclear medicine (4.6 mSv) than for medical x rays (1.2 mSv).

IV. TELETHERAPY AND BRACHYTHERAPY

133. Therapeutic uses of ionizing radiations are quite different in purpose from diagnostic radiological procedures. The aim in radiotherapy is to achieve cytotoxic levels of irradiation to well-defined target volumes of the patient, while as far as possible sparing the exposure of surrounding healthy tissues. Treatments generally involve multiple exposures (fractions) spaced over a period of time for maximum therapeutic effect. Radiotherapy is an important treatment modality for malignant disease, often in combination with surgery or chemotherapy [M77, S97, S98, W22]. The utilization of radiation treatment in oncology varies significantly between the different sites of disease and also countries. In the United States, for example, about 41% of all new patients with cancer in 1995 received radiation treatment, with specific rates for some particular sites/conditions being 80% for lung, 70% for breast, 30% for uterine cervix, 75% for uterine body and 1% for leukaemia [I23]. Corresponding radiotherapy utilization rates for cancer patients in Russia in 1995 were 23% (all cancer patients), 21% (lung cancer), 2% (breast cancer), 68% (uterine cervix), 7% (uterine body) and 3% (leukaemia) [C50]. Less commonly, radiation is also used in the treatment of benign disease [O19].

134. The clinical intention in radiotherapy may be either the eradication of cancer (curative treatment) or the relief of symptoms associated with it (palliative treatment [U14]). Most radiotherapy is carried out with radiation generators or encapsulated (sealed) radionuclide sources using the techniques of teletherapy and brachytherapy, as discussed below; these techniques are often used together. Less frequent therapeutic practice with unsealed radionuclides (radiopharmaceuticals) is considered in Chapter V. In view of the intense radiation sources used in radiotherapy and

the very nature of such treatments, there is a significant potential for accidents that would have serious consequences for the health of both patients and staff; such incidents are discussed further in Chapter VII.

A. TECHNIQUES

135. The principal treatment modality in radiotherapy is with external beams of radiation from x-ray or sealed radionuclide sources focused on the target volume (teletherapy). X-ray beam therapy machines are broadly classified into kilovoltage units (40–300 kV) and, for deep-seated tumours, megavoltage (or supervoltage) units (above 1 MV) [P34]. Kilovoltage units are further classified into contact units (40–50 kV), superficial units (50–150 kV), and orthovoltage (deep therapy) units (150–300 kV). Contact, superficial and orthovoltage machines utilize conventional x-ray tubes, whereas megavoltage therapy is based on photon beams from linear accelerators (LINACS) typically operating up to 25 MV or sealed radionuclide sources, principally ^{60}Co. Superficial treatments can also be carried out using electron beams from LINACS. In the United Kingdom, for example, approximately 15% of patients at the larger radiotherapy centres are treated with electrons, mostly using a single static field technique [A18]. Therapeutic irradiations are generally partial-body in nature, although large-field techniques are also used: total-body irradiation in conjunction with bone marrow transplantation for the treatment of leukaemias, hemi-body irradiation for the palliation of painful bone metastases, mantle irradiation in the treatment of lymphomas, and irradiation of the whole central nervous system in the treatment of medulloblastoma [S24, W22]. Radiotherapy with external beams seeks to provide an optimal distribution of dose to the target volume relative to normal tissue. This aim is pursued through careful planning and delivery of treatment. The process involves appropriate attention to radiation type, beam energy, and field size as well as the use of multifield techniques, individual blocks, multileaf collimators, wedges, bolus material, compensators, immobilization devices, simulation, port films, on-line digital imaging devices, and *in vivo* dosimetry.

136. The second important treatment modality in radiotherapy is brachytherapy, in which an encapsulated source or a group of such sources is positioned on or in the patient by surface, intracavitary, or interstitial application so as to deliver gamma or beta radiation at a distance of up to a few centimetres [D46]. Radium-226 sources, on the basis of which many brachytherapy techniques were developed, are not ideal, and the trend, particularly in developed countries, is for their replacement by a variety of artificial radionuclides [T4]. Sources may be implanted temporarily or permanently using four basic techniques of application: direct implantation into body tissues, as in conventional interstitial therapy; implantation of holders, applicators, or moulds preloaded with sources (as in intracavitary and surface therapy); positioning of empty sleeves, containers, or applicators for the manual afterloading of sources; and remote afterloading of sources into applicators by mechanical transport along a coupling to a storage safe [S25].

137. Permanent brachytherapy implants are generally used for deep-seated tumours such as cancers of the pancreas, lung, brain, pelvis, and prostate, often for palliative treatment [S25]. The most commonly used sources are ^{125}I, ^{198}Au, and ^{103}Pd, either as individual grains (seeds) or loaded in sutures. Temporary implants of ^{192}Ir (wire or pellets), ^{137}Cs (needles or pellets), and ^{60}Co (pellets) are used for superficial and easily accessible tumours. Interstitial applications are used in treatments of the breast, head and neck, cervix, vagina, rectum, and prostate. The intracavitary implant technique 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 [S26]. Removable ophthalmic plaques are used for treating malignant melanoma of the uvea and other tumours of the eye [H19]; medium-sized and large tumours are usually treated with ^{103}Pd or ^{125}I applicators, and small tumours with beta-ray applicators incorporating ^{106}Ru or ^{90}Sr.

138. Brachytherapy is 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 parametria and pelvic nodes, with intracavitary treatment being used principally for the primary tumour. 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. Various multi-centre studies are in progress to investigate the efficacy of endovascular brachytherapy treatment for the inhibition of restenosis after angioplasty [W29].

139. Conventional low-dose-rate (LDR) brachytherapy using ^{137}Cs (or ^{226}Ra) sources involves dose rates at the prescribed point or surface in the range 0.4–2.0 Gy h^{-1}, with most treatments given over a period of several days in one or possibly two fractions; higher-activity ^{137}Cs sources can provide medium dose rates (MDR) of up to 12 Gy h^{-1}. High-dose-rate (HDR) brachytherapy utilizes ^{192}Ir or ^{60}Co sources to provide even higher dose rates, generally 2–5 Gy min^{-1}, with treatment times reduced to hours or even less and perhaps using several fractions [B5, I14]. Remote afterloading is essential, from a radiological protection point of view, for HDR and MDR techniques. Other developments in radiotherapy are discussed below in Section IV.E.2 in relation to trends in the practice.

B. DOSIMETRY

140. The success of radiotherapy depends on the accurate and consistent delivery of high doses of radiation to specified volumes of the patient, while minimizing the

irradiation of healthy tissue. 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 ICRU [I11, I12, I13, I14, I15, I16, I21, I33], IAEA [I8, I9, I10, I20], and others [A12, B18, B19, W24], as well as various codes of practice (see, for example, [K10, N14, N17, N43, T6]). Special treatment and dosimetry techniques are required for pregnant patients to minimize potential risks to the fetus from exposure *in utero* [A37, M74, S27]; approximately 4,000 such women required treatment for malignancy in the United States in 1995. Radiotherapy can cause permanently implanted cardiac pacemakers to malfunction, and special techniques have been recommended for the planning and administration of treatment on such patients [L21]. Quality assurance measures and dosimetry intercomparisons are widely recommended to ensure continuing performance to accepted standards [D3, D13, K3, K14, N18, N44, W14].

141. Broadly, the elements of clinical radiation oncology include assessment of the extent of the disease (staging); identification of the appropriate treatment; specification of a prescription defining the treatment volume (encompassing the tumour volume), intended tumour doses and consideration of critical normal tissues, number of fractions, dose per fraction, frequency of treatment, and overall treatment period; preparation of a treatment plan to provide optimal exposure; and delivery of treatment and follow-up. X-ray imaging, and CT in particular, is widely used throughout this process; applications include the assessment of disease, preparation of the plan, checking the location of brachytherapy sources, or, using treatment simulators, checking correct patient set-up for external beam therapy. In view of the largely empirical nature of current practice in radiotherapy, significant variations are apparent in the dose/time schedules used in the treatment of specific clinical problems [D19, D24, G20, N19, P4, U14].

142. *In vivo* dosimetry is conducted to monitor the actual dose received by the patient during treatment in order to check the accuracy of delivery and as a means of determining the dose to critical organs, such as the lens of the eye or the spinal cord [E5, M17]. Both TLD [D18, K24] and solid state [A9, B34, C15, E6, S94, V4, W36] detectors are used. *In vivo* dosimetry is particularly useful during conformal radiotherapy [L46]. Also, electron spin resonance (ESR) in dental enamel has been investigated as a potential means of retrospective dosimetry for validating doses delivered to the head and neck regions [P7]. 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 [A8, S31, T10]. Radiochromic film is also used for quantitative planar dosimetry to map dose distributions, for example, in low- and high-dose-rate brachytherapy, stereotactic radiosurgery, and beta-ray ophthalmic plaque therapy [N42, Z7].

C. ANALYSIS OF EXPOSURES

1. Frequency of treatments

143. Differences in the resources available for radiotherapy lead to wide variations in national practice, with many smaller countries or LDCs having no treatment facilities or only a few. Annual numbers of treatments reported by different countries from 1991 to 1996 are summarized in Tables 51 and 52 for teletherapy and brachytherapy procedures, respectively. The data are presented in terms of numbers of treatments per 1,000 population by disease category, with countries grouped according to health-care level. Important qualifications regarding the derivation of some of these figures are given in the footnotes. The percentage contributions by disease category to the annual total frequencies of radiotherapy treatments are shown in Tables 53 and 54 for teletherapy and brachytherapy, respectively. Mean values of frequencies have been derived for each health-care level by averaging total numbers of procedures over total populations.

144. Patterns of practice vary significantly from country to country, even within a single health-care level. Annual frequencies of teletherapy treatments differ by a factor of over 30 within the sample of 28 countries in health-care level I (0.1–3.7 treatments per 1,000 population); disregarding countries with zero practice, similarly large variations exist in level II (0.05–3.1 treatments per 1,000 population in a sample of 19 countries) and level III (0.05–2.1 treatments per 1,000 population in a sample of 6 countries). Information was available from only one country in health-care level IV (United Republic of Tanzania: 0.05 treatments per 1,000 population). The average total frequencies for teletherapy in levels II and III are smaller by factors of 2.2 and 3.2, respectively, than the average for level I (about 1.5 treatments per 1,000 population). These averages are very much less than the corresponding average for the use of x rays in each level. Teletherapy treatments are, in general, also less common than diagnostic nuclear medicine procedures, by a factor of over 10 in the case of level I, but by nearer a factor of 2 for the lower levels. The average frequency of brachytherapy treatments in level I (0.2 treatments per 1,000 population) is less than one seventh of that for teletherapy. In levels II and III, practice in brachytherapy is lower by a factor of about 10 compared with level I.

145. Notwithstanding differences between the individual countries, some broad patterns of practice in radiotherapy 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 levels II and III. Brachytherapy practice is universally dominated by treatments of gynaecological tumours. Temporal trends in the frequency of examinations are discussed in Section IV.E.

2. Exposed populations

146. The distributions reported by different countries of the age and sex of patients undergoing teletherapy and brachytherapy treatments for various diseases in 1991–1996 are presented in Tables 55 and 56, respectively. 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; some qualifications to the data are given in the footnotes. As might be expected since radiotherapy is primarily employed in the treatment of cancer, therapeutic exposures are largely conducted on older patients (>40 years), with the skew in ages being even more pronounced than for the populations of patients undergoing diagnostic examinations with x rays or radiopharmaceuticals. However, significant numbers of children undergo teletherapy for the treatment of leukaemia and lymphoma. Once again, 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].

147. For certain teletherapy and brachytherapy procedures, there are obvious links to patient sex, for example, the treatment of breast and gynaecological tumours in females and prostate tumours in males. For other treatments, there is a general bias towards males in the populations of patients.

3. Doses from treatments

148. In the present review, the doses received by patients from radiotherapy are summarized in terms of the prescribed doses to target volumes for complete courses of treatment, as discussed in Section I.C. The typical prescribed doses reported by different countries for 1991–1996 are presented in Tables 57 and 58 for practices in teletherapy and brachytherapy, respectively. The average doses shown for each type of treatment and health-care level include weightings for 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 relation to radiotherapy for leukaemia and benign disease.

149. Some information is available concerning the doses to individual organs and tissues during radiotherapy treatments and examples can be given (see, for example, [D45, G46, H56, H57, L47, T23]). *In vivo* and phantom measurements have been performed to study inhomogeneities in dose during total body irradiation prior to bone marrow transplant [B37, B38]. A comparison of two commonly used techniques for external beam therapy of nasopharyngeal carcinoma concluded that the extended neck technique generally resulted in lower doses to most normal structures, although the flexed neck technique provided better coverage and uniformity of dose to the target volume [W27]. Measurements have been reported in relation to the distributions of dose over different body parts for patients undergoing radiotherapy treatments in Bangladesh [B44, M26]. A study of the doses to 13 specific sites in children undergoing radiotherapy for Hodgkin's disease has demonstrated wide variations between individual patients in a multicentre European cohort [S43]. During the treatment of cervical cancer with external ^{60}Co therapy in Mexico, the mean doses to the circulating blood and lymphocytes were estimated by probabilistic modeling to be about 2% and 7%, respectively, of the tumour dose [B24]. Dosimetric modeling for ophthalmic brachytherapy of the sclera with an ideal ^{90}Sr applicator has indicated a dose rate to the most radiosensitive areas of the lens of the eye ranging from 88 to 155 mGy s^{-1} [G24].

150. In teletherapy with photon beams, the doses at great distances from the target volume arise from several sources: radiation scattered in the patient; leakage and scattered radiation from the treatment head of the machine (the collimator-related radiation); and radiation scattered from the floor, walls, or ceiling [V6]. The first and third contributions depend on field size, distance, and photon energy and can be measured and applied generally. The second contribution is machine-dependent and in principle requires 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. When the distance between the gonads and the primary beam is large (around 40 cm, for example, in the treatment of breast cancer), gonad dose is determined primarily by the leakage radiation. Specific data have also been reported in relation to the peripheral dose during therapy using a LINAC equipped with multileaf collimation [S96]. 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 [M14].

151. The broad ranges of gonad doses from photon teletherapy treatments for some specific tumour sites shown in Table 59 are based on measurements in a patient population [V6]. 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 in distance to the gonads between men and women. 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.

152. 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 [V6].

153. The skin-sparing nature and clinical efficacy of high-energy photon beams can be compromised by electron contamination arising from the treatment head of the machine and the air volume, and comprehensive dosimetric assessment requires taking into consideration the effect of this component on the depth-dose distribution [H58, S12, Z8]. Electrons and photons with energies above 8 MeV can produce neutrons through interactions with various materials in the target, the flattening filter, and the collimation system of the LINAC, as well as in the patient [K17]. 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 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 [V6]. High-energy x-ray beams will also undergo photonuclear reactions in tissue to produce protons and alpha particles [S95], 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

154. The data in Tables 51 and 52 provide robust estimates of the annual total numbers of teletherapy and brachytherapy treatments per 1,000 population within each health-care level; the frequencies of teletherapy in levels II and III may have been overestimated since some of the national data used refer to numbers of cancer patients rather than treatments, although these sources of uncertainty will be reduced when considering global practice. However, the mean values shown in Table 51 and 52 for the individual types of treatment within each health-care level have had to be averaged over different populations due to the lack of comprehensive information for all countries listed and so do not represent a self-consistent set of data. More robust estimates have therefore been derived by scaling the observed average relative frequencies for each type of treatment (Tables 53 and 54) by the mean total frequencies calculated for each health-care level. These final data for the global model of radiotherapy practice for 1991–1996 are shown in Table 60. Analyses are presented separately for both teletherapy and brachytherapy, although the limited data available for the latter practice in health-care levels III and IV have been pooled so as to provide more reliable estimates for a combined population. The estimates of world practice have been calculated using the global model of population described in Section I.D. 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.

155. According to the model developed, the global annual frequencies assessed for radiotherapy treatments during 1991–1996 are dominated by the national practices in health-care level I, which provide contributions of about 50% and 80% to the total numbers of teletherapy and brachytherapy treatments, respectively, in the world (Table 9). The most important uses of teletherapy are for treatments of breast, lung and gynaecological tumours, whilst practice in brachytherapy is principally concerned with the treatment of gynaecological tumours, although some differences are apparent between the mean frequencies for the different health-care levels. The global frequency assessed for brachytherapy treatments (0.07 per 1,000 population) is less than one tenth that for teletherapy treatments (0.8 per 1,000).

156. Global resources for high-energy radiation therapy using teletherapy equipment with ^{60}Co sources or higher-energy photon beams were summarized for the 1980's by WHO [H20]. This analysis suggested that in some parts of the world, such as Africa and South-East Asia, there might have been only one high-energy radiation therapy machine for 20–40 million people, and one machine might be used to treat more than 600 new patients per year. Many cancer patients had no access to radiotherapy services [B33]. The results of a more recent analysis for 1998 are presented in Table 61 [D27]. The resources for radiotherapy are still very unevenly distributed around the world, with equipment numbers per million population being much higher in North America, Australasia and Western Europe, than in Central Africa, the Indian Subcontinent and East Asia. Only 22 out of 56 countries in Africa were known with confidence to have megavoltage therapy, and these are concentrated in the southern and northern extremes of the continent [L45]. The total of 155 megavoltage units operating in Africa in 1998 represented an increase by more than a factor of 2 over the total for 1991. The population served by each megavoltage machine ranged from 0.6 to 70 million; overall, only half of the population of Africa had some access to radiation oncology services.

157. Radiation therapy equipment and services are also very unevenly distributed in the Latin American and Caribbean countries [B33]. In 1994, there were approximately 500 ^{60}Co units, 10 ^{137}Cs units, and 124 LINACS. Services tend to be concentrated in the larger countries of South America (especially Argentina, Brazil, Colombia, and Venezuela) and in Mexico. A similar pattern prevails in the countries of the English-speaking Caribbean; the most well-equipped services are found in Barbados (which also treats patients from some other countries), Jamaica, and Trinidad and Tobago.

E. TRENDS IN TELETHERAPY AND BRACHYTHERAPY

1. Frequencies of treatments

158. Temporal trends in the normalized annual frequencies of teletherapy treatments and brachytherapy treatments are summarized in Table 62. When comparing these data, it should be remembered that the averages for each time period have been made over different populations and often with small sample sizes. The present estimates of average total frequency of teletherapy treatments per 1,000 population in each health-care level are larger than the previous values for 1985–1990: 1.5 versus 1.2 in level I, 0.7 versus 0.2 in level II, and 0.5 versus 0.1 in level III, respectively. These apparent increases will be due in part to the inclusion in the present analysis of some data concerning numbers of new cancer patients in lieu of more specific treatment data. No particular trends with time are apparent from the estimated data concerning the frequencies of brachytherapy treatments. Notwithstanding these overall trends in average frequency for the different health-care levels of the global model, national frequencies for individual countries have increased in some and decreased in others between 1985–1990 and 1991–1996; some specific examples are given below. The available data concerning temporal trends in the average annual numbers of different types of treatment per 1,000 population by health-care level are summarized in Table 63.

159. In many countries, the utilization of radiotherapy has increased steadily over the last thirty years. In the United States, for example, the resources available for radiotherapy rose from 1,047 facilities (with a total of 1,377 treatment machines) in 1975 to 1,321 facilities (and 2,397 machines) in 1990 [I23]. Over this period, the annual number of new patients undergoing radiation therapy has correspondingly increased from 1.5 to 2.0 per 1,000 population. In Russia, the annual number of radiotherapy treatments increased steadily from a rate of 1.0 per 1,000 population in 1980 to 1.7 per 1,000 in 1997. Steady increases have also been reported elsewhere, such as in New Zealand and Sweden (Table 62). In other countries, rates of practice have either remained fairly static (in Australia and Japan, for example) or have apparently declined (in Romania, for example).

2. Therapeutic practices

(a) Teletherapy

160. Over the last 50 years, there have been continuing advances in engineering, the planning and delivery of treatment, and clinical radiotherapy practice, all with the aim of improving performance [B75]; some key technical developments in teletherapy are listed in Table 64. In developed countries at least, there has been growing use of high-energy linear accelerators for the effective treatment of deep-seated tumours; Figure VII illustrates the decline in the number of telecobalt units and the increase in linear accelerators in France over the last 10 years [L13]. Similar trends are broadly apparent in Table 7 for the mean numbers of the different types of radiotherapy equipment per million population in the different health-care levels. 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 [D14]. Units with ^{60}Co sources remain important for developing countries in view of the lower initial and maintenance costs and simpler dosimetry in comparison with LINACS, although replacement sources of the longer-lived radionuclide ^{152}Eu are under consideration as being potentially more efficient for such units [A5].

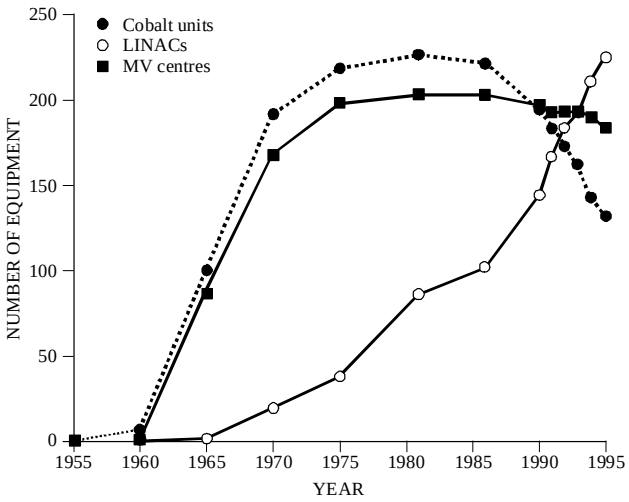

Figure VII. Radiotherapy centres (with mega-voltage equipment), telecobalt units and linear accelerators in France [L13].

161. Developments in diagnostic imaging, such as CT and MRI, have benefitted the assessment of disease and also the planning and delivery of therapy [C52, R39]. Treatment plans are calculated using sophisticated computer algorithms to provide three-dimensional dose distributions, including so-called beams-eye views, and Monte Carlo simulation techniques are being adopted [M76, S100]. Computer control of the linear accelerator has facilitated the development of new treatment techniques. Multileaf collimators 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 [G23]. This type of therapy seeks to provide optimal shaping of the dose distribution in three dimensions so as to fit the target volume [D26, F3, L10, S34]; developments include tomotherapy, which uses slit beams provided by dynamic control of multileaf collimators coupled with movement of the gantry during treatment [Y7]; intensity-modulated arc therapy, which combines spatial and temporal intensity modulation [B36, K15, Y3]; and adaptive radiation therapy, in which treatment plans for individual patients are automatically re-optimized 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 of the radiation beam with respiration is being investigated [K8]. *In vivo* dosimetry [B20, B26, M17, S17], phantom dosimetry [D17, M15, O5] and imaging [H59, R39] are increasingly being used to verify that the machine and patient set-up are as required for the prescribed treatment and to assure the accuracy of plans. In particular, electronic portal imaging provides real-time verification of patient position and is being developed for transit dosimetry so as to allow comparison of the delivered dose distribution relative to the treatment plan [H4, H13, K58, M16, P36, S32].

162. Technical advances in the execution of radiotherapy have stimulated further research into clinical radiobiology [D20, G19, L10, S99, W23]. New methods are required to summarize and report the inhomogeneous dose distributions delivered to irradiated organs and volumes of interest [N20]. Studies in cellular and tissue biology have provided a scientific rationale for developments in hyper-fractionation and accelerated treatments to improve the therapeutic ratio in radiotherapy (normal tissue tolerance dose relative to tumoricidal dose). Several clinical trials are in progress [B21, D4, S33], and the use of hyperfractionation is likely to increase.

163. Radiotherapy is performed less often to treat benign disorders, because there is no clear biological rationale or experimental data, and also because there are concerns that such treatments might induce cancer in the exposed patients [B79, S22]. A survey conducted in 1996 detected large variations in practice throughout the world in relation to the indications and treatment schedules for radiotherapy of benign diseases [L24]. In the United States and Europe (especially Germany), low-dose orthovoltage therapy is currently well-accepted practice for the treatment of several selected benign conditions such as the prevention of heterotopic ossification after hip replacement, the stabilization and improvement of patients with Graves disease, keloid prevention, and achillodynia syndrome. Radiotherapy is also employed in the treatment of benign tumours and, using radiosurgery, vascular malformation. It has been argued that radiation therapy should also be considered as the primary modality for treating refractory pain in plantar heel spur [S22]. It has also been suggested, on the basis of experiments with animal coronary models and anecdotal reports of treatment to human femoral arteries, that acute localized delivery of 15–20 Gy to the walls of blood vessels can reduce the rate of restenosis following angioplasty [A4, W29]. Although external beam therapy has been proposed as one possible approach, most interest has centred on the development of endovascular brachytherapy techniques [F23, N45], and these are reviewed briefly in the next Section.

(b) Brachytherapy

164. 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 in developed countries by ^{137}Cs, although radium sources are still utilized for economic reasons in some areas of the developing world and eastern Europe [B5]. The remote afterloading technique is becoming standard practice in Europe for the treatment of carcinoma of the cervix and is increasingly being used for interstitial implants in relation to the bronchus, breast, and prostate [S25]. HDR brachytherapy offers advantages over the LDR technique in terms, for example, 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 [J1, J17, T5]. Pulsed dose-rate (PDR) brachytherapy has been developed in the hope of combining the advantages of the two techniques, while avoiding their disadvantages [B25, 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 a 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.

165. Endovascular brachytherapy treatments to inhibit restenosis after angioplasty have been performed experimentally using catheters for the temporary implantation of radioactive seeds and wires (^{192}Ir and ^{90}Sr/^{90}Y) and also for the permanent implantation of radioactive stents (^{32}P) [C16, J7, J18, T11, V7]. The proton-beam activation of nickel-titanium alloy stents to produce ^{48}V could provide a unique mixed gamma/beta source to allow an improved dose distribution for this application [L22]. One other possible irradiation technique in the course of an angioplasty procedure would involve filling the dilatation catheter balloon with a high-activity beta-emitter such as ^{90}Y [A4] or ^{188}Re [K60]. Preliminary human trials of such endovascular treatments are in progress at several centres around the world [P45, W29].

(c) Other modalities

166. The continuing obstacle to definitive radiotherapy 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]. The entire dose is delivered as a single fraction in complex configuration, which makes dose control and measurement particularly critical [B22]. 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 radiotherapy, in which the afflicted bone is temporarily excised surgically so that it can undergo high-level irradiation in isolation before immediate re-implanting [W15]. 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. Modeling has been reported for therapeutic applications of iodine contrast agents in association with a CT scanner modified for rotation x-ray therapy [M75, S35] and for a silver metalloporphyrin for use in interstitial brachytherapy with ^{125}I seeds [Y8].

167. Stereotactic radiosurgery (SRS) refers to the use of thin, well-defined beams of ionizing radiation for the precise destruction of a well-defined intracranial target volume at the focus of a stereotactic guiding device, without significant damage to adjacent (healthy) tissues. Since introduction of the technique in 1951, clinical studies have been undertaken with high-energy photons from linear accelerators [F12] and ^{60}Co sources, with protons, and with heavy particles. The Leksell Gamma Knife (LGK) contains 201 fixed ^{60}Co sources arranged in a concave half-spherical surface and is the most common equipment for conducting SRS [E7, G25]. There were 90 such devices in use worldwide in 1997, of which 32 were in the United States. Data from the present UNSCEAR Survey of Medical Radiation Usage and Exposures indicate a total of 20 gamma knives in Japan and 36 in China; some limited additional information is given in Table 5. An analysis published in 1996 indicated that nearly 30,000 patients had been treated with the LGK since 1968. 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 [N22]. SRS treatments for small lesions (up to approximately 4 cm in diameter) are delivered in a single session, although fractionated regimes are under development for larger tumours. Isocentric ^{60}Co units could represent viable alternatives to LINACS as radiation sources for conducting SRS [P35]. Diamond detectors are expected to allow more accurate dosimetry for SRS in comparison with traditional methods involving diodes, films, ionization chambers, or TLDs [E8, H14, V5]. 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 [M20]. 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 [B23, B74, D10, Y17].

168. New and improved radiation sources for radiotherapy are also being developed. Pencil beams of high-energy photons can theoretically be produced by the Compton backscattering process during collisions between low-energy photons and high-energy electrons stored in magnetic ring structures [W25]. Such photon beams could be used for the production of radionuclides, the generation of positrons and neutrons, conventional high-energy teletherapy, and, for example, functional radiosurgery through the intact skull of small deep-lying targets within the brain [G9]. Whereas most radionuclides for medical use are produced in a nuclear reactor or cyclotron, it is possible that small amounts of radionuclides could be produced by the mechanism of direct electron activation using a medical linear accelerator [W26].

169. There are potential advantages in conducting radiotherapy with high-energy, heavy charged-particles such as protons and heavy ions. Such charged-particle beams can provide superior localization of dose at depth within target volumes. Furthermore, heavy 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 or protons [B72]. Proton beams have been used therapeutically since 1955 and represent the treatment of choice for ocular melanoma [B73, I33]. Protons have also been used to treat deep-seated tumours. As of 1996, there had been approximately 17,000 patient treatments worldwide, with 17 facilities actively engaged in proton therapy and another 14 in various stages of planning [M12, S13, S108]. Secondary neutrons and photons make small contributions to the patient dose during proton therapy [A17]. Over 2,500 patients have been treated worldwide with heavy ions (helium or carbon) on the basis of their favourable physical and radiobiological characteristics, such as high relative biological effectiveness, small oxygen effect and small cell-cycle dependence [K9]. In 1996, only two facilities were operational in the world: HIMAC, Japan and GSI, Germany [J16]. About 600 patients with various types of tumour located in various organs have already been treated with a carbon beam at the HIMAC facility since 1994 [K57]. In addition, about 1,100 patients were treated with negative pi mesons between 1974 and 1994, although with no active facilities in 1996, this is not a significant modality [J16].

170. 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 [G10]. Later studies in the United Kingdom in the 1960s 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 10 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 conven-

tional radiotherapy alone [D21]. Neutron brachytherapy using ^{252}Cf sources is being carried out at one medical centre in the United States [M24].

171. There is also renewed interest in the bimodal treatment technique of boron neutron capture therapy (BNCT), in which boron (^{10}B) is selectively concentrated in malignant tissue for subsequent activation (transmutation to ^{11}B with the emission of alpha particles and ^{7}Li ions) when irradiated with thermal neutrons [B35, C51, D16, G21]. Early clinical trials in the United States in the 1950s were followed by large studies in Japan and proposals for further work in the United States and Europe as a result of the development of second-generation boron compounds and the availability of reactor-based epithermal neutron beams [A6, G45, R8]. Particle accelerators can also be used to provide beams of neutrons for BNCT, and this approach offers the potential for application in hospitals [G22]. By its nature, BNCT will be most suited to the treatment of localized tumours such as high-grade gliomas that cannot be treated effectively by other types of therapy. The technique is also under investigation for synovial ablation in the treatment of rheumatoid arthritis [Y16].

172. Cancer is likely to remain an increasingly important disease in populations with increasing lifespans, and this will probably cause radiotherapy practice to grow in most countries. WHO estimates that, worldwide, by the year 2015 the annual number of new cancer cases will have risen from 9 million in 1995 to about 15 million, with about two thirds of these occurring in developing countries [W12]. If one half of these 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.

173. Radiotherapy 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 staff; this topic is discussed further in Chapter VII. 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 radiotherapy, 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 [D3, D13, K3, W14].

F. SUMMARY

174. Radiotherapy involves the delivery to patients of high absorbed doses to target volumes for the treatment of malignant or benign conditions. Resources for radiation therapy are distributed unevenly around the world (Tables 61, 6 and 9), with there being significant variations in radiotherapy practice both between and often within individual countries (Tables 51 and 52); many cancer patients have little or no access to radiotherapy services. Global annual numbers of complete treatments by the two main modalities of teletherapy and brachytherapy have been estimated from the scarce national survey data available using a global model, although the uncertainties in this approach are likely to be significant; the results of this analysis are summarized in Table 65. The world annual total number of treatments for 1991–1996 is estimated to be about 5.1 million, with over 90% arising from teletherapy. The corresponding average frequency of 0.9 treatments per 1,000 world population is similar to the level quoted for 1985–1990 [U3] on the basis of an estimated total number of 4.9 million treatments. The present global total of treatments is distributed amongst the different health-care levels of the model as follows: 51% in countries of level I (at a mean rate of 1.7 per 1,000 population), 43% in countries of level II (0.7 per 1,000 population), 6% in countries of level III (0.5 per 1,000 population) and 1% in countries of health-care level IV (0.07 per 1,000 population). Radiation treatments by teletherapy and brachytherapy are very much less common than diagnostic medical and dental examinations with x rays (annual global totals of 1,910 million and 520 million examinations, respectively).

V. THERAPEUTIC ADMINISTRATIONS OF RADIOPHARMACEUTICALS

175. Unsealed radionuclides (radiopharmaceuticals) have also been used as therapeutic agents for over 60 years by direct administration to the patient. Such treatments play a small but important role in the management of patients with cancer, generally from a palliative point of view, and with other conditions such as thyroid disease and arthritis [B76]. For several benign disorders, radionuclide therapy provides an alternative to surgical or medical treatment; for the treatment of malignant disease, this modality combines the advantage of being selective (like teletherapy or brachytherapy) with that of being systemic (like chemotherapy) [H60].

A. TECHNIQUES

176. Radiotherapy with unsealed radionuclides offers the potential advantage of allowing the biological targeting of the radiation absorbed dose to particular tissues or regions

of the body. In clinical practice, biologically targeted radiotherapy for cancer requires a molecule that has a relative specificity for tumour tissue (delivery to the target tissue) coupled to a radionuclide with appropriate physical characteristics (imparting the dose) [G6]. When administered systemically (by ingestion or injection) or regionally (by infusion) to a patient, this combination in principle allows for the selective irradiation of target tumour cells, even in widespread disease, with relative sparing of normal tissues. The choice of an appropriate radionuclide is governed by the quality and path length of the radiation (relative to target size), physical half-life, gamma yield, chemistry, cost, and availability. Clinical practice at present is centred on radionuclides that emit medium-energy beta radiation with a range of a few millimeters in tissue.

177. The most common examples of such biologically targeted therapies involve simple ions and small molecules that follow physiological pathways, such as ^{131}I sodium iodide for the treatment of thyroid carcinoma, ^{32}P sodium orthophosphate for the treatment of polycythemia rubra vera, ^{89}Sr strontium chloride for the management of painful bone metastases, and ^{131}I meta-iodobenzylguanidine (mIBG) for the treatment of neuroblastoma [O21]. Efficient biological targeting is also possible through the use of tumour-specific monoclonal antibodies (MAbs) for delivery of appropriate radionuclides such as ^{186}Re and ^{188}Re [G6, R40]. Such techniques of radioimmunotherapy are not yet common in routine practice, although it is likely that these new therapeutic approaches will become increasingly important [B76]. Some current clinical applications of radionuclide therapy in cancer are summarized in Table 66 [Z3]; only the first four examples can be considered as established treatments. Clinical data on cancer therapy using a range of bone-seeking radionuclides has been reviewed by Lewington [L8].

178. Radionuclide therapy is important for the treatment of both malignant and benign diseases. Most of this type of cancer therapy is palliative in nature, although the treatment of thyroid carcinomas with radioiodine, which represents the earliest and most established form of therapy with unsealed radionuclides, is reliably curative [G6]. For treatment to be effective, activities of ^{131}I in the range 3–10 GBq are given to ablate the normal thyroid gland and to treat metastases [N5]. These doses may be repeated at intervals of 4–6 months until there is no clinical evidence of residual functioning thyroid tissue or metastases [G7]. Iodine-131 is also commonly used in the treatment of hyperthyroidism, although activities are generally 100–1,000 MBq, depending on the size of the gland and its ability to take up the sodium iodide [N5]. In Germany, for example, such treatments of benign thyroid disease accounted for the majority (70%) of all radionuclide therapy in 1991, with the use of ^{131}I for thyroid malignancies accounting for 22% of the total [B32].

179. Radionuclide therapy is also carried out by the direct introduction of a radiopharmaceutical into a body cavity [G7]. Colloidal yttrium silicate labelled with ^{90}Y is used for the intrapleural, intraperitoneal, and occasionally intrapericardial therapy of malignant effusions and intracavitary therapy for carcinomas of the bladder, intracystic treatment of craniopharyngioma, and intra-articular treatment of arthritic conditions of various joints (radiation synovectomies). Intracavitary injections of colloidal suspension of ^{198}Au are used for the treatment of malignant pleural effusions and malignant ascites in the abdomen. Intra-arterial administrations of microspheres labelled with ^{90}Y or ^{166}Ho are also in limited clinical use for the treatment of liver tumours [Z4].

B. DOSIMETRY

180. Radionuclide therapy requires detailed patient dosimetry in order to balance the therapeutic aim of treatment against the protection of normal tissues. A wide range of complex techniques is used, including macroscopic approaches to dosimetry on the scale of organs. These methods are similar to those used for diagnostic examinations with unsealed radionuclides [I35] and are based on information about uptake and retention in target and other tissues derived from quantitative imaging [B16, F1, F2, O2]. Microdosimetric techniques at the cellular and subcellular levels are under development for radioimmunotherapy in order to model heterogeneities in dose distributions [B15, O22] and so evaluate and improve the efficacy of such treatments [D11, N10]. Pre-therapy imaging of patients is used to plan individual treatments, whereas imaging during therapy allows confirmation or correction of the dosimetry [E2]. Studies have also been undertaken into biological dosimetry [M81], cancer death [M82] and fetal thyroid doses [P43] following ^{131}I therapy for thyrotoxicosis. Recommendations are available concerning standard administered activities for the different types of treatment (see, for example, [A38, L48]).

181. For the purposes of this review, the practice in radionuclide therapy is summarized in terms of the broad frequency of procedures with radiopharmaceuticals and the typical levels of administered activities, for the reasons already discussed in Section I.C.

C. ANALYSIS OF EXPOSURES

1. Frequency of treatments

182. Annual numbers of therapeutic administrations of radiopharmaceuticals reported by different countries for 1991–1996 are summarized in Table 67 by category of disease. Data are presented in terms of administrations per 1,000 population, with some analysis by radionuclide and with countries grouped according to health-care level. Some important qualifications to the data are given in the footnotes. The percentage contributions by disease category to the annual total frequencies of treatments are shown in Table 68. Mean values have been derived for each health-care level by dividing the total number of procedures by the total population.

183. Patterns of practice vary significantly from country to country, with some not conducting these types of treatment at all. Annual total frequencies range from 0.01 to 0.5 treatments per 1,000 population in the sample of 33 countries of health-care level I. The average total frequencies for levels II, III, and IV are smaller by factors of 5, 8, and 400, respectively, than the average for level I, about 0.2 examinations per 1,000 population. Relative to average diagnostic practice with radiopharmaceuticals in each level, frequencies of therapeutic administrations are typically lower by factors of between 13 (in the case of level III) and 110 (level I). In turn, radionuclide therapy is less common than teletherapy, with ratios of average frequencies ranging from about 9 (for level I) to 125 (level IV), although it is broadly similar in frequency to practice in brachytherapy.

184. In all countries, practice is dominated by ^{131}I therapy for hyperthyroidism, with other conditions, particularly thyroid malignancy, also being treated in the upper health-care levels (I–II). Temporal trends in the frequency of examinations are discussed in Section V.C.

2. Exposed populations

185. The distributions by age and sex of patients undergoing various types of therapy with radiopharmaecuticals in 1991–1996 are presented in Table 69 for different countries, grouped by health-care level; some of these data are derived from surveys of limited scope, as indicated in the footnotes. There are considerable variations in the national distributions reported for the various types of treatment, although the data often relate to quite small numbers of patients. In general, few treatments are carried out on children. However, since practice is dominated by treatments of the thyroid, the populations of patients receiving radionuclide therapy are younger than those undergoing most other types of radiotherapy (teletherapy and brachytherapy). Averages for the four health-care levels once again suggest in general a downward shift in age for patients in countries classified in the lower levels, relative to the distribution for level I. In line with underlying patterns of disease, the majority of thyroid treatments are conducted on female patients.

3. Doses from treatments

186. The doses from treatments with radiopharmaceuticals are presently characterized in terms of the activities of radionuclide administered to the patient (Section I.C). The typical activities per treatment reported by different countries for practice during 1991–1996 are presented in Table 70. The average activities shown for each type of radionuclide treatment and health-care level include weightings for the numbers of such treatments in each country. In general, the activities of ^{131}I administered for the treatment of thyroid malignancy are about ten times higher than those used for therapy of hyperthyroidism.

D. ASSESSMENT OF GLOBAL PRACTICE

187. The estimated annual numbers of patients undergoing common types of radionuclide therapy in the world are summarized in Table 71. This analysis is based on the global model of population described in Section I.D and the average relative frequencies observed for each type of treatment (Table 68) in combination with the mean total frequencies calculated for each health-care level (Table 67). The uncertainties in this approach are difficult to quantify, but will be significant, particularly when extrapolations have been made on the basis of small samples of data.

188. The global annual frequency assessed for therapy with radiopharmaceuticals during 1991–1996 is dominated by the national practices in health-care level I, which provide a contribution of about 70% to the global total number of such treatments (Table 9). Nearly 90% of global practice is concerned with the thyroid, with about two thirds of all treatments being for hyperthyroidism, and about one quarter for thyroid cancer.

E. TRENDS IN THERAPY WITH RADIOPHARMACEUTICALS

189. The role of therapeutic nuclear medicine is expanding with the development of more pharmaceuticals, the emergence of new indications for treatment and improvements in results [I34, S101]. A survey in Europe suggested that nuclear medicine was underutilized as a therapeutic modality and numbers of such treatments were likely to undergo a rapid increase, particularly for oncological indications requiring high-dose radionuclide treatments with isolation of the patient [E15, H60]. Specific trends in practice are discussed further in the two sections following.

1. Frequencies of treatment

190. Temporal trends in the normalized annual frequencies of radiopharmaceutical treatments are summarized in Table 72. When comparing these data, it should be remembered that the averages for each time period have been made over different populations and often with small sample sizes. In general, the trend from data reported by individual countries is for an increase in their national frequency of radionuclide treatments per 1,000 population between 1985–1990 and 1991–1996. The average frequencies estimated for health-care levels I and II have also increased over this period: from 0.10 to 0.17 per 1,000 in level I, and from 0.021 to 0.036 per 1,000 in level II. No particular trend with time is apparent for the practice in health-care level III. The estimated total annual number of treatments in the world has risen from 0.21 million for 1985–1990 to 0.38 million for 1991–1996 (Table 9). The available data concerning temporal trends in the average annual numbers of different types of treatment per 1,000 population by health-care level are summarized in Table 73.

191. Some examples can be given of the trends reported by particular countries. Surveys in the United Kingdom for 1993 [E11] and 1995 [C27] have confirmed both an overall increasing use of radionuclide therapy and also a widening spectrum of the therapies being undertaken; annual numbers of treatments rose from 13,000 to 14,500, and the annual cumulative administered activity of ^{131}I, the most commonly used radionuclide, increased by 100%. In Denmark, the total number of treatments increased from 1,819 in 1993 to 2,337 in 1995. In New Zealand, the annual frequency of therapeutic administrations per 1,000 population rose from 0.09 in 1960 to a peak level of 0.18 in 1983, before falling slightly to 0.16 in 1993 [L28]. Recent levels of practice have also been fairly static in Finland, where the total numbers of treatments were 2,150 in 1994 and 2,240 in 1997 [K59]. In contrast, the annual frequency of radionuclide treatments in Russia has fallen from 0.02 per 1,000 population in 1980 to 0.01 per 1,000 in 1997.

192. On a national scale, therapeutic administrations of radionuclides are reported to account for only small fractions of the annual totals of all nuclear medicine procedures carried out: approximately 1% of practice in Australia in 1991 [C7], 2% of practices in the United States in 1991 [N13] and in New Zealand in 1993 [L28], 3% of practice in the United Kingdom in 1990 [E1], and 4% of practice in Finland in 1997 [K59].

2. Therapeutic practices

193. Targeted radionuclide therapy is becoming an increasingly popular treatment modality for cancer as an alternative or as an adjunct to external beam radiotherapy or chemotherapy [O2]. However, the full potential of such techniques will only be realized with the introduction of new radionuclides whose radiations have physical properties to match tumour size and, in particular, with the development of target-specific carrier molecules such as monoclonal antibodies [B77]. The most attractive candidates for radioimmunotherapy (RIT) are radionuclides with medium energy beta emission and a half-life of several days, such as ^{47}Sc, ^{67}Cu, ^{153}Sm, ^{188}Re and ^{199}Au [M78]; however, it has been suggested [H61] that longer-lived radionuclides such as ^{114m}In and ^{91}Y could prove more effective for RIT than the shorter-lived ^{90}Y currently in use [S102]. More effective therapy should be possible using a cocktail of radioisotopes with differing beta particle energies and ranges so as to optimize energy deposition [Z3]. Also, work is in progress on DNA-targeting molecules in combination with Auger-emitting radionuclides (such as ^{125}I, ^{193m}Pt, or ^{195m}Pt) [O1] and with alpha-emitters (such as ^{211}At, ^{212}Bi, ^{213}Bi, ^{233}Ra and ^{255}Fm) [M79, M80, V2] to provide enhanced specificity of tumour-cell cytotoxicity. Another concept under consideration is that of the *in vivo* generator, in which a parent radionuclide (such as ^{166}Dy) is administered to the patient and attached to the target molecule, with subsequent decay *in situ* to the daughter radionuclide (^{166}Ho) as a source of continuing irradiation [K61]. In the longer term, it has been suggested that ^{124}I has the potential to become a universal radionuclide in nuclear oncology, with applications for both imaging and therapy [W60].

194. In addition to the treatment of cancer, there is also continuing development and growth in therapeutic applications of radiopharmaceuticals for the palliation of bone pain [K62] (using ^{89}Sr, ^{153}Sm, ^{186}Re, ^{117m}Sn and ^{177}Lu [A38, A39]) and radiation synovectomy for the treatment of rheumatoid arthritis (using ^{90}Y, ^{198}Au, ^{169}Er, ^{153}Sm, ^{188}Re, ^{186}Re and ^{166}Ho [K63, O20, P37, W61]).

195. Computer simulations have suggested that some radionuclide therapies could be made much more effective by the use of magnetic fields to constrain the paths of beta particles and so increase the absorbed dose delivered to small tumours [R3] or to enhance the protection of bone marrow in therapeutic uses of bone-seeking radionuclides [R6]. The development of measurement methods that provide estimates of absorbed dose in bone using techniques of electron paramagnetic resonance (EPR) could lead to improvements in the dosimetry of systemic radiotherapy for osseous masses [B27].

F. SUMMARY

196. 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 67). Global annual numbers of radiopharmaceutical treatments have been broadly estimated from the limited national survey data available using a global model and the results are summarized in Table 74; the uncertainties in these data are likely to be significant. The world annual total number of treatments for 1991–1996 is estimated to be about 0.4 million, corresponding to an average frequency of 0.065 treatments per 1,000 world population; previous estimates of these quantities for 1985–1990 were 0.2 million and 0.04 per 1,000 population, respectively. The present global total of treatments is distributed amongst the different health-care levels of the model as follows: 68% in countries of level I (at a mean rate of 0.2 per 1,000 population), 29% in countries of level II (0.04 per 1,000 population), 3% in countries of level III (0.02 per 1,000 population) and <0.1% in countries of health-care level IV (0.0004 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 similar in frequency to brachytherapy (total of 0.4 million).

VI. EXPOSURES OF VOLUNTEERS IN MEDICAL RESEARCH

197. The vast majority of medical exposures are conducted on individual patients or selected subgroups of the population in the routine management of health. There will also be some use of medical radiations in medical research programmes, which will involve the exposure of patients in experimental trials of diagnosis or treatment, or of healthy volunteers, for example, in the development and clinical testing of new pharmaceuticals [I22, W28]. No systematic information on such exposures of volunteers is readily available, although some examples can be given from particular countries.

198. An analysis of the research studies involving administrations of radiopharmaceuticals to volunteers conducted in Germany during 1997 and 1998 is presented in Table 75 [B78]; the majority of these studies involved PET imaging. The calculated doses exceeded 10 mSv for 70% of the volunteers in 1997 and 57% in 1998; in general, the doses to volunteers who were patients were higher than those who were healthy persons. In the United States, an analysis for the period 1996–1998 of the effective doses to 2,709 volunteers receiving administrations of radiopharmaceuticals in the course of research studies at a large hospital yielded a collective dose of 24.5 man Sv (17% of this being to healthy volunteers, 83% to diseased volunteers) [V25]; the distribution of individual effective doses was as follows: 12% of these volunteers received <0.1 mSv, 72% 0.1–10 mSv and 16% >10 mSv. In general, only small fractions of whole populations are likely to be exposed to medical radiations as volunteers in medical research programmes. For example, the number of volunteers reported to have received administrations of radionuclides in the course of medical or clinical research in the Federal Republic of Germany in 1988 represented less than 0.1% of the annual total number of routine diagnostic nuclear medicine procedures performed on patients [U3].

VII. ACCIDENTAL EXPOSURES OF PATIENTS

199. In the context of this review, an accident is any unintended event, including an operating mistake, equipment failure, or other mishap, that causes an exposure to a patient that is significantly different from an exposure received in normal practice. Such accidents can occur during diagnostic examinations utilizing x rays and administrations of radionuclides, as well as during radiotherapy. There are no universally accepted definitions of the deviations in dose inherent in "accidents", although some examples can be given from the practices in particular countries. In the United States, for example, the misadministration of radioactive material in medicine is defined by the regulatory authority as the administering of: a radiopharmaceutical or radiation from a sealed source other than the one intended; a radiopharmaceutical or radiation to the wrong patient; a radiopharmaceutical or radiation by a route of administration other than that intended by the prescribing physician; a diagnostic dosage of a radiopharmaceutical differing from the prescribed dosage by more than 50%; a therapy dosage of a radiopharmaceutical differing from the prescribed dosage by more than 10%; or a therapy radiation dose from a sealed source such that errors in the source calibration, time of exposure, and treatment geometry result in a calculated total treatment dose differing from the final prescribed total treatment dose by more than 10% [N46]. Guidelines from the United Kingdom are summarized in Table 76 in relation to the formal notification of incidents involving radiation equipment used for medical exposure [H62].

200. Radiotherapy, by its very nature, has the greatest potential for accidents with serious consequences, because the patients are deliberately exposed to intense sources of radiation. From the standpoint of the health care of a radiotherapy patient, the delivery of a dose that is too small could be just as important as the delivery of one that is too large. In general, accidents are relatively infrequent as a result of the radiation protection and quality assurance measures that are applied. However, accidental exposures continue to occur, owing to scientific, technical, and managerial failures. An analysis of two serious radiotherapy accidents in the United Kingdom argued that they might well have been avoided if a formal quality system had been adopted [M13]. A study of accidental exposures to patients in Germany yielded similar conclusions [S103].

201. In the absence of more systematic information, it is difficult from isolated reports of particular incidents (see for example [I25]) and only a limited number of broader reviews to assess with confidence the extent of accidental exposures on a global scale. However, some sources of data and examples of the different types of accident can be given. Further useful information is expected to be provided by databases on incidents involving medical radiations that are under development [H2, O4, T7]. In particular, IAEA has conducted a review of 90 accidents in radiotherapy (including teletherapy, brachytherapy, and some therapy with unsealed radionuclides) that were reported to regulatory authorities and professional associations or published in scientific journals [I40, O4]. An analysis of the initiating events and contributing factors for these accidents will allow the development of lessons to be learned and measures for prevention. The most important causes identified by IAEA, often found in combination, were the following: deficiencies in education and training;

lack of procedures and protocols for essential tasks (such as commissioning, calibration, and treatment delivery); deficient communication and information transfer; absence of defence-in-depth; and deficiencies in design, manufacturing, testing, and maintenance of equipment. A detailed study has also been conducted on the causes and impact of human error in remote afterloading brachytherapy [N21].

202. Many countries have systems for the central reporting of incidents involving medical radiations. Some of these programmes include minor occurrences not of direct relevance to the present review of accidental exposures of patients. In the United States, for example, health professionals and consumers voluntarily submit reports on all types of safety hazard encountered in radiation therapy devices to the Food and Drug Administration under the MedWatch programme. Summaries are published by the Center for Devices and Radiological Health every six months as a means of improving the quality of equipment. Formal reporting of adverse incidents in the United States is required for some diagnostic and therapeutic practice involving radionuclides. Such instances of errors and unintended events reported to the Nuclear Regulatory Commission have been used to derive some estimates of national rates of misadministration, expressed as percentages of the total number of administrations in 1992: these amounted to about 0.0002% for diagnostic nuclear medicine administrations and 0.004% for therapeutic administrations (fractions) using teletherapy and brachytherapy [I23]. However, these estimates should be regarded as very approximate.

203. In the United Kingdom, 54 instances of unnecessary or excessive medical exposures to radiation (excluding overexposures due to faulty radiation equipment) were investigated by the regulatory inspectorate between 1988 and 1994 [W18]. Since the reporting of such incidents is not mandatory, this figure is likely to be an underestimate of the true rate. Analysis by discipline reveals 39% involved diagnostic radiology, 37% radiotherapy, 20% nuclear medicine, and 4% dental radiology. Reports were most frequent in radiotherapy (involving one in three of all such departments nationally), followed by nuclear medicine (1 in 25 departments); reports were least frequent in diagnostic radiology (1 in 100 departments). About one half of the incidents involved only one patient and in general "one-off" errors. Between 1982 and 1994 in the United Kingdom, there were 47 incidents in dental radiology conducted by general dental practitioners in which ionizing radiation played a part, although only 6 of these involved possible excessive exposure [L18].

204. Some examples can also be given of audits of practice undertaken in radiotherapy departments. The detailed analysis of incident reports at one radiotherapy department in the United Kingdom indicated that problems of a technical nature affected, on average, the delivery of treatment for 4 in every 1,000 patients, although none of these incidents was regarded as being of clinical significance [W19]. Elsewhere, independent checks on dosimetry at two other departments showed serious errors in delivered doses (a deviation of more than 5% from the prescribed dose for a single field) occurring at rates of up to 11 per 1,000 [C17] and 50 per 1,000 patients [A13] in the two departments, with appropriate corrective actions having been taken where necessary.

205. Overall, it is not possible to make any worthwhile quantitative estimates of the extent worldwide of accidental exposures with medical radiations, although it can be concluded that the numbers of patients involved will generally be small in comparison with normal practice.

CONCLUSIONS

206. The use of ionizing radiation for medical diagnosis and therapy is widespread throughout the world, although there are significant country-to-country variations in national resources for and practice in medical radiology (Tables 4, 6, 8 and 9). In general, medical exposures are confined to an anatomical region of interest and dispensed for specific clinical purposes so as to be of direct benefit to the examined or treated individuals. Diagnostic exposures are characterized by relatively low doses to individual patients (effective doses are typically in the range 0.1–10 mSv) that in principle are just sufficient to provide the required clinical information, although the resulting collective doses to populations are significant. In contrast, therapeutic exposures involve very much higher doses precisely delivered to target volumes (prescribed doses typically in the range 20–60 Gy) to eradicate disease, principally cancer, or to alleviate symptoms. Relatively small numbers of diagnostic or therapeutic exposures are conducted on volunteers in controlled studies for the purposes of research.

207. Medical radiology involves a broad range of well-established techniques, and practice continues to evolve with new developments in technology. Examinations that use x rays are the most common source of medical exposure, while diagnostic nuclear medicine is conducted by administering radiopharmaceuticals to patients. Radiotherapy is mostly carried out using external beams of radiation (teletherapy), although some patients receive direct applications of sealed radionuclide sources (brachytherapy) or therapeutic administrations of radiopharmaceuticals. In general, practice in medical radiology is conducted systematically and accidents are relatively infrequent.

208. Information on medical radiation usage and the resulting exposures in different countries has been obtained by means of a widely distributed questionnaire, the UNSCEAR Survey of Medical Radiation Usage and Exposures, together with results from published studies. Assessments of practice for the entire world have once again been made on the basis of a global model in which countries are stratified into four levels of health care determined by the number of physicians per unit population; level I (at least 1 physician per 1,000 population), level II (1 physician per 1,000–3,000 population), level III (1 physician per 3,000–10,000 population), and level IV (1 physician for more than 10,000 population). The available data within each level have been averaged to provide representative frequencies or exposures that allow extrapolation to total populations.

209. The present estimates of global practice from the medical uses of radiation are summarized in Table 77, in terms of the numbers of procedures and, for diagnostic examinations, collective doses and per caput doses. These exposures are distributed unevenly amongst the population, often to elderly and sick patients, and the doses should not be used to assess detriment. Practice is concentrated in the countries of health-care level I, which collectively represent only one quarter of the world population, yet account for over 80% of the collective dose from all diagnostic procedures and over 50% of the total number of treatments. The global estimates for the annual frequencies of diagnostic and therapeutic procedures and the annual per caput doses from diagnostic practices are summarized in Figures VIII and IX, respectively. Detailed analyses of practice have already been given for medical and dental x rays (Table 30), diagnostic nuclear medicine (Table 46), teletherapy and brachytherapy (Table 60), and therapeutic radiopharmaceuticals (Table 71).

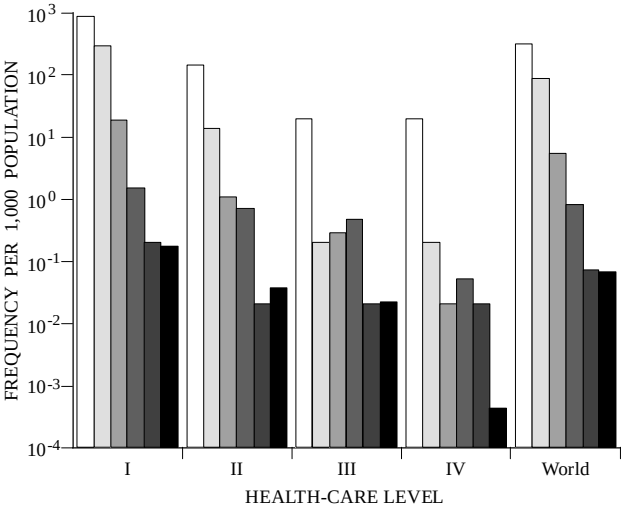

Figure VIII. Estimated global annual frequencies of medical diagnostic and therapeutic procedures (1991-1996). *The six columns in each group represent medical x rays, dental x rays, nuclear medicine (diagnosis), teletherapy, brachytherapy, and nuclear medicine (therapy), respectively.*

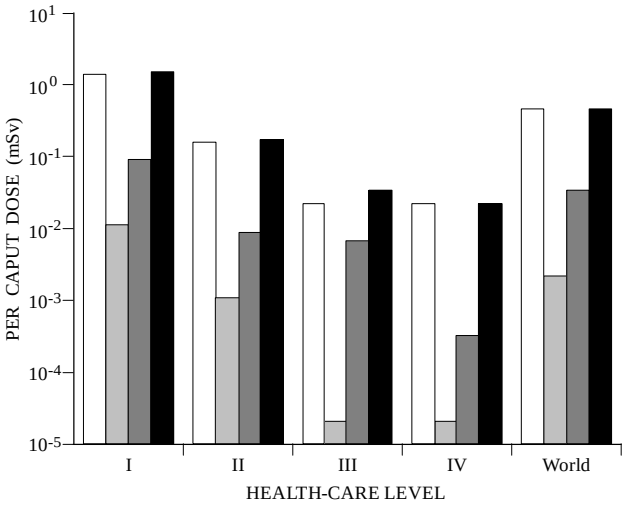

Figure IX. Estimated global annual per caput doses from medical diagnostic radiological procedures (1991-1996). *The four columns in each group represent medical x rays, dental x rays, nuclear medicine (diagnosis), and all diagnostic practices, respectively.*

210. Diagnostic exposures (2,500 million in total) outweigh the number of therapeutic exposures (5.5 million) by about 450 to 1, largely through the widespread use of x rays. Medical x rays account for 78% of this diagnostic total (at a mean rate of 330 per 1,000 population); dental x rays provide 21% (mean rate 90 per 1,000) and nuclear medicine only 1% (mean rate 5.6 per 1,000). The total collective dose from all diagnostic exposures is estimated to be about 2,500 million man Sv (corresponding to 0.4 mSv per caput); nuclear medicine provides only 6% of this total (at 0.03 mSv per caput). Over 90% of the total of radiation treatments are conducted by teletherapy or brachytherapy, with mean rates of 0.8 and 0.07 per 1,000 population, respectively; radiopharmaceuticals are used in only 7% of all treatments (with a mean rate of 0.065 per 1,000 population).

211. Notwithstanding such global average values, there are wide differences in the radiology practices between different countries (Tables 32, 34, 48, 62 and 72) and, on average, between the four levels of health-care adopted in this review (Figures VIII and IX). For example, the mean frequencies of diagnostic examinations per 1,000 population vary between the health-care levels by factors of about 50 for medical x-ray examinations, 1,500 for dental x-ray examinations and 1,000 for nuclear medicine procedures. Corresponding variations in the mean frequencies of radiation treatments amount to factors of about 30 for teletherapy, 10 for brachytherapy and more than 200 for nuclear medicine treatments. The mean per caput doses from each diagnostic practice vary between the health-care levels by factors of about 60 for medical x-ray examinations, more than 100 for dental x-ray examinations and 300 for diagnostic nuclear medicine procedures.

212. Temporal trends in the estimates of global practice in medical radiology from the various reviews undertaken by

the Committee are summarized in Table 78 for diagnostic uses and in Table 79 for therapeutic uses. Relative to the previous analysis for 1993, the world population has risen by about 10% to a total of 5,800 million in 1996 and there have been increases in the estimated annual numbers of all types of exposure and, importantly, in the per caput dose from medical x rays; the present mean effective dose per examination of 1.2 mSv is larger than the estimate of 1.0 mSv for 1985–1990. Estimates of the collective doses from diagnostic examinations with dental x rays and radiopharmaceuticals remain largely unchanged. In consequence, the estimated per caput global exposure from all diagnostic medical procedures has been revised from 0.3 to 0.4 mSv per person per year. The present estimates of the corresponding per caput dose by health-care level (with previous estimates for 1985–1990 in brackets) are as follows: 1.3 (1.1) mSv per person per year in level I, 0.15 (0.1) mSv in level II, 0.03 (0.05) mSv in level III, and 0.02 (0.05) mSv in level IV. Overall, the global annual per caput dose from diagnostic procedures worldwide is broadly similar to previous estimates made since 1982 [U3, U4, U6], although the present analysis is made on a somewhat firmer basis. Nevertheless, in general the estimates of global frequencies and doses remain fairly crude and should not be overinterpreted.

213. Further increases in the uses of medical radiations and resultant doses can be expected following changes in the patterns of health care that are being facilitated by advances in technology and economic developments. For example, increases are likely in the utilization of x rays, with in particular a growth in importance for CT, digital imaging and, with the attendant potential for deterministic effects on skin, interventional procedures; practice in nuclear medicine will be driven by the use of new and more specific radiopharmaceuticals for diagnosis and therapy, and there will be increased demand for radiotherapy owing to population ageing. In addition, further growth in medical radiology can be expected in developing countries where present facilities and services are often lacking.

214. Accordingly, there is a need for the Committee to undertake further authoritative reviews of global practice, with the systematic compilation of new national survey data, particularly from regions where knowledge is presently sparse, and the exploration of improved modeling in order to provide refined assessments of worldwide exposures. This major task will help monitor and inform on levels and trends in dose from the rapidly evolving and important practice of medical radiology, and also stimulate further assessments and critical review of practices by individual countries.

Table 1
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)*	*Ref.*
	I	*II*	*III*	*IV*		
1977	29	35	23	13	4 200	[U6]
1984	27	50	15	8	5 000	[U4]
1990	25	50	16	9	5 290	[U3]
1996	26	53	11	10	5 800	Present

Table 2
Physicians and dentists per million population (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	*Population (thousands)*	*Number per million population*		
		All physicians	*Physicians conducting radiological procedures*	*Dentists*
Health-care level I				
Albania	3 400	1 370 [a]	50	340 [a]
Argentina	35 672	2 489	22	614
Armenia	3 638	-	- [c]	-
Australia	17 684	2 590	107	515
Austria	8 000	3 008 [b]	-	90 [b]
Bahrain	570	1 290 [a]	-	130 [a]
Belarus	10 312	4 102	113	358
Belgium	10 000	3 360 [a]	113	660 [a]
Bulgaria	8 492	3 249	94	674
Canada	27 952	1 891	74	515
Cayman Islands	34	1 559	29	353
China, Taiwan Province	21 743	1 183	30	348
Croatia	4 760	2 056	93	382
Cuba	10 906	3 010 [a]	3	590 [a]
Cyprus	651	2 540	71	834
Czech Republic	10 363	3 371	141	592
Denmark	5 100	3 039	59	1 353
Ecuador	13 000	2 000	15	615
Estonia	1 500	-	-	-
Finland	5 117	3 261	111	923
France	57 660	3 000 [a]	119 [d]	670 [a]
Germany	81 500	3 279	405	726
Greece	10 500	3 810	171	1 048
Hungary	10 300	3 592	126	473
Ireland	3 626	3 000	77	452
Israel	5 664	2 415 [b]	-	497 [b]
Italy	56 411	4 750 [a]	106 [d]	190 [a]
Japan	125 034	1 766	94	633
Kazakhstan	16 820	-	-	-
Kuwait	1 691	1 959	56	384
Kyrgyzstan	4 469	-	-	-
Latvia	2 504	-	-	-
Lebanon	4 000	1 825	50	875
Lithuania	3 710	4440	155	461
Luxembourg	407	2 086	246	499
Netherlands	15 000	3 558	87	467
New Zealand	3 643	2 196	49	538
Norway	4 325	3 554	88	1 208
Panama	2 674	1 751	21	440
Poland	38 601	2 140 [a]	39 [d]	480 [a]
Portugal [F11]	9 860	2 870	54	65 [b]
Qatar	540	1 958 [b]	-	288 [b]
Republic of Moldova	4 444	-	-	-
Romania	22 681	1 771	38	267
Russian Federation	148 300	4 100	100	480 [a]

Table 2, continued

Country / area	*Population (thousands)*	*Number per million population*		
		All physicians	*Physicians conducting radiological procedures*	*Dentists*
Slovakia	5 325	3 335	83	389
Slovenia	1 987	2 139	63	568
South Africa	42 393	-	-	-
Spain	39 674	3 820 [a]	-	270 [a]
Sweden	8 800	2 841	125	1 364
Switzerland	7 097	3 839	-	641
Ukraine	52 464	-	95	-
United Arab Emirates	2 390	2 056	31	255
United Kingdom	58 200	1 660	41	388
United States [M2]	260 000	2 381	92	-
Uruguay	3 168	1 881 [b]	3	752 [b]
Uzbekistan	23 209	-	-	-
Venezuela	21 377	1 282 [b]	5	-
Average for level		2 784	106	526
Health-care level II				
Algeria	28 784	940 [a]	-	290 [a]
Antigua and Barbuda	65	908 [a]	31	200 [a]
Bahamas	272	900 [b]	-	129 [b]
Barbados	250	1 176 [a]	56	132 [a]
Belize	189	450 [a]	-	63 [a]
Bolivia	7 238	390 [a]	2	50 [a]
Bosnia and Herzegovina	3 628	-	-	-
Brazil	150 000	1 111	222	667
Chile	13 994	1 060 [a]	3	400 [a]
China	1 196 360	839 [b]	-	30 [b]
Colombia	34 545	940 [a]	1	440 [a]
Costa Rica	3 500	880 [a]	-	-
Dominica	80	475 [a]	0	50 [a]
Dominican Republic	7 684	1 070 [a]	1	100 [a]
El Salvador	5 530	640 [a]	1	160 [a]
Grenada	95	537 [a]	11	42 [a]
Honduras	5 494	790 [a]	0.4	90 [a]
India	944 580	410 [a]	-	10 [a]
Jordan	5 198	1 540 [a]	-	356 [a]
Libyan Arab Jamahiriya	5 225	1 040 [a]	-	150 [a]
Malaysia	19 570	451	5	80 [a]
Mauritius	1 129	850 [a]	-	130 [a]
Mexico	92 718	392	33	17
Nicaragua	4 008	500 [a]	1	100 [a]
Oman	2 256	852	13	37
Pakistan	140 000	500 [a]	-	20 [a]
Paraguay	4 703	630 [a]	1	250 [a]
Peru	23 500	979	11	240
Philippines	73 000	1 160	8	486
Puerto Rico	3 818	1 190 [b]	3	217 [b]
Saint Kitts and Nevis	36	1 194 [a]	0	306 [a]
Saint Lucia	140	421 [a]	7	64 [a]
Saint Vincent and the Grenadines	110	500 [a]	9	55 [a]
Trinidad and Tobago	1 292	730 [a]	3	90 [a]
Tunisia	9 000	944	19	60
Turkey	63 898	1 036	35	261
Average for level		695	76	87
Health-care level III				
Afghanistan	20 883	130 [a]	-	20 [a]
Congo	2 668	280 [a]	-	20 [a]
Egypt	63 271	185 [b]	-	158 [b]
Ghana	17 832	241	0.3	2 [a]
Guatamala	9 715	250 [a]	0.6	30 [a]
Guyana	838	124 [b]	-	11 [b]
Haiti	7 035	140 [a]	-	10 [a]
Jamaica	2 429	140 [a]	0.4	20 [a]
Madagascar	14 000	400	14	50
Morocco	26 702	205 [b]	6	59

Table 2, continued

Country / area	*Population (thousands)*	*Number per million population*		
		All physicians	*Physicians conducting radiological procedures*	*Dentists*
Namibia	1 575	220 [a]	-	30 [a]
Nigeria	115 020	170 [a]	-	10 [a]
Sudan	26 000	409	3	39
Suriname	432	-	-	-
Zimbabwe	11 439	130 [a]	-	10 [a]
Average for level		208	5	49
Health-care level IV				
Angola	11 185	40 [a]	-	1 [a]
Cameroon	13 560	80 [a]	-	4 [a]
Ethiopia	60 000	34	0.02	-
Kenya	27 800	50 [a]	-	10 [a]
Liberia	2 245	-	-	-
Mozambique	17 796	30 [a]	-	1 [a]
Nepal	22 000	60 [a]	-	0 [a]
Senegal	8 532	60 [a]	-	10 [a]
Uganda	20 256	40 [a]	-	1 [b]
United Rep. of Tanzania	28 400	45	0.4	1
Average for level		45	0.1	3

a Data from reference [W20].
b Data from reference [S37].
c No data available.
d Data from reference [R19].

The entries in this Table are qualified as follows:

Albania: Data on physicians conducting radiological procedures from reference [C28].
Argentina: Data for physicians conducting radiological procedures refer only to practice in nuclear medicine, teletherapy, and brachytherapy.
Barbados: Data for physicians conducting radiological procedures from reference [B43].
Belgium: Data for physicians conducting radiological procedures from reference [C26].
Brazil: Data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil).
Dominica: Data for physicians conducting radiological procedures from reference [B43].
Ghana: Data on physicians from reference [S38].
Russia: Number of dentists refers to data for USSR in 1990 from reference [W20].
Trinidad and Tobago: Data for physicians conducting radiological procedures refer only to radiotherapy practice from reference [B43].
Ukraine: Data on physicians conducting radiological procedures from reference [W33].

Bolivia, Chile, Colombia, Cuba, Dominican Rep., El Salvador, Guatemala, Honduras, Jamaica, Nicaragua, Paraguay, Puerto Rico, Trinidad and Tobago, Uruguay, and Venezuela:
Data for physicians conducting radiological procedures refer only to radiotherapy practice from reference [B43].

Antigua, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines:
Data for physicians conducting radiological procedures in public sector from reference [B43].

Table 3
Diagnostic imaging equipment (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	*X-ray generators*			*CT scanners*	*MRI scanners*	*Nuclear medicine equipment*		
	Medical	*Mammography*	*Dental*			*Gamma cameras*	*Rectilinear scanners*	*PET scanners*
Health-care level I								
Albania [C28]	-	-	-	1	0	-	-	-
Argentina	12 000	-	-	-	-	311	122	1
Australia	-	258	-	332	42	-	-	-
Belarus	2 400	3	92	14	4	15	0	0
Belgium	-	-	-	210	36	-	-	-
Bulgaria	1 813	26	431	22	1	12	37	0
Canada	9 725	565	36 978	223	35	500	-	5
Cayman Islands	6	0	0	0	0	0	0	0
China, Taiwan Province	3 662	61	6 212	293	47	87	2	2
Croatia	620	21	250	29	2	6	3	0
Cuba	1 000	-	-	10	4	9	-	-
Cyprus	72	13	550	8	2	4	0	0
Czech Republic	2 380	68	3 100	62	7	80	35	0
Denmark	1 225	55	4 970	50	18	58	0	3
Ecuador	619	26	771	27	8	12	7	0
Estonia [S29]	392	21	107	3	1	2	-	-
Finland	1 600	192	4 746	60	22	58	0	1
France [A14]	18 312	2 431	36 386	561	146	350	43	-
Germany	50 000	3 550	74 000	1 400	400	850	50	40
Greece	1 200	170	7 000	150	20	150	15	0
Hungary	1 170	46	350	54	13	53	34	1
Ireland	360	29	1 305	26	6	23	0	0
Israel [S48]	-	-	-	42	-	-	-	-
Italy	9 946	1 354	-	550	210	315	20	5
Japan	77 000	1 461 [a]	57 515	7 959	1 559	1 387	-	33
Kuwait	217	11	155	13	2	19	0	0
Lebanon	400	50	400	45	5	26	-	-
Lithuania	847	21	308	15	0	4	11	0
Luxembourg	70	10	313	9	1	4	0	0
Netherlands	3 000	130	7 500	120	55	180	-	1
New Zealand	734	66	1 790	30	6	22	0	0
Norway	2 000	60	6 000	75	15	43	4	0
Panama	416	16	0	10	2	7	0	0
Poland [R25]	-	-	-	75	11	-	-	-
Qatar	38	2	7	2	1	2	0	0
Romania	2 529	37	900	35	1	-	-	-
Russian Federation	27 340	1 210	6 730	320	100	300	-	-
Slovakia	1 351	48	551	31	3	17	3	1
Slovenia	270	15	259	9	2	13	0	0
Spain	6 371	-	-	226	131	190	-	-
Sweden	1 400	170	13 500	115	50	90	1	5
Switzerland	8 419	240	8 583	187	99	110	-	7
Ukraine [W33]	-	-	-	70	18	-	-	-
United Arab Emirates	342	22	790	17	2	9	0	0
United Kingdom	-	258	20 350	350	140	365	7	5
United States	55 177	10 022	-	6 800	3 500	2 000	-	-
Uruguay	350	-	-	-	-	-	-	-
Venezuela [B33]	3 000	-	-	-	-	-	-	-
Health-care level II								
Algeria [V9]	-	-	-	8	1	7	-	-
Antigua and Barbuda [B33, B43]	4	-	-	-	0	0	0	0
Bahamas [B33]	5	-	-	-	-	-	-	-
Barbados [B33]	20	2	1	2	0	-	-	-
Belize [B33]	12	-	-	-	-	-	-	-
Bolivia [B33]	1 458	-	-	-	-	-	-	-
Brazil	16 667	-	75 000	800	-	150 [a]	-	0 [a]
Chile [B33]	1 350	-	-	-	-	-	-	-
China	65 522	393	1 633	2 750	242	287	362	3
Colombia [B33]	1 500	-	-	-	-	-	-	-
Costa Rica [B33]	190	-	-	-	-	-	-	-
Dominica [B33, B43]	6	0	5	0	0	0	0	0

Table 3 (continued)

Country / area	*X-ray generators*			*CT scanners*	*MRI scanners*	*Nuclear medicine equipment*		
	Medical	*Mammography*	*Dental*			*Gamma cameras*	*Rectilinear scanners*	*PET scanners*
Dominican Republic [B33]	180	-	-	-	-	-	-	-
El Salvador [B33]	136	-	-	-	-	-	-	-
Grenada [B33, B43]	3	0	-	0	0	0	0	0
Honduras [B33]	87	-	-	-	-	-	-	-
India [R20]	-	-	-	-	40	-	-	-
Libyan Arab Jamahiriya	-	-	-	14	2	4	-	-
Malaysia	1 270	23	-	38	8	8	-	-
Mexico	1 469	10	635	56	2	26	0	0
Nicaragua [B33]	50	-	-	-	-	-	-	-
Oman	94	2	12	7	1	2	0	0
Paraguay	100	-	-	-	-	-	-	-
Peru	1 400	40	1 800	30	5	10	2	0
Philippines	2 079	56	140	95	6	27	1	0
Saint Kitts and Nevis [B33, B43]	3	-	-	0	0	0	0	0
Saint Lucia	14	-	0	1	0	0	0	0
Saint Vincent and the Grenadines [B33, B43]	4	-	-	0	0	0	0	0
Trinidad and Tobago	20	-	-	-	-	-	-	-
Tunisia	538	23	400	24	1	8	0	0
Turkey	5 000	120	10 000	173	35	100	6	0
Health-care level III								
Ghana	121	4	-	3	-	-	-	-
Guatamala [B33]	95	-	-	-	-	-	-	-
Haiti	20	-	-	-	-	-	-	-
Jamaica	30	-	-	-	-	-	-	-
Madagascar	66	1	300	1	-	1	-	0
Morocco	3272	6	411	29	7	5	4	-
Sudan	344	4	47	4	0	3	1	0
Health-care level IV								
Ethiopia	-	-	-	-	-	1	1	0
Kenya [B41]	-	-	-	4	2	2	-	-
United Rep. of Tanzania	125	4	2	2	0	1	0	0

a These revised data were received by the Committee after completion of the global analysis.

The entries in this Table are qualified as follows:

Argentina: Data for medical x-ray units from reference [B33]. Total for gamma cameras includes 100 SPECT scanners.
Belgium: Data for CT scanners from reference [C26]. Data for MRI scanners from reference [R33].
Brazil: Except for data on gamma cameras and PET scanners, numbers extrapolated from data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil). Estimate for national total of CT scanners from M. T. Carlos, University of Rio de Janeiro (1998).
Canada: Total for dental x-ray generators extrapolated from data for province of Alberta (representing about 9.5% of population); totals for medical x-ray generators and gamma cameras extrapolated from data for province of Manitoba (representing about 4% of population).
Cuba: Data for medical x-ray units from reference [B33]. Other data from reference [H32].
Ghana: Data from reference [S38]. Nuclear medicine conducted only at Korle Bu Teaching Hospital [A16].
Italy: Data on x-ray generators (medical and mammography), and CT and MRI scanners from reference [B40]; total for medical x-ray generators includes dental equipment.
Oman: Total for dental x-ray generators refers to panoramic equipment.
Philippines: Totals shown for medical and dental x-ray generators refer to facilities and not individual machines.
Russian Federation: Data for MRI scanners and gamma cameras from reference [W33].
Saint Lucia: Data from references [B33] and [B43]. Total for dental x-ray generators refers to public sector.
Spain: Data from reference[B40]. Total for medical x-ray generators includes dental equipment. Total for gamma cameras includes public sector only.
Turkey: Data for CT scanners from reference [S47]; 60% of the total operate in the private sector.
United States: Data from reference [B40]. Total for medical x-ray generators includes dental equipment. Total for gamma cameras includes all nuclear medicine imaging equipment.

Haiti, Jamaica, Paraguay, Trinidad and Tobago, Uruguay: Estimated number of medical x-ray generators from reference [B33].

Table 4
Diagnostic imaging equipment per million population (1991-1996)
Based on data and qualifications from Table 3

Country / area	*X-ray generators*			*CT scanners*	*MRI scanners*	*Nuclear medicine equipment*		
	Medical	*Mammography*	*Dental*			*Gamma cameras*	*Rectilinear scanners*	*PET scanners*
Health-care level I								
Albania	-	-	-	0.3	0	-	-	-
Argentina	336	-	-	-	-	8.72	3.42	0.03
Australia	-	14.6	-	18.8	2.37	-	-	-
Belarus	233	0.3	9	1.4	0.39	1.45	0	0
Belgium	-	-	-	21.0	3.60	-	-	-
Bulgaria	213	3.1	51	2.6	0.12	1.41	4.36	0
Canada	348	20.2	1 323	8.0	1.25	17.9	-	0.18
Cayman Islands	176	0	0	0	0	0	0	0
China, Taiwan Province	168	2.8	286	13.5	2.16	4.00	0.09	0.09
Croatia	130	4.4	53	6.1	0.42	1.26	0.63	0
Cuba	92	-	-	0.9	0.37	0.83	-	-
Cyprus	111	20.0	844	12.3	3.07	6.14	0	0
Czech Republic	230	6.6	299	6.0	0.68	7.72	3.38	0
Denmark	240	10.8	975	9.8	3.53	11.4	0	0.59
Ecuador	48	2.0	59	2.1	0.62	0.92	0.54	0
Estonia	261	14.0	71	2.0	0.67	1.33	-	-
Finland	313	37.5	928	11.7	4.30	11.3	0	0.20
France	318	42.2	631	9.7	2.53	6.07	0.75	-
Germany	614	43.6	908	17.2	4.91	10.4	0.61	0.49
Greece	114	16.2	667	14.3	1.90	14.3	1.43	0
Hungary	114	4.5	34	5.2	1.26	5.15	3.30	0.10
Ireland	99	8.0	360	7.2	1.65	6.34	0	0
Israel	-	-	-	7.4	-	-	-	
Italy	176	24.0	-	9.8	3.72	5.58	0.35	0.09
Japan	616	11.7	460	63.7	12.5	11.1	-	0.26
Kuwait	128	6.5	92	7.7	1.18	11.2	0	0
Lebanon	100	12.5	100	11.3	1.25	6.50	-	-
Lithuania	228	5.7	83	4.0	0	1.08	2.97	0
Luxembourg	172	24.6	770	22.1	2.46	9.84	0	0
Netherlands	200	8.7	500	8.0	3.67	12.0	-	0.07
New Zealand	202	18.1	491	8.2	1.65	6.04	0	0
Norway	462	13.9	1 387	17.3	3.47	9.94	0.92	0
Panama	156	6.0	0	3.7	0.75	2.62	0	0
Poland	-	-	-	1.9	0.28	-	-	-
Qatar	70	3.7	13	3.7	1.85	3.70	0	0
Romania	112	1.6	40	1.5	0.04	-	-	-
Russian Federation	184	8.2	45	2.2	0.67	2.02	-	-
Slovakia	254	9.0	103	5.8	0.56	3.19	0.56	0.19
Slovenia	136	7.6	130	4.5	1.01	6.54	0	0
Spain	161	-	-	5.7	3.30	4.79	-	-
Sweden	159	19.3	1 534	13.1	5.68	10.2	0.11	0.57
Switzerland	1 186	33.8	1 209	26.4	14.0	15.5	-	0.99
Ukraine	-	-	-	1.3	0.34	-	-	-
United Arab Emirates	143	9.2	331	7.1	0.84	3.77	0	0
United Kingdom	-	4.4	350	6.0	2.41	6.27	0.12	0.09
United States	212	38.6	-	26.2	13.5	7.69	-	-
Uruguay	110	-	-	-	-	-	-	-
Venezuela	140	-	-	-	-	-	-	-
Average	293	23.7	440	17.4	5.71	7.19	0.92	0.20
Health-care level II								
Algeria	-	-	-	0.28	0.03	0.24	-	-
Antigua and Barbuda	62	-	-	-	0	0	0	0
Bahamas	18	-	-	-	-	-	-	-
Barbados	80	8.0	4.0	8.00	0	-	-	-
Belize	63	-	-	-	-	-	-	-
Bolivia	201	-	-	-	-	-	-	-
Brazil	111	-	500	5.33	-	1.0	-	-
Chile	96	-	-	-	-	-	-	-
China	55	0.33	1.4	2.30	0.20	0.24	0.30	0.003
Colombia	43	-	-	-	-	-	-	-
Costa Rica	54	-	-	-	-	-	-	-

Table 4 (continued)

Country / area	*X-ray generators*			*CT scanners*	*MRI scanners*	*Nuclear medicine equipment*		
	Medical	*Mammography*	*Dental*			*Gamma cameras*	*Rectilinear scanners*	*PET scanners*
Dominica	75	0	63	0	0	0	0	0
Dominican Republic	23	-	-	-	-	-	-	-
El Salvador	25	-	-	-	-	-	-	-
Grenada	32	0	-	0	0	0	0	0
Honduras	16	-	-	-	-	-	-	-
India	-	-	-	-	0.04	-	-	-
Libyan Arab Jamahiriya	-	-	-	2.7	0.38	0.77	-	-
Malaysia	65	1.2	-	1.9	0.41	0.41	-	-
Mexico	16	0.11	6.9	0.60	0.02	0.28	0	0
Nicaragua	12	-	-	-	-	-	-	-
Oman	42	0.89	5.3	3.1	0.44	0.89	0	0
Paraguay	21	-	-	-	-	-	-	-
Peru	60	1.7	77	1.3	0.21	0.43	0.09	0
Philippines	28	0.77	1.9	1.3	0.08	0.37	0.01	0
Saint Kitts and Nevis	83	-	-	0	0	0	0	0
Saint Lucia	100	-	0	7.1	0	0	0	0
Saint Vincent and the Grenadines	36	-	-	0	0	0	0	0
Trinidad and Tobago	15	-	-	-	-	-	-	-
Tunisia	60	2.6	44	2.7	0.11	0.89	0	0
Turkey	78	1.9	157	2.9	0.55	1.56	0.09	0
Average	58	0.45	56	2.4	0.14	0.32	0.25	0.002
Health-care level III								
Ghana	6.8	0.22	-	0.17	-	-	-	-
Guatamala	9.8	-	-	-	-	-	-	-
Haiti	2.8	-	-	-	-	-	-	-
Jamaica	12.4	-	-	-	-	-	-	-
Madagascar	4.7	0.07	21.4	0.07	-	0.07	-	0
Morocco	123	0.22	15.4	1.09	0.26	0.19	0.15	-
Sudan	13.2	0.15	1.8	0.15	0	0.12	0.04	0
Average	38	0.18	11.4	0.44	0.13	0.13	0.09	0
Health-care level IV								
Ethiopia	-	-	-	-	-	0.02	0.02	0
Kenya	-	-	-	0.14	0.07	0.07	-	-
United Rep. of Tanzania	4.4	0.14	0.07	0.07	0	0.04	0	0
Average	4.4	0.14	0.07	0.11	0.04	0.03	0.01	0

Table 5
Radiotherapy equipment (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	Teletherapy units				Brachytherapy afterloading units				Clinical therapy facilities	
	X-ray	Radio-nuclide [a]	LINACs	SRS [b]	Manual [c]	Remote LDR [d]	Remote HDR [e]	Total	Neutrons	Heavy ions
Health-care level I										
Albania [D27]	-	3 (0)	0	0	-	-	-	-	-	-
Argentina	-	103(2)	41	1	74	0	3	77	0	0
Armenia [D27]	-	4	0	0	-	-	-	-	-	-
Australia	40	2 (0)	77	3	20	16	2	38	-	-
Belarus	15	29 (0)	4	0	0	2	12	14	-	-
Belgium	14	16	34	-	16	15	10	41	-	-
Bulgaria	35	12 (0)	0	0	9	0	1	10	0	0
Canada	10	44 (0)	107	0	30	28	20	78	0	1
Cayman Islands	0	0	0	0	0	0	0	0	0	0
China, Taiwan Province	3	23 (0)	56	1	6	0	36	42	0	0
Croatia	10	14 (8)	2	0	2	0	0	2	0	1
Cuba	30	9 (0)	1	-	8	4	-	12	-	-
Cyprus	2	2 (0)	0	0	1	0	0	1	0	0
Czech Republic	48	59 (23)	18	1	21	6	6	33	-	-
Denmark	5	1 (0)	25	0	1	3	3	7	0	0
Ecuador	7	9 (0)	0	0	2	2	0	4	0	0
Estonia	-	3	2	-	-	3	-	3	-	-
Finland	11	1 (0)	23	0	1	3	7	11	0	0
France [A14]	138	133	223	1	-	173	21	194	3	-
Germany	800	160	230	1	-	-	-	190	2	0
Greece	3	24 (0)	14	2	0	0	10	10	0	0
Hungary	25	12 (2)	10	1	0	0	11	11	0	0
Ireland	3	3 (0)	8	0	1	1	2	4	0	0
Japan	0	298 (0)	564	-	-	-	-	219	-	2
Kazakhstan	-	1	2	-	-	1	-	1	-	-
Kuwait	2	2 (0)	1	0	0	1	0	1	-	-
Kyrgyzstan	-	2	1	-	-	4	-	4	-	-
Latvia	-	5	5	-	-	3	-	3	-	-
Lebanon	-	11 (6)	6	7	-	-	-	-	-	-
Lithuania	9	12 (0)	0	0	1	0	5	6	1	-
Luxembourg	0	0	0	0	0	0	0	0	0	0
Netherlands	34	0	60 [f]	1	-	25 [f]	12 [f]	37 [f]	1	0
New Zealand	11	2 (1)	14	1	6	1	1	8	0	0
Norway	30	1 (0)	19	1	1	0	3	4	0	0
Panama	2	3 (0)	0	0	2	0	0	2	0	0
Poland	-	17	24	-	3	12	-	15	-	-
Qatar	0	0	0	0	0	0	0	0	0	0
Rep. of Moldova [D27]	-	3	0	0	-	-	-	-	-	-
Romania	140	21 (0)	3	0	2	4	4	10	0	0
Russian Federation [D27]	-	-	5	-	-	-	-	-	-	-
Slovakia	25	21 (5)	5	0	2	4	9	15	0	0
Slovenia	5	2 (0)	3	0	3	2	0	5	0	0
South Africa	-	23	24	-	5	12	-	17	-	-
Sweden	26	3 (0)	56	1	0	7	5	12	0	1
Switzerland	77	12(0)	38	1	0	5	14	19	-	1
Ukraine [D27]	-	10	1	-	-	-	-	-	-	-
United Arab Emirates	0	2 (0)	4	1	2	0	2	4	0	0
United Kingdom	70	15 (0)	150	1	3	30	20	53	0	1
United States	-	504	1893	-	-	-	-	-	-	-
Uruguay [B43]	-	10 (0)	3	-	0	0	0	0	-	-
Uzbekistan [D27]	-	-	1	-	-	-	-	-	-	-
Venezuela	-	24 (0)	15	-	30	2	0	32	-	-
Health-care level II										
Algeria [D27]	-	15 (0)	8	-	5	7	-	12	-	-
Antigua and Barbuda [B33, B43]	0	0	0	0	0	0	0	0	0	0
Bahamas [B43]	0	0	0	0	0	0	0	0	0	0
Barbados	-	1 (0)	0	-	2	1	-	3	-	-
Belize [B43]	0	0	0	0	0	0	0	0	0	0
Bolivia	0	0	0	0	0	0	0	0	0	0
Bosnia and Herzegovina [D27]	-	2	1	-	-	-	-	-	-	-

Table 5 (continued)

Country / area	*Teletherapy units*				*Brachytherapy afterloading units*				*Clinical therapy facilities*	
	X-ray	*Radio-nuclide* [a]	*LINACs*	*SRS* [b]	*Manual* [c]	*Remote LDR* [d]	*Remote HDR* [e]	*Total*	*Neutrons*	*Heavy ions*
Brazil	169 [f]	126 [f]	68 [f]	3 [f]	100 [f]	- [f]	22 [f]	124	0	0
Chile	-	21 (0)	14	-	19	1	-	20	-	-
China	225	541(40)	282	36	0	0	309	309	1	0
Colombia	-	28 (0)	11	-	15	7	-	22	-	-
Costa Rica	2	3 (0)	0	-	7	0	0	7	-	-
Dominica [B43]	0	0	0	0	0	0	0	0	0	0
Dominican Republic	-	8 (0)	1	-	3	1	-	4	0	0
El Salvador	-	3 (0)	0	-	9	0	0	9	-	-
Grenada [B43]	0	0	0	0	0	0	0	0	0	0
Honduras	-	2 (0)	0	-	2	0	0	2	-	-
Jordan	1	2(0)	3	-	0	1	0	1	0	0
Libyan Arab Jamahiriya	2	3	-	-	-	-	-	-	-	-
Malaysia	1	8 (1)	7	0	7	0	0	7	0	0
Mauritius [D27]	-	2	2	-	2	-	-	2	-	-
Mexico	7	92 (0)	24	0	65	7	-	72	0	0
Nicaragua	-	1 (0)	0	-	5	0	0	5	-	-
Oman	0	0	0	0	0	0	0	0	0	0
Pakistan [L57]	-	2 (0)	1	-	-	-	-	-	-	-
Paraguay [B43]	-	4 (0)	3	-	0	0	0	0	-	-
Peru	10	9 (0)	3	-	25	0	0	25	-	-
Philippines	2	12 (0)	3	2	1	2	2	5	0	0
Puerto Rico	-	2	2	-	0	0	0	0	-	-
Saint Kitts and Nevis [B43]	0	0	0	0	0	0	0	0	0	0
Saint Lucia [B43]	0	0	0	0	0	0	0	0	0	0
Saint Vincent and the Grenadines [B43]	0	0	0	0	0	0	0	0	0	0
Trinidad & Tobago	-	2 (0)	0	-	2	0	0	2	-	-
Tunisia	2	7 (0)	1	-	5	10	-	15	0	0
Turkey	22	41 (0)	20	3	6	3	9	18	0	0
Health-care level III										
Afghanistan [L57]	0	0	0	0	0	0	0	0	0	0
Congo [D27]	-	1	0	0	-	-	-	-	-	-
Egypt	-	13	13	-	4	2	-	6	-	-
Ghana	-	2	0	0	4	4	-	8	-	-
Guatamala	-	6 (0)	0	-	8	1	0	9	-	-
Guyana [D27]	-	0	0	0	0	0	0	0	-	-
Haiti [B33]	-	2 (0)	0	-	-	-	-	-	-	-
Jamaica [B43]	-	2 (0)	0	-	0	0	0	0	-	-
Madagascar	1	1	-	-	-	-	-	-	-	-
Morocco	1	9 (4)	1	-	-	-	-	-	-	-
Namibia [D27]	-	1	0	0	-	-	-	-	-	-
Nigeria	-	5	0	0	2	3	-	5	-	-
Sudan	1	3 (0)	1	0	0	2	1	3	0	0
Suriname [D27]	-	0	0	0	0	0	0	0	-	-
Zimbabwe [B42]	-	3 (0)	3	-	1	2	-	3	0	0
Health-care level IV										
Angola [D27]	-	1	0	0	-	-	-	-	-	-
Cameroon	-	2	0	0	2	3	-	5	-	-
Ethiopia	-	1	0	0	0	1	-	1	-	-
Kenya [B41]	-	3 (0)	0	0	2	1	1	4	0	0
Liberia [D27]	-	1	0	0	-	-	-	-	-	-
Mozambique [D27]	-	1	0	0	-	-	-	-	-	-
Nepal [D22]	0	1 (0)	0	0	0	0	0	0	0	0
Senegal [D27]	-	1	0	0	-	-	-	-	-	-
Uganda [D27]	-	2	0	0	1	-	-	1	-	-
United Rep. of Tanzania	1	2 (1)	0	0	0	0	1	1	0	0

a Includes both ^{60}Co and ^{137}Cs units; total of the latter type shown in brackets.
b Stereotactic radiosurgery; includes units based on radionuclides (Gammaknife), Linacs and other specialist radiation sources.
c Number of treatment rooms.
d Remote low dose rate.
e Remote high dose rate.
f These revised data were received by the Committee after completion of the global analysis.

Table 5 (continued)

The entries in this Table are qualified as follows:

Afghanistan: No radiotherapy or oncology services in country [L57].
Algeria: Total for LDR refers to all types of remote unit.
Belgium: Total for manual afterloading brachytherapy units refers to the sum, over all centres performing this technique, of the number of diferent radionuclides in use at each centre.
Cameroon: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Canada: Total for x-ray teletherapy units extrapolated from data for province of Alberta (representing about 9.5% of population). 77 of the 107 Linacs operate above 10 MeV. Data for manual and remote-HDR brachytherapy afterloading units refer to number of licenses issued by Atomic Energy Control Board of Canada for practice; data for remote-LDR units refer to number of devices listed on licenses. Heavy ion facility refers to proton therapy.
Costa Rica: Data for ^{60}Co units and Linacs from reference [B33]. Data for x-ray teletherapy units from reference [I25]. Data for brachytherapy afterloading units from reference [D27].
Croatia: Heavy ion facility refers to betatron.
Egypt: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Estonia: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Ethopia: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Ghana: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Kazakstan: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Kyrgyztan: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Latvia: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Mexico: All data from reference [D27], except in relation to x-ray teletherapy units. Total for LDR refers to all types of remote unit.
Nigeria: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Pakistan: Data for IRNUM, Peshawar, North-West Frontier Province (serving population of 200 million including Afghanistan) [L57].
Poland: Data from reference [D27]. Total for LDR refers to all types of remote unit.
South Africa: Data from reference [D27]. Total for LDR refers to all types of remote unit.
Sweden: Heavy ion facility refers to the Svedberg Laboratory, Uppsala (180 MeV protons).
Tunisia: Data for brachytherapy afterloading units from reference [D27]. Total for LDR refers to all types of remote unit.
United Kingdom: Heavy ion facility refers to the use of protons at the Clatterbridge Centre for Oncolgy.
United States: Data for 1990 from reference [I23].
Zimbabwe: Data for brachytherapy afterloading units from reference [D27]. Total for LDR refers to all types of remote unit.

Barbados, Bolivia, Chile, Colombia, Cuba, Dominican Republic, Guatemala, Puerto Rico and Venezuela:
Data from reference [B43]. In relation to brachytherapy afterloading equipment, total for manual refers to number of sources and total for LDR refers to all types of remote unit.

El Salvador, Honduras, Nicaragua, Honduras, Tiniidad and Tobago:
Data from reference [B43]. In relation to brachytherapy afterloading equipment, total for manual refers to number of sources.

Table 6
Radiotherapy equipment per million population (1991–1996)
Based on data and qualifications from Table 5

Country / area	*Teletherapy units*			*Brachytherapy afterloading units*
	X-ray	*Radionuclide*	*LINACs*	
Health-care level I				
Albania	–	0.88	0	–
Argentina	–	2.89	1.15	2.16
Armenia	–	1.10	0	–
Australia	2.26	0.11	4.35	2.15
Belarus	1.45	2.81	0.39	1.36
Belgium	1.40	1.60	3.40	4.10
Bulgaria	4.12	1.41	0	1.18
Canada	0.36	1.57	3.83	2.79
Cayman Islands	0	0	0	0
China, Taiwan Province	0.14	1.06	2.58	1.93
Croatia	2.10	2.94	0.42	0.42
Cuba	2.75	0.83	0.09	1.10
Cyprus	3.07	3.07	0	1.54
Czech Republic	4.63	5.69	1.74	3.18
Denmark	0.98	0.20	4.90	1.37
Ecuador	0.54	0.69	0	0.31
Estonia	–	2.00	1.33	2.00
Finland	2.15	0.20	4.49	2.15
France	2.39	2.31	3.87	3.36
Germany	9.82	1.96	2.82	2.33
Greece	0.29	2.29	1.33	0.95
Hungary	2.43	1.17	0.97	1.07
Ireland	0.83	0.83	2.21	1.10
Japan	0	2.38	4.51	1.75
Kazakhstan	–	0.06	0.12	0.06
Kuwait	1.18	1.18	0.59	0.59
Kyrgyzstan	–	0.45	0.22	0.90
Latvia	–	2.00	2.00	1.20
Lebanon	–	2.75	1.75	–
Lithuania	2.43	3.23	0	1.62
Luxembourg	0	0	0	0
Netherlands	2.27	0	4.00	2.47
New Zealand	3.02	0.55	3.84	2.20
Norway	6.94	0.23	4.39	0.92
Panama	0.75	1.12	0	0.75
Poland	–	0.44	0.62	0.39
Qatar	0	0	0	0
Republic of Moldova	–	0.68	0	–
Romania	6.17	0.93	0.13	0.44
Russian Federation	–	–	0.03	–
Slovakia	4.70	3.94	0.94	2.82
Slovenia	2.52	1.01	1.51	2.52
South Africa	–	0.54	0.57	0.40
Sweden	2.95	0.34	6.36	1.36
Switzerland	10.9	1.69	5.35	2.68
Ukraine	–	0.19	0.02	–
United Arab Emirates	0	0.84	1.67	1.67
United Kingdom	1.20	0.26	2.58	0.91
United States	–	1.94	7.28	–
Uruguay	–	3.16	0.95	0
Uzbekistan	–	–	0.04	–
Venezuela	–	1.12	0.70	1.50
Average	2.84	1.56	3.04	1.69
Health-care level II				
Algeria	–	0.52	0.28	0.42
Antigua and Barbuda	0	0	0	0
Bahamas	0	0	0	0
Barbados	–	4.00	0	12.0
Belize	0	0	0	0
Bolivia	0	0	0	0
Bosnia and Herzegovina	–	0.55	0.28	–
Brazil	1.1	0.84	0.45	0.83
Chile	–	1.50	1.00	1.43

Table 6 (continued)

Country / area	*Teletherapy units*			*Brachytherapy afterloading units*
	X-ray	*Radionuclide*	*LINACs*	
China	0.19	0.45	0.24	0.26
Colombia	–	0.81	0.32	0.64
Costa Rica	0.57	0.86	0	2.00
Dominica	0	0	0	0
Dominican Republic	–	1.04	0.13	0.52
El Salvador	–	0.54	0	1.63
Grenada	0	0	0	0
Honduras	–	0.36	0	0.36
Jordan	0.19	0.38	0.58	0.19
Libyan Arab Jamahiriya	0.38	0.57	–	–
Malaysia	0.05	0.41	0.36	0.36
Mauritius	–	1.77	1.77	1.77
Mexico	0.08	0.99	0.26	0.78
Nicaragua	–	0.25	0	1.25
Oman	0	0	0	0
Pakistan	–	0.01	0.01	–
Paraguay	–	0.85	0.64	0
Peru	0.43	0.38	0.13	1.06
Philippines	0.03	0.16	0.04	0.07
Puerto Rico	–	0.52	0.52	0
Saint Kits and Nevis	0	0	0	0
Saint Lucia	0	0	0	0
Saint Vincent and the Grenadines	0	0	0	0
Trinidad and Tobago	–	1.55	0	1.55
Tunisia	0.22	0.78	0.11	1.67
Turkey	0.34	0.64	0.31	0.28
Average	0.22	0.52	0.26	0.38
Health-care level III				
Afghanistan	0	0	0	0
Congo	–	0.37	0	–
Egypt	–	0.21	0.21	0.09
Ghana	–	0.11	0	0.45
Guatemala	–	0.62	0	0.93
Guyana	–	0	0	0
Haiti	–	0.28	0	–
Jamaica	–	0.82	0	0
Madagascar	0.07	0.07	–	–
Morocco	0.04	0.34	0.04	–
Namibia	–	0.63	0	–
Nigeria	–	0.04	0	0.04
Sudan	0.04	0.12	0.04	0.12
Suriname	–	0	0	0
Zimbabwe	–	0.26	0.26	0.26
Average	0.03	0.15	0.06	0.13
Health-care level IV				
Angola	–	0.09	0	–
Cameroon	–	0.15	0	0.37
Ethiopia	–	0.02	0	0.02
Kenya	0	0.11	0	0.14
Liberia	–	0.45	0	–
Mozambique	–	0.06	0	–
Nepal	0	0.05	0	0
Senegal	–	0.12	0	–
Uganda	0.02	0.07	0	0.07
United Rep. of Tanzania	0.04	0.07	0	0.04
Average	0.02	0.07	0	0.07

Table 7
Temporal trends in average provision for medical radiology per million population
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures

Resource	*Years*	*Number per million population at health-care level*			
		I	*II*	*III*	*IV*
Physicians	1970–1974	–	–	–	–
	1980–1984	–	–	–	–
	1985–1990	2 600	550	180	53
	1991–1996	2 780	695	210	45
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
Dentists	1991–1996	530	87	49	3
Medical x-ray generators	1970–1974	450	14	–	0.6
	1980–1984	380	71	16	10
	1985–1990	350	86	18	4
	1991–1996	290	60	40	4
Mammography x-ray generators	1991–1996	24	0.5	0.2	0.1
Dental x-ray generators	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
Computed tomography scanners	1991–1996	17	2.4	0.4	0.1
Nuclear medicine gamma cameras	1991–1996	7.2	0.3	0.1	0.03
Nuclear medicine rectilinear scanners	1991–1996	0.9	0.3	0.1	0.01
Nuclear medicine PET scanners	1991–1996	0.2	0.002	0	0
Therapy x-ray units	1970–1974	14	0.2	–	–
	1980–1984	13	1.7	0.7	–
	1985–1990	4.8	5.0	0.1	0.1
	1991–1996	2.8	0.2	0.03	0.02
Radionuclide teletherapy units	1970–1974	3.1	0.1	0.1	–
	1980–1984	3.4	0.4	0.4	–
	1985–1990	2.6	0.4	0.2	0.09
	1991–1996	1.6	0.5	0.2	0.1
LINACs	1970–1974	1.0	–	–	–
	1980–1984	1.2	0.1	0.02	–
	1985–1990	2.0	0.1	0.09	–
	1991–1996	3.0	0.3	0.06	0
Brachytherapy afterloading units	1991–1996	1.7	0.4	0.1	0.1
Stereotactic radiosurgery units	1991–1996	0.04	0.03	0	0
Neutron therapy facilities	1991–1996	0.02	0.001	0	0
Heavy ion therapy facilities	1991–1996	0.01	0	0	0

Table 8
Annual numbers of medical radiation examinations and treatments (1991–1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	*Diagnostic examinations (thousands)*			*Therapeutic treatments [a] (thousands)*		
	Medical x rays	*Dental x rays [b]*	*Radionuclide administrations*	*Teletherapy*	*Brachytherapy*	*Radionuclide administrations*
Health-care level I						
Argentina	–	–	396	–	–	6.85
Australia	10 000	–	212	32.5	1.13	–
Austria [H60]	–	–	–	–	–	2.30
Bahrain	115	28	–	–	–	–
Belarus	7 489	835	4.98	4.68	0.986	–
Bulgaria	5 000	–	27.7	1.57	4.73	0.258
Canada	24 933	–	1 805	47.3	1.95	8.37
Cayman Islands	–	–	0	0	0	0
China, Taiwan Province	10 446	–	135	–	–	–
Croatia	4 300	1 100	11.3	9.43	0.350	0.145
Cuba	–	–	–	22.2	–	–
Cyprus	610	7.87	4.33	0.605	0.012	0.052
Czech Republic	9 154	2 000	293	36.2	2.83	2.60
Denmark	2 600	2 400	77.5	7.85	–	2.34
Ecuador	1 959	184	10.3	1.35	0.124	0.452
Estonia [S29]	1 500	–	12.0	–	–	–
Finland	3 600	1 484	50.9	–	–	2.24
France	92 000	–	–	100	–	7.00
Germany	102 240	22 520	2 780	–	–	31.4
Greece [H60]	–	–	–	–	–	1.63
Hungary	4 891	420	158	37.7	3.20	1.08
Ireland	–	–	22.3	5.87	0.339	0.445
Israel [H60]	–	–	–	–	–	0.30
Italy	–	–	621	–	–	6.00
Japan	184 652	104 860	1 460	95.2 [c]	5.51 [c]	3.78 [c]
Kuwait	1 515	168	21.5	0.386	0.025	0.227
Lithuania	3 287	400	39.2	–	–	1.087
Luxembourg	425	191	21.2	0	0	–
Netherlands	9 000	2 700 [c]	240	34 [c]	2.3 [c]	4.3 [c]
New Zealand	–	–	29.1	6.25	0.172	0.562
Norway	3 062	–	–	–	–	1.02
Panama	803	–	9.22	0.790	0.141	–
Poland	24 760	2 840	–	–	–	–
Portugal [F11]	8 381	986	39.4	–	–	0.682
Qatar	248	–	2.56	0	0	0.024
Romania	10 197	632	68.5	10.5	3.67	1.53
Russian Federation	170 700	14 240	1 869	144	65.3	1.483
Slovakia	4 261	503	49.9	4.07	1.38	0.612
Slovenia	691	110	22.2	4.84	0.278	0.591
South Africa	5 580	–	–	–	–	–
Spain	25 059 [c]	5 515 [c]	474 [c]	45.7 [c]	2.64 [c]	8.38 [c]
Sweden	5 000	6 500	120	11.5	0.964	3.50
Switzerland	5 320	4 050	67.5	–	–	1.607
Ukraine	31 478	–	262	–	–	–
United Arab Emirates	904	36.7	17.3	0.552	0.022	0.058
United Kingdom	28 876	12 500	478	135	–	14.5
United States [I23]	250 000	–	8 202	515	30.0	–
Uruguay	–	–	–	4.78	0	–
Venezuela	–	–	–	34.3	–	–
Health-care level II						
Antigua and Barbuda [B33, B43]	17.6	–	0	0	0	0
Bahamas [B43]	–	–	–	0	0	–
Barbados	43.4	–	–	0.783	–	–
Belize	–	–	–	0	0	–
Bolivia	–	–	–	6.00	–	–
Brazil	39 083	16 667	1 000 [c]	200	5.5 [c]	5.00
Chile	–	–	–	30.0	–	–
China [Z9, Z13, Z29]	207 000 [c]	2 000	620 [c]	410 [c]	–	48 [c]
Colombia	–	–	–	54.7	–	–
Dominica	14.8	–	0	0	0	0
Dominican Republic	–	–	–	14.6	–	–

Table 8 (continued)

Country / area	*Diagnostic examinations (thousands)*			*Therapeutic treatments [a] (thousands)*		
	Medical x rays	*Dental x rays [b]*	*Radionuclide administrations*	*Teletherapy*	*Brachytherapy*	*Radionuclide administrations*
El Salvador	–	–	–	11.2	–	–
Grenada	15.0	–	0	0	0	0
Honduras	–	–	–	11.0	–	–
Iran (Islamic Republic of)	–	–	110	–	–	–
Jordan	235	16.0	8.13	1.39	–	0.701
Libyan Arab Jamahiriya	–	–	–	0.411	–	–
Malaysia	3 578	–	–	–	–	–
Mexico	28 365	106	98.0	10.3	1.99	3.53
Nicaragua	–	–	–	8.80	–	–
Oman	606	5.18	1.44	0	0	0
Pakistan	–	–	77.1	7.47	0.158	3.93
Paraguay	–	–	–	10.0	0	–
Peru	–	–	13.7	3.28	0.850	0.800
Puerto Rico	–	–	–	5.54	–	–
Saint Kitts and Nevis	7.30	–	0	0	0	0
Saint Lucia	18.7	–	0	0	0	0
Saint Vincent and the Grenadines	16.2	–	0	0	0	0
Trinidad and Tobago	–	–	–	1.96	–	–
Tunisia	–	–	7.08	1.20	0.200	0.380
Turkey	6 262	2 000	132	24.6	2.37	3.03
Health-care level III						
Afghanistan [L57]	–	–	–	0	–	–
Ghana	118	4.42	0.970	–	–	–
Guatamala	–	–	–	20.0	–	–
Haiti	–	–	–	13.0	–	–
Jamaica	–	–	–	5.00	0	–
Madagascar	151	–	–	0.904	–	–
Morocco	216	–	16.5	9.60	0.800	0.920
Sudan	956	–	2.21	1.17	0.024	0.167
Health-care level IV						
Ethiopia	–	–	0.848	–	–	0.025
United Rep. of Tanzania	831	1.90	0.666	1.42	–	0.007

a Complete courses of treatment.
b Some values may refer to number of films.
c These revised data were received by the Committee after completion of the global analysis.

The entries in this Table are qualified as follows:

Afghanistan: No radiotherapy or oncology services in country [L57].
Argentina: Totals for diagnostic and therapeutic procedures with radionuclides inferred from data for about 25% of Nuclear Medicine Centres.
Barbados: Data from reference [B43]. Total for medical x-ray examinations refers to public sector. Total for teletherapy refers to estimated annual number of new patients with cancer.
Brazil: Except for data on diagnostic radionuclide administrations and brachytherapy treatments, numbers extrapolated from data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil). Data for diagnostic dental x-ray examinations include only intraoral procedures.
Canada: Total for diagnostic medical x-ray examinations from reference [A15]. Totals for diagnostic and therapeutic radionuclide procedures extrapolated from data for the province of Ontario (representing about 37% of population). Totals for teletherapy and brachytherapy treatments extrapolated from data for the Nova Scotia Cancer Treatment and Research Foundation, the Cross Cancer Institute (Northern Alberta) and the province of Manitoba (collectively representing about 14% of the population).
China: Data shown for teletherapy also include brachytherapy.
China (Taiwan): Data on diagnostic radionuclide procedures from reference [L6].
Cyprus: Data for medical and dental x rays extrapolated from information for 50% of poulation; data for diagnostic and therapeutic radionuclide procedures extrapolated from information for 90% of population.
Finland: Data for therapeutic radionuclide administrations from reference [K59].
France: Data on diagnostic medical x rays from reference [B40]; this total includes dental x rays. Data for therapeutic treatments represents annual number of patients undergoing radiotherapy [S50]. Data on therapeutic radionuclide administrations from reference [H60].
Ghana: Data on diagnostic medical and dental x rays from reference [S38]. Data on diagnostic radionuclide examinations from reference [A16].
Italy: Data on diagnostic medical x-rays from reference [B40]; this total includes dental x rays.
Japan: Data on diagnostic dental x-rays from reference [I30].
Mexico: Total for diagnostic medical x-ray examinations inferred from data for about 35% of radiology Institutions. Data for diagnostic dental x-ray examinations include only panoramic procedures.
Morocco: Total for brachytherapy treatments includes only gynaecological tumours.
New Zealand: Data for therapeutic radionuclide administrations from reference [L28].
Norway: Data on therapeutic radionuclide administrations from reference [H60].

Table 8 (continued)

Poland: Data on diagnostic x-rays from reference [S49].
Portugal: Data on diagnostic exminations from reference [F11]. Data on therapeutic radionuclide administrations from reference [H60].
Switzerland: Data on therapeutic radionuclide administrations from reference [H60].
Ukraine: Total for medical x-ray examinations includes dental x-ry examinations.
United Kingdom: Data for medical and dental x-ray examinations from reference [T15]. Data for diagnostic examinations with radionuclides from reference [E11]. Estimated total for 'Teletherapy' includes also brachytherapy treatments. Data for therapeutic radionuclide administrations from reference [C27].
Uruguay: Data from reference [B43]. Total for teletherapy refers to estimated annual number of new patients with cancer.

Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines:
Data from reference [B43]. Total for medical x-ray examinations refers to public sector.

Bolivia, Chile, Colombia, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Paraguay, Puerto Rico, Trinidad and Tobago, Venezuela:
Data from reference [B43]. Total for teletherapy refers to estimated annual number of new patients with cancer.

Table 9
Global use of medical radiology (1991-1996)
Estimates derived from UNSCEAR Survey of Medical Radiation Usage and Exposures [a]

P A R T A: NORMALIZED VALUES

Quantity		*Number per million population 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
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

P A R T B: TOTAL VALUES

Quantity	*Total number (millions) at health-care level*				
	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	0.0001	0.4

Table 9 (continued)

Quantity		*Total number (millions) at health-care level*				
		I	*II*	*III*	*IV*	*Globally*
X-ray imaging						
Equipment	Medical	0.45	0.2	0.02	0.002	0.7
	Dental	0.67	0.2	0.01	< 0.0001	0.9
	Mammography	0.04	0.001	0.0001	0.0001	0.04
	CT	0.027	0.007	0.0003	0.0001	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	0.0001	0.00002	0.012
	Rectilinear scanners	0.001	0.001	0.0001	0.00001	0.002
	PET scanners	0.0003	0.00001	0	0	0.00031
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	0.0002	0.4
Teletherapy						
Equipment	X-ray	0.004	0.001	0.00002	0.00001	0.005
	Radionuclide	0.002	0.002	0.0001	0.00004	0.004
	LINAC	0.005	0.001	0.00004	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	0.0001	0.00004	0.004
Annual number of patients [g]		0.3	0.05	0.01	(0.01) [h]	0.4
Population						
Total Population		1 530	3 070	640	565	5 800

a Extrapolated, with rounding, from limited samples of data.
b Estimates based on following population sample sizes for global model: 67% for level I, 50% for level II, 9% for levels III/IV, and 46% overall.
c Estimates based on following population sample sizes for global model: 39% for level I, 49% for level II, 4% for levels III/IV, and 37% overall.
d Estimates 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 Estimates 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 Estimates 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 Estimates 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 10
Chronology of key technical advances in diagnostic radiology

Date	*Development*
1895	Discovery of x rays (Röntgen); first clinical image
1920s	Barium contrast studies
1930s	Intravenous contrast media
1940s	Angiography
1950s	Fluoroscopic image intensifiers; catheter techniques
1960s	Early work on rare-earth intensifying screens
1970s	Computed tomography (CT)
1980s	Magnetic resonance imaging (MRI); digital radiology
1990s	Interventional radiological techniques; picture archive and communications systems (PACS); teleradiology

Table 11
Aspects of practice that influence doses to patients from x-ray examinations
[B11, B53, C1, C3, C11, G30, G31, G32, H1, H10, H11, J2, L1, L4, L30, M42, M43, M49, N7, N8, N28, S3, S19, S20, S21, S52, S59, S64, T1, U3, V3, V13, W16, W40]

Aspect	*Influence*
Procedure-related	
Strict referral criteria	Reduce per caput doses by removing clinically unhelpful examinations
Availability of previously taken films	Promotes elimination of retakes and thus reduction of per caput doses
Number of radiographs per examination	Positively correlated with dose
Fluoroscopy time and current	Positively correlated with dose
Quality assurance programmes	Promote reductions in per caput doses
Routine patient dosimetry and reference doses	Promote reductions in per caput doses
X-ray beam collimation	Beam area positively correlated with dose
Shielding of sensitive organs	Facilitates dose reduction
Choice of projection	Organ doses can depend on beam projection
Optical density of radiographs	Positively correlated with dose
Compression of attenuating tissue	Reduces dose and scatter and improves image quality
Matching exposure factors to patient stature	May reduce doses
Equipment-related	
Exposure time	Use of long times and low currents may increase dose due to reciprocity law failure
Applied potential	Higher settings may reduce dose and contrast
X-ray tube voltage waveform	Three-phase and constant potential generators reduce dose and contrast
X-ray target material	Molybdenum may increase dose and contrast compared with tungsten
Beam filtration, thickness	Increasing thickness reduces dose and contrast
Beam filtration, material	Rare-earth K-edge filters and other materials can reduce dose and contrast
Beam filtration, shape	Dose reduction with special semitransparent filters in radiography and fluoroscopy
Anti-scatter grids	Appropriate design and use to increase image quality and dose when required
Air gap technique	May obviate need for grid
Attenuation between patient and image receptor	Low attenuation materials (e.g. carbon fibre tables) reduce dose
Screen/film combination	Dose reductions through appropriate use of faster (rare earth) screens
Film processing	Reductions in per caput doses through adherence to manufacturers instructions
Image intensifiers	Sensitive (e.g. CsI) photocathodes facilitate dose reduction
Digital image processing	May facilitate dose reduction
Fluoroscopy recording method	Video recorder reduces fluoroscopy dose compared with cine camera
Pulsed fluoroscopy with image storage device	Reduces fluoroscopy dose
Spot film photofluorography	Dose reduction with 100 mm camera compared with radiography
Picture archiving and communications systems (PACS)	Potential reductions in per caput doses from improved availability of images
Computed radiography	Potential for dose reduction from greater reliability of image reproduction
Digital imaging techniques	Potential for improved image quality, but often at expense of increased dose

Table 12
Annual numbers of examinations per 1,000 population for common types of diagnostic medical [a] x-ray procedures (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

PART A

Country / area	Chest			Limbs and joints	Spine				Pelvis and hips	Head	Abdomen	GI tract		Cholecystography	Urography	Pelvimetry
	Radiography	Photofluorography	Fluoroscopy		Lumbar	Thoracic	Cervical	All				Upper	Lower			
Health-care level I																
Australia	113	0.0003	0.57	160	28	44	15	100	37	23	15	8.1	5.8	0.85	11	0.38
Bahrain	49	– [b]	–	64	–	–	–	13	6.8	21	19	2.7	1.0	0.03	2.8	0.12
Belarus	11	435	123	84	5.8	2.0	3.9	12	4.7	12	2.8	27	3.9	0.48	3.8	–
Belgium [C26]	260	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Canada	260	–	0.38	284	–	–	–	112	25	44	22	36	15	1.0	7.8	0.04
China, Taiwan Prov.	200	–	–	–	–	–	–	112	–	29	58	51	–	12	–	–
Croatia	147	59	11	–	–	–	–	252	147	147	168	–	–	–	5.0	–
Cyprus	254	23	0	292	–	–	–	95	20	81	47	19	–	0.15	11	0
Czech Republic	145	25	5.0	229	55	38	54	150	65	87	20	12	5.2	3.7	12	–
Denmark	–	0	0	–	–	–	–	–	–	–	–	–	–	–	–	–
Ecuador	45	–	–	26	11	5.9	6.6	24	15	13	9.7	1.3	1.2	2.0	7.9	0.17
Finland	240	–	–	–	20	6.1	16	42	14	51	8.2	1.0	5.6	–	2.9	1.0
Germany	266	–	–	306	–	–	–	151	99	138	32	11	5.5	2.7	28	–
Hungary	50	24	22	126	–	–	–	33	51	90	–	12	19	0.07	2.7	–
Japan	616	17	15	172	88	14	57	159	15	63	97	118	15	6.0	14	0.91
Kuwait	323	145	0	181	35	–	31	–	19	71	63	4.7	0.77	0.11	5.7	0.29
Lithuania	79	108	69	332	–	–	–	–	–	–	92	–	–	–	–	–
Luxembourg	205	1.5	–	320	119	23	94	236	26	63	18	7.8	6.6	1.4	22	–
Netherlands	120	–	–	67	27	3.3	13	43	25	33	9.3	12	7.0	0	11	0
Norway	146	34	0.70	181	21	11	21	53	59	2.6	7.6	8.1	8.7	–	9.3	–
Panama	117	–	–	36	12	4.4	11	27	9.4	26	17	13	11	4.3	20	–
Poland [S49]	149	181	2.6	108	42	21	31	94	15	46	11	10	2.3	0	6.0	0
Qatar	235	0.04	–	–	–	–	–	30	112	26	35	2.4	1.5	0.06	7.5	0.50
Romania	54	106	112	40	10	3.6	9.2	21	14	20	15	45	10	2.7	3.0	–
Russian Federation	127	449	–	322	–	–	–	–	–	–	–	104	–	–	–	–
Slovakia	145	64	9.5	62	–	–	–	62	33	64	43	38	17	1.1	13	–
Slovenia	83	–	–	106	–	–	–	56	6.3	9.5	12	3.1	0.53	0.09	3.9	0.47
South Africa [M22]	69	–	–	–	7.3	2.2	6.1	16	8.3	–	7.7	2.9	1.5	–	3.7	–
Sweden	136	–	0.09	136	16	7.4	11	34	40	8.0	8.0	5.1	11	0.74	11	0.57
Switzerland	207	7.2	0.52	247	39	11	23	73	49	36	22	3.0	3.9	1.7	8.5	–
United Arab Emirates	111	65	0.56	79	28	2.1	2.7	33	9.2	23	26	2.9	1.1	0.19	3.3	3.8
United Kingdom	141	–	–	147	19	5.0	14	40	31	28	21	4.9	6.1	1.2	4.6	–
Average	236	202	21	212	45	12	30	100	36	60	41	54	8.6	3.1	12	0.56

Table 12 (continued)

Country / area	Chest			Limbs and joints	Spine				Pelvis and hips	Head	Abdo-men	GI tract		Chole-cysto-graphy	Uro-graphy	Pelvi-metry
	Radio-graphy	Photo-fluorography	Fluoro-scopy		Lumbar	Thoracic	Cervical	All				Upper	Lower			
Health-care level II																
Brazil	77	–	–	70	5.3	2.4	25	33	20	36	7.1	2.6	1.1	0.89	5.0	–
China [Z9, Z13]	11	–	83	11	–	–	–	4.0	–	–	12	5.4	–	–	–	–
Costa Rica	29	–	–	1.8	–	–	–	12	1.9	8.3	8.6	–	–	–	–	–
Jordan	10	–	–	5.1	–	–	–	4.4	3.2	5.7	6.8	–	0.19	0.02	0.58	–
Malaysia	115	0	0	41	–	–	–	–	–	–	15	0.34	–	0.02	0.65	–
Mexico	88	0.24	0.84	60	–	–	–	28	12	34	33	4.3	2.7	1.9	7.1	2.9
Oman	81	0	0	89	–	–	–	34	6.8	27	22	2.5	–	0.12	2.2	0
Turkey	29	1.1	0.02	15	–	–	–	14	3.7	10	6.8	0.96	0.49	0.03	1.9	0.0003
Average	24	0.50	72	20	5.3	2.4	25	8.9	14	30	13	4.8	1.5	0.94	4.7	1.7
Health-care level III																
Ghana	3.0	–	–	–	0.62	–	–	–	0.54	0.55	–	–	–	–	–	–
Madagascar	4.9	–	–	2.4	–	–	–	–	–	1.9	1.1	0.06	0.03	0.001	0.05	0.006
Sudan	6.2	–	–	8.7	2.0	0.72	0.94	3.6	2.2	6.5	2.2	1.4	2.9	0.26	2.2	0.72
Average	4.9	–	–	6.5	1.4	0.72	0.94	3.6	1.5	3.5	1.8	0.96	1.9	0.17	1.4	0.47
Health-care level IV																
United Rep. Tanzania	4.9	0	0	7.4	–	–	–	3.5	2.1	2.8	2.3	1.6	1.4	0.01	0.003	0
Average	4.9	0	0	7.4	–	–	–	3.5	2.1	2.8	2.3	1.6	1.4	0.01	0.003	0

PART B

Country / area	Mammography			CT			Angiography			Interventional procedures		Total of all medical examinations
	Screening	Clinical	All	Head	Body	All	Cerebral	Cardiac	All	PTCA	All	
Health-care level I												
Australia	–	–	27	24	28	52	0.35	4.9	6.8	–	–	565
Bahrain	–	–	1.4	3.4	2.0	5.4	–	–	0.21	–	–	202
Belarus	–	–	–	–	–	5.6	–	–	1.0	–	0.02	726
Belgium [C26]	–	–	–	–	–	–	–	–	–	0.52	–	–
Bulgaria	–	–	–	–	–	–	–	–	–	–	–	589
Canada	–	–	79	19	22	41	–	–	7.0	–	0.31	892

Table 12 (continued)

Country / area	*Mammography*			*CT*			*Angiography*			*Interventional procedures*		*Total of all medical examinations*
	Screening	*Clinical*	*All*	*Head*	*Body*	*All*	*Cerebral*	*Cardiac*	*All*	*PTCA*	*All*	
Health-care level I (continued)												
China, Taiwan Prov.	–	–	0.18	–	–	21	–	–	0.89	–	–	480
Croatia	–	–	1.7	–	–	9.7	0.13	0.21	0.80	–	–	903
Cyprus	–	–	17	–	–	69	–	5.4	6.4	0.07	0.12	937
Czech Republic	0	12	12	22	11	34	0.45	1.1	5.6	–	31	883
Denmark	–	–	–	–	–	–	–	–	–	–	–	510
Ecuador	–	–	1.1	–	–	3.5	–	–	0.16	–	0.09	151
Estonia [S29]	–	–	–	–	–	–	–	–	–	–	–	1 000
Finland	27	6.4	34	15	9.4	25	–	0.96	–	0.20	1.7	704
France [B40]	–	–	–	–	–	33	–	–	–	–	–	–
Germany	–	–	68	20	44	64	–	–	24	1.1	2.2	1 254
Greece [P12]	–	–	–	25	61	87	–	–	–	–	–	–
Hungary	–	–	2.1	26	17	43	0.13	–	1.2	0.08	0.30	475
Israel [S48]	–	–	–	–	–	78	–	–	–	–	–	–
Italy [B40]	–	–	–	–	–	29	–	–	–	–	–	–
Japan	–	5.2	–	–	–	–	1.1	1.2	5.6	–	–	1 477
Kuwait	0	2.0	2.0	7.5	4.2	12	0.06	–	1.0	–	2.1	896
Lithuania	–	4.8	–	–	–	–	–	–	4.2	–	–	886
Luxembourg	17	33	50	31	45	76	0.99	–	13	–	–	1 046
Netherlands	35 [c]	12	47 [c]	13	19	32	–	–	0.63	0.80	1.3	600
Norway	–	43	–	21	27	48	–	–	11	–	–	708
Panama	–	–	8.8	6.4	3.8	10	0.22	0.52	0.90	–	–	300
Poland [S49]	–	–	7.3	3.0	1.4	4.4	0.20	0.80	2.8	–	0.80	641
Portugal [F11]	–	–	20	–	–	30	–	–	–	–	–	850
Qatar	–	–	0.72	–	–	8.3	–	–	0.21	–	0.58	459
Romania	–	–	1.8	–	–	0.02	–	–	0.63	–	–	450
Russian Federation	–	–	4.6	–	–	–		–	–	–	–	1 151
Slovakia	3.5	7.0	11	20	34	54	2.0	0.69	5.6	0.38	1.0	800
Slovenia	–	–	14	–	–	25	–	–	3.7	–	1.3	348
South Africa [M22]	–	–	–	–	1.9	–	–	–	1.2	–	–	180
Spain	–	–	–	–	–	15	–	1.5	2.0	0.32	0.6	–
Sweden	63	17	80	20	18	39	0.51	4.2	8.1	0.68	3.0	568
Switzerland	–	–	29	16	26	43	1.4	4.4	11	1.2	4.7	750
Ukraine [K18]	–	–	–	1.0	1.8	2.8	–	–	–	–	–	600
United Arab Emirates	0.79	0.52	1.3	9.2	2.7	12	0.09	0.02	0.45	–	0.13	378
United Kingdom	21	5.6	27	9.5	12	21	0.21	2.8	5.2	–	4.5	489
United States	–	–	–	–	–	91	–	–	–	–	–	962
Average	21	7.1	25	14	19	48	0.68	1.8	6.8	0.75	2.7	920

Table 12 (continued)

Country / area	*Mammography*			*CT*			*Angiography*			*Interventional procedures*		*Total of all medical examinations*
	Screening	*Clinical*	*All*	*Head*	*Body*	*All*	*Cerebral*	*Cardiac*	*All*	*PTCA*	*All*	
Health-care level II												
Antigua and Barbuda	–	–	–	–	–	–	–	–	–	–	–	271
Barbados	–	–	–	–	–	–	–	–	–	–	–	174
Brazil	–	–	3.3	–	–	4.8	–	–	0.33	–	–	261
China [Z9, Z13]	–	–	–	–	–	10.3 [c]	–	–	–	–	–	173 [c]
Dominica	–	–	–	–	–	–	–	–	–	–	–	185
Grenada	–	–	–	–	–	–	–	–	–	–	–	158
Jordan	0	0.25	0.25	1.0	0.86	1.9	–	–	–	–	–	45
Malaysia	0	1.3	1.3	0.79	0.58	1.4	0.05	0.24	–	–	–	183
Mexico	1.1	1.8	2.9	4.2	2.8	7.0	–	–	0.68	–	1.3	306
Oman	–	–	0.49	–	–	2.0	0.10	0.42	0.52	–	0.003	269
Saint Kitts and Nevis	–	–	–	–	–	–	–	–	–	–	–	203
Saint Lucia	–	–	–	–	–	–	–	–	–	–	–	134
Saint Vincent and the Grenadines	–	–	–	–	–	–	–	–	–	–	–	147
Turkey	–	–	1.5	–	–	13	–	–	0.54	–	0.45	98
Average	0.85	1.7	2.7	3.5	2.3	6.7	0.06	0.25	0.48	–	0.94	154
Health-care level III												
Ghana	–	–	0.011	–	–	0.08	–	–	–	–	–	7
Madagascar	–	–	0.003	–	–	0.09	–	–	0	–	0	11
Morocco	–	–	–	–	–	–	–	–	–	–	–	8
Sudan	–	–	–	–	–	–	–	–	–	–	–	37
Average	–	–	0.01	–	–	0.08	–	–	0	–	0	17
Health-care level IV												
United Rep. Tanzania	–	–	–	–	–	0.21	–	–	0	–	0	29
Average	–	–	–	–	–	0.21	–	–	0	–	0	29

a Excluding dental x-ray examinations.
b No data available.
c These revised data were received by the Committee after completion of the global analysis.

The entries in this Table are qualified as follows:

Brazil: Survey data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil).
Canada: Data for total of all medical x-ray examinations from reference [A15]; data for specific examinations on the basis of information (excluding procedures in private clinics) for the province of Ontario (representing about 37% of population).
China: Data for 'GI tract' include both 'Upper' and 'Lower' categories.

Table 12 (continued)

China, Taiwan Province: Data for 'Chest radiography' include all chest examinations. Data for 'GI tract' include both 'Upper' and 'Lower' categories.
Costa Rica: Data from Hospital Calderón Guardia (serving one third of the population).
Cyprus Survey data relating to 50% of population.
Ghana: Data from reference [S38]. Data for 'Pelvis/hip' include 'Abdomen' examinations.
Lithuania: Data from Vilnius University Hospital.
Madagascar: Data for 'Head' include examinations of the spine.
Malaysia: Data for 'Limbs and joints' include 'Head' examinations. Data for 'GI tract' include both 'Upper' and 'Lower' categories.
Mexico: Data for 'Head' include examinations of the neck.
Oman: Data for 'GI tract' include both 'Upper' and 'Lower' categories.
Romania: Data from all counties except Bucharest.
Russian Federation: Data for 'Limbs and joints' include all examinations of the skeleton. Data for 'GI tract' include all examinations of digestive organs.
Slovakia: Survey data relating to population base of about 2 million.
Slovenia: Survey data relating to population base of about 1.8 million.
Spain: Data for CT from reference [B40]; data for angiography and interventional procedures from reference [V8].
Sweden: Survey data from a sample of health districts covering about one−quarter of the population.
Turkey: On the basis of data from Hacettepe University Hospital.
United Arab Emirates: 1% of pelvimetry examinations conducted using CT/digital techniques.
United Kingdom: Data from reference [T15]. Data for 'Chest radiography' include all chest examinations.
United States: Data for CT from reference [B40]. Data for total of all medical examinations from [I23].

Antigua, Barbados, Dominica,, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines: Data for public sector from [B43].

Table 13
Percentage contributions by types of procedure to annual total numbers of diagnostic medical [a] x-ray examinations (1991–1996)
Based on data and qualifications from Table 12

PART A

Country / area	Chest			Limbs and joints	Spine				Pelvis and hips	Head	Abdomen	GI tract		Cholecystography	Urography	Pelvimetry
	Radiography	Photofluorography	Fluoroscopy		Lumbar	Thoracic	Cervical	All				Upper	Lower			
Health-care level I																
Australia	20	0.0001	0.1	28	5.0	7.7	2.6	18	6.6	4.0	2.7	1.4	1.0	0.2	2.0	0.07
Bahrain	24	–	–	31	–	–	–	6.7	3.4	10	9.3	1.3	0.5	0.01	1.4	0.06
Belarus	1.5	60	17	12	0.8	0.3	0.5	1.6	0.7	1.7	0.4	3.7	0.5	0.07	0.5	–
Canada	29	–	0.04	32	–	–	–	13	2.8	4.9	2.4	4.1	1.7	0.1	0.9	0.004
China, Taiwan Prov.	42	–	–	–	–	–	–	23	–	6.1	12	11	–	2.6	–	–
Croatia	16	6.5	1.2	–	–	–	–	28	16	16	19	–	–	–	0.6	–
Cyprus	27	2.4	0	31	–	–	–	10	2.1	8.7	5.1	2.0	–	0.02	1.2	0
Czech Republic	16	2.8	0.6	26	6.2	4.3	6.1	17	7.4	9.9	2.3	1.4	0.6	0.4	1.4	–
Denmark	–	0	0	–	–	–	–	–	–	–	–	–	–	–	–	–
Ecuador	30	–	–	17	7.3	3.9	4.4	16	9.9	8.8	6.4	0.9	0.8	1.3	5.3	0.1
Finland	34	–	–	–	2.9	0.9	2.2	6.0	1.9	7.2	1.2	0.2	0.8	–	0.4	0.1
Germany	21	–	–	24	–	–	–	12	7.9	11	2.5	0.8	0.4	0.2	2.2	–
Hungary	10	5.0	4.6	27	–	–	–	6.9	11	19	–	2.6	4.0	0.02	0.6	–
Japan	42	1.2	1.0	12	6.0	0.9	3.9	11	1.0	4.3	6.5	8.0	1.0	0.4	0.9	0.06
Kuwait	36	16	0	20	3.9	–	3.5	–	2.1	7.9	7.0	0.5	0.1	0.01	0.6	0.03
Lithuania	8.9	12	7.8	37	–	–	–	–	–	–	10	–	–	–	–	–
Luxembourg	20	0.14	–	31	11	2.2	9.0	23	2.5	6.0	1.7	0.8	0.6	0.1	2.1	–
Netherlands	20	–	–	11	4.5	0.6	2.2	7.2	4.2	5.5	1.6	2.0	1.2	0	1.8	0
Norway	21	4.8	0.1	26	3.0	1.5	3.0	7.5	8.3	0.4	1.1	1.1	1.2	–	1.3	–
Panama	39	–	–	12	4.1	1.5	3.6	9.1	3.1	8.6	5.6	4.3	3.6	1.4	6.6	–
Poland	23	28	0.4	17	6.6	3.2	4.8	15	2.3	7.1	1.7	1.6	0.4	0	0.9	0
Qatar	51	0.01	–	–	–	–	–	6.5	24	5.6	7.6	0.5	0.3	0.01	1.6	0.1
Romania	12	23	25	9.0	2..3	0.8	2.0	4.6	3.2	4.5	3.3	10	2.3	0.6	0.7	–
Russian Federation	11	39	–	28	–	–	–	–	–	–	–	9.0	–	–	–	–
Slovakia	18	7.9	1.2	7.7	–	–	–	7.7	4.2	8.0	5.4	4.8	2.1	0.1	1.6	–
Slovenia	24	–	–	30	–	–	–	16	1.8	2.7	3.4	0.9	0.2	0.03	1.1	0.1
South Africa	38	–	–	–	4.1	1.2	3.4	8.7	4.6	–	4.3	1.6	0.8	–	2.1	–
Sweden	24	–	0.02	24	2.8	1.3	1.9	6.0	7.0	1.4	1.4	0.9	2.0	0.1	2.0	0.1
Switzerland	28	1.0	0.07	33	5.2	1.5	3.0	9.7	6.6	4.8	2.9	0.4	0.5	0.2	1.1	–
United Arab Emirates	29	17	0.2	21	7.3	0.6	0.7	8.6	2.4	6.1	6.9	0.8	0.3	0.1	0.9	1.0
United Kingdom	29	–	–	30	3.9	1.0	2.9	8.1	6.3	5.8	4.2	1.0	1.2	0.2	0.9	–
Average [b]	25	19	2.1	21	5.2	1.5	3.6	11	4.0	6.5	4.6	5.7	1.0	0.3	1.3	0.1

Table 13 (continued)

Country / area	Chest			Limbs and joints	Spine				Pelvis and hips	Head	Abdo-men	GI tract		Chole-cysto-graphy	Uro-graphy	Pelvi-metry
	Radio-graphy	Photo-fluorography	Fluoro-scopy		Lumbar	Thoracic	Cervical	All				Upper	Lower			
Health-care level II																
Brazil	29	–	–	27	2.1	0.9	9.7	13	7.6	14	2.7	1.0	0.4	0.3	1.9	–
China	8.1	–	63	8.1	–	–	–	3.0	–	–	9.1	4.1	–	–	–	–
Costa Rica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Jordan	22	–	–	11	–	–	–	9.7	7.2	13	15	–	0.4	0.04	1.3	–
Malaysia	63	0	0	22	–	–	–	–	–	–	8.3	0.2	–	0.01	0.4	–
Mexico	29	0.08	0.3	20	–	–	–	9.2	3.9	11	11	1.4	0.9	0.6	2.3	0.9
Oman	30	0	0	33	–	–	–	13	2.5	10	8.2	0.9	–	0.05	0.8	0
Turkey	29	1.1	0.02	15	–	–	–	14	3.8	10	6.9	1.0	0.5	0.03	2.0	0.0003
Average [b]	16	0.2	50	13	2.1	0.9	9.7	5.8	5.9	13	8.2	3.0	0.6	0.4	2.0	0.8
Health-care level III																
Ghana	45	–	–	–	9.3	–	–	–	8.1	8.3	–	–	–	–	–	–
Madagascar	46	–	–	22	–	–	–	–	–	17	11	0.6	0.2	0.01	0.5	0.05
Sudan	17	–	–	24	5.3	2.0	2.6	9.8	5.9	18	5.9	3.9	7.8	0.7	5.9	2.0
Average [b]	23	–	–	23	5.7	2.0	2.6	9.8	6.1	17	6.5	3.5	6.8	0.6	5.2	1.7
Health-care level IV																
United Rep. Tanzania	17	–	–	25	–	–	–	12	7.2	9.6	7.8	5.4	4.8	0.02	0.01	0
Average [b]	17	–	–	25	–	–	–	12	7.2	9.6	7.8	5.4	4.8	0.02	0.01	0

PART B

Country / area	Mammography			CT			Angiography			Interventional procedures		Total of all medical examinations
	Screening	Clinical	All	Head	Body	All	Cerebral	Cardiac	All	PTCA	All	
Health-care level I												
Australia	–	–	4.7	4.2	5.0	9.2	0.06	0.9	1.2	–	–	100
Bahrain	–	–	0.7	1.7	1.0	2.7	–	–	0.1	–	–	100
Belarus	–	–	–	–	–	0.8	–	–	0.1	–	0.003	100
Canada	–	–	8.9	2.1	2.5	4.6	–	–	0.8	–	0.04	100
China, Taiwan Prov.	–	–	0.04	–	–	4.3	–	–	0.2	–	–	100
Croatia	–	–	0.2	–	–	1.1	0.01	0.02	0.1	–	–	100

Table 13 (continued)

Country / area	*Mammography*			*CT*			*Angiography*			*Interventional procedures*		*Total of all medical examinations*
	Screening	*Clinical*	*All*	*Head*	*Body*	*All*	*Cerebral*	*Cardiac*	*All*	*PTCA*	*All*	
Health–care level I (continued)												
Cyprus	–	–	1.8	–	–	7.3	–	0.6	0.7	0.01	0.01	100
Czech Republic	0	1.3	1.3	2.5	1.3	3.8	0.05	0.1	0.6	–	3.5	100
Ecuador	–	–	0.8	–	–	2.3	–	–	0.1	–	0.06	100
Finland	3.9	0.9	4.8	2.2	1.3	3.5	–	0.1	–	0.03	0.2	100
Germany	–	–	5.4	1.6	3.5	5.1	–	–	1.9	0.09	0.2	100
Hungary	–	–	0.4	5.5	3.5	9.0	0.03	–	0.3	0.02	0.06	100
Japan	–	0.4	–	–	–	–	0.08	0.08	0.4	–	–	100
Kuwait	0	0.2	0.2	0.8	0.5	1.3	0.01	–	0.1	–	0.2	100
Lithuania	–	0.5	–	–	–	–	–	–	0.5	–	–	100
Luxembourg	1.6	3.2	4.8	3.0	4.3	7.3	0.09	–	1.2	–	–	100
Netherlands	5.8[c]	2.0	7.8 [c]	2.1	3.2	5.3	–	–	0.1	0.1	0.2	100
Norway	–	6.1	–	2.9	3.8	6.7	–	–	1.5	–	–	100
Panama	–	–	2.9	2.1	1.3	3.4	0.07	0.2	0.4	–	–	100
Poland	–	–	1.1	0.5	0.2	0.7	0.03	0.1	0.4	–	0.1	100
Portugal	–	–	2.4	–	–	3.5	–	–	–	–	–	100
Qatar	–	–	0.2	–	–	1.8	–	–	0.05	–	0.1	100
Romania	–	–	0.4	–	–	0.004	–	–	0.1	–	–	100
Russian Federation	–	–	0.4	–	–	–	–	–	–	–	–	100
Slovakia	0.4	0.9	1.3	2.5	4.2	6.8	0.3	0.1	0.7	0.05	0.1	100
Slovenia	–	–	4.0	–	–	7.3	–	–	1.1	–	0.4	100
South Africa	–	–	–	–	1.1	–	–	–	0.7	–	–	100
Sweden	11	3.0	14	3.6	3.2	6.8	0.09	0.7	1.4	0.1	0.5	100
Switzerland	–	–	3.8	2.2	3.5	5.7	0.2	0.6	1.4	0.2	0.6	100
Ukraine	–	–	–	0.2	0.3	0.5	–	–	–	–	–	100
United Arab Emirates	0.2	0.1	0.3	2.4	0.7	3.1	0.02	0.01	0.1	–	0.03	100
United Kingdom	4.4	1.1	5.5	1.9	2.4	4.4	0.04	0.6	1.1	–	0.9	100
United States	–	–	–	–	–	9.5	–	–	–	–	–	100
Average [b]	3.7	0.7	2.9	1.7	2.5	6.4	0.1	0.2	0.8	0.1	0.4	100
Health-care level II												
Brazil	–	–	1.3	–	–	1.8	–	–	0.1	–	–	100
Jordan	0	0.5	0.5	2.2	1.9	4.1	–	–	–	–	–	100
Malaysia	0	0.7	0.7	0.4	0.3	0.8	0.03	0.1	–	–	–	100
Mexico	0.4	0.6	1.0	1.4	0.9	2.3	–	–	0.2	–	0.4	100
Oman	–	–	0.2	–	–	0.8	0.04	0.2	0.2	–	0.001	100
Turkey	–	–	1.6	–	–	13	–	–	0.6	–	0.5	100
Average [b]	0.3	0.6	1.2	1.3	0.8	2.9	0.03	0.1	0.2	–	0.4	100

Table 13 (continued)

Country / area	*Mammography*			*CT*			*Angiography*			*Interventional procedures*		*Total of all medical examinations*
	Screening	*Clinical*	*All*	*Head*	*Body*	*All*	*Cerebral*	*Cardiac*	*All*	*PTCA*	*All*	
Health-care level III												
Ghana	–	–	0.2	–	–	1.2	–	–	–	–	–	100
Madagascar	–	–	0.02	–	–	0.8	–	–	0	–	0	100
Average [b]	–	–	0.1	–	–	1.0	–	–	0	–	0	100
Health-care level IV												
United Rep. Tanzania	–	–	–	–	–	0.7	–	–	0	–	0	100
Average [b]	–	–	–	–	–	0.7	–	–	0	–	0	100

a Excluding dental x-ray examinations.
b Overall averages for sample calculated as total number of each particular type of examination divided by total number of all examinations.
c These revised data were received by the Committee after completion of the global analysis.

Table 14
Distribution by age and sex of patients undergoing types of diagnostic x-ray examination (1991–1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Chest radiography						
I	Australia	9	18	73	49	51
	Bahrain	21	33	46	59	41
	China, Taiwan Province	6	27	67	58	42
	Croatia	0	30	70	55	45
	Czech Republic	10	18	72	50	50
	Ecuador	31	34	35	53	47
	Japan	7	21	72	56	44
	Kuwait	19	53	28	62	38
	New Zealand	10	18	72	58	42
	Norway	15	14	71	54	46
	Panama	17	22	61	46	54
	Poland	9	24	67	54	46
	Romania	22	31	47	64	36
	Slovakia	14	33	53	47	53
	South Africa [M22]	20	40	40	54	46
	Sweden	7	14	79	55	45
	Switzerland	5	15	80	52	48
	United Arab Emirates	15	70	15	60	40
	Average	8	22	70	56	44
II	Brazil	– [a]	–	–	44	56
	Costa Rica	4	31	65	47	53
	Mexico	23	37	40	52	48
	Turkey	22	40	38	59	41
	Average	23	37	40	48	52
III	Sudan	22	58	20	39	61
IV	United Republic of Tanzania	15	65	20	50	50
Chest photofluorography						
I	Australia	–	–	–	50	50
	Croatia	0	35	65	55	45
	Kuwait	0	73	27	62	38
	Poland	0	60	40	59	41
	Romania	3	58	39	56	44
	Russian Federation	22	31	47	64	36
	Slovakia	11	43	46	48	52
	United Arab Emirates	0	80	20	55	45
	Average	19	35	46	63	37
II	Mexico	29	47	24	51	49
	Turkey	0	80	20	78	22
	Average	7	72	21	71	29
Chest fluoroscopy						
I	Australia	20	23	57	40	60
	Croatia	0	40	60	50	50
	Japan	1	33	66	66	34
	Poland	0	61	39	68	32
	Romania	11	38	51	55	45
	Slovakia	8	50	42	56	44
	Average	7	36	57	60	40
II	Mexico	15	43	42	50	50
	Turkey	10	63	27	69	31
	Average	15	43	42	50	50

Table 14 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Limbs and joints						
I	Australia	16	33	51	52	48
	Bahrain	31	45	24	67	33
	Czech Republic	18	31	51	48	52
	Ecuador	32	42	26	61	39
	Japan	16	28	56	49	51
	Kuwait	22	58	20	63	37
	New Zealand	21	46	33	57	43
	Panama	22	28	50	55	45
	Poland	16	35	49	55	45
	Romania	24	36	40	60	40
	Slovakia	22	35	43	53	47
	Sweden	15	30	55	45	55
	Switzerland	15	31	54	50	50
	United Arab Emirates	20	50	30	60	40
	Average	17	30	53	50	50
II	Costa Rica	0	5	95	24	76
	Mexico	21	44	35	56	44
	Turkey	18	45	37	59	41
	Average	21	44	35	56	44
III	Sudan	8	25	67	67	33
IV	United Republic of Tanzania	10	50	40	50	50
Lumbar spine						
I	Australia	3	27	70	44	56
	Czech Republic	6	28	66	43	57
	Japan	3	21	76	51	49
	Kuwait	9	65	26	59	41
	New Zealand	6	36	58	49	51
	Norway	1	38	61	44	56
	Panama	9	25	66	44	56
	Poland	2	26	72	47	53
	Romania	5	34	61	49	51
	Slovakia	17	37	46	52	48
	South Africa [M22]	4	53	43	51	49
	Sweden	4	26	70	45	55
	Switzerland	2	29	69	47	53
	Average	3	23	74	50	50
III	Sudan	19	37	44	74	26
Thoracic spine						
I	Australia	6	27	67	36	64
	Czech Republic	10	35	55	44	56
	Ecuador	8	59	33	58	42
	Japan	9	25	66	57	43
	New Zealand	8	36	56	45	55
	Norway	3	40	57	42	58
	Panama	9	29	62	45	55
	Poland	11	31	58	48	52
	Romania	8	31	61	53	47
	Slovakia	17	39	44	52	48
	South Africa [M22]	8	56	36	47	53
	Sweden	4	19	77	45	55
	Switzerland	6	36	58	43	57
	Average	9	29	62	49	51
III	Sudan	20	30	50	60	40
Cervical spine						
I	Australia	4	28	68	38	62
	Czech Republic	6	30	64	37	63

Table 14 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Japan	3	29	68	51	49
	Kuwait	13	60	29	60	40
	New Zealand	9	53	38	57	43
	Norway	2	39	59	43	57
	Panama	8	27	65	44	56
	Poland	1	25	74	41	59
	Romania	5	34	61	48	52
	Slovakia	21	37	42	50	50
	South Africa [M22]	7	58	35	53	47
	Sweden	3	24	73	45	55
	Switzerland	4	32	64	42	58
	Average	3	30	67	48	52
III	Sudan	16	46	38	62	38
Spine (general)						
I	Australia	5	29	66	40	60
	Bahrain	8	56	36	59	41
	China, Taiwan Province	7	31	62	53	47
	Croatia	13	25	63	40	60
	Poland	4	27	69	45	55
	Switzerland	3	31	66	45	55
	United Arab Emirates	0	60	40	55	45
	Average	6	29	65	46	54
II	Costa Rica	6	49	45	43	57
	Mexico	9	48	43	55	45
	Turkey	9	42	49	61	39
	Average	9	46	45	56	44
III	Sudan	18	38	44	68	32
IV	United Republic of Tanzania	5	20	75	50	50
Pelvis and hip						
I	Australia	8	16	76	37	63
	Bahrain	28	35	38	58	42
	Croatia	2	38	60	30	70
	Czech Republic	20	15	65	35	65
	Ecuador	33	47	20	40	60
	Japan	7	30	63	50	50
	Kuwait	20	54	26	61	39
	New Zealand	8	49	43	42	58
	Norway	3	14	83	29	71
	Panama	21	19	60	52	48
	Poland	25	17	58	43	57
	Romania	19	26	55	48	52
	Slovakia	34	27	39	50	50
	South Africa [M22]	8	44	48	47	53
	Sweden	7	7	86	35	65
	Switzerland	5	16	79	45	55
	United Arab Emirates	5	70	25	53	47
	Average	12	25	63	42	58
II	Costa Rica	13	30	57	19	81
	Mexico	22	42	36	37	63
	Turkey	23	39	38	53	47
	Average	22	41	37	40	60
III	Sudan	20	20	60	50	50
IV	United Republic of Tanzania	5	40	55	40	60

Table 14 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Head						
I	Australia	27	41	32	45	55
	Bahrain	36	47	17	62	38
	China, Taiwan Province	10	37	53	57	43
	Czech Republic	24	36	40	48	52
	Ecuador	45	35	20	62	38
	Japan	24	30	46	55	45
	Kuwait	30	53	17	63	37
	New Zealand	29	48	23	62	38
	Panama	26	40	34	47	53
	Poland	16	43	41	51	49
	Romania	14	45	41	48	52
	Slovakia	20	49	31	49	51
	Sweden	30	9	61	45	55
	Switzerland	21	40	39	54	46
	United Arab Emirates	15	60	25	65	35
	Average	22	34	44	53	47
II	Costa Rica	22	51	27	47	53
	Mexico	30	42	28	55	45
	Turkey	20	39	41	62	38
	Average	28	42	30	56	44
III	Sudan	11	67	22	67	33
IV	United Republic of Tanzania	10	50	40	50	50
Abdomen						
I	Australia	13	22	65	45	55
	Bahrain	15	53	32	65	35
	China, Taiwan Province	6	26	68	55	45
	Croatia	6	35	59	50	50
	Czech Republic	5	20	75	49	51
	Ecuador	28	44	28	55	45
	Japan	5	18	77	55	45
	Kuwait	12	61	27	63	37
	New Zealand	15	65	20	51	49
	Norway	10	24	66	48	52
	Panama	21	25	54	47	53
	Poland	7	26	67	53	47
	Romania	8	39	53	51	49
	Slovakia	11	38	51	48	52
	South Africa [M22]	15	48	37	53	47
	Sweden	14	16	70	45	55
	Switzeland	7	22	71	48	52
	United Arab Emirates	18	57	25	70	30
	Average	6	22	72	54	46
II	Brazil	–	–	–	28	72
	Costa Rica	5	56	39	50	50
	Mexico	22	45	33	48	52
	Turkey	21	42	47	62	38
	Average	21	44	35	45	55
III	Sudan	33	37	30	40	60
IV	United Republic of Tanzania	10	35	55	35	65
Upper gastrointestinal tract						
I	Australia	6	25	69	45	55
	Bahrain	12	43	45	47	53
	China, Taiwan Province	3	65	32	82	18
	Croatia	0	33	67	50	50
	Czech Republic	3	25	72	43	57

Table 14 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Ecuador	5	35	60	58	42
	Japan	1	22	77	62	38
	Kuwait	15	50	35	59	41
	New Zealand	31	7	62	60	40
	Norway	2	20	78	35	65
	Panama	11	25	64	43	57
	Poland	2	25	73	51	49
	Romania	4	31	65	55	45
	Slovakia	4	46	50	57	43
	South Africa [M22]	9	39	52	48	52
	Sweden	11	18	71	45	55
	Switzerland	4	12	84	43	57
	United Arab Emirates	8	60	32	55	45
	Average	1	26	73	62	38
II	Mexico	11	51	38	53	47
	Turkey	6	57	37	57	43
	Average	10	52	38	54	46
III	Sudan	20	33	47	60	40
IV	United Republic of Tanzania	10	15	75	50	50
Lower gastrointestinal tract						
I	Australia	1	3	86	42	58
	Bahrain	18	33	49	55	45
	Croatia	0	22	78	50	50
	Czech Republic	2	16	82	41	59
	Ecuador	5	35	60	58	42
	Japan	1	22	77	54	46
	Kuwait	11	49	40	51	49
	New Zealand	4	9	87	49	51
	Norway	1	21	78	35	65
	Panama	5	18	77	45	55
	Poland	1	6	93	50	50
	Romania	4	33	63	54	46
	Slovakia	6	49	45	52	48
	South Africa [M22]	3	34	63	33	67
	Sweden	3	17	80	40	60
	Switzerland	2	13	85	42	58
	United Arab Emirates	12	58	30	59	41
	Average	2	23	75	52	48
II	Mexico	6	52	42	42	58
	Turkey	3	43	54	57	43
	Average	6	51	43	44	56
III	Sudan	20	30	50	70	30
IV	United Republic of Tanzania	5	15	80	50	50
Cholecystography						
I	Australia	0	17	83	30	70
	China, Taiwan Province	2	23	75	56	44
	Croatia	0	20	80	80	20
	Czech Republic	0	11	89	36	64
	Ecuador	0	55	45	39	61
	Japan	0	17	83	51	49
	Kuwait	0	55	45	55	45
	Panama	6	32	62	44	56
	Romania	2	38	60	24	76
	Slovakia	2	42	56	51	49
	Sweden	0	25	75	40	60
	Switzerland	0	13	87	37	63
	Average	1	20	79	49	51

Table 14 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
II	Mexico	1	51	48	31	69
	Turkey	0	39	61	35	65
	Average	1	51	48	31	69
III	Sudan	0	73	27	44	56
IV	United Republic of Tanzania	10	25	65	–	–
Urography						
I	Australia	10	23	67	55	45
	Bahrain	4	59	37	66	34
	Croatia	0	20	80	100	0
	Czech Republic	11	18	71	55	45
	Ecuador	2	70	28	57	43
	Japan	3	21	76	58	42
	Kuwait	5	63	32	64	36
	New Zealand	22	30	48	55	45
	Norway	3	26	71	51	49
	Panama	10	29	61	59	41
	Poland	13	23	64	52	48
	Romania	7	33	60	55	45
	Slovakia	14	38	48	58	42
	South Africa [M22]	9	47	44	54	46
	Sweden	6	29	65	45	55
	Switzerland	16	25	59	51	49
	United Arab Emirates	5	65	30	70	30
	Average	6	25	69	57	43
II	Mexico	7	48	45	54	46
	Turkey	10	48	42	54	46
	Average	7	48	45	54	46
III	Sudan	13	60	27	50	50
IV	United Republic of Tanzania	0	10	90	75	25
Mammography (screening)						
I	Slovakia	0	32	68	0	100
	Sweden	0	0	100	0	100
	United Arab Emirates	0	0	100	0	100
	Average	0	1	99	0	100
II	Mexico	2	27	71	5	95
	Average	2	27	71	5	95
Mammography (clinical)						
I	Czech Republic	0	37	63	1	99
	Japan	0	29	71	0	100
	Kuwait	0	68	32	1	99
	New Zealand	0	14	86	0	100
	Norway	0	17	83	0	100
	Sweden	0	15	85	0	100
	United Arab Emirates	0	0	100	0	100
	Average	0	26	74	0.1	99.9
II	Mexico	0	37	63	3	97
Mammography (general)						
I	Australia	0	27	73	0	100
	Bahrain	0	33	66	1	99
	China, Taiwan Province	1	40	59	1	99

Table 14 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Croatia	0	30	70	0	100
	Ecuador	0	28	72	0	100
	Kuwait	0	68	32	1	99
	Panama	0	28	72	2	98
	Poland	0	21	79	0	100
	Romania	1	43	56	1	99
	Switzerland	0.1	9	91	0.2	99.9
	United Arab Emirates	0	4	96	0	100
	Average	0.1	23	77	0.1	99.9
II	Mexico	1	33	66	4	96
	Turkey	0	38	62	1	99
	Average	1	34	65	3	97
Computed tomography (head)						
I	Australia	6	30	64	44	56
	Bahrain	23	36	42	56	44
	Czech Republic	8	23	69	47	53
	Kuwait	17	39	44	60	40
	New Zealand	10	26	64	53	47
	Panama	17	25	58	51	49
	Poland	13	20	67	50	50
	Slovakia	3	42	55	48	52
	Sweden	5	19	76	50	50
	Switzerland	4	23	73	51	49
	United Arab Emirates	15	50	35	60	40
	Average	7	27	67	48	52
II	Mexico	9	40	51	48	52
Computed tomography (body)						
I	Australia	1	21	78	48	52
	Bahrain	7	40	53	53	47
	Czech Republic	5	15	80	49	51
	Kuwait	6	43	51	56	44
	New Zealand	4	26	70	52	48
	Panama	5	29	66	50	50
	Poland	8	23	69	55	45
	Slovakia	4	44	52	51	49
	South Africa [M22]	5	46	49	52	48
	Sweden	3	20	77	55	45
	Switzerland	2	17	81	54	46
	United Arab Emirates	10	55	35	55	45
	Average	3	24	73	51	49
II	Mexico	21	33	46	47	53
Computed tomography (general)						
I	China, Taiwan Province	5	24	71	60	40
	Croatia	10	30	60	40	60
	Ecuador	6	24	70	50	50
	Norway	8	25	67	50	50
	Poland	11	21	68	52	48
	Romania	0	21	79	83	17
	Switzerland	3	19	78	53	47
	Ukraine	7	27	66	–	–
	United Arab Emirates	14	51	35	59	41
	Average	6	24	70	54	46
II	Mexico	14	37	49	48	52
	Turkey	16	46	38	57	43
	Average	15	42	43	53	47

Table 14 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
IV	United Republic of Tanzania	5	35	60	50	50
Angiography (cerebral)						
I	Australia	1	10	89	55	45
	Czech Republic	4	22	74	56	44
	Japan	0	16	84	54	46
	Kuwait	0	28	72	67	33
	Panama	17	25	58	70	30
	Poland	8	30	62	59	41
	Slovakia	6	41	53	52	48
	Sweden	2	27	71	50	50
	Switzerland	2	22	76	50	50
	Average	1	19	80	54	46
Angiography (cardiac)						
I	Australia	1	2	97	66	34
	Czech Republic	0	5	95	76	24
	Japan	14	0	86	53	47
	New Zealand	0	7	93	71	29
	Panama	17	24	59	66	34
	Poland	4	7	89	78	22
	Slovakia	7	41	52	50	50
	Sweden	2	7	91	70	30
	Switzerland	1	11	88	62	38
	Average	7	4	89	62	38
Angiography (other)						
I	Australia	1	5	94	60	40
	Croatia	0	25	75	55	45
	Czech Republic	6	9	85	66	34
	Japan	4	1	95	64	36
	Kuwait	0	28	72	67	33
	Panama	4	22	74	42	58
	Poland	11	17	72	38	62
	Slovakia	12	40	48	55	45
	Sweden	2	10	88	50	50
	Switzerland	1	17	82	55	45
	Average	5	6	89	60	40
II	Mexico	0	30	70	55	45
Angiography (general)						
I	Bahrain	4	45	51	63	37
	China, Taiwan Province	4	20	76	60	40
	Ecuador	30	40	30	55	45
	Poland	8	15	77	54	46
	Romania	0	25	75	92	8
	South Africa [M22]	2	23	75	70	30
	Switzerland	1	15	84	57	53
	Average	5	17	78	60	40
II	Mexico	6	38	56	59	41
	Turkey	9	51	40	59	41
	Average	7	43	50	59	41
Interventional (PTCA)						
I	Slovakia	6	44	50	48	52
	Sweden	0	15	85	75	25
	Switzerland	0	3	97	79	21
	Average	1	12	87	74	26

Table 14 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Interventional (other)						
I	Sweden	2	11	87	60	40
	Switzerland	1	14	85	58	42
	Average	1	13	86	59	41
Interventional (general)						
I	Czech Republic	9	16	75	59	41
	Ecuador	7	60	33	50	50
	Kuwait	2	43	55	69	31
	Poland	7	19	74	59	41
	Switzerland	0	12	88	63	37
	United Arab Emirates	1	80	19	15	85
	Average	8	16	76	59	41
II	Mexico	9	51	40	39	61
	Turkey	4	36	60	51	49
	Average	8	48	44	41	59
Pelvimetry						
I	Australia	2	97	1	1	99
	Bahrain	1	97	1	10	90
	Czech Republic	3	87	10	15	85
	Ecuador	0	82	18	0	100
	Japan	0	100	0	0	100
	Kuwait	0	98	2	0	100
	Sweden	0	98	2	0	100
	United Arab Emirates	0	100	0	0	100
	Average	0.1	99.5	0.4	0.1	99.9
II	Mexico	8	82	10	22	78
	Turkey	0	100	0	0	100
	Average	8	82	10	22	78
III	Sudan	0	100	0	0	100
Other examinations						
I	Australia (CT extremities)	8	38	54	50	50
	Australia (tomography)	2	26	72	54	46
	Australia (ribs)	5	33	62	50	50
	Australia (arthrography)	4	32	64	58	42
	Poland (densitometry)	3	55	42	2	98
	Romania (hysterosalpingography)	0	100	0	0	100
	Romania (lung tomog.)	13	33	54	68	32
	Switzerland (bone mineral dens.)	1	1	98	6	94
	Switzerland (tomography)	0	30	70	44	56
All medical [b] x rays						
I	Australia	10	27	63	45	55
	Bahrain	24	42	34	62	38
	Czech Republic	13	25	62	45	55
	Ecuador	26	43	31	54	46
	Kuwait	17	59	24	63	37
	Netherlands	7	18	74	45	55
	Panama	13	26	61	47	53
	Poland	–	–	–	52	48
	Romania	10	41	49	56	44
	Slovakia	17	38	45	50	50
	Sweden	9	20	71	40	60
	Switzerland	9	19	72	46	54
	Average	11	29	60	49	51

Table 14 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
II	Mexico	20	43	37	52	48
III	Morocco	16	54	30	43	57
Dental (intraoral)						
I	Ecuador	8	73	19	31	69
	Japan	8	32	60	45	55
	Poland	5	56	38	45	55
	Romania	11	54	35	44	56
	Slovakia	10	53	37	45	55
	Switzerland	5	38	57	45	55
	Average	8	33	59	45	55
IV	United Republic of Tanzania	25	35	40	–	–
Dental (panoramic)						
I	Ecuador	16	66	18	48	52
	Japan	8	40	52	44	56
	Poland	7	49	44	54	46
	Slovakia	13	45	42	46	54
	Switzerland	21	39	40	45	55
	Average	8	40	52	44	56
II	Mexico	33	50	17	36	64
Dental (general)						
I	Bahrain	21	33	46	59	41
	Ecuador	8	73	19	31	69
	Poland	6	56	38	45	55
	Romania	11	54	35	44	56
	Slovakia	11	52	37	45	55
	Switzerland	9	38	53	45	55
	Average	8	47	45	45	55
IV	United Republic of Tanzania	25	35	40	–	–

a No data available.
b Excluding dental x-ray examinations.

The entries in this Table are qualified as follows:

Brazil: Survey data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil).
China, Taiwan Province: Data for 'Upper GI tract' relate to all barium studies.
Costa Rica: Data from Hospital Calderón Guardia (serving one-third of the population).
Czech Republic: Survey data relating to Prague (about 10% of national population).
New Zealand: Data from one large teaching hospital in public sector.
Romania: Data from 8 counties in East and South-East of country (with population of about 5.7 million).
Slovakia: Survey data relating to population base of about 660,000.
Sweden: Survey data from a small sample of health districts.
Turkey: Survey data from Hacettepe University Hospital, Atatürk University Hospital, Gülhane Military Hospital and Ankara University Hospital.

Table 15
Typical effective doses to patients undergoing some common types of diagnostic medical [a] x-ray procedures (1991–1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

PART A

Country	*Typical effective dose per procedure [b] (mSv)*												
	Chest			*Limbs and joints*	*Spine*			*Pelvis and hips*	*Head*	*Abdomen*	*GI tract*		*Chole-cysto-graphy*
	Radio-graphy	*Photo-fluorography*	*Fluoro-scopy*		*Lumbar*	*Thoracic*	*Cervical*				*Upper*	*Lower*	
Health-care level I													
Australia	0.025 (±0.008)	– [c]	–	–	2 (±1)	–	–	0.6	–	1 (±0.7)	–	–	–
Belarus	0.25 (30–50%)	0.5 (30–50%)	1.0 (30-50%)	0.2 (30-50%)	1.1 (30-50%)	1.6 (±30-50%)	1.1 (30-50%)	1.1 (30-50%)	0.12 (30-50%)	1.4 (30-50%)	0.6 (30-50%)	1 (30-50%)	0.2 (30-50%)
Bulgaria	0.16 (0.04-0.18)	0.91 (0.77–1.05)	1.85 (1.6–2.1)	–	–	–	–	–	–	–	–	–	–
China, Taiwan Prov.	0.02	–	–	–	0.48	–	–	–	–	0.19	3.8	4.1	–
Czech Republic	0.05	0.7	–	–	2	1.76	0.28	1.26	0.28	3	3	8.5	1.26
Finland	0.1	–	–	–	2.3	1	0.2	1.3	0.1	2.2	9	9.7	–
Germany	0.3 (0.01–5.5)	–	–	0.06 (0.001-0.5)	2	0.7	0.2	0.8 (0.1-4.8)	0.03 (0.001-0.7)	1.2 (0.1-5.3)	8.3 (0.1-38)	17.7 (0.2-85)	7.1 (0.7-36)
Japan	0.057	0.053	1.14	–	1.45	0.65	0.26	0.58	0.09	0.24	3.33	2.68	0.88
Netherlands	0.06 (±0.08)	–	–	–	2	1	1	1	0.1	1	6.4 (±3.4)	4.7 (±2.4)	–
New Zealand	–	–	–	–	–	–	–	–	–	–	5	10	–
Norway	0.13	0.23	–	–	1.1	0.5	0.2	0.5	0.2	1	4	8	–
Panama	0.021 (±0.013)	–	–	0.003 (±0.003)	2.17 (±1.0)	1.20 (±0.43)	0.07 (±0.01)	0.44 (±0.13)	0.045 (±0.02)	0.30 (±0.12)	6.9 (±2.9)	3.12 (±0.76)	0.87 (±0.14)
Poland	0.11	0.82	4.1	0.02	4.33	3.03	–	0.61	0.1	2.2	14	22.7	–
Romania	0.25 (±0.11)	0.63 (±0.3)	0.95 (±0.4)	0.08 (±0.03)	3 (±1.4)	2.1 (±1.2)	0.21 (±0.1)	2.6	0.17 (±0.12)	1.9 (±1)	4.1 (±1.9)	9 (±3.8)	1.6 (±0.9)

Table 15 (continued)

Country	*Typical effective dose per procedure [b] (mSv)*												
	Chest			*Limbs and joints*	*Spine*			*Pelvis and hips*	*Head*	*Abdomen*	*GI tract*		*Chole-cysto-graphy*
	Radio-graphy	*Photo-fluorography*	*Fluoro-scopy*		*Lumbar*	*Thoracic*	*Cervical*				*Upper*	*Lower*	
Russian Federation	0.4	0.67	–	–	–	–	–	–	–	–	3.3	–	–
Sweden	0.15	–	–	0.1	3	1	0.2	1.5	0.1	2.5	3	8	6
Switzerland	0.1 (±0.03)	0.5 (±0.2)	0.2 (±0.1)	0.05 (±0.05)	1.5 (±0.5)	0.8 (±0.5)	0.2 (±0.2)	1 (±0.5)	0.1 (±0.1)	0.5 (±0.3)	5 (±4)	5 (±4)	8 (±4)
United Arab Emirates	0.059	0.018 (0.011-0.028)	–	–	0.47	0.35	0.28	0.35 (0.11-0.67)	1.06	0.43	4.4	9.8	–
United Kingdom	0.02	–	–	–	1.3	0.7	–	0.7	0.04	0.7	2.6	7.2	–
Average [d]	0.14	0.65	1.08	0.06	1.8	1.4	0.27	0.83	0.07	0.53	3.6	6.4	2.3
Health-care level II													
Brazil	0.053	–	–	–	–	–	–	–	–	0.5 (± 0.36)	–	–	–
Malaysia [N26]	0.03	–	–	0.04	1.04	0.46	0.03	0.74	0.04	1.05	6	–	1.5
Average	0.05	–	–	0.04	1.0	0.46	0.03	0.74	0.04	0.62	6	–	1.5

PART B

Country	*Typical effective dose per procedure (mSv)*											
	Urography	*Mammography*			*Computed tomography*			*Angiography*			*PTCA*	*Total of all medical examinations*
		Screening	*Clinical*	*All*	*Head*	*Body*	*All*	*Cerebral*	*Cardiac*	*All*		
Health-care level I												
Australia	–	–	–	0.4 (±0.16)	2.6 (±2.0)	10.6 (±7.5)	6.9	–	–	–	–	1.33
Belarus	2 (±30-50%)	–	–	–	–	–	–	–	–	–	–	–
Bulgaria	–	–	–	–	–	–	–	–	–	–	–	1.28
Canada	–	–	–	–	–	–	–	–	–	–	–	1.05

Table 15 (continued)

Country	*Typical effective dose per procedure (mSv)*											
	Urography	*Mammography*			*Computed tomography*			*Angiography*			*PTCA*	*Total of all medical examinations*
		Screening	*Clinical*	*All*	*Head*	*Body*	*All*	*Cerebral*	*Cardiac*	*All*		
China, Taiwan Prov.	–	–	–	–	–	–	–	–	–	–	–	0.43
Czech Republic	2.04	–	0.5	–	1.1	9.2	3.8	2.8	3.6	7.3	–	–
Denmark	–	–	–	–	–	–	–	–	–	–	–	0.7
Finland	4.5	0.1	0.2	–	1.3	7.9	3.8	–	14.8	–	–	0.64
Germany	4.9 (0.2–19)	–	–	0.5 (0.1–2)	2.6 (1–5)	15.4 (4–50)	11.3	–	–	12.3 (1–190)	23 (1–190)	1.5 (0.001–190)
Japan	2.47	–	–	–	–	–	–	–	5.56	–	–	–
Netherlands	4	0.1 [e]	0.1	0.1 [e]	1.7 [e]	10.2 [e]	6.7 [e]	–	5 [e]	5 [e]	5 [e]	1.0 [e]
New Zealand	–	–	0.07 (±0.02)	–	2.2 (±1.1)	7.8 (±4)	–	–	12.3 (±5.4)	–	16.2 (±9.2)	–
Norway	2	–	0.12	–	2	10	6.5	–	–	–	–	–
Panama	2.07 (±0.39)	–	–	0.24 (±0.11)	1.06 (±0.12)	3.8 (±0.51)	2.1	3.7 (±1.1)	–	–	–	–
Poland	3.1	–	–	1 (±0.3)	–	–	3.5	–	–	25	7	1.2
Portugal	–	–	–	–	–	–	–	–	–	–	–	0.83
Romania	5.8 (±2.9)	–	–	0.62 (±0.3)	–	–	–	–	–	0.22	–	1.35 (±0.63)
Russian Federation	–	–	–	0.56	0.4	5.8	–	–	–	–	–	0.73
Sweden	5	0.1	0.2	–	2	10	5.8	1	12	9.2	22	1.2
Switzerland	4 (±2)	–	–	0.1 (±0.1)	2 (±1)	5 (±2)	3.9	2 (±1)	10 (±1)	6.7	10	0.8 (±0.4)
Ukraine	–	–	–	–	–	–	–	–	–	–	–	0.83
United Arab Emirates	2.66	0.13	0.11 (0.01–0.14)	–	2.62 (1.75–3.3)	9.83 (6.8–11.8)	–	–	–	–	–	–
United Kingdom	2.4	0.06	–	–	2	9	6	–	–	–	–	–

Table 15 (continued)

Country	*Typical effective dose per procedure (mSv)*											
	Urography	*Mammography*			*Computed tomography*			*Angiography*			*PTCA*	*Total of all medical examinations*
		Screening	*Clinical*	*All*	*Head*	*Body*	*All*	*Cerebral*	*Cardiac*	*All*		
United Kingdom	2.4	0.06	–	–	2	9	6	–	–	–	–	–
United States	–	–	–	–	–	–	–	–	–	–	–	0.52
Average	3.7	0.07	0.21	0.51	2.3	13.3	8.8	2.0	7.3	12.4	22	0.83
Health-care level II												
Brazil	3.89 (±2.8)	–	–	–	–	–	–	–	–	–	–	0.26
China [Z10]	–	–	–	–	–	–	–	–	–	–	–	0.57
Malaysia [N26]	2.4	–	0.1	0.1	2.8	7.8	4.9	6.8	6.8	–	–	0.28
Average	3.9	–	0.1	0.1	2.8	7.8	4.9	6.8	6.8	–	–	0.56

a Excluding dental x-ray examinations.
b Variations shown in brackets (standard deviation, coefficient of variation or range).
c No data available.
d Frequency-weighted average of national values.
e These revised data were received by the Committee after completion of the global analysis.

The entries in this Table are qualified as follows:

Brazil: Survey data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil).
China (Taiwan): Data for lumbar spine, GI tract and total of all medical examinations from reference [L23].
Germany: Mean effective dose for general classification of spine is 1.2 mSv (range: 0.1–20 mSv).
Malaysia: Data for chest, spine and head refer to AP/PA projections. Data for 'GI tract' relate to both 'Upper' and 'Lower' categories.
Norway: Data from national survey involving about 50 hospitals and 5000 measurements.
Romania: Additional survey data in relation to 'Chest fluoroscopy': mean entrance surface dose of 13.4 mGy and mean dose-area product of 3.6 mGy cm^2 [I28].
Russia: Additional survey data in relation to effective doses from 'Chest fluoroscopy': dose rates without and with electronic image intensification of 1.4 mSv per minute and 0.9 mSv per minute, respectively. Data shown for 'GI tract' relate to both 'Upper' and 'Lower' categories. Effective dose rates from fluoroscopy without and with electronic image intensification of 4.2 mSv per minute and 2.3 mSv per minute, respectively during upper GI examinations, and 3.6 mSv per minute and 2.2 mSv per minute, respectively, during lower GI examinations. Data for 'CT - Body' refer to examinations of the abdomen; mean effective dose for CT chest is 2.8 mSv.
United Arab Emirates: Survey data from one hospital, except those for chest radiography and pelvis/hip (from seven hospitals), and chest photofluorography (from four units at two hospitals).

Table 16
Patient dose from diagnostic x-ray examinations
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

PART A

Country / area	*Scope of data*	*Dose quantity* [a]	*Mean value of dose quantity per radiograph* [b]										
			Skull		*Chest*		*Thoracic spine*		*Lumbar spine*			*Abdomen*	*Pelvis*
			AP / PA	*LAT*	*PA*	*LAT*	*AP*	*LAT*	*AP*	*LAT*	*LSJ*	*AP*	*AP*
Health-care level I													
Australia [B29]	State	ESD	1.9 (0.9–2.7)	1.2 (0.5–2.3)	0.12 (0.02-0.21)	0.63 (0.22-1.42)	– [c]	–	6.1 (2.3–19.7)	15.1 (3.7–32.5)	22.4 (5.3–43.3)	4.2 (1.4–7.3)	3.9 (1.5–7.0)
Argentina [I4]	3 hospitals	ESD ESD	–	–	0.38 (pre) (0.24-0.48) 0.33 (post) (0.31-0.34)	–	–	–	–	–	–	5.10 (pre) 3.31 (post)	–
Canada	Regional	ESD ESD	–	0.68 (man.) (± 0.23) 0.74 (auto.) (± 0.21)	0.11 (man.) (± 0.03) 0.13 (auto.) (± 0.04)	–	1.82 (man.) (± 0.6) 1.50 (auto.) (± 0.05)	–	3.34 (man.) (± 1.0) 3.69 (auto.) (± 1.3)	–	–	2.35 (man.) (± 0.5) 1.64 (auto.) (± 0.5)	–
China, Taiwan Province [Y9]	National	E	–	–	0.040 (± 0.12)	–	–	–	–	–	–	0.21 (± 0.10)	–
Czech Republic [I4]	3 hospitals	ESD ESD	–	–	0.41 (pre.) (0.08-0.99) 0.12 (post.) (0.1-0.13)	–	–	–	8.36 (pre.) (5.56-10.8) 5.64 (post.) 3.87-8.39)	–	–	–	6.37 (pre.) (5.59-6.99) 4.12 (post.) 3.09-6.99)
Estonia [S29]	4 hospitals	ESD	15.1 (2.2–30.1)	8.1 (1.1–14.3)	0.30 (0.15-0.49)	0.86	–	–	13.8 (0.84-31.7)	30.3 (7.3–61.0)	–	14.0 (2.2–26.8)	15.8 (2.5–29.9)
Finland [R11]	National	ESD DAP E	3.37 (1.06-8.53) 1.63 (020-5.82) 0.12 (0.03-0.42)	1.93 (0.57-8.01)	0.24 (0.06-3.28) 0.44 (0.08-3.47) 0.10 (0.03-1.10)	0.73 (0.15-4.44)	4.89 (0.49-11.3) 4.14 (1.10-22.2) 1.02 (0.23-3.92)	11.6 (2.10-26.2)	8.80 (0.49-43.5) 8.25 (0.88-68.8) 2.27 (0.25-11.4)	18.2 (2.10-111)	–	7.08 (0.76-19.0) 6.90 (0.86-20.8) 2.22 (0.60-5.89)	6.15 (2.02-22.0) 3.80 (0.79-16.0) 1.25 (0.31-4.49)
Germany [B9]	National	DAP	1.07		1.37		3.51		9.32			3.62	3.62
Greece [O3]	1 hospital	ESD E	3.5 (± 1.95) 0.094	2.68 (± 1.49) 0.034	0.69 (± 0.4) 0.11	2.94 (± 1.57) 0.22	8.25 (± 4.63) 0.74	10.9 (±8.1) 0.33	18.9 (± 6.76) 1.88	44.9 (± 22.9) 0.94	–	11.2 (± 7.3) 1.45	12.5 (± 6.85) 1.35

Table 16 (continued)

Country / area	*Scope of data*	*Dose quantity* [a]	*Mean value of dose quantity per radiograph* [b]										
			Skull		*Chest*		*Thoracic spine*		*Lumbar spine*			*Abdomen*	*Pelvis*
			AP / PA	*LAT*	*PA*	*LAT*	*AP*	*LAT*	*AP*	*LAT*	*LSJ*	*AP*	*AP*
Ireland [J10]	National	ESD	–	–	0.22 (0.02-0.65)	–	–	–	6.47 (0.27-20.3)	16.9 (1.8–67.1)	36.9 (1.5–102)	4.75 (0.5–18.3)	5.63 (1.2–26.5)
Lithuania	National	ESD	2.11	2.73	0.81	1.39	–	–	22.8	35.5	37.4	20.43	21.43
Norway [O6]	National	DAP E	–	–	0.64 0.12	–	–	–	–	–	–	7.61	3.48
Panama	National	ESD	–	–	0.17 (±0.10)	–	–	–	–	–	–	2.33 (±0.91)	3.28 (±1.0)
Poland	National	ESD E	–	–	0.20 (0.16-2.76) 0.06 (0.06-0.49)	0.88 0.10	5.1 (0.7-18.5) 0.9 (0.63-12.6)	8.3 (1.2-23.2) 2.13 (0.98-8.9)	7.50 (1.38-25.3) 3.43 (0.77-11.5)	12.0 (3.45-38.4) 0.9 (0.71-2.27)	–	4.7 (0.75-23.2) 2.18 (0.12-7.12)	2.54 (1.97-25.8) 0.61 (0.40-10.3)
Romania [I28]	21 hospitals	ESD	11.0 (1.0–31)	9.4 (1.2–28)	1.7 (0.3–6.0)	4.2 (0.7–13)	11.2 (2.0–41)	24.0 (3.5–97)	17.6 (2.0–71)	42.0 (4.4–162)	–	10.9 (2.1–37)	13.2 (1.9–35)
Russian Federation	National	E	–	–	0.4	0.6	0.8	0.3	1.7	1.2	–	–	0.75
New Zealand	National	ESD DAP E	3.0 (± 2.04) 0.96 (± 0.65) 0.03 (± 0.02)	1.56 (± 1.04) 0.57 (± 0.37) 0.02 (± 0.05)	0.22 (± 0.25) 0.17 (± 0.2) 0.03 (± 0.03)	1.24 (± 1.92) 0.62 (± 0.67) 0.1 (± 0.11)	4.32 (± 2.67) 1.54 (± 1.01) 0.44 (± 0.26)	13.3 (± 9.72) 3.53 (± 2.68) 0.31 (± 0.21)	5.47 (± 2.89) 1.88 (± 1.16) 0.6 (± 0.33)	18.9 (± 11.6) 3.92 (± 2.33) 0.47 (± 0.29)	31.2 (± 21.8) 3.83 (± 2.79) 0.36 (± 0.24)	4.57 (± 2.57) 2.67 (± 1.61) 0.58 (± 0.33)	3.98 (± 2.33) 2.37 (± 1.49) 0.63 (± 0.38)
Slovenia	Local	ESD E	–	–	0.29 0.05	1.02 0.06	4.89 0.37	7.22 0.21	6.11 0.63	15.65 0.48	15.00 0.14	3.52 0.04	4.72 0.65
South Africa [M22, H29]	National	ESD	6.4	3.6	1.5	3.2	13.1	35.6	27.3	59.1	–	13.1	15.4
United Arab Emirates	Local	E	0.68	0.38	0.020 (0.005-0.028)	0.039 (0.0084–0.094)	–	–	–	–	–	–	–
United Kingdom [H11]	National	ESD E	3.0 (0.5–10.0) 0.03	1.5 (0.56-4.43) 0.01	0.16 (0.01-0.94) 0.02	0.57 (0.11–2.6) 0.04	4.7 (1.3–18.0) 0.40	13.0 (1.3–43.0) 0.29	6.1 (1.4–31.0) 0.69	16.0 (3.9–75.0) 0.29	29.0 (4.2–84.0) 0.29	5.6 (0.75-16.6) 0.7	4.4 (1.0–16.0) 0.66
United States	National	ESD	–	–	0.15	–	–	–	–	–	–	–	–

Table 16 (continued)

Country / area	*Scope of data*	*Dose quantity* [a]	*Mean value of dose quantity per radiograph* [b]										
			Skull		*Chest*		*Thoracic spine*		*Lumbar spine*			*Abdomen*	*Pelvis*
			AP / PA	*LAT*	*PA*	*LAT*	*AP*	*LAT*	*AP*	*LAT*	*LSJ*	*AP*	*AP*
Health-care level II													
Brazil	3 hospitals	ESD E	4.55 (3.08-7.34)	–	0.33 0.021 (±0.01)	1.01 0.032 (±0.02)	–	–	6.82 (4.36–9.38)	–	–	7.88	5.28 (4.35-6.20)
Costa Rica	1 hospital	ESD	4.45 (±2.3)	2.92 (±2.4)	1.97 (±2.3)	5.33 (±5.3)	7.14 (±4.6)	12.4 (±8.9)	10.6 (±12.0)	27.9 (±18.1)	–	7.74 (±5.3)	6.39 (±3.3)
Iran (Islam. Rep. of) [I4]	2 hospitals	ESD ESD	–	–	0.21 (pre.) (0.19-0.26) 0.06 (post.) (0.04-0.09)	–	–	–	–	–	–	3.57 (pre.) (2.83-4.25) 1.87 (post.) 1.47–2.08)	–
Malaysia [N15, N26]	12 hospitals	ESD E	4.78 0.04	3.34 0.04	0.28 0.03	1.40 0.09	7.03 0.46	16.5	10.6 1.04	18.7	–	10.0	8.41
Peru	–	ESD	3.5 (±1.0)	–	0.4 (± 0.3)	–	–	–	7.0 (±3.0)	–	–	8.5 (± 2.0)	6.0 (± 3.0)
Turkey	Local	ESD	4.27 (± 0.88)	–	0.32 (± 0.05)	0.70 (± 0.20)	7.45 (± 0.54)	–	2.81 (± 1.49)	–	–	10.73 (± 2.01)	19.35 (± 1.16)
Health–care level III													
Egypt [H28]	14 hospitals	ESD	0.3	–	0.5	–	–	–	3.3	–	–	1.5	1.5
Ghana [S39]	12 hospitals	ESD E	5.7 (2.7–9.1) 0.08 (±38%)	–	0.74 (0.1–1.5) 0.10 (±61%)	–	–	–	9.2 (3.1–16.0) 1.61 (±52%)	–	–	–	7.9 (2.0–13.1) 1.71 (±40%)
Indonesia [L19]	4 hospitals	ESD	3.61 (± 1.24)	3.52 (± 1.48)	0.51 (± 0.18)	–	–	–	6.30 (± 1.50)	9.36 (± 3.0)	9.57 (± 6.22)	–	3.72 (±1.23)
Morocco	–	ESD	9.39 (± 2)	–	0.23 (± 0.2)	0.72 (± 0.2)	–	–	12.3	–	–	–	10.2
Thailand [L19]	4 hospitals	ESD ESD	1.37 (pre.) (± 0.76) 0.72 (post.) (± 0.26)	1.10 (pre.) (± 0.64) 0.52 (post.) (± 0.17)	0.26 (pre.) (± 0.16) 0.16 (post.) (± 0.09)	0.97 (pre.) (± 0.48) 0.52 (post.) (± 0.27)	–	–	2.81 (pre.) (± 2.1) 1.21 (post.) (± 0.65)	7.97 (pre.) (± 5.3) 4.08 (post.) (± 3.5)	–	–	1.52 (pre.) (± 1.09) 0.93 (post.) (± 0.47)

Table 16 (continued)

Country / area	*Scope of data*	*Dose quantity* [a]	*Mean value of dose quantity per radiograph* [b]										
			Skull		*Chest*		*Thoracic spine*		*Lumbar spine*			*Abdomen*	*Pelvis*
			AP / PA	*LAT*	*PA*	*LAT*	*AP*	*LAT*	*AP*	*LAT*	*LSJ*	*AP*	*AP*
Health-care level IV													
Ethiopia [I4]	2 hospitals	ESD ESD	–	–	1.34 (pre.) (0.94-1.74) 0.57 (post.) (0.43-0.70)	–	–	–	–	–	–	–	5.26 (pre.) 5.11–5.41) 10.57(post) (9.74-11.4)
Unitd Rep. of Tanzania [M37]	5 hospitals	ESD	–	–	0.5 (± 0.3)	–	–	–	7.7 (± 3.8)	17.5 (± 8.5)	–	8.3 (± 5.6)	6.4 (± 4.5)

PART B

Country	*Scope of data*	*Dose quantity* [a]	*Mean value of dose quantity per examination* [b]						
			Upper GI tract		*Lower GI tract*		*Urography*	*ERCP*	*Venogram*
			Swallow	*Meal*	*Enema*	*Colonoscopy*			
Health-care level I									
Germany [B9]	National	DAP	13.05	35.9	61.5	–	20.3	33.7	7.8
Iceland [W42]	5 hospitals	DAP	–	–	(43.6–77.4)	–	–	–	–
New Zealand	National	E	–	3	9	0.4	–	4	–
Norway [O6]	National	DAP E	7.41 1.5	24.8 5.9	49.1 13.7	–	18.1 3.8	31.8 8.3	–
Romania [I18] [I28]	5 hospitals 21 hospitals	DAP E DAP	–	37.7 (± 17.5) 3.7 22.0 (2–100)	32.2 (± 3.3) 8.12 34.7 (2–116)	–	–	–	–
Switzerland [M45]	–	DAP	13.5 (± 10.2)	68.5 (± 42.9)	–	–	–	37.1 (± 32.8)	–
United Kingdom [H11] [B56]	National Regional	DAP DAP	9.3 5.63	13.0 7.60	25.8 15.7	–	13.4 –	– 9.0	3.8 1.92

a ESD: entrance surface dose with backscatter (mGy); DAP: dose-area product (Gy cm^2); E: effective dose (mSv).
b Variations shown in brackets (standard deviation or range).
c No data available.

Table 16 (continued)

The entries in this Table are qualified as follows:

Argentina: Pairs of values represent surveys before and after the introduction of a programme of quality control. Interhospital variation in brackets.
Brazil: Survey data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil); data for skull, lumbar spine, and pelvis from reference [I4].
Brazil: Pairs of values represent surveys before and after the introduction of a programme of quality control. Interhospital variation in brackets.
Canada: Survey data from Manitoba (4% of Canadian population) for standard pressed wood phantoms (unit density) under manual and automatic exposure control and for rare-earth intensifying techniques.
Costa Rica: Data from Hospital Calderón Guardia (serving one-third of the population).
Czech Republic: Pairs of values represent surveys before and after the introduction of a programme of quality control. Interhospital variation in brackets.
Egypt: Maximum recommended doses derived from the following published maximum entrance surface exposures: 26 mR skull; 45 mR chest; 272 mR lumbar spine; 125 mR abdomen; 125 mR pelvis [H28].
Estonia: Interhospital variation in brackets.
Ethiopia: Pairs of values represent surveys before and after the introduction of a programme of quality control. Interhospital variation in brackets.
Finland: DAP and E data represent mean values for complete examinations.
Germany: DAP data refer to complete examinations (rather than doses per radiograph).
Ghana: Data for AP pelvis also includes radiography of the abdomen.
Iceland: Data for barium enema examinations refer to range of mean DAP values observed in survey of 5 hospitals.
Iran (Islamic Rep. of): Pairs of values represent surveys before and after the introduction of a programme of quality control. Interhospital variation in brackets.
Lithuania: Data from Vilnius University Hospital.
Morocco: Data from IAEA Coordinated Research Programme.
Norway: Data for 'Upper GI- Meal' and 'Lower GI - Enema' refer to double contrast technique (corresponding data for single contrast technique: 14.0 Gy cm^2 & 3.4 mSv, and 32.3 Gy cm^2 & 9.0 mSv, respectively).
Peru: Data may refer to complete examinations.
Romania: Pairs of values represent surveys before and after the introduction of a programme of quality control. Inter-hospital variation in brackets.
South Africa: Derived from free-in-air data calculated for average exposure conditions.
United Rep. of Tanzania: Survey data for 500 patients per examination spread over 4 referral hospitals and 1 regional hospital; these hospitals are collectively responsible for nearly 50% of the annual national total of patients examined with x-rays.
Thailand: Pairs of values represent surveys before and after the introduction of a programme of quality control.
Turkey: Survey data from Ankara University Hospital and Gülhane Military Hospital.
United Arab Emirates: Survey data for 'Head' examinations from one hospital, data for 'Chest' from seven hospitals.
United Kingdom: Inter-hospital variation in brackets. Data from reference [B56] represent median values from regional survey.
United States: On the basis of entrance surface exposure of 0.12 mGy from NEXT programme for 1994.

Table 17
Patient dose per procedure from diagnostic angiographic examinations

Procedure	*Technique*	*Fluoroscopy time [a] (min)*	*Dose-area product [a] (Gy cm²)*	*Effective dose [a] (mSv)*	*Ref.*
Coronary	Children [b]	–	13.3 (1.4–98)	–	[B48]
	Cine film [c]	8 (70 max.)	41 (228 max.)	–	[H6]
	Cine film [d]	4.3 (1.5–15)	(21–40)	(2–9)	[C22]
	-	3.9	16.1 [h]	3.1 (1–12)	[L3]
	Cinefluorography [e]	7 (SD 3.6)	–	10.6	[K5]
	-	–	55.9	–	[Z12]
	-	9.8 (± 65%)	30.4 (± 57%)	5.6	[B3]
	-	–	38.9	8.9	[O6]
	Digital cine [f]	5.7	47.7	9.4	[B54]
	-	–	58.7 [i]	–	[W41]
	No. frames [a]: 878 (302 SD)	3.6 (3.3 SD)	39.3 (18 SD)	–	[P20]
	Cine film [g]	(3.1–5.6)	(23–79)	(4.6–15.8)	[N29]
Cerebral	DSA	4.7	48.5	3.6	[M9]
	–	–	–	Eye/thyroid data [k]	[H24]
	DSA/conventional [j]	–	–	10.6 (2.7–23.4)	[F15]
	Carotid (DSA)	3.9 (1.2–11.8)	27.4 (9.5–80)	4 (1–12)	[S3]
	DSA/conventional	15 (± 10)	59 (12–120)	–	[K23]
	Digital	12.1 (2.9–36)	74 (21–196)	7.4 (2.1–19.6)	[M34]
	–	–	55.2	1.6	[O6]
	–	–	50	–	[V14]
	Carotid	7.8 (3.1–17.9)	98 (44–208)	–	[M46]
Abdominal	Hepatic (DSA)	10.3 (2.3–28.6)	137 (28–279)	23 (4–48)	[S3]
	Renal (DSA)	12.1 (5.5–21)	95 (41–186)	16 (6–34)	[S3]
	Renal (DSA)	5.1	43	6	[K26]
	Mesenteric and/or coeliac art.	14.7	65	10	[K26]
	DSA/conventional	1.0 (± 0.5)	57 (31–89)	–	[K23]
	Digital	8.0 (1.8–27)	118 (21.6–301)	18.9 (3.5–48)	[M34]
	Renal angiography	5.1 (2.9–7.6)	39.8 (17.4–72)	6.4 (2.8–11.5)	[M34]
	Renal angiography	2.8 (0.5–9.3)	177 (90–327)	–	[M46]
	Digital	6.7 (± 6.5)	61 (8–192)	8.2	[R17]
	Aortagram	–	98 (297 max.)	–	[W32]
	Mesenteric	–	112 (352 max.)	–	[W32]
Peripheral	Femoral (DSA)	3.7 (1.2–19)	42.9 (13–122)	4 (1–16)	[S3]
	Aorto–iliac + 1 leg	2.9 (± 2.8)	13 (2–52)	–	[K23]
	Aorto–iliac + 2 legs	4.5 (± 1.2)	32 (19–68)	–	[K23]
	Aorto–iliac + thighs	1.2 (± 0.4)	47 (16–100)	–	[K23]
	Aortogram/femoral runoff	3.9 (1.8–10.8)	–	14.0 (7.0–21.8)	[C23]
	Femoral arteriogram	2.4 (± 1.9)	26	4	[T8]
	Femoral (DSA/conventional)	1.7 (0.4–6.7)	24.4 (5.6–100)	2.7	[H25]
	Femoral (DSA)	2.3 (0.9–13.7)	74 (19.8–184)	9.0	[H25]
	Femoral (DSA)	–	13	3.1 (± 1.8)	[C24]
	Femoral	7.2 (1.8–17.2)	46.7 (3–114)	7.5 (0.5–18.2)	[M34]
	Femoral	2.4 (13–8.3)	16 (8–91)	–	[M46]
	Lower limbs	3.7 (± 3.1)	30 (9–77)	6.2	[R17]
	Lower limbs (arteries)	–	35.5	6.4	[O6]
	Lower limbs (veins)	–	4.9	0.9	[O6]
	Lower limb	–	78 (306 max.)	–	[W32]
	Venography (arm)	–	23 (57 max.)	–	[W32]

a Mean values of parameters (with range, standard deviation, or coefficient of variation in parentheses).
b Ages 0.01-12 years. Calculated entrance surface doses: mean 99 mGy, range 10-526 mGy.
c Mean length of cine film 28 m (maximum 85 m).
d Range of cine film length: 25-100 m.
e Mean time of cinefluorography (25-30 frames per second) was 60 seconds (standard deviation 30 seconds).
f Mean number of frames: 689.
g Range of cine film length: 16-43 m.
h 61% of total DAP from radiography.
i Data refer to right and left heart angiography.
j Mean contributions to effective dose: 67% from fluoroscopy, 26% from cut films, and 7% from DSA.
k Maximum dose to right ocular lens of 125 mGy; maximum dose to thyroid of 88 mGy.

Table 18
Patient dose per procedure [a] during interventional radiology

Procedure	*Fluoroscopy time (min)*	*Localized dose to skin (Gy)*	*Dose-area product (Gy cm²)*	*Effective dose (mSv)*	*Ref.*
PTCA (Percutaneous transluminal coronary angioplasty)	11.5 (2.4–28)	– [e]	93 (33–402)	28.9 (7.5–57)	[N6]
	30 (9–70)	0.15 (0.05–0.3)	28.5 (20–50.5)	–	[F4]
	15	1	–	10	[P3]
	(56 max.)	–	–	–	[K5]
	11 (92 max.)	–	42 (266 max.)	–	[H6]
	31.3	–	–	–	[G4]
	43.8 [b]	–	–	–	[G4]
	31 [c] (8–62)	0.46 [c]	–	–	[B6]
	43 [d] (3–53)	0.39 [d]	–	–	[B6]
	–	(1–5)	–	–	[H7]
	–	0.1 (1 max.)	87.5 (67–122)	–	[V3]
	–	–	110 (40–340)	–	[B9]
	–	–	143 (83 SD)	–	[B10]
	–	–	–	22	[L4]
	18.7	1.1	–	–	[P15]
	–	–	91.8	–	[Z12]
	21 (± 63%)	0.038 (at spine)	37.6 (± 41%)	6.9	[B3]
	12.4	–	72.2	14.2	[B54]
	–	0.5 (0.01–2.2)	–	–	[V14]
	–	–	45.8	–	[W41]
	18.5 (15.5 SD)	0.14 (LAO proj.)	102 (85 SD)	–	[P20]
PTA (Percutaneous transluminal angioplasty)	14	0.4	75	10	[S14]
	19.7 (5.3–26)	–	68.5 (22–150)	–	[F5]
	(21.8–68) [f]	–	–	–	[N6]
	6	–	65.1	–	[F6]
	–	–	43.5 (5–184)	–	[B9]
	24 [b] (5–45)	0.3 [b]	140 [b] (73–223)	12.5 [b]	[H27]
	–	–	67.3 (289 max.)	–	[W32]
	17.9 (6.9–57.3)	–	68 (15–338)	–	[M46]
	(6.3–26.3)	–	(19–109)	–	[K50]
TIPS (Transjugular intrahepatic portosystemic shunt)	46	–	–	–	[M8]
	–	–	354	–	[V3]
	48.4 (21.7–100)	–	525 (273–1131)	83.9 (43.7–181)	[M34]
	32 (9–79)	1.7	226 (111–354)	27 (14–44)	[Z11]
	59 (26–115)	0.4	77 (7–240)	8 (2–40)	[Z11]
	48	1.2 (5 max.)	220	50	[S14]
	–	–	182 (470 max.)	–	[W32]
Radiofrequency ablation	42 (27–108)	–	116 (26–217)	–	[N6]
	50 (31 SD)	–	–	17	[L4]
	21.4 (142 max.)	0.9 (6.2 max.)	–	–	[B7]
	(190 max.)	(8.4 max.)	–	–	[C3]
	28 (3–109)	–	103 (7–516)	–	[F6]
	–	0.07 (1.4 max.)	–	–	[C9]
	–	–	56.4 [g] (12–184)	–	[H8]
	–	–	77.5 [h] (13–367)	–	[H8]
	–	–	97.3 [i] (9–532)	–	[H8]
	53 (± 50)	1.3 (± 1.3)	–	17 / 25 [j]	[R16]
	–	0.93 (± 0.62)	–	–	[P14]
	65 (5–195)	1.0 (0.08–3.1)	–	–	[N25]
	28.9	–	91.1	17.3	[B54]
	–	–	43.6	–	[W41]
Valvuloplasty	53 [k] (40–120)	–	56 [k]	–	[S15]
	–	–	44 [l]	–	[S15]
	31.8	–	162	29.3	[B54]
Lysis	21	–	–	–	[M8]
Embolization	25	-	180	25	[S14]
	37.4 (8.1–58)	-	121 (34–286)	–	[F5]
	(8.4–6.4) [m]	-	–	–	[N6]
	(17.5–90) [n]	-	–	–	[N6]
	23 [o] (1–75)	-	114 [o] (7–394)	–	[F6]
	–	(0.2–1.4) [p]	–	(6–43)	[B8]
	–	0.5 [q]	81.7 [q]	–	[V3]
	–	–	391 (93–918)	–	[B9]

Table 18 (continued)

Procedure	*Fluoroscopy time (min)*	*Localized dose to skin (Gy)*	*Dose-area product (Gy cm²)*	*Effective dose (mSv)*	*Ref.*
Embolization (continued)	21 [p] (6–54) 34.1 [p] (15.2–55.8) 43 [o] (31–74) 24.3 [m] (5–48) – – –	– 0.34 [p] (019–0.66) 0.62 [o] (0.13–1.34) 0.44 [m] – – –	122 [p] 105 [p] (57.2–201) 116 [o] (29–243) 79 [m] (55–100) – – 105 (352 max.)	10.6 [p] 10.5 [p] (5.7–20) 1.67 [o] (0.44–3.44) 15.9 [m] 20 [o] (± 14) adult 68 [o] (± 51) child. –	[M9] [M34,M36] [B17] [H27] [G12] [G12] [W32]
Biliary	– 7.1 (0.6–26.3) 30.4 (3.6–141) 34.2 (± 11.5) –	2.1 0.11 (0.01–0.37) – – –	68.9 (30–163) 43.1 (3.8–149) 20.1 (1.2–122) 150 (51–291) 43 (167)	– 6.9 (0.6–23.9) – 38.2 –	[V3] [M34,M36] [M35] [R17] [W32]
Stent (superior vena cava)	17 (± 9)	2 (max.)	42 (± 29)	5.8	[O9]

a Mean values of parameters (with range, standard deviation, or coefficient of variation in parentheses).
b Procedure carried out with laser.
c Total occlusion.
d Subtotal stenosis.
e No data available.
f Leg.
g Atrioventricular.
h Atrioventricular nodal reentry.
i Wolff–Parkinson–White.
j Values for males and females, respectively.
k Children (1–16 years).
l Infants (<1 year).
m Liver.
n Kidney.
o Neurological.
p Cerebral.
q Hepatic.

Table 19
Doses to patients from computed tomography

Country / area	*Year*	*Mean effective dose per procedure (mSv)*							
		Head	*Cervical spine*	*Chest*	*Abdomen*	*Liver*	*Kidneys*	*Pelvis*	*Lumbar spine*
Health-care level I									
Australia [T17]	1995	2.6	5.2	10.4	16.7	12.7	-	11.0	5.2
Finland [S67]	1994	1.3	-	5.1	11.6	-	-	-	5.0
Germany [B58]	1993	2.6	9 [b]	20.5	27.4	-	-	-	9 [b]
Japan [N16]	1994	-	-	4.6-10.8 [c]	6.7-13.3 [c]	-	-	-	-
Netherlands [V15]	1993	0.8-5.0 [a]	-	6-18	6-24 [a]	-	-	-	2-12 [a]
New Zealand [P5]	1992	1.8	3.3	8.9	9.7	6.5	7.6	6.9	4.7
Norway [O12]	1993	2.0	-	11.5	12.8	11.9	9.9	9.8	4.5
Sweden [S68]	1991	2.1	6	10 [d]	10 [d]	10 [d]	10 [d]	10 [d]	6 [b]
United Kingdom (Wales) [H33]	1994	1.6	1.5	9.7	12.0	10.3	9.1	9.8	3.3
Health-care level II									
Oman [G37]	1998	2.4	3.5	3.4	9.5	-	-	-	-

a Reported range for survey of 22 scanners.
b Published value for spine.
c Reported range for survey of 4 scanners.
d Published value for trunk.

Table 20
Patient dose [a] per procedure from chest radiography

Technique	*Conditions*	*Projection*	*Entrance surface dose (mGy)*	*Effective dose (mSv)*	*Ref.*
Film-screen	–	PA	0.168	–	[S77]
	–	PA	–	0.007–0.017	[S78]
	With lung filter	PA	–	0.008–0.011	[S78]
	With grid	PA	0.128	–	[C38]
	Without grid	PA	0.087	–	[C38]
	With air gap	PA	0.025	–	[C38]
	Asymmetric combination	PA	0.131	–	[C38]
	Twin combinations	PA	0.4	–	[M65]
Computed radiography	–	PA	0.68	0.10	[M4]
	–	LAT	1.70	0.15	[M4]
Beam equalization (AMBER)	–	PA	0.16	0.024	[M4]
	–	LAT	0.65	0.066	[M4]
Selenium drum	150 kV	PA	0.145	–	[L33]
	90 kV Standard dose	PA	0.16	–	[L33]
	90 kV Low dose	PA	0.07	–	[L33]
Digital Image Intensifier	–	PA	0.11	0.016	[M4]
	–	LAT	0.15	0.013	[M4]
100 mm film	–	PA	0.10	0.015	[M4]
	–	LAT	0.77	0.069	[M4]
Photofluorography	Survey of 80 units	–	5.8	0.36 (0.05–2.4)	[P26]
Mobile	–	PA	–	0.013	[S78]
	Intensive therapy unit	–	0.31–0.56	0.15	[L34]
	Intensive therapy unit	–	0.33 ± 0.11	–	[S79]
	Wards	–	0.2	–	[S79]

a Mean value, standard deviation or range.

Table 21
Frequencies of examinations and doses in dental radiology (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	*Number of examinations [a] per 1,000 population*			*Effective dose per examination [b] (μSv)*		
	Intraoral	*Panoral*	*All*	*Intraoral*	*Panoral*	*All*
Health-care level I						
Australia	–	23	–	–	–	–
Bahrain	–	–	49	–	–	–
Belarus	75	6	81	80 (30–50%)	150 (30–50%)	–
Croatia	168	63	231	–	–	–
Cyprus	–	12	12	–	–	–
Czech Republic	–	–	193	–	–	100
Denmark	–	–	471	–	–	–
Ecuador	14	0.24	14	–	–	–
Finland	254	36	290	5 (1–24)	–	–
Germany	276	–	276	10 (1–1 000)	–	10 (1–1 000)
Hungary	–	–	41	–	–	–
Japan [c]	743	88	839	14	11	14
Kuwait	–	–	100	–	–	–
Lithuania	–	–	108	–	–	–
Luxembourg	438	31	469	–	–	–
Netherlands [d]	170 [d]	8 [d]	182 [d]	8 [d]	10	8 [d]
New Zealand [c]	–	–	–	5	26	–
Poland [S49]	70	3.4	74	–	–	–
Portugal [F11]	–	–	100	–	–	–
Romania	28	0	28	100 (± 70)	–	100 (± 70)
Russian Federation	–	–	96	–	–	36
Slovakia	77	17	94	–	–	–
Slovenia	46	9.8	55	–	–	–
Sweden	682	57	739	10	10	10
Switzerland	524	34	571	10 (± 10)	50 (± 20)	30 (± 30)
United Arab Emirates	7.8	7.6	15	–	–	–
United Kingdom	161	49	212	10 (3–19)	11	10
Average	365	47	309	13	12	16
Health-care level II						
Brazil	111	–	111	–	–	–
China	–	–	1.7	–	–	–
Jordan	3.0	0.1	3.1	–	–	–
Mexico	–	1.2	1.2	–	–	–
Oman	0	2.3	2.3	–	–	–
Turkey	–	–	31	–	–	–
Average	106	1.1	14	–	–	–
Health-care level III						
Ghana	–	–	0.25	–	–	–
Health-care level IV						
United Rep. of Tanzania	0.07	0	0.07	–	–	–

a Some values may represent numbers of films rather than complete examinations.
b Some doses may relate to individual films rather than complete examinations. Variations in parentheses (standard deviation, coefficient of variation or range).
c Data refer to individual films.
d These revised data were received by the Committee after completion of the global analysis.

Table 22
Doses to patients from dental x-ray examinations
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	*Year*	*Technique*	*Condition of measurement*	*Typical entrance surface dose [a] per exposure (mGy)*	
				Survey mean	*S.D. [b]*
Health-care level I					
Canada	1995	Intraoral	Survey of 56 units	2.5	(1.6–3.6)
Greece [Y11]	1997	Intraoral (50 kV)		6.5	4.9
		Intraoral (60 kV)		4.9	3.7
		Intraoral (65 kV)		3.1	1.2
		Intraoral (70 kV)		1.9	0.9
Denmark [H31]	1993	Intraoral (D speed film)	National survey	4.9	4.3
		Intraoral (E speed film)	National survey	3.2	3.6
United Arab Emirates	1997	Intraoral	4 units	2.77	(2.61–3.2)
		Intraoral	RVG filmless system	0.72	–
United Kingdom [N23]	1998	Intraoral (All)	Sample of 6344 measurements	3.3	(0.14–46)
		Intraoral (E speed film)	Sample of 1577 measurements	2.6	(0.14–21)
		Intraoral (45-55 kV)	Sample of 2175 measurements	5.0	(0.6–46)
		Intraoral (60-70 kV)	Sample of 3105 measurements	2.2	(0.2–9.6)
		Panoral	Sample of 387 measurements	57.4 mGy mm [c]	(2–328 mGy mm) [c]
United States	1993	Intraoral	NEXT programme	1.9	–
		Cephalometric	NEXT programme	0.21	–
Health-care level II					
Brazil	1996	Intraoral	Survey data for Paraná State	7.9	(0.9–61)

a Without backscatter.
b Dose range given in parentheses.
c Dose-width product [N23].

Table 23
Variation with technique of the typical effective dose from dental radiography
[N3]

Radiographic technique		*Effective dose (μSv)*
Two bitewing films	70 kV [a], 200 mm fsd [b], rectangular collimation, E speed film	2
	70 kV, 200 mm fsd, circular collimation, E speed film	4
	50-60 kV, 100 mm fsd, circular collimation, E speed film	8
	50-60 kV, 100 mm fsd, circular collimation, D speed film	16
Single panoral film	Rare-earth intensifying screens	7
	Calcium tungstate intensifying screens	14

a Applied potential.
b Focus to skin distance.

Table 24
Doses to patients from mammography
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	Year	Technique	Condition of measurement	Typical dose per film (mGy)			
				Entrance surface dose [a]		Dose to glandular tissue	
				Survey mean	S.D. [b]	Survey mean	S.D. [b]
Health-care level I							
Argentina [c] [I4]	1993	400 speed film/screen	Patient surveys	11.08 (pre)	–	–	–
				7.26 (post)	–	–	–
Australia [H48]	1996	Screening	Patient survey (2 units; 2051 films)	–	–	2.26	(0.4–7.2)
Belgium [P28]	1997	Screening	24 centres (4.5 cm phantom)	7.5	2.4	1.4	0.4
		Screening	24 centres (patient survey)	8.0	2.9	1.5	0.5
Canada	1994	-	Standard breast phantom	–	–	1.1	(0.36–4.68)
[F19]	1999	Screening	Survey in Ontario (phantom)	–	–	1.5	–
Finland [S16]	1993	Screening	4.5 cm Acrylic phantom	6.3	3.1	1.0	0.48
France [M7]	1991	Screening	Survey in Bas-Rhin (phantom)	15.2	–	–	–
	1993	Screening	Survey in Bas-Rhin (phantom)	8.5	–	–	–
Germany [K49]	1992	W anode	Patient survey (1678 women)	8.36	4.22	1.59	0.56
	1993	Mo/W anode	Patient survey (945 women)	11.0	5.05	2.07	0.66
Greece [F7]	1990	Grid	4 cm Acrylic phantom	8.5	(5–15)	–	–
		Non-grid	4 cm Acrylic phantom	5.2	(1–25)	–	–
Italy [M6]	1997	-	Tuscany region (phantom)	7.9	–	–	–
		-	Tuscany region (patients)	9.5	–	–	–
Japan [S81]	1994	Screening	4 cm compressed breast	–	–	1.80	–
New Zealand	1996	-	Average breast thickness	–	–	1.45	0.47
[B12]	1993	Screening	Patient survey in Otago (phantom)	–	–	–	(0.7–8.5)
Norway [O10]	1994	Non-grid	Standard phantom	–	–	–	(0.4–0.8)
		Grid	Standard phantom	–	–	–	(0.7–2.0)
Panama	1995	-	-	5.97	2.70	–	–
Slovenia	1996	-	Standard phantom	6.82	2.59	–	–
Spain [C40]	1997	Screening	4.5 cm Acrylic phantom	6.1	2.0	1.3	0.4
	1997	Screening	Patient survey	5.7	2.6	1.0	0.4
Sweden	1996	Screening	Standard breast phantom	–	–	1.5	(0.7–3.2)
United Arab	1998	Screening	Standard breast phantom	–	–	2.65	(2.48–2.81)
Emirates [d]		Clinical	Standard breast phantom	–	–	2.71	(2.66–2.76)
		Clinical [e]	Standard breast phantom	–	–	0.23	–
United Kingdom [Y12]	1991	Screening	Standard breast phantom	–	–	1.28	(0.6–2.6)
	1996	Screening	Standard breast phantom	–	–	1.36	(0.7–2.5)
[B66]	1995	Screening	Patient survey (4 633 women)	–	–	2.0 [f]	–
	1995	Screening	Patient survey (4 633 women)	–	–	1.6 [g]	–
United States [S82]	1992	-	Standard breast phantom	–	–	1.49	–
	1997	-	Standard breast phantom	–	–	1.60	–
[K43]	1999	-	Survey of 6 000 patients (phantom)	–	–	2.6	–
Health-care level II							
Iran (Islamic	1993	–	Patient surveys	5.45 (pre)	1.94	–	–
Republic of) [h] [I4]		–		4.27 (post)	–	–	–
Turkey	1997	-	Localized survey	3.29	0.23	–	–

a Entrance surface dose or entrance surface air kerma; backscatter factor is generally <1.1 for mammographic exposures.
b Dose range given in parentheses.
c Values represent surveys before and after the introduction of a programme of quality control; data from two hospitals.
d Diagnostic data from four units with grid and one without grid; screening data from two units.
e Without grid.
f Mediolateral oblique view (mean breast thickness 57 mm).
g Craniocaudal view (mean breast thickness 52 mm).
h Data from one hospital. Values represent surveys (with mean breast thickness of 3 cm) before and after the introduction of a programme of quality control.

Table 25
Estimates of mean absorbed dose to the uterus from x-ray examinations
[W30]

Examination	*Typical dose (mGy)*	*Reported range (mGy)*
Dental	– [a]	0.0003–0.001
Head / cervical spine	–	<0.005–0.03
Extremities	–	<0.005–0.18
Shoulder	–	<0.005–0.03
Thoracic spine	–	<0.10–0.55
Chest (radiography)	–	0.002–0.43
Chest (photofluorography)	–	0.009–0.40
Mammography	–	<0.1
Abdomen	2.5	0.25–19.0
Upper GI	1	0.05–12.0
Cholecystography / cholangiography	1	0.05–16.0
Lumbar spine	4	0.27–40.0
Lumbosacral spine	4	0.30–24.0
Urography	6	0.70–55.0
Urethrocystography	–	2.7–41.0
Barium enema	10	0.28–130
Hysterosalpingography	10	2.7–92
Pelvis	2	0.55–22.0
Hips and femur	3	0.73–14.0
Femur (distal)	–	0.01–0.50

a No data available.

Table 26
Provision for dual energy x-ray absorptiometry in various countries
[C10]

Health-care level	*Country*	*Scanners per million population*
I	Australia	3.4
	Austria	6.5
	Belgium	10.4
	Canada	2.3
	Cyprus	7.1
	Denmark	3.5
	Finland	3.4
	France	6.6
	Germany	6.8
	Greece	13.5
	Israel	2.6
	Japan	2.6
	Malta	2.5
	Netherlands	1.8
	Portugal	1.6
	Spain	3.5
	Switzerland	4.1
	United Kingdom	1.6
	United States	2.9
II	Chile	1.6

Table 27
Summary of entrance surface dose measurements from surveys of paediatric radiography in Europe (1989-1995)
[K4]

X-ray examination	*Entrance surface dose (μGy)*								
	Infant (10 months)			*5-year old*			*10-year old*		
	Median	*Minimum*	*Maximum*	*Median*	*Minimum*	*Maximum*	*Median*	*Minimum*	*Maximum*
Chest AP (1 kg newborn)	45	11	386	– [a]	–	–	–	–	–
Chest PA/AP	75	21	979	67	19	1 347	71	17	1 157
Chest AP (mobile)	90	34	718	68	29	333	91	29	760
Chest lateral	–	–	–	140	37	554	153	39	1 976
Skull PA/AP	930	152	4 514	967	242	4 626	1 036	130	5 210
Skull lateral	–	–	–	703	138	2 358	577	113	3 787
Pelvis AP (4 month)	260	18	1 369	–	–	–	–	–	–
Pelvis AP	–	–	–	485	86	2 785	812	89	4 167
Full spine PA/AP	867	107	4 351	–	–	–	–	–	–
Thoracic spine AP	–	–	–	–	–	–	887	204	4 312
Thoracic spine lateral	–	–	–	–	–	–	1 629	303	6 660
Lumbar spine AP	–	–	–	–	–	–	1 146	131	5 685
Lumbar spine lateral	–	–	–	–	–	–	2 427	249	23 465
Abdomen AP/PA	440	77	3 210	588	56	2 917	729	148	3 981

a No data available.

Table 28
Examples of reduced doses in paediatric radiography with attention to good technique
[C20]

Radiograph	*Age or weight*	*Entrance surface dose* [a] *(mGy)*	*Dose-area product (Gy cm²)*	*Effective dose (mSv)*
Chest - neonatal [b]	1 kg	0.01	–	0.02
	2 kg	0.02	–	0.04
	3 kg	0.03	–	0.07
Chest - AP/PA	0–1 month	0.02	0.002	≤0.01
	1–12 months	0.02	0.003	≤0.01
	1–4 years	0.03	0.005	≤0.01
	5–9 years	0.04	0.016	≤0.01
	10–15 years	0.05	0.029	≤0.01
Abdomen - AP	0–1 month	0.05	0.004	≤0.01
	1–12 months	0.05	0.009	≤0.01
	1–4 years [c]	0.09 / 0.16	0.017 / 0.030	0.02 / 0.04
	5–9 years	0.25	0.074	0.06
	10–15 years	0.66	0.36	0.13
Pelvis/hips - AP/Frog LAT	0–1 month	0.05	0.003	≤0.01
	1–12 months	0.07	0.005	≤0.01
	1–4 years [c]	0.08 / 0.22	0.011 / 0.068	≤0.01 / 0.03
	5–9 years	0.42	0.15	0.06
	10–15 years	1.13	0.29	0.17
Skull - AP	0–1 month	0.12	0.015	≤0.01
	1–12 months	0.15	0.022	≤0.01
	1–4 years	0.48	0.08	≤0.01
	5–9 years	0.73	0.11	≤0.01
	10–15 years	0.94	0.20	≤0.01
Skull - LAT	0–1 month	0.07	0.009	≤0.01
	1–12 months	0.09	0.014	≤0.01
	1–4 years	0.30	0.053	≤0.01
	5–9 years	0.36	0.060	≤0.01
	10–15 years	0.46	0.11	≤0.01

Table 28 (continued)

Lumbar spine - AP	0–1 month 1–12 months 1–4 years 5–9 years 10–15 years	0.07 0.19 0.37 0.98 1.75	0.006 0.010 0.048 0.23 0.54	≤0.01 0.02 0.05 0.14 0.22
Lumbar spine	0–1 month 1–12 months 1–4 years 5–9 years 10–15 years	0.08 0.14 0.70 1.52 8.46	0.006 0.012 0.10 0.30 2.22	≤0.01 ≤0.01 0.04 0.09 0.43
Full spine (scoliosis) - PA	0–1 month 1–12 months 1–4 years 5–9 years 10–15 years	– – 0.21 0.22 0.30	– – 0.069 0.070 0.095	– – – – –
Full spine (scoliosis) - LAT	0–1 month 1–12 months 1–4 years 5–9 years 10–15 years	– – 0.37 0.40 0.54	– – 0.086 0.12 0.14	– – – – –
Barium meal / barium swallow	< 1 years 1–5 years	– –	0.34 [d] (0.18–0.56) 0.60 [d] (0.36–0.94)	– –
Micturating cystourethrography (MCU)	< 1 years 1–4 years 5–10 years	– – –	0.26 [d] (0.06–0.62) 0.25 [d] (0.10–0.49) 0.45 [d] (0.29–0.60)	– – –

a With backscatter.
b Examinations conducted in a special care baby unit using mobile x-ray equipment. Data given by patient weight (kg).
c Dual dose data refer to small and large children, respectively.
d Mean and range from survey with screening times of 0.5–5.2 min and 3–10 films (100 mm format).

Table 29
Some reported annual individual and collective effective doses from diagnostic medical x-ray examinations [a]
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	*Effective dose (mSv)*		*Collective effective dose (man Sv)*	*Ref.*
	Per examination	*Per caput*		
Health-care level I				
Australia	1.3	0.8	13 000	[W34]
Bulgaria	1.28	0.75	6 400	-
Canada	1.05	0.94	26 200	[A15]
China, Taiwan Province	0.43	0.23	4 700	[L23]
Denmark	0.7	0.36	1 820	-
Finland	0.63	0.45	2 270	-
France	-	1.0	57 660	[S50]
Germany	1.5	1.9	153 360	-
Netherlands	1.0	0.6	9 000	-
Poland	1.2	0.8	32 300	-
Portugal	0.83	0.71	7 000	[F11]
Romania	1.35	0.61	13 800	-
Russian Federation	0.7	0.9	128 000	-
Sweden	1.2	0.68	6 000	-
Ukraine	0.83	0.50	26 250	[K18]
United States	0.5	0.5	130 000	-
Health-care level II				
Brazil [b]	0.26	0.09	-	-
China	0.57	0.08	91 600	[Z10]
Malaysia	0.28	0.05	1 000	[N26]

a Since, as discussed in Section I.C, many of these exposures are received by patients nearing the end of their lives and the doses are not distributed evenly amongst the population, these doses should not be used for the assessment of detriment. Some data may erroneously include dental examinations.

b Data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil).

Table 30
Frequencies, effective doses and collective doses[a] assumed in global model for diagnostic practice with medical and dental x-ray examinations[b] (1991-1996)

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*
Medical examinations												
Chest radiography	281	23	3.8	87	0.14	0.14	0.20	0.14	60 200	10 050	920	71 200
Chest photofluoroscopy	35	0.1	0.01	9.4	0.65	0.65	0.65	0.65	35 100	200	10	35 300
Chest fluoroscopy	12	63	0.01	37	1.1	1.1	1.1	1.1	20 900	214 000	10	234 700
Limbs and joints	166	19	4.8	55	0.06	0.06	0.1	0.06	15 200	3 600	600	19 400
Lumbar spine	48	4.4	0.92	15	1.8	1.8	2	1.8	132 000	24 200	2 200	159 000
Thoracic spine	13	1.2	0.42	4.1	1.4	1.4	1.5	1.4	27 600	5 000	770	33 400
Cervical spine	32	2.9	0.64	10	0.27	0.27	0.3	0.27	13 300	2 400	230	15 900
Pelvis and hip	35	2.8	1.5	11	0.83	0.83	1	0.83	44 300	7 200	1 800	53 300
Head	59	6.0	2.8	19	0.1	0.1	0.15	0.1	9 050	1 850	510	11 400
Abdomen	41	12	1.4	18	0.5	0.6	1	0.55	31 100	22 600	1 700	55 400
Upper GI tract	42	3.2	0.85	13	3.6	4	4	3.7	231 000	39 500	4 080	274 000
Lower GI tract	8.7	1.7	1.2	3.4	6.4	6.4	6.4	6.4	85 100	32 500	9 260	127 000
Cholecystography	3.1	0.19	0.07	0.94	2	2	2	2	9 500	1 200	170	10 900
Urography	12	0.97	0.59	3.8	3.7	3.9	4	3.7	66 800	11 700	2 860	81 300
Mammography	25	0.58	0.01	7.0	0.5	0.5	0.5	0.5	19 400	900	10	20 300
CT	57	1.5	0.07	16	8.8	5	5	8.6	762 000	22 400	430	785 000
Angiography	7.6	0.10	0.01	2.1	12	12	12	12	140 000	3 600	100	143 000
Interventiona1 procedures	3.0	0.10	0.01	0.84	20	20	20	20	91 800	6 000	170	98 000
Total	920	150	20	330	-	-	-	-	1 875 000	425 000	27 000	2 330 000
Average effective dose per medical x-ray examination (mSv)					1.3	0.9	1.1	1.2				
Average effective dose per caput from medical x-ray examinations (mSv)									1.2	0.14	0.02	0.40
Dental examinations												
Total	310	14	0.2	90	-	-	-	-	9 500	4 300	24	14 000
Average effective dose per dental x-ray examination (mSv)					0.02	0.1	0.1	0.03				
Average effective dose per caput from dental x-ray examinations (mSv)									0.01	0.001	0.00002	0.002

a Since, as discussed in Section I.C, many of these exposures are received by patients nearing the end of their lives and the doses are not distributed evenly amongst the population, these doses should not be used for the assessment of detriment.

b Rounded estimates based on self-consistent frequency data from a selected sample of representative countries and typical (or assumed) doses from the UNSCEAR Survey of Medical Radiation Usage and Exposures.

Table 31
Contributions to frequency and collective dose from the various types of diagnostic medical x-ray examinations assumed for global model (1991-1996)

Examination	*Contribution (%)*			
	Level I	*Level II*	*Levels III-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
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 32
Temporal trends in the annual frequency of diagnostic medical x-ray examinations per 1,000 population [a]
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures unless otherwise indicated.

Country / area	*1970-1979*	*1980-1984*	*1985-1990*	*1991-1996*
Health-care level I				
Australia	490	– [b]	560	565
Bahrain	–	–	–	202
Belarus	–	–	–	726
Belgium	–	–	1290	–
Bulgaria	(980)	(1100)	(800)	589
Canada	860	1020	1050	892
China, Taiwan Province	–	–	–	480
Croatia	–	–	–	903
Cuba	–	140	620	–
Cyprus	–	–	–	937
Czechoslovakia	1110	1050	920	–
Czech Republic	–	–	–	883
Denmark	–	–	510	510
Ecuador	(26)	–	(53)	151
Estonia	–	–	–	1000
Finland	1080	–	870	704
France	–	840	990	–
Germany	900	–	1050	1254
Hungary	–	–	–	475
Italy	–	740	–	–
Japan	830	–	1160	1477
Kuwait	–	–	720	896
Lithuania	–	–	–	886
Luxembourg	–	–	810	1046
Malta	100	–	320	–
Netherlands	570	550	530	598
New Zealand	610	710	640	–
Norway	–	640	620	708
Panama	–	–	–	300
Poland [S49]	900	–	540	641
Portugal	–	–	700	850
Qatar	–	–	–	495
Romania	790	600	470	450
Russian Federation	(1340)	(1560)	(1260)	1151
Slovakia	–	–	–	800
Slovenia	–	–	–	348
South Africa	–	–	–	180
Spain	–	–	570	–
Sweden	590	–	520	568
Switzerland	1040	1040	–	750
Ukraine [K18]	–	–	948	600
United Arab Emirates	–	–	–	378
United Kingdom	420	460	–	489
United States	–	790	800	962
Average	820	810	890	920
Health-care level II				
Antigua and Barbuda	–	–	–	271
Barbados	–	–	160	174
Brazil	–	180	93	261
Chile	–	170	–	–
China	–	110	150	173 [c]
Colombia	–	210	–	–
Costa Rica	–	270	–	–
Dominica	–	–	(180)	185
Dominican Republic	–	20	–	–
Grenada	–	–	–	158
India	(23)	–	110	–
Iran (Islamic Rep. of)	–	180	–	–
Jordan	–	–	–	45
Malaysia	–	–	–	183
Mexico	–	70	–	306
Nicaragua	–	57	13	–
Oman	–	–	–	269
Peru	–	–	15	–

Table 32 (continued)

Country / area	*1970-1979*	*1980-1984*	*1985-1990*	*1991-1996*
Saint Kitts and Nevis	–	–	–	203
Saint Lucia	–	–	(130)	134
Saint Vincent and the Grenadines	–	–	–	147
Turkey	–	–	524	98
Average	26	140	120	154
Health-care level III				
Belize	–	–	83	–
Cape Verde	–	–	69	–
Ghana	22	–	–	7
Liberia	80	–	–	–
Madagascar	–	–	–	11
Morocco	–	–	–	8
Myanmar	–	–	10	–
Philippines	–	–	110	–
Sri Lanka	21	–	–	–
Sudan	–	–	53	37
Thailand	50	75	79	–
Vanuatu	–	–	100	–
Average	23	75	67	17
Health-care level IV				
Cote d'Ivoire	40	–	–	–
Kenya	36	–	–	–
Nigeria	25	–	–	–
Rwanda	8.0	–	8.8	–
Tanzania	–	–	–	29
Average	27	–	8.8	29

a Dental x-ray examinations not included.
b No data available.
c These revised data were received by the Committee after completion of the global analysis.

The entries in this Table are qualified as follows:

Bulgaria: Historical data were not included in previous analyses.
Czechoslovakia: Historical data.
Dominica: Categorized in health-care level III in previous analysis.
Ecuador: Categorized in health-care level II in previous analyses.
Germany: Data for 1970–1979 and 1985–1990 represent combined historical data for German Democratic Republic and Federal Republic of Germany.
India: Categorized in health-care level III for period 1970–1979.
Russian Federation : Historical data were not included in previous analyses.
Saint Lucia: Categorized in health-care level III in previous analysis.

Table 33
Temporal trends in the average annual number of diagnostic x-ray examinations per 1,000 population
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures

Examination	*Period*	*Average annual number of examinations per 1,000 population* [a]		
		Health-care level I	*Health-care level II*	*Health-care levels III-IV*
Chest	1970–1979	588	11	18
	1980–1984	588	80	45
	1985–1990	527(52%)	118 (73%)	51 (70%)
	1991–1996	368 (39%)	89 (58%)	4.9 (21%)
Limbs and joints	1970–1979	87	3.3	3.2
	1980–1984	151	7.8	7.4
	1985–1990	137 (14%)	15 (8.9%)	6.2 (8.8%)
	1991–1996	212 (21%)	20 (13%)	6.8 (24%)
Spine	1970–1979	25	1.7	1.9
	1980–1984	58	1.7	5
	1985–1990	61 (6.1%)	3.9 (2.4%)	2 (2.8%)
	1991–1996	100 (11%)	8.9 (5.8%)	3.6 (11%)
Pelvis and hip	1970–1979	22	2.7	0.57
	1980–1984	31	0.44	1.5
	1985–1990	38 (3.7%)	3.4 (2.1%)	2 (2.8%)
	1991–1996	36 (4.0%)	14 (5.9%)	1.7 (6.6%)
Head	1970–1979	13	2.3	1.8
	1980–1984	37	1.5	3.4
	1985–1990	46 (4.5%)	5.8 (3.5%)	3.7 (5.2%)
	1991–1996	60 (6.5%)	30 (13%)	3.3 (14%)
Abdomen	1970–1979	15	4.1	4.7
	1980–1984	22	14	6.5
	1985–1990	36 (3.6%)	7.9 (4.8%)	3.4 (4.7%)
	1991–1996	41 (4.6%)	13 (8.2%)	2.0 (7.1%)
GI tract	1970–1979	73	0.92	1.6
	1980–1984	51	2.7	2.6
	1985–1990	72 (7.1%)	5 (3.1%)	1.8 (2.5%)
	1991–1996	60 (6.4%)	5.1 (3.3%)	2.9 (10%)
Cholecystography and urography	1970–1979	19	0.48	1.2
	1980–1984	28	0.35	2.6
	1985–1990	26 (2.6%)	2.7 (1.6%)	2.2 (3.1%)
	1991–1996	15 (1.6%)	5.6 (2.4%)	0.9 (3.3%)
Mammography	1970–1979	5.2	0.07	–
	1980–1984	4.6	0.09	–
	1985–1990	14 (1.4%)	0.57 (0.3%)	(0.1%)
	1991–1996	25 (2.9%)	2.7 (1.2%)	0.01 (0.1%)
CT	1970–1979	6.1	0	0.14
	1980–1984	11	0	1.3
	1985–1990	44 (4.4%)	0.42 (0.3%)	0.42 (0.6%)
	1991–1996	48 (6.4%)	6.7 (2.9%)	0.14 (0.8%)
Angiography	1970–1979	1.6	0	0.3
	1980–1984	5.7	0	0.3
	1985–1990	7.1 (0.7%)	0.27 (0.2%)	0.11 (0.2%)
	1991–1996	6.8 (0.8%)	0.48 (0.2%)	0
Interventional procedures	1991–1996	2.7 (0.4%)	0.94 (0.4%)	0
Pelvimetry	1991–1996	0.6 (0.1%)	1.7 (0.8%)	0.3 (1.0%)
Total	1970–1979	814	26	29
	1980–1984	804	141	75
	1985–1990	887 (100%)	124 (100%)	64 (100%)
	1991–1996	920 (100%)	154 (100%)	20 (100%)

a Overall averages calculated from national data as the total number of examinations divided by the total population for each examination category. The figures in parentheses indicate an average percentage contribution of each examination category to total frequency, calculated on a similar basis. Data for 1991–1996 from Tables 12 and 13; since the total population is not the same for each examination category due to the lack of comprehensive national data for all countries listed in the tables, these average numbers can not be expected to be additive.

Table 34
Temporal trends in annual frequency of diagnostic dental x-ray examinations per 1,000 population
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures

Country	*1970-1979*	*1980-1984*	*1985-1990*	*1991-1996*
Health-care level I				
Australia	80	–	–	–
Bahrain	–	–	–	49
Belarus	–	–	–	81
Belgium	–	–	288	–
Croatia	–	–	–	231
Cyprus	–	–	–	12
Czechoslovakia [a]	72	86	85	–
Czech Republic	–	–	–	193
Denmark	–	–	471	471
Ecuador [b]	(1.5)	(4.4)	(6.2)	14
Finland	–	–	223	290
France	–	540	–	–
Germany [c]	–	–	264	276
Hungary	–	–	–	41
Italy	–	119	–	–
Japan	831	834	783	839
Kuwait	–	–	219	100
Lithuania	–	–	–	108
Luxembourg	–	–	186	469
Malta	3	6.2	8.2	–
Netherlands	(75) [e]	(200) [e]	(205) [e]	182 [e]
New Zealand	321	–	275	–
Norway	641	805	833	–
Poland [S49]	–	–	32	74
Portugal	–	–	86	100
Romania	20	32	42	28
Russian Federation [d]	–	(74)	(82)	96
Slovakia	–	–	–	94
Slovenia	–	–	–	55
Spain	–	–	232	–
Sweden	433	841	832	739
Switzerland	296	325	–	571
United Arab Emirates	–	–	–	15
United Kingdom	112	165	–	212
United States	350	456	402	–
Average	320	390	350	310
Health–care level II				
Brazil	–	–	4.7	111
Chile	–	3.9	–	–
China	–	0.8	2.1	1.7
Jordan	–	–	–	3.1
Mexico	–	–	–	1.2
Oman	–	–	–	2.3
Tunisia	–	–	1.3	–
Turkey	–	–	–	31
Average	–	0.8	2.5	14
Health–care level III				
Egypt	0.7	–	–	–
Ghana	–	–	–	0.3
Myanmar	–	–	1.6	–
Sri Lanka	0.8	–	–	–
Thailand	1.4	2.3	2.1	–
Average	–	0.8	1.7	0.3

Table 34 (continued)

Health–care level IV				
United Rep. of Tanzania	–	–	–	0.1
Average	–	–	–	0.1

a Historical data.
b Categorized in health-care level II in previous analyses.
c Data for 1985–1990 represent historical data for Federal Republic of Germany.
d Historical data were not included in previous analyses.
e These revised data were received by the Committee after completion of the global analysis.

Table 35
Trends in average effective doses from diagnostic medical x-ray examinations
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures

Examination	*Average [a] effective dose per examination (mSv)*				
	Health-care level I			*Health-care level II*	
	1970–1979	*1980–1990*	*1991–1996*	*1980–1990*	*1991–1996*
Chest radiography	0.25	0.14	0.14	0.04	0.05
Chest photofluoroscopy	0.52	0.52	0.65	–	–
Chest fluoroscopy	0.72	0.98	1.1	0.29	–
Limbs and joints	0.02	0.06	0.06	0.04	0.04
Lumbar spine	2.2	1.7	1.8	2.6	1.0
Pelvis and hip	2.1	1.2	0.83	2.0	0.74
Head	0.50	0.16	0.07	0.13	0.04
Abdomen	1.9	1.1	0.53	0.22	0.62
Upper GI tract	8.9	7.2	3.6	1.6	6.0
Lower GI tract	9.8	4.1	6.4	5.0	6.0
Cholecystography	1.9	1.5	2.3	1.6	1.5
Urography	3.0	3.1	3.7	1.7	3.9
Mammography	1.8	1.0	0.51	–	0.1
CT	1.3	4.3	8.8	–	4.9
Angiography	9.2	6.8	12	–	6.8
PTCA	–	–	22	–	–

a Frequency-weighted average of national values from survey data. Values for 1991–1996 from Table 15.

Table 36
Estimated doses to the world population from diagnostic medical and dental x-ray examinations [a]
1991–1996

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	< 0.0001	14 000	13
IV	565	0.02	< 0.0001	13 000	11
World	5 800	0.4	0.002	2 330 000	14 000

a Since, as discussed in Section I.C, many of these exposures are received by patients nearing the end of their lives and the doses are not distributed evenly amongst the population, these doses should not be used for the assessment of detriment.

Table 37
Chronology of key technical advances in diagnostic nuclear medicine

Date	*Development*
1896	Discovery of natural radioactivity (Becquerel)
1920s	Biological tracer studies with radionuclides in plants and animals (Hevesey)
1930s	First cyclotron; production of artificial radioactivity (Fermi)
1940s	Controlled uranium fission; early clinical nuclear medicine with radioiodine; first artificial radioactive element named (^{99m}Tc)
1950s	Invention of rectilinear scanner (Cassen); invention of gamma camera (Anger)
1960s	Invention of ^{99m}Tc generator; early development of single-photon computed tomography (SPECT)
1970s	Increased use of computers; early development of positron emission tomography (PET)
1980s	Growth in SPECT
1990s	Growth in PET; more specific radiopharmaceuticals

Table 38
Annual numbers of diagnostic nuclear medicine procedures per 1,000 population by broad category and radionuclide (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

PART A

Country /area	*Bone (^{99m}Tc)*	*Cardiovascular*			*Lung perfusion (^{99m}Tc)*	*Lung ventilation*				*Thyroid scan*		
	Total	*^{99m}Tc*	*^{201}Tl*	*Total*	*Total*	*^{99m}Tc*	*^{81m}Kr*	*^{133}Xe*	*Total*	*^{99m}Tc*	*^{131}I / ^{123}I*	*Total*
Health-care level I												
Argentina	3.38	1.12	1.88	3.01	0.32	0.26	0	0	0.26	0.65	1.09	1.74
Belarus	0.23	–	–	–	–	–	–	–	–	0.012	0	0.012
Bulgaria	0.068	–	–	0.065	0.047	0.014	0	0	0.014	–	–	1.23
Canada	22.0	–	–	30.4	0.17	–	–	–	0.94	–	–	2.79
Cayman Islands	0	0	0	0	0	0	0	0	0	0	0	0
China, Taiwan Province [L6]	1.55	0.55	0.43	0.98	0.14	–	–	–	–	0.31	0	0.31
Croatia	0.53	0.033	0.23	0.27	0.066	0.0063	0	0	0.0063	0.47	0.071	0.54
Cyprus	1.83	0.40	1.42	1.82	0.12	0	0	0	0	1.33	0.065	1.39
Czech Republic	5.14	–	–	2.43	2.67	0.40	0	0	0.40	–	–	2.60
Denmark	2.91	1.29	0	1.29	0.90	0.024	0.34	0.18	0.54	2.05	0	2.05
Ecuador	0.25	0.057	0	0.057	0.029	0.015	0	0	0.015	0	0.21	0.21
Finland	3.86	0.90	0.34	1.25	1.18	0.22	0	0.002	0.22	0.11	0.051	0.17
Germany	8.96	–	–	2.82	2.58	–	–	–	–	17.2	0	17.2
Hungary	[3.93]	–	–	1.00	[1.05]	–	–	–	0.087	–	–	4.08
Ireland	2.74	0.33	0	0.33	0.66	0.15	0	0	0.15	0.047	0	0.047
Italy	3.68	0.83	0.67	1.50	0.44	0.063	0	0	0.063	2.40	0.11	2.51
Japan	2.74	0.44	0.39	0.84	0.27	–	–	–	–	0.36	0.58	0.94
Kuwait	0.90	2.55	0	2.55	0.27	–	–	–	–	3.95	0	3.95
Lithuania	0.33	0.013	0	0.013	0.025	0	0	0	0	0	1.65	1.65
Netherlands	6.12	–	–	3.12	1.10	–	–	–	1.14	–	–	0.84
New Zealand [L28]	4.10	0.60	0.007	0.61	0.75	0.40	0	0.17	0.57	0.62	0.041	0.66
Panama	0.18	0.20	0	0.20	0.19	0.22	0	0	0.22	1.73	0	1.73
Qatar	1.18	0.97	0	0.97	0.17	–	–	–	–	0.58	0	0.58
Romania	0.37	–	–	–	0.032	–	–	–	–	0.14	0.69	0.82
Slovakia	2.69	–	–	0.24	1.54	–	–	–	–	–	–	2.50
Slovenia	2.00	1.34	0.016	1.35	0.70	0.042	0	0.41	0.45	2.33	0.19	2.52
Sweden	3.84	0.68	0.40	1.08	1.48	0.60	0	0	0.60	1.01	0.21	1.22
Switzerland	4.09	–	–	0.54	1.30	0	0	–	0.61	–	–	1.44
United Arab Emirates	1.93	0.86	0.25	1.11	0.17	0.020	0	0	0.020	0.95	0	0.95
United States [I23]	7.72	–	–	4.05	5.08	–	–	–	–	–	–	–
Average	5.85	–	–	3.57	2.33	–	–	–	0.35	–	–	4.04

Table 38 (continued)

Country /area	Bone (^{99m}Tc)	Cardiovascular			Lung perfusion (^{99m}Tc)	Lung ventilation				Thyroid scan		
	Total	^{99m}Tc	^{201}Tl	Total	Total	^{99m}Tc	^{81m}Kr	^{133}Xe	Total	^{99m}Tc	^{131}I / ^{123}I	Total
Health-care level II												
Jordan	0.34	0.0066	0.004	0.011	0.008	0.0049	0	0	0.0049	–	–	0.73
Mexico	0.16	0.32	0	0.32	0.023	0.015	0	0	0.015	–	–	0.13
Oman	[0.17]	0	0	0	[0.020]	–	–	–	0.0009	–	–	0.043
Pakistan	0.071	0.0069	0	0.0069	0.0030	0	0	0	0	0.22	0	0.22
Peru	0.41	0.0068	0	0.0068	0.0085	–	–	–	0.0034	0.073	0.026	0.099
Tunisia	[0.033]	–	–	0.020	[0.056]	0	0	0	0	–	–	0.56
Turkey	0.49	–	–	0.30	0.038	0.023	0	0	0.023	0.53	0	0.53
Average	0.20	–	–	0.15	0.017	–	–	–	0.0089	–	–	0.26
Health-care level III												
Ghana [A16]	0.0022	–	–	–	–	–	–	–	–	0.024	0	0.024
Morocco	0.13	–	–	0.045	0.019	0	0	0	0	0.37	0	0.37
Sudan	0.011	0	0	0	0	0	0	0	0	0.046	0	0.046
Average	0.054	–	–	0.023	0.0095	–	–	–	0	–	–	0.16
Health-care level IV												
Ethiopia	0.0001	0	0	0	0.0001	0	0	0	0	0	0.0048	0.0048
Tanzania	0.0043	0	0	0	0.00007	0	0	0	0	0	0	0
Average	0.0014	–	–	0	0.0001	–	–	–	0	–	–	0.0033

PART B

Country / area	Thyroid uptake			Renal			Liver / spleen (^{99m}Tc)	Brain			Total of all nuclear medicine examinations
	^{131}I	^{123}I/^{125}I	Total	^{99m}Tc	^{131}I / ^{123}I	Total	Total	^{99m}Tc	Other	Total	
Health-care level I											
Argentina	1.19	0	1.24	0.79	0.03	0.82	0.13	0.22	0	0.22	11
Australia [C7]	–	–	–	–	–	–	–	–	–	–	12
Belarus	0.0041	0	0.0041	0.17	0	0.17	0.0020	0.0020	0	0.0020	0.48
Bulgaria	0	1.48	1.48	0.22	0	0.22	0.057	0.052	0	0.052	3.26

Table 38 (continued)

Country / area	*Thyroid uptake*			*Renal*			*Liver / spleen (^{99m}Tc)*	*Brain*			*Total of all nuclear medicine examinations*
	^{131}I	*$^{123}I/^{125}I$*	*Total*	*^{99m}Tc*	*^{131}I / ^{123}I*	*Total*	*Total*	*^{99m}Tc*	*Other*	*Total*	
Canada	–	–	2.95	1.63	0	1.63	0.59	1.54	0	1.54	64.6
Cayman Islands	0	0	0	0	0	0	0	0	0	0	0
China, Taiwan Province [L6]	–	–	0.35	0.29	0	0.29	1.33	0.65	0	0.65	6.63
Croatia	0.037	0	0.037	0.64	0	0.64	0.057	0.13	0	0.13	2.38
Cyprus	0.015	0	0.0015	1.07	0	1.07	0.020	0	0	0	6.65
Czech Republic	1.00	0	1.00	8.15	0	8.15	1.15	2.17	0	2.17	28.3
Denmark	0.31	0	0.31	3.44	0	3.44	0.018	0.17	0.17 (^{133}Xe)	0.34	15.2
Ecuador	0.17	0	0.17	0.029	0	0.029	0.021	0.0017	0	0.0017	0.79
Estonia [S29]	–	–	–	–	–	–	–	–	–	–	8.00
Finland	0.055	0.035	0.090	1.54	0.12	1.66	0.013	0.24	0.044 (^{123}I)	0.28	9.95
Germany	–	–	–	–	–	1.60	0.037	0.49	0	0.49	34.1
Hungary	–	–	0.68	–	–	2.54	[0.39]	–	–	0.34	15.3
Ireland	–	–	0.10	1.50	0	1.50	0.023	0.010	0	0.010	6.15
Italy	0.26	0	0.26	1.07	0.29	1.35	0.36	0.35	0	0.35	11.0
Japan	–	–	–	0.40	–	0.69	0.61	0.53	–	1.24	11.7
Kuwait	2.07	0	2.07	0.97	0	0.97	0.075	0.045	0	0.045	12.7
Lithuania	1.66	0	1.66	1.11	0	1.11	0.13	–	–	0.0013	10.6
Luxembourg	–	–	–	–	–	–	–	–	–	–	52.2
Netherlands	–	–	0.48	1.19	0	1.19	0.094	–	–	0.25	16.0
New Zealand [L28]	0.022	0	0.022	0.79	0	0.85	0.086	0.25	0	0.25	8.35
Panama	0.38	0	0.38	0.25	0	0.25	0.17	0.13	0	0.13	3.45
Portugal [F11]	–	–	–	–	–	–	–	–	–	–	4.00
Qatar	–	–	–	1.39	0	1.39	0.065	0	0	0	4.73
Romania	0.62	0	0.62	0.072	0.21	0.28	0.73	0.11	0	0.11	3.02
Russian Federation	–	–	–	–	–	–	–	–	–	–	12.6
Slovakia	–	0	0.0051	–	–	0.88	0.62	0.044	0	0.044	9.37
Slovenia	0.28	–	0.38	1.45	0	1.45	0.17	0.44	–	0.47	11.2
Sweden	0.52	0	0.52	0.43	0	0.43	0.077	0.055	0.039 (^{11}C)	0.093	13.6
Switzerland	–	–	–	–	–	0.39	0.049	–	–	0.17	9.51
Ukraine [K18]	–	–	–	–	–	–	–	–	–	–	5.00
United Arab Emirates	0	0	0.95	1.38	0	1.38	0.097	0.044	0	0.044	7.25
United Kingdom [E11]	–	–	–	–	–	–	–	–	–	–	8.21
United States [I23]	–	–	–	–	–	1.01	6.83	–	–	3.46	31.5
Average	–	–	0.80	–	–	1.11	2.60	–	–	1.62	18.8

Table 38 (continued)

Country / area	*Thyroid uptake*			*Renal*			*Liver / spleen (^{99m}Tc)*	*Brain*			*Total of all nuclear medicine examinations*
	^{131}I	*$^{123}I/^{125}I$*	*Total*	*^{99m}Tc*	*^{131}I / ^{123}I*	*Total*	*Total*	*^{99m}Tc*	*Other*	*Total*	
Health-care level II											
Antigua and Barbuda [B43]	–	–	–	–	–	–	–	–	–	–	0
Brazil	–	–	–	–	–	–	–	–	–	–	1.11
Dominica [B43]	–	–	–	–	–	–	–	–	–	–	0
Grenada [B43]	–	–	–	–	–	–	–	–	–	–	0
Iran (Islamic Rep of [M10]	–	–	–	–	–	–	–	–	–	–	1.89
Jordan	0.18	0	0.18	0.18	0	0.18	0.040	–	–	–	1.56
Mexico	0.022	0	0.022	0.16	0	0.16	0.093	0.075	0	0.075	1.06
Oman	–	–	0.051	–	–	0.22	[0.0035]	0	0	0	0.64
Pakistan	0	0	0.020	0.064	0	0.064	0.056	0.032	0	0.032	0.55
Peru	0.020	0	0.020	0.015	0	0.015	0.017	0.0034	0	0.0034	0.58
Saint Kitts and Nevis [B43]	–	–	–	–	–	–	–	–	–	–	0
Saint Lucia [B43]	–	–	–	–	–	–	–	–	–	–	0
Saint Vincent and the Grenadines [B43]	–	–	–	–	–	–	–	–	–	–	0
Tunisia	–	–	0.056	–	–	0.056	0	0	0	0	0.79
Turkey	–	–	–	0.32	0	0.32	0.14	0.037	0	0.037	2.07
Average	–	–	0.025	–	–	0.14	0.078	–	–	0.042	1.13
Health-care level III											
Ghana [A16]	–	–	–	0.0007	0	0.0007	0.0009	0.027	0	0.027	0.054
Morocco	0	0	0	0.038	0	0.038	0.0067	0	0	0	0.62
Sudan	0	–	0	0.014	0	0.014	0.0046	0.0092	0	0.0092	0.085
Average	–	–	0	–	–	0.019	0.0045	–	–	0.010	0.28
Health-care level IV											
Ethiopia	0.048	0	0.0048	0.0003	0	0.0003	0.0003	0.0038	0	0.0038	0.014
United Rep. of Tanzania	0	0	0.012	0.0061	0	0.0061	0	0.0008	0	0.0008	0.024
Average	–	–	0.0072	–	–	0.0021	0.0002	–	–	0.0028	0.017

Table 38 (continued)

The entries in this Table are qualified as follows:

Argentina: On the basis of data from a sample of 25% of nuclear medicine centres. Total shown for lung perfusion includes use of ^{67}Ga (frequency of 0.0017). Total shown for thyroid uptake includes use of ^{99m}Tc (frequency of 0.056). Total shown for bone scan includes use of ^{67}Ga (frequency of 0.034).
Brazil: Survey data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil).
Canada: On the basis of data from Ontario (representing about 37% of population).
Cyprus: Survey data relating to 90% of population.
Finland: Total shown for lung perfusion scans includes use of ^{133}Xe (frequency of 0.002).
Ghana: Data for thyroid scan represent total of all thyroid studies.
Japan: Total frequency for bone scans is 2.77; total frequency for lung perfusion scans is 0.45.
Lithuania: Data from Vilnius Oncology Centre.
New Zealand: Total shown for renal scans includes use of ^{51}Cr (frequency of 0.064).
Peru: Survey data from IPEN (Centre of Nuclear Medicine, serving population of about 5 million).
Romania: Survey data relating to population base of about 4.5 million. Total for liver/spleen is 0.79 (includes use of ^{198}Au with frequency of 0.065).
Slovakia: Survey data relating to population base of about 2 million. Total for thyroid uptake includes use of ^{99m}Tc (frequency of 0.096).
Slovenia: Survey data relating to population base of about 1.8 million. Total frequency for lung perfusion is 0.82; total for thyroid uptake includes use of ^{99m}Tc (with frequency of 0.096).
Switzerland: Total for lung ventilation refers to use of ^{133}Xe and ^{127}Xe. Data for thyroid scans include uptake studies.
Turkey: On the basis of data from Hacettepe University Hospital.
United Arab Emirates: Thyroid uptake done simultaneously with thyroid scan using a single dose of ^{99m}Tc.
United Republic of Tanzania: Total shown for thyroid uptake refers to use of ^{99m}Tc.
Hungary, Oman, Tunisia: No information available on radionuclides used.

Table 39
Percentage contributions by types of procedure to annual total numbers of diagnostic nuclear medicine procedures (1991-1996)
Based on data and qualifications from Table 38

Country / area	*Bone*	*Cardiovascular*	*Lung perfusion*	*Lung ventilation*	*Thyroid scan*	*Thyroid uptake*	*Renal*	*Liver/spleen*	*Brain*	*Total of all procedures*
Health-care level I										
Argentina	30	27	2.9	2.3	16	11	7.4	1.2	1.9	100
Belarus	48	–	–	–	2.4	0.8	35	0.4	0.4	100
Bulgaria	2.1	2.0	1.4	0.4	38	45	6.8	1.7	1.6	100
Canada	34	47	0.3	1.5	4.3	4.6	2.5	0.9	2.4	100
China, Taiwan Prov.	23	15	2.1	–	4.7	5.3	4.4	20	9.8	100
Croatia	22	11	2.8	0.3	23	1.5	27	2.4	5.3	100
Cyprus	27	27	1.8	0	21	0.02	16	0.3	0	100
Czech Republic	18	8.6	9.5	1.4	9.2	3.5	29	4.1	7.7	100
Denmark	19	8.5	5.9	3.6	13	2.0	23	0.1	2.2	100
Ecuador	32	7.2	3.7	1.9	27	21	3.6	2.7	0.2	100
Finland	39	13	12	2.2	1.7	0.9	17	0.1	2.8	100
Germany	26	8.3	7.6	–	50	–	4.7	0.1	1.4	100
Hungary	26	6.5	6.8	0.6	27	4.4	17	2.5	2.2	100
Ireland	45	5.3	11	2.5	0.8	1.7	24	0.4	0.2	100
Italy	33	14	4.0	0.6	23	2.3	12	3.2	3.2	100
Japan	24	7.0	3.9	–	8.1	–	6.0	5.3	11	100
Kuwait	7.1	20	2.1	–	31	16	7.7	0.6	0.4	100
Lithuania	3.2	0.1	0.2	0	16	16	10	1.3	0.01	100
Netherlands	39	20	7.0	7.3	5.3	3.1	7.6	0.6	1.6	100
New Zealand	49	7.3	9.0	6.9	7.9	0.3	10	1.0	3.0	100
Panama	5.2	5.7	5.5	6.5	50	11	7.1	5.0	3.8	100
Qatar	25	20	3.5	–	12	–	29	1.4	0	100
Romania	12	–	1.0	–	27	20	9.4	26	3.5	100
Slovakia	29	2.6	16	–	27	0.05	9.4	6.6	0.5	100
Slovenia	18	12	7.3	4.0	23	3.4	13	1.5	4.3	100
Sweden	28	7.9	11	4.4	9.0	3.8	3.1	0.6	0.7	100
Switzerland	43	5.6	14	6.4	15	–	4.2	0.5	1.8	100
United Arab Emirates	27	15	2.3	0.3	13	13	19	1.3	0.6	100
United States	24	13	16	–	–	–	3.2	22	11	100
Average [a]	26	15	10	2.0	23	5.3	5.0	12	7.3	100
Health-care level II										
Jordan	22	0.7	0.5	0.3	47	11	11	2.6	–	100
Mexico	15	30	2.2	1.4	13	2.1	15	8.8	7.1	100
Oman	26	0	3.1	0.1	6.8	7.9	34	0.6	0	100
Pakistan	13	1.3	0.6	0	41	3.6	12	10	5.9	100

Table 39 (continued)

Country / area	*Bone*	*Cardiovascular*	*Lung perfusion*	*Lung ventilation*	*Thyroid scan*	*Thyroid uptake*	*Renal*	*Liver/spleen*	*Brain*	*Total of all procedures*
Health-care level II (continued)										
Peru	70	1.2	1.5	0.6	17	3.5	2.6	2.9	0.6	100
Tunisia	4.2	2.5	7.1	0	71	7.1	7.1	0	0	100
Turkey	24	14	1.8	1.1	26	–	15	6.7	1.8	100
Average [a]	20	15	1.7	0.9	26	3.3	14	7.7	4.2	100
Health-care level III										
Ghana	4.1	–	–	–	44	–	1.3	1.7	49	100
Morocco	21	7.3	3.0	0	61	0	6.1	1.1	0	100
Sudan	13	0	0	0	54	0	16	5.4	11	100
Average [a]	19	6.4	2.7	0	59	0	7.0	1.6	3.7	100
Health-care level IV										
Ethiopia	0.7	0	0.5	0	34	34	1.9	1.8	27	100
United Republic of Tanzania	18	0	0.3	0	0	52	26	0	3.6	100
Average [a]	8.4	0	0.4	0	19	42	13	1.0	16	100

a Overall averages for sample calculated as total number of each particular type of examination divided by total number of all examinations.

Table 40
Distribution by age and sex of patients undergoing diagnostic nuclear medicine procedures (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Bone scan						
I	Argentina	6	22	72	41	59
	Bulgaria	0	22	78	41	59
	Canada	6	15	79	50	50
	Croatia	4	33	63	47	53
	Czech Republic	7	7	86	41	59
	Ecuador	9	34	57	44	56
	Finland	3	–	–	–	–
	Ireland	<1	–	–	–	–
	Italy	1	8	91	34	66
	Japan	–	–	–	56	44
	Kuwait	8	42	50	58	42
	New Zealand [L28]	6	23	71	–	–
	Panama	12	18	70	52	48
	Romania	17	12	71	36	64
	Slovakia	3	37	60	–	–
	Slovenia	3	13	84	45	55
	Sweden	3	–	–	–	–
	United Arab Emirates	12	44	44	53	47
	Average	5	15	80	48	52
II	Jordan	3	32	65	20	80
	Mexico	7	18	75	45	55
	Pakistan	19	38	43	49	51
	Peru	10	30	60	30	70
	Turkey	6	28	66	52	48
	Average	9	27	64	46	54
III	Morocco	0	100	0	30	70
	Sudan	0	80	20	25	75
	Average	0	98	2	30	70
IV	Ethiopia	17	66	17	67	33
	United Rep. of Tanzania	4	24	72	36	64
	Average	5	26	69	37	63
Cardiovascular scan						
I	Argentina	0	12	88	68	32
	Bulgaria	0	22	78	62	38
	Canada	0	6	94	58	42
	Croatia	5	38	57	64	36
	Czech Republic	13	22	65	54	46
	Ecuador	0	19	81	66	34
	Finland	3	–	–	–	–
	Italy	0	11	89	76	24
	Japan	–	–	–	63	37
	Kuwait	0	20	80	73	27
	New Zealand [L28]	1	7	92	0	0
	Panama	14	30	56	30	70
	Slovakia	0	30	70	–	–
	Slovenia	0	8	92	–	–
	United Arab Emirates	0	42	58	38	62
	Average	0	7	93	60	40
II	Jordan	0	14	86	50	50
	Mecixo	0	14	86	58	42
	Pakistan	0	14	86	80	30
	Peru	0	40	60	45	55
	Turkey	0	11	89	60	40

Table 40 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
	Average	0	13	87	59	41
III	Morocco	0	100	0	–	–
Lung perfusion study						
I	Argentina	6	10	84	47	53
	Bulgaria	25	50	25	50	50
	Canada	2	17	81	51	49
	Croatia	2	38	60	51	49
	Czech Republic	2	9	89	45	55
	Ecuador	1	38	61	46	54
	Finland	0.1	–	–	–	–
	Ireland	<1	–	–	–	–
	Italy	0	6	94	54	46
	Japan	–	–	–	49	51
	Kuwait	7	41	52	66	34
	New Zealand [L28]	1	17	82	–	–
	Panama	15	28	57	38	62
	Romania	1	28	71	77	23
	Slovakia	0	36	64	–	–
	Slovenia	1	10	89	–	–
	Sweden	0.3	–	–	–	–
	United Arab Emirates	15	45	40	60	40
	Average	2	13	85	49	51
II	Jordan	9	36	55	29	71
	Mexico	5	19	76	51	49
	Pakistan	18	31	51	57	43
	Peru	0	40	60	30	70
	Turkey	3	40	57	45	55
	Average	5	31	64	48	52
III	Morocco	90	–	–	–	–
IV	Ethiopia	0	75	25	50	50
	United Rep. of Tanzania	0	50	50	0	100
	Average	0	67	33	33	67
Lung ventilation study						
I	Argentina	4	10	86	47	53
	Bulgaria	17	66	17	58	42
	Canada	1	18	81	51	49
	Croatia	0	33	67	48	52
	Czech Republic	1	7	92	45	55
	Ecuador	0	40	60	40	60
	Finland	1	–	–	–	–
	Italy	0	6	94	54	46
	Panama	14	29	57	30	70
	Slovenia	1	14	85	–	–
	Sweden	0.1	–	–	–	–
	United Arab Emirates	23	23	54	64	36
	Average	2	15	83	50	50
II	Jordan	0	65	35	90	10
	Mexico	2	10	88	36	64
	Peru	0	40	60	30	70
	Turkey	0	33	67	67	33
	Average	1	23	76	52	48
Thyroid scan						
I	Argentina	3	53	44	18	82
	Bulgaria	4	48	48	10	90
	Canada	2	37	61	20	80
	Croatia	3	51	46	21	79
	Czech Republic	1	22	77	17	83

Table 40 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Ecuador	5	46	49	17	83
	Finland	1	–	–	–	–
	Ireland	<1	–	–	–	–
	Italy	1	37	62	16	84
	Japan	–	–	–	19	81
	New Zealand [L28]	2	29	69	–	–
	Panama	18	39	43	17	83
	Romania	1	48	51	19	81
	Slovakia	2	45	53	–	–
	Slovenia	1	16	83	–	–
	United Arab Emirates	3	50	47	30	70
	Average	2	40	58	18	82
II	Jordan	13	63	24	7	93
	Mexico	7	51	42	23	77
	Pakistan	15	64	21	31	69
	Peru	15	32	53	37	63
	Turkey	1	64	35	13	87
	Average	8	61	31	22	78
III	Morocco	10	85	5	35	65
	Sudan	10	60	30	10	90
	Average	10	82	8	32	68
IV	Ethiopia	6	72	22	18	82
Thyroid uptake						
I	Argentina	4	50	46	13	87
	Bulgaria	4	50	46	19	81
	Canada	3	39	58	21	79
	Croatia	0	37	63	19	81
	Czech Republic	0	15	85	15	85
	Ecuador	5	46	49	16	84
	Finland	0	–	–	–	–
	Ireland	<1	–	–	–	–
	Italy	1	37	62	16	84
	Japan	0	–	–	–	–
	Panama	4	45	51	22	78
	Romania	1	44	55	23	77
	Slovakia	0	23	77	–	–
	United Arab Emirates	3	50	47	30	70
	Average	3	41	56	18	82
II	Jordan	2	52	46	19	81
	Mexico	4	5	91	19	81
	Pakistan	9	53	38	41	59
	Peru	0	40	60	10	90
	Average	6	36	58	28	72
IV	Ethiopia	6	72	22	18	82
	United Rep. of Tanzania	3	31	66	16	84
	Average	4	50	46	17	83
Renal scan						
I	Argentina	7	41	52	47	53
	Bulgaria	3	56	41	48	52
	Canada	29	15	56	52	48
	Croatia	30	34	36	50	50
	Czech Republic	33	24	43	47	53
	Ecuador	22	47	31	55	45
	Finland	25	–	–	–	–
	Ireland	22	–	–	–	–
	Italy	14	21	65	54	46

Table 40 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Kuwait	48	28	24	57	43
	New Zealand [L28]	33	24	43	–	–
	Panama	17	27	56	45	55
	Romania	1	35	64	40	60
	Slovakia	20	38	42	–	–
	Sweden	16	–	–	–	–
	United Arab Emirates	10	43	47	67	33
	Average	22	25	53	51	49
II	Jordan	50	21	29	53	47
	Mexico	12	41	47	39	61
	Pakistan	21	37	42	62	38
	Peru	61	23	16	50	50
	Turkey	36	46	18	74	26
	Average	26	42	32	60	40
III	Morocco	90	–	–	–	–
	Sudan	20	70	10	50	50
IV	Ethiopia	6	69	25	63	37
	United Rep. of Tanzania	7	45	48	38	62
	Average	7	47	46	40	60
Liver/spleen study						
I	Argentina	6	22	72	31	69
	Bulgaria	9	62	29	36	64
	Canada	16	16	68	55	45
	Croatia	0	37	63	50	50
	Czech Republic	14	25	61	48	52
	Ecuador	7	42	51	47	53
	Finland	1	–	–	–	–
	Italy	1	37	62	48	52
	Japan	–	–	–	62	38
	Kuwait	29	12	59	65	35
	Panama	4	11	85	54	46
	Romania	1	22	77	57	43
	Slovakia	5	30	65	–	–
	United Arab Emirates	5	20	75	45	55
	Average	7	26	67	56	44
II	Jordan	8	35	57	53	47
	Mexico	10	33	57	43	57
	Pakistan	12	41	47	50	50
	Peru	20	30	50	30	70
	Turkey	1	83	16	14	86
	Average	8	52	40	35	65
III	Morocco	100	0	0	–	–
	Sudan	0	5	95	25	75
	Average	60	2	38	25	75
IV	Ethiopia	0	67	33	73	27
Brain scan						
I	Argentina	4	10	86	33	67
	Bulgaria	54	34	12	48	52
	Canada	36	36	28	68	32
	Croatia	0	49	51	41	59
	Czech Republic	7	21	72	45	55
	Ecuador	0	100	0	50	50
	Finland	9	–	–	–	–
	Italy	0	10	90	53	47
	Japan	–	–	–	56	44
	Panama	33	24	43	40	60
	Romania	3	20	77	69	31

Table 40 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Slovakia	8	46	46	–	–
	Sweden	20	–	–	–	–
	United Arab Emirates	0	42	58	42	58
	Average	18	25	57	56	43
II	Mexico	11	38	51	51	49
	Pakistan	25	40	35	55	45
	Peru	0	0	100	30	70
	Turkey	8	45	47	63	37
	Average	15	40	45	54	46
III	Sudan	0	10	90	30	70
IV	Ethiopia	9	67	24	60	40
	United Rep. of Tanzania	4	50	46	33	67
	Average	9	65	26	57	43
Other procedures						
I	Bulgaria (Testicles)	27	50	23	100	0
	Croatia (Infection)	0	41	59	42	58
	Croatia (GI bleeding)	2	42	56	58	42
	Croatia (Haemangioma)	0	37	63	35	65
	Coatia (Adrenal)	0	41	59	42	58
	Croatia (Biliary tract)	21	28	51	58	42
II	Peru (Cysternography)	50	30	20	30	70
	Peru (Gall bladder)	50	30	20	30	70
	Peru (VPT)	0	20	80	30	70
III	Morocco (sur. renal)	60	40	0	–	–
IV	Ethiopia (Meckel's divert.)	0	100	0	50	50
All diagnostic procedures						
I	Argentina	4	28	68	42	58
	Bulgaria	5	49	46	21	79
	Czech Republic	13	15	72	44	56
	Ecuador	7	39	54	33	67
	Finland	7	–	–	–	–
	Japan	3	9	88	49	51
	Netherlands	3	14	83	44	56
	New Zealand [L28]	7	21	72	–	–
	Panama	15	28	57	37	63
	Slovakia	3	39	58	–	–
	Ukraine	3	–	–	–	–
	United Arab Emirates	7	44	49	46	54
	Average	5	12	83	47	53
II	Mexico	8	28	64	45	55
IV	Ethiopia	7	70	23	31	69

The entries in this Table are qualified as follows:

Argentina: On the basis of data from a sample of 25% of nuclear medicine centres.
Canada: Data from London Health Sciences Centre, SW Ontario (representing 50% of the services provided to population of about 1 million).
Czech Republic: Survey data relating to Prague (about 10% of national population).
Jordan: Survey data from one hospital.
New Zealand: Data shown for 'Lung Perfusion' refer to both perfusion and ventiliation studies.
Peru: Survey data from IPEN (Centre of Nuclear Medicine, serving population of about 5 million).
Romania: Survey data relating to population base of about 4.5 million.
Slovakia: Survey data relating to population base of about 2 million.
Turkey: Survey data from Gülhane Military Hospital, Hacettepe University Hospital and Samsun Ondokuz Mayis University Hospital.

Table 41
Average activities administered in diagnostic examinations with radiopharmaceuticals (1991–1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

PART A

Country / area	*Average activity administered (MBq) (range or standard deviation in parentheses)*								
	Bone		*Cardiovascular*			*Brain*			
	^{99m}Tc phosphates	*^{99m}Tc other*	*^{99m}Tc MIBI*	*^{99m}Tc other*	*^{210}Tl chloride*	*^{99m}Tc DTPA*	*^{99m}Tc HMPAO*	*^{99m}Tc pertechnetate*	*Other*
Health-care level I									
Argentina	– [a]	781 [a] (± 192)	–	877 (±192)	89 (±11)	–	–	–	866 [d] (±137)
Belarus	–	720 [a] (680-760)	–	–	–	–	–	–	740 [d] (700–780)
Bulgaria	300 (150–450)	–	666	555 [b]	74	(550–740)	–	–	–
Canada	925 (±10%)	–	600 (±10%)	–	–	–	740 (±5%)	–	–
China, Taiwan Pr. [L6]	545 (370–750)	–	–	540 [c]	70	420	–	420	–
Croatia	555 (100–740)	–	–	370 [a] (185–740)	80 (70–111)	–	–	–	555 [d] (185–740)
Cyprus	630	–	–	600–1 100	75	–	–	–	–
Czech Republic	730 (350-1 210)	–	680	–	90 (80–100)	–	740 (460–860)	650 (600–700)	–
Denmark	637 (180–820)	–	615 (450–860)	710 [c] (73–1 110)	–	–	667 (125–945)	–	1629 [e] (60-3 000)
Ecuador	740 (±5%)	–	1 100 (±5%)	–	–	1 100 (±5%)	–	–	–
Finland	620	620 [a]	–	890 [a]	100	–	–	–	655 [d]; 124 [f]
France [E10]	–	–	1000	–	–	–	750	–	–
Germany	600	–	–	700 [c]	75	–	700	–	–
Ireland	500 (40–660)	–	–	800 [c] (600-1 100)	–	–	575 (550–600)	–	–
Italy	630 (555–740)	620 [b] (555–740)	600 (185–740)	–	90 (74–111)	630 (555–740)	720 (555–925)	–	–
Japan [J11]	–	740 [a]	–	740 [a]	131	740	787	–	650 [a] (740–555)
Kuwait	925 (740-1 110)	–	–	925 [c] (555–925)	–	–	555 (185–555)	–	–
Lithuania	600 (400–600)	–	–	–	–	–	–	–	–
Netherlands	–	500 [a] (400–800)	650 (600–700)	–	125 (100–150)	–	500	–	200 [f]
New Zealand [L28]	674 (50–920)	–	688 (341-1 080)	585 [c] (250–944)	80 (37–111)	744 (710–750)	705 (450–907)	740	–
Panama	555 (292–618)	–	555 (292–818)	–	–	555 (424–686)	–	–	–
Portugal [E10]	–	–	–	740 [a]	–	–	600	–	–
Romania	660 (480–840)	–	–	–	–	460 (330–590)	–	355 (210–500)	–
Slovakia	740 (260–740)	–	–	740 [a]	100	–	–	740 (200–740)	–
Slovenia	500 (370–740)	–	400 (37–555)	–	74	–	–	–	500 [d] (500–740)
Spain [E10]	740	–	740	–	–	–	740	–	–
Sweden	450 (60–600)	–	800 (400-1 400)	–	80 (60–120)	–	940 (600–1 000)	–	550 [g] (400–570)
Switzerland	670 (150-1 000)	–	570 (110–740)	–	80 (70–110)	–	610 (370–740)	620 (460–930)	930 [e]
United Arab Emirates	720 (74–820)	–	740 (700-1 000)	–	93 (80–95)	–	740 (700–760)	–	–
United Kingdom [A20]	600	–	300 (400 SPECT)	800 [c]	80	500 (800 SPECT)	–	500	500 [h]
Average	719	–	622	–	100	482	721	419	–

Table 41 (continued)

Country / area	*Average activity administered (MBq) (range or standard deviation in parentheses)*								
	Bone		*Cardiovascular*			*Brain*			
	^{99m}Tc phosphates	*^{99m}Tc other*	*^{99m}Tc MIBI*	*^{99m}Tc other*	*^{210}Tl chloride*	*^{99m}Tc DTPA*	*^{99m}Tc HMPAO*	*^{99m}Tc pertechnetate*	*Other*
Health-care level II									
Jordan	750 (±10%)	–	–	1000 [a]	75	–	–	–	–
Mexico	463 (185–740)	–	148 (111–185)	379 [b] (111–647)	–	262 (80–444)	262 (80–444)	–	–
Peru	740 (700–800)	–	740 (700–800)	740 [c] (700–800)	–	740 (700–800)	–	–	–
Turkey	851 (638-1 064)	–	1 221 (858-1 584)	–	97 (79–115)	–	601 (368–834)	–	–
Average	730	–	740	–	75	740	601	–	–
Health-care level III									
Ghana [A16]	446	–	–	–	–	–	–	409	–
Morocco	–	740 [a] (555–925)	–	925 [a]	92.5 (92.5–111)	–	–	–	–
Sudan	560	–	–	–	–	–	–	–	5 610 [d]
Average	546	–	–	–	93	–	–	–	–
Health-care level IV									
Ethiopia	555	–	–	–	–	666 (370–740)	–	666 (370–740)	–
United Rep. of Tanzania	600 (±5%)	–	–	–	–	800 (±5%)	–	–	–
Average	598	–	–	–	–	679	–	666	–

PART B

Country / area	*Average activity administered (MBq) (range in parentheses)*							
	Lung perfusion		*Lung ventilation*			*Liver/spleen*		
	^{99m}Tc MAA	*Other*	*^{99m}Tc DTPA*	*^{99m}Tc aerosol*	*Other*	*^{99m}Tc colloid*	*^{99m}Tc IDA*	*Other*
Health-care level I								
Argentina	–	181 [d] (±78); 200 [i]	–	–	988 [d] (±281)	–	–	229 [d] (±107)
Belarus	–	(±33)	–	–	–	–	–	120 [d] (111–129)
Bulgaria	74	–	925	–	–	185	333	–
Canada	185 (±10%)	–	–	–	–	111 (±10%)	–	–
China, Taiwan Pr. [L6]	120	–	–	–	–	150	140	–
Croatia	148 (111–222)	–	–	37 (17–74)	–	148 (74–222)	–	–

Table 41 (continued)

Country / area	*Average activity administered (MBq) (range in parentheses)*							
	Lung perfusion		*Lung ventilation*			*Liver/spleen*		
	^{99m}Tc MAA	*Other*	*^{99m}Tc DTPA*	*^{99m}Tc aerosol*	*Other*	*^{99m}Tc colloid*	*^{99m}Tc IDA*	*Other*
Cyprus	150	–	–	–	–	185	–	–
Czech Republic	188 (90–210)	–	970 (600–1 200)	–	–	148 (80–230)	–	–
Denmark	112 (50–185)	–	–	13 (7–80)	396 [e] (200–826)	83 (45–217)	–	–
Ecuador	870 (±5%)	–	370 (±5%)	–	–	370 (±10%)	–	–
Finland	105 [d]	460 [e]	–	–	580 [d]; 185 [e]	–	–	180 [d]
France [E10]	300	–	–	–	–	–	–	–
Germany	100	–	–	100	–	–	150	–
Ireland	80 (60–110)	–	80	–	–	110 (100–130)	110 (100–130)	–
Italy	150 (111–185)	–	555 (370–700)	–	–	150 (111–370)	–	148 [d] (111–185)
Japan [J11]	–	240 [d]	740	–	–	–	–	200 [d]
Kuwait	111 (74–185)	–	1 480 (1 110-1 850)	–	–	185 (74–185)	–	–
Lithuania	100 (80–100)	–	–	–	–	80 (80–100)	–	–
Netherlands	100	–	–	–	(450–750 min^{-1}) [j]	80	–	–
New Zealand [L28]	145 (56–286)	–	81 (37–136)		734 [e] (370–1 112)	196 (110–278)	–	–
Panama	185	–	925 (662–1188)	–	–	241 (110–372)	–	–
Portugal [E10]	111	–	–	444	–	185	–	–
Romania	125 (55–195)	–	–	–	–	140 (35–245)	–	9 [l] (7.4–10.6)
Slovakia	185 (80–185)	–	–	–	–	–	185	185 [d] (40–185)
Slovenia	170 (120–222)	74 [a] (37–84)	175 (84–185)	–	140 [e] (100–200)	–	180	(296–500) [d]
Spain [E10]	–	–	–	370	–	185	–	–
Sweden	100 (27–150)	–	200 (7–1 500)	240 (15-1 700)	–	170 (20–800)	–	–
Switzerland	140 (70–230)	–	–	–	390 [e] (110-750); 220 [k] (100-370)	120 (20–160)	100 (10–200)	
United Arab Emirates	140 (111–260)	–	222 (200–300)	–	–	148 (140–185)	–	–
United Kingdom [A20]	100 (200 SPECT)	–	80	–	400[e]; 6 000[j] (max)	80	–	–
Average	118	–	662	–	–	141	–	–
Health-care level II								
Jordan	150	–	1 000	–	–	150	–	–
Mexico	130 (74–185)	–	463 (185–740)	–	–	111 (36–185)	131 (40–222)	–
Peru	185 (150–200)	–	–	–	185 [a] (150–200)	185 (150–200)	–	–
Turkey	159 (124–194)	–	925	–	–	148 (96–200)	–	–
Average	147	–	703	–	–	150	–	–
Health-care level III								
Ghana [A16]	–	–	–	–	–	87	–	–
Morocco	–	185 [d] (185–259)	–	–	–	–	–	296 [d] (37–740)
Sudan	–	–	–	–	–	740	–	–
Average	–	–	–	–	–	454	–	–

Table 41 (continued)

Country / area	Average activity administered (MBq) (range in parentheses)							
	Lung perfusion		Lung ventilation			Liver/spleen		
	^{99m}Tc MAA	Other	^{99m}Tc DTPA	^{99m}Tc aerosol	Other	^{99m}Tc colloid	^{99m}Tc IDA	Other
Health-care level IV								
Ethiopia	111	–	–	–	–	111 (111–185)	–	–
United Rep. of Tanzania	–	1 180 [d] (±5%)	–	–	–	–	–	–
Average	111	–	–	–	–	111	–	–

PART C

Country / area	Average activity administered (MBq) (range in parentheses)									
	Thyroid scan			Thyroid uptake			Renal scan			
	^{99m}Tc pertechnetate	^{131}I iodide	Other	^{99m}Tc pertechnetate	^{131}I iodide	^{123}I iodide	^{99m}Tc DMSA	^{99m}Tc DTPA	^{99m}Tc MAG3	Other
Health-care level I										
Argentina	248 (±107)	3 (±1)	–	7 (±3)	2 (±1)	–	–	–	–	215[d] (±122); 6[n] (±2)
Belarus	111 (101-121)	–	–	–	0.4 (0.35-0.45)	–				185 [d] (174–196)
Bulgaria	(37–74)	–	(1–10) [m]	–	–	–	60 (40–80)	185 (85–285)	185 (85–285)	–
Canada	–	–	185 [d] (±10%)	–	–	–	–	400 (±15%)	–	–
China (Taiwan) [L6]	80	–	–	–	0.8	20	150	150	–	–
Croatia	148 (111-222)	148 (74–185)	–	–	17	–	74 (37–111)	74 (37–111)	–	–
Cyprus	–	75	150 [d]	–	75	–	75	220	–	–
Czech Republic	130 (70–180)	8 (8–12)	–	–	0.62 (0.4–1)	–	188 (80–250)	250 (110–360)	–	–
Denmark	150 (37–370)	–	–	–	86 (0.3-3 700)	–	–	165 (20–350)	92 (3–210)	–
Ecuador	–	3.7 (±10%)	–	–	3.7 (±10%)	–	–	370 (±10%)	370 (±10%)	–
Finland	130	–	12 [f]	–	3	6	–	–	–	9 [n]; 150 [d]
France [E10]	–	185	–	–	–	–	200	200 (74–740)	280	(74–740) [f]
Germany	50	–	–	50	–	–	75	–	–	25 [f]
Ireland	110 (27–130)	–	–	27 (11–72)	0.185	–	84 (26–185)	84 (26–185)	84 (26–185)	–
Italy	111 (74–185)	1.1 (0.74-1.85)	–	–	1.1 (0.74-1.85)	–	148 (111–180)	148 (111–180)	–	26 [n] (18.5–37)
Japan [J11]	–	26	200 [d]	192	23	8.8	197	377	–	49 [m]
Kuwait	185 (74–185)	–	–	–	1.5 (1.1–2.6)	–	–	370 (185–370)	370 (185–370)	–
Lithuania	–	60 (60–80)	–	–	–	–	150 (100–150)	–	–	–
Netherlands	100 (80–180)	–	20 [f]	–	0.2	20	–	(40–350)	80	–
New Zealand [L28]	168 (23-740)	113 (21–200)	–	–	5.5 (2–20)	–	65 (12–155)	314 (22–617)	228 (130–444)	3.3 [o] (1–5)
Panama	463 (332-594)	–	–	–	1.85	–	56 (30–82)	463 (432–594)	185 (107–263)	–
Portugal [E10]	–	–	–	–	–	–	111	111	111	111 [f]
Romania	90 (34–146)	1.6 (0.6–2.6)	–	–	1.3 (0.6–2)	–	–	300 (100–500)	–	1.5 [n] (0.7–2.3)

Table 41 (continued)

Country / area	*Average activity administered (MBq) (range in parentheses)*									
	Thyroid scan			*Thyroid uptake*			*Renal scan*			
	^{99m}Tc pertechnetate	*^{131}I iodide*	*Other*	*^{99m}Tc pertechnetate*	*^{131}I iodide*	*^{123}I iodide*	*^{99m}Tc DMSA*	*^{99m}Tc DTPA*	*^{99m}Tc MAG3*	*Other*
Slovakia	70 (40–110)	1.8 (0.18–1.8)	–	74	(0.18–1.8)	–	185 (80–370)	185 (80–370)	–	18.5 [n]
Slovenia	74 (37–74)	5 (3.7–7.4)	–	75 (50–100)	2 (1.5–3.7)	–	80	185	100	–
Spain [E10]	–	1.1	–	–	–	–	–	–	–	–
Sweden	120 (10–220)	2 (0.1–80)	–	–	2 (0.2–6)	–	40 (10–200)	–	85 (67–175)	–
Switzerland	90 (30–200)	2 (1–7)	13 [f] (5–20)	–	–	–	60 (20–130)	360 (10–800)	110 (100–150)	20 [f] (5–40)
United Arab Emirates	185 (148-260)	–	–	185 (148–260)	–	–	148 (140–185)	148 (140–185)	–	–
United Kingdom [A20]	80	20	–	40	0.2	2	80	300	100	3 [o]
Average	65	17	–	–	3.1	–	140	236	127	–
Health-care level II										
Jordan	–	–	–	–	3.7	–	140	740	–	–
Mexico	130 (74–185)	5.6 (3.8–7.4)	–	–	5.6 (3.8–7.4)	–	–	170 (80–259)	170 (80–259)	–
Peru	185 (150-200)	185 (150–200)	–	–	1 (0.5–1.2)	–	370 (300 min)	740 (700–800)	–	–
Turkey	134 (99–169)	–	–	–	–	–	161 (118–204)	321 (167–475)	–	–
Average	136	185	–	–	4.4	–	370	181	170	–
Health-care level III										
Ghana [A16]	97	–	–	–	–	–	–	99	–	–
Morocco	130 (93–167)	–	–	–	–	–	–	–	–	111 [d] (74–222)
Sudan	560	–	–	–	–	–	740	1800	–	–
Average	173	–	–	–	–	–	–	–	–	–
Health-care level IV										
Ethiopia	–	1.7 (1.3–2)	–	–	1.7 (1.3–2)	–	74	–	–	–
United Rep. of Tanzania	–	–	–	200	–	–	–	200	–	–
Average	–	1.7	–	–	1.7	–	74	200	–	–

a No further information available.
b Pertechnetate.
c Red blood cells.
d ^{99m}Tc.
e ^{133}Xe.
f ^{123}I.
g ^{11}C metiomin.
h ^{99m}Tc ECD.
i ^{67}Ga.
j ^{81m}Kr.
k ^{127}Xe.
l ^{128}Au colloid.
m ^{131}I, ^{125}I, ^{123}I.
n ^{131}I.
o ^{51}Cr EDTA.

Table 41 (continued)

The entries in this Table are qualified as follows:

Argentina: On the basis of data from a sample of 25% of nuclear medicine centres. Bone scans also performed using ^{67}Ga (204 ± 41 MBq).
Canada: Data from London Health Sciences Centre, SW Ontario (representing 50% of the services provided to population of about 1 million).
Cyprus Survey data relating to 90% of population.
Ghana: Data for thyroid scan refer to all thyroid studies.
Jordan: Survey data from one hospital.
Lithuania: Data from Vilnius Oncology Centre.
Morocco: Bone scans also performed using ^{131}I (mean 111 MBq; range 92.5–111 MBq).
Peru: Survey data from IPEN (Centre of Nuclear Medicine, serving population of about 5 million).
Portugal: Data from one large department and some additional data.
Romania: Survey data relating to population base of about 4.5 million. Alternative technique employed for bone scans using ^{99m}Tc phosphates: mean 110 MBq, range 60–160 MBq.
Slovakia: Survey data relating to population base of about 2 million.
Switzerland: Lung ventilation studies also performed using ^{127}Xe (mean 220 MBq; range 100–370 MBq).
Turkey: Survey data from Gülhane Military Hospital, Hacettepe University Hospital and Samsun Ondokuz Mayis University Hospital.
United Arab Emirates: Thyroid uptake done simultaneously with thyroid scan using a single dose.
United Kingdom: Data represent recommended maximum usual activities (diagnostic reference levels).

Table 42
Typical effective doses to patients from common types of diagnostic nuclear medicine procedures

Country	*Effective dose per procedure (mSv)*								
	Bone [a]	*Cardiovascular*	*Lung perfusion* [b]	*Lung ventilation*	*Thyroid scan*	*Thyroid uptake*	*Renal* [c]	*Liver / spleen* [c]	*Brain* [c]
Health-care level I									
Canada [A15]	4.3	4.9 (^{99m}Tc) 11.8 (^{201}Tl)	1.5	1.0 (^{99m}Tc)	1.7 (^{123}I)	–	0.5 (DTPA) 1.6 (MAG3) 1.3 (DMSA)	1.7 (S colloid)	6.9 (HMPAO)
China, Taiwan Province [L6]	3.3	3.2 (^{99m}Tc) 13.3 (^{201}Tl)	1.4	–	1.1 (^{99m}Tc)	14.4 (^{131}I)	0.84	1.2 (colloid) 2.1 (HIDA)	2.4
Germany [K12]	3.5	4.6 (^{99m}Tc) 17 (^{201}Tl)	1.1	–	0.6 (^{99m}Tc)	–	0.3 (^{123}I) 0.7 (DMSA)	2.3 (HIDA)	6.6 (HMPAO)
Romania [I36]	3.4	–	1.4	–	1.1 (^{99m}Tc) 38.4 (^{131}I)	31.2 (^{131}I)	0.1 (^{131}I) 1.6 (DTPA)	9.9 (^{198}Au) 1.4 (colloid)	2.0
New Zealand [L28]	4.3	3.9 (^{99m}Tc RBC) 7.6 (^{99m}Tc MIBI)	1.6	0.4 (DTPA)	2.0 (^{99m}Tc)	–	2.0 (DTPA) 0.6 (DMSA)	1.8 (Sn colloid)	4.8 (DTPA)

Table 42 (continued)

Country	*Effective dose per procedure (mSv)*								
	Bone [a]	*Cardiovascular*	*Lung perfusion* [b]	*Lung ventilation*	*Thyroid scan*	*Thyroid uptake*	*Renal* [c]	*Liver / spleen* [c]	*Brain* [c]
Slovakia [F8]	6.5	7.4 (^{99m}Tc RBC) 20.3 (^{201}Tl)	1.8	–	8.9	4.4	0.5	2.1	8.8
Sweden [M87]	3.5	10 (^{99m}Tc MIBI) 20 (^{201}Tl)	1.1	0.2 (^{99m}Tc)	2.4 (^{99m}Tc)	72 [d] (3 MBq ^{131}I) 6 [d] (0.5 MBq ^{131}I)	0.7 (MAG3) 0.008 (^{51}Cr EDTA)	–	8.4 (HMPAO)
United Kingdom [A20]	3 (5 [e])	8 (^{99m}Tc) 18 (^{201}Tl)	1 (2 [e])	0.2 (^{81m}Kr) 0.4 (^{99m}Tc) 0.4 (^{133}Xe)	1 (^{99m}Tc)	6 (^{131}I) 0.4 (^{123}I) 0.5 (^{99m}Tc)	2 (DTPA) 0.7 (DMSA) 0.7 (MAG3) 0.2 (^{123}I)	0.8 (2 [e]) (colloid)	5
United States [I23]	4.4	10.4 (^{201}Tl)	–	–	2 (^{99m}Tc) 59 (^{131}I) 0.2 (^{123}I)	–	4.8 (DTPA) 0.5 (^{131}I)	–	–
Health-care level II									
Iran (Islam. Rep. of) [M10]	6.5	2.9 (^{99m}Tc) 6.9 (^{201}Tl)	2.5	–	1.4 (^{99m}Tc) 25 (^{131}I) [f]	14.6 (^{131}I)	3.3 (DTPA) 10 (DMSA)	1.9 (S colloid) 0.6 (^{113m}In)	12.4 (TcO_4) 5.9 (DTPA)
Health-care level III									
Ghana [A16]	2.85	–	–	–	1 (^{99m}Tc)	–	0.4	0.62	5.4

a ^{99m}Tc phosphonates.
b ^{99m}Tc MAA.
c ^{99m}Tc.
d 35% uptake.
e SPECT.
f Uptake and scan.

Table 43
Typical effective doses to patients from diagnostic PET imaging
[A20]

Radionuclide	*Chemical form*	*Investigation*	*Administered activity (MBq)*	*Effective dose (mSv)*	*Dose to uterus (mGy)*
^{11}C	L-methyl-methionine	Brain tumour imaging	400	2	1
^{11}C	L-methyl-methionine	Parathyroid imaging	400	2	1
^{13}N	Ammonia	Myocardial blood flow imaging	550	2	1
^{15}O	Water (bolus)	Cerebral blood flow imaging	2 000	2	1
^{15}O	Water (bolus)	Myocardial blood flow imaging	2 000	2	1
^{18}F	FDG	Tumour imaging	400	10	7
^{18}F	FDG	Myocardial imaging	400	10	7
^{18}F	Fluoride	Bone imaging	250	7	5

Table 44
Typical effective doses to paediatric patients from diagnostic nuclear medicine procedures
[G47]

Radiopharmaceutical	*Activity for adult patient (MBq)*	*Effective dose per procedure by patient age [a] (mSv)*				
		Adult 70 kg [1.0]	*15 years-old 55 kg [0.9]*	*10 years-old 33 kg [0.69]*	*5 years-old 18 kg [0.44]*	*1 year-old 10 kg [0.27]*
^{99m}Tc-MAG3 (normal renal function)	100	0.7	0.8	0.7	0.6	0.6
^{99m}Tc-MAG3 (abnormal renal function)	100	0.6	0.7	0.7	0.5	0.5
^{99m}Tc-DTPA (normal renal function)	300	1.6	1.8	2.1	1.8	2.2
^{99m}Tc-DTPA (abnormal renal function)	300	1.4	1.6	1.9	1.8	2.0
^{99m}Tc-DMSA (normal renal function)	80	0.7	0.7	0.8	0.8	0.8
^{99m}Tc-pertechnetate (no thryoid block)	80	1.0	1.2	1.3	1.4	1.4
^{99m}Tc-IDA (normal biliary function)	150	2.3	2.4	2.9	3.0	3.7
^{99m}Tc-HMPAO	500	4.7	5.0	5.9	5.7	6.5
^{99m}Tc-leukocytes	200	2.2	2.7	3.0	2.9	3.4
^{99m}Tc-erythrocytes	800	5.3	6.0	6.6	6.7	7.6
^{99m}Tc-phosphates	600	3.6	3.7	4.1	4.2	4.9
^{99m}Tc-MIBI (resting)	400	3.3	4.0	4.4	4.8	5.4
^{201}Tl-chloride	80	20	30	129	95	86
^{123}I-iodide (55% thyroid uptake)	20	7.2	10.2	12.1	16.3	18.8
^{123}I-iodide (total thyroid block)	20	0.2	0.3	0.3	0.3	0.3
^{123}I-MIBG (no impurity)	400	5.6	6.5	9.1	8.8	10.1
^{67}Ga-citrate	150	15	18.9	22.8	23.1	27.9

a Figures in brackets are scaling factors for activity based on body weights shown. Doses calculated using age-specific coefficients from [I19].

Table 45
Some reported annual individual and collective effective doses from diagnostic nuclear medicine procedures [a]
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country /area	*Effective dose (mSv)*		*Collective effective dose (man Sv)*	*Ref.*
	Per examination	*Per caput*		
Health-care level I				
Australia	5.3	0.064	1 110	[C7]
Canada	4	0.16	4 500	[A15]
China, Taiwan Province	4.4	0.029	600	[L6]
Finland	4.0	0.04	207	[K59]
Germany	3	0.1	5 000 [b]	[K12]
Netherlands	4.2	0.067	1 000	-
New Zealand	3.1	0.026	90	[L28]
Romania	16.2	0.049	1 124	[I36]
Russian Federation	5.4	0.075	10 000	-
Slovakia	4.0	0.022	111	[F8]
Switzerland	4.2	0.04	300	[R18]
Ukraine	1.2	0.006	320	[K18]
United Kingdom	4.2	0.036	2 000	[E11]
United States	4.4	0.14	35 400	[I23]
Health-care level II				
Iran (Islam. Rep. of)	4.3	0.008	450	[M10]
Health-care level III				
Ghana	3	0.0002	3	[A16]

a Since, as discussed in Section I.C, many of these exposures are received by patients nearing the end of their lives and the doses are not distributed evenly amongst the population, these doses should not be used for the assessment of detriment.
b Collective dose data refer only to states of former Federal Republic of Germany.

Table 46
Frequencies, effective doses and collective doses [a] assumed in global model for diagnostic practice with radiopharmaceuticals [b] (1991-1996)

Procedure	*Number of procedures per 1,000 population*					*Effective dose per procedure (mSv)*					*Annual collective dose (man Sv)*				
	Level I	*Level II*	*Level III*	*Level IV*	*World*	*Level I*	*Level II*	*Level III*	*Level IV*	*World*	*Level I*	*Level II*	*Level III*	*Level III*	*World*
Bone	4.5	0.24	0.053	0.001	1.3	4.5	4.5	4	4	4.5	31 000	3 300	140	3	35 000
Cardiovascular	2.7	0.17	0.018	0.00002	0.80	8	8	12	12	8	33 000	4 150	140	0.1	37 000
Lung perfusion	1.8	0.023	0.007	0.0001	0.49	1.5	2	2	2	1.5	4 150	140	9	0.1	4 300
Lung ventilation	0.34	0.011	0.0003	0.00002	0.095	1	1	1	1	1	520	35	0.2	0.01	600
Thyroid scan	4.1	0.30	0.16	0.003	1.3	2	10	30	30	3.4	12 500	9 300	3 200	55	25 000
Thyroid uptake	0.92	0.038	-	0.007	0.26	15	20	30	30	15	21 000	2 400	-	120	24 000
Renal	0.89	0.16	0.020	0.002	0.32	1.5	3	3	3	1.9	2 000	1 500	40	4	3 500
Liver / spleen	2.1	0.090	0.005	0.0002	0.59	1.7	2	2	2	1.7	5 300	600	6	0.2	5 900
Brain	1.3	0.050	0.010	0.003	0.37	6	6	6	6	6	12 000	900	40	9	13 000
Total	19	1.1	0.28	0.02	5.6	-	-	-	-	-	123 000	23 000	3 500	200	150 000
Average effective dose per diagnostic nuclear medicine procedure (mSv)						4.3	6.7	20	20	4.6					
Average effective dose per caput from diagnostic nuclear medicine procedures (mSv)											0.081	0.008	0.006	0.0003	0.026

a Since, as discussed in Section I.C, many of these exposures are received by patients nearing the end of their lives and the doses are not distributed evenly amongst the population, these doses should not be used for the assessment of detriment.

b Rounded estimates based on frequency data and typical (or assumed) doses from the UNSCEAR Survey of Medical Radiation Usage and Exposures.

Table 47
Contributions to frequency and collective dose from the various types of diagnostic nuclear medicine procedures assumed for global model (1991-1996)

Procedure	*Contribution (%)*				
	Level I	*Level II*	*Level III*	*Level IV*	*World*
Contribution to total annual frequency					
Bone	24	21	19	8	24
Cardiovascular	14	15	6	0.1	14
Lung perfusion	10	2	2	0.4	9
Lung ventilation	2	1	0.1	0.1	2
Thyroid scan	22	27	59	19	22
Thyroid uptake	5	3	-	42	5
Renal	5	14	7	13	6
Liver / spleen	11	8	2	1	11
Brain	7	4	4	16	7
All	100	100	100	100	100
Contribution to total annual collective dose					
Bone	25	14	4	2	23
Cardiovascular	27	18	4	0.1	25
Lung perfusion	3	0.6	0.3	<0.1	3
Lung ventilation	0.4	0.1	<0.1	<0.1	0.4
Thyroid scan	10	40	89	28	17
Thyroid uptake	17	10	-	62	16
Renal	2	6	1	2	2
Liver / spleen	4	2	0.2	0.1	4
Brain	10	4	1	5	8
All	100	100	100	100	100

Table 48
Temporal trends in annual frequency of diagnostic nuclear medicine procedures per 1,000 population
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures

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

Table 48, continued

Country / area	*1970–1979*	*1980–1984*	*1985–1990*	*1991–1996*
Kuwait	–	–	13.1	12.7
Lithuania	–	–	–	10.6
Luxembourg	–	–	23.5	52.2
Netherlands	–	–	11.6	15.7
New Zealand	5.6	7.3	7.5	8.3
Norway	3.9	–	9.3	–
Panama	–	–	–	3.4
Portugal	–	–	–	4.0
Qatar	–	–	–	4.7
Romania	–	3.0	3.5	3.0
Russian Federation [d]	(9)	(11)	(15)	12.6
Slovakia [d]	–	–	(4.9)	9.4
Slovenia	–	–	–	11.2
Sweden	9.8	–	12.6	13.6
Switzerland	44.9	–	–	9.5
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
Health-care level II				
Antigua and Barbuda	–	–	–	0
Barbados	–	–	1.0	–
Brazil	–	–	1.7	1.1
China	–	–	0.6	–
Dominica	–	–	–	0
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
Tunisia	–	–	1.0	0.8
Turkey	–	–	2.5	2.1
Average	0.9	0.1	0.5	1.1
Health-care level III				
Egypt	0.07	0.21	0.48	–
Ghana	–	–	–	0.05
Jamaica [a]	(2.8)	–	(2.0)	–
Morocco	–	–	–	0.62
Myanmar	0.54	0.36	0.11	–
Sudan	0.12	0.28	0.28	0.09
Thailand	0.25	0.18	0.26	–
Average	0.25	0.25	0.30	0.28
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 49
Temporal trends in the average annual number [a] of the various types of diagnostic radionuclide procedures per 1,000 population
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures

Type of study	*Period*	*Average annual number of procedures per 1,000 population*			
		Health-care level I	*Health-care level II*	*Health-care level III*	*Health-care level IV*
Bone scan	1970–1979	0.84	0	0.001	0.001
	1980–1984	2.6	–	0.041	0.041
	1985–1990	4.8	0.016	0.084	0.084
	1991–1996	5.8	0.20	0.054	0.001
Cardiovascular	1970–1979	0.53	0	0.0007	0.0007
	1980–1984	0.58	–	0.003	0.003
	1985–1990	2.6	0.008	0.014	0.014
	1991–1996	3.6	0.15	0.023	0
Lung perfusion	1970–1979	0.34	0.024	0.0003	0.0003
	1980–1984	0.94	–	0.002	0.002
	1985–1990	2.2	0.002	0.008	0.008
	1991–1996	2.3	0.017	0.009	0.0001
Lung ventilation	1970–1979	0.13	0	0.0001	0.0001
	1980–1984	0.26	–	0.0001	0.0001
	1985–1990	1.2	0.001	0.008	0.008
	1991–1996	0.35	0.009	0	0
Thyroid scan	1970–1979	1.3	0.4	0.066	0.066
	1980–1984	2.5	–	0.048	0.048
	1985–1990	1.8	0.062	0.066	0.066
	1991–1996	4.0	0.26	0.16	0.003
Thyroid uptake	1970–1979	2.2	0.25	0.10	0.10
	1980–1984	0.17	–	0.063	0.063
	1985–1990	0.55	0.17	0.052	0.052
	1991–1996	0.80	0.03	0	0.007
Renal	1970–1979	1.8	0.041	0.006	0.006
	1980–1984	1.3	–	0.009	0.009
	1985–1990	1.4	0.096	0.023	0.023
	1991–1996	1.1	0.14	0.019	0.002
Liver / spleen	1970–1979	1.7	0.087	0.086	0.086
	1980–1984	1.2	–	0.034	0.034
	1985–1990	1.4	0.023	0.016	0.016
	1991–1996	2.6	0.078	0.004	0.0002
Brain	1970–1979	1.3	0.23	0.022	0.022
	1980–1984	1.1	–	0.013	0.013
	1985–1990	0.42	0.006	0.007	0.007
	1991–1996	1.6	0.04	0.010	0.003
Total of all diagnostic radionuclide procedures	1970–1979	10.9	0.86	0.25	0.25
	1980–1984	6.9	0.10	0.19	0.19
	1985–1990	16.2	0.54	0.25	0.25
	1991–1996	18.8	1.13	0.28	0.02

a Overall averages calculated from national data as the total number of procedures divided by the total population for each type of procedure. Data for 1991–1996 from Table 38; since the total population is not the same for each type of procedure due to the lack of comprehensive national data for all countries included in the analysis, these average numbers can not be expected to be additive.

Table 50
Estimated doses to the world population from diagnostic nuclear medicine procedures [a] 1991–1996

Health-care level	*Population (millions)*	*Annual per caput effective dose (mSv)*	*Annual collective effective dose (man Sv)*
I	1 530	0.08	123 000
II	3 070	0.008	23 000
III	640	0.006	3 500
IV	565	0.0003	200
World	5 800	0.03	150 000

a Since, as discussed in Section I.C, many of these exposures are received by patients nearing the end of their lives and the doses are not distributed evenly amongst the population, these doses should not be used for the assessment of detriment.

Table 51
Annual numbers of teletherapy treatments [a] per 1,000 population by disease category (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	*Leukaemia*	*Lymphoma*	*Breast tumour*	*Lung/ thorax tumour*	*Gynae-cological tumour*	*Head/neck tumour*	*Brain tumour*	*Skin tumour*	*Bladder tumour*	*Prostate tumour*	*Tumour of rectum*	*Benign disease*	*Total of all teletherapy treatments*
Health-care level I													
Australia	0.051	0.058	0.320	0.281	0.099	0.153	0.045	0.123	0.039	0.154	0.069	0.050	1.838
Belarus	0.001	0.027	0.078	0.082	0.073	0.056	0.011	0.033	0.017	0.006	0.019	-	0.454
Bulgaria	0.004	0.005	0.061	0.007	0.033	0.024	0.004	0.003	0.001	-	0.003	0.030	0.185
Canada	0.008	0.158	0.351	0.442	0.101	0.082	0.036	0.045	0.029	0.120	0.051	0.036	1.693
Cayman Islands	0	0	0	0	0	0	0	0	0	0	0	0	0
Croatia	0.001	0.063	0.789	0.182	0.194	0.273	0.059	0.131	0.017	0.012	0.060	0.004	1.981
Cuba [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	2.036
Cyprus	0.003	0.018	0.256	0.077	0.028	0.015	0.031	0.184	0.015	0.034	0.031	0.006	0.929
Czech Republic	0.008	0.029	0.197	0.141	0.166	0.057	0.029	0.044	0.021	0.027	0.081	2.68	3.493
Denmark	0.029	0.098	0.275	0.069	0.157	0.275	0.098	0.059	0.078	0	0.049	-	1.539
Ecuador	0.004	0.007	0.015	0.003	0.040	0.010	0.007	0.003	0.002	0.003	0.005	0.0006	0.104
France [S50]	-	-	-	-	-	-	-	-	-	-	-	-	1.734
Hungary	-	-	-	-	-	-	-	0.431	-	-	-	1.214	3.655
Ireland	0.005	0.070	0.267	0.180	0.095	0.127	0.044	0.070	0.019	0.050	0.065	-	1.619
Japan [c]	-	0.050	0.083	0.178	0.059	0.065	0.028	-	0.015	0.019	0.099	-	0.762
Kuwait	0.018	0.015	0.063	0.022	0.016	0.033	0.010	0.0006	0.007	0.009	0.007	0	0.228
Luxembourg	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	-	0.053	0.553	0.447	0.122	0.103	0.024	0.083	0.225	-	0.073	0.021	2.2 [c]
New Zealand	0.017	0.092	0.395	0.231	0.077	0.064	0.040	0.220	0.035	0.259	0.103	0.025	1.715
Panama	0.006	0.005	0.058	0.031	0.077	0.059	0.022	0.003	0.003	0.023	0.008	0.001	0.295
Qatar	0	0	0	0	0	0	0	0	0	0	0	0	0
Romania	0.0009	0.006	0.106	0.053	0.114	0.061	0.012	0.060	0.004	0.003	0.012	0.002	0.461
Russian Federation	-	-	-	-	-	-	-	-	-	-	-	-	0.970
Slovakia	0.001	0.013	0.145	0.096	0.160	0.080	0.024	0.039	0.012	0.009	0.045	0.0008	0.764
Slovenia	0.011	0.081	0.232	0.341	0.188	0.242	0.030	0.120	0.026	0.034	0.061	0.017	2.437
Sweden	-	0.093	0.391	0.151	0.142	0.073	0.049	0.038	0.044	0.214	0.071	0.039	1.305
United Arab Emirates	0.007	0.011	0.046	0.021	0.016	0.027	0.011	0.004	0.010	0.008	0.006	0.003	0.231
United Kingdom	-	-	-	-	-	-	-	-	-	-	-	-	2.320
United States [I23]	0.001	0.069	0.494	0.548	0.135	0.033	0.056	0.013	0.046	0.282	0.074	0.017	1.981
Uruguay [d] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	1.509
Venezuela [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	1.603
Average	0.005	0.060	0.401	0.355	0.113	0.054	0.046	0.047	0.039	0.206	0.069	0.088	1.50

Table 51 (continued)

Country / area	*Leukaemia*	*Lymphoma*	*Breast tumour*	*Lung/ thorax tumour*	*Gynae-cological tumour*	*Head/neck tumour*	*Brain tumour*	*Skin tumour*	*Bladder tumour*	*Prostate tumour*	*Tumour of rectum*	*Benign disease*	*Total of all teletherapy treatments*
Health-care level II													
Antigua and Barbuda [B43]	-	-	-	-	-	-	-	-	-	-	-	-	0
Bahamas [B43]	-	-	-	-	-	-	-	-	-	-	-	-	0
Barbados [d] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	3.132
Belize [B43]	-	-	-	-	-	-	-	-	-	-	-	-	0
Bolivia [d] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	0.829
Brazil	-	-	-	-	-	-	-	-	-	-	-	-	1.333
Chile [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	2.144
Colombia [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	1.583
Dominica [B43]	-	-	-	-	-	-	-	-	-	-	-	-	0
Dominican Republic [b]	-	-	-	-	-	-	-	-	-	-	-	-	1.900
El Salvador [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	2.025
Grenada [B43]	-	-	-	-	-	-	-	-	-	-	-	-	0
Honduras [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	2.002
Jordan	0.018	0.026	0.052	0.024	0.013	0.023	0.022	0.004	0.009	0.006	0.009	0.005	0.268
Libyan Arab Jamahiriya	0.002	0.006	0.009	0.014	0.005	0.015	0.012	0.005	0.007	0.002	0.003	-	0.079
Mexico	0.005	0.005	0.025	0.007	0.029	0.016	0.006	0.003	0.001	0.004	0.002	0.002	0.111
Nicaragua [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	2.196
Oman	0	0	0	0	0	0	0	0	0	0	0	0	0
Pakistan	0.003	0.004	0.007	0.004	0.005	0.010	0.002	0.003	0.002	0.002	0.002	0.0006	0.053
Paraguay [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	2.126
Peru	0.002	0.007	0.013	0.006	0.068	0.013	0.006	0.002	0.001	0.004	0.002	-	0.139
Puerto Rico [b]	-	-	-	-	-	-	-	-	-	-	-	-	1.450
Saint Kitts and Nevis [B43]	-	-	-	-	-	-	-	-	-	-	-	-	0
Saint Lucia [B43]	-	-	-	-	-	-	-	-	-	-	-	-	0
Saint Vincent and the Grenadines [B43]	-	-	-	-	-	-	-	-	-	-	-	-	0
Trinidad and Tobago [d] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	1.516
Tunisia	-	-	-	-	-	-	-	-	-	-	-	-	0.133
Turkey	0.022	0.024	0.066	0.056	0.029	0.044	0.039	0.006	0.010	0.006	0.011	0.002	0.385
Average	0.007	0.009	0.025	0.015	0.021	0.019	0.011	0.004	0.003	0.004	0.004	0.001	0.694
Health-care level III													
Afghanistan	-	-	-	-	-	-	-	-	-	-	-	-	0
Guatemala [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	2.059
Haiti [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	1.848
Jamaica [b] [B43]	-	-	-	-	-	-	-	-	-	-	-	-	2.059
Madagascar	0.0001	0.004	0.022	0.003	0.017	0.008	0.0001	0.002	0.0004	0.0008	0.002	0.002	0.065
Morocco	0.0009	-	-	-	-	-	-	-	-	-	-	-	0.360
Sudan	0.005	0.003	0.010	-	0.005	0.002	0.0006	0.001	0.002	-	0.0008	-	0.045
Average	0.002	0.003	0.014	0.003	0.009	0.004	0.0004	0.001	0.001	0.0008	0.001	0.002	0.465

Table 51 (continued)

Country / area	*Leukaemia*	*Lymphoma*	*Breast tumour*	*Lung/ thorax tumour*	*Gynae-cological tumour*	*Head/neck tumour*	*Brain tumour*	*Skin tumour*	*Bladder tumour*	*Prostate tumour*	*Tumour of rectum*	*Benign disease*	*Total of all teletherapy treatments*
Health-care level IV													
United Rep. of Tanzania	0.0004	0.003	0.003	0.004	0.020	0.001	0	0.003	0.0004	0.0005	0	0.002	0.050
Average	0.0004	0.003	0.003	0.004	0.020	0.001	0	0.003	0.0004	0.0005	0	0.002	0.050

a Complete courses of treatment.
b Data referring to number of new patients with cancer.
c These revised data were received by the Committee after completion of the global analysis.
d Data referring to estimated number of new patients with cancer.

The entries in this Table are qualified as follows:

Australia: Survey data from only 8 of 31 radiotherapy treatment centres (representing about 42% of national practice).
Brazil: Survey data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil).
Canada: On the basis of data from the Nova Scotia Cancer Treatment and Research Foundation, the Cross Cancer Institute (Northern Alberta), and the province of Manitoba (collectively representing about 14% of the population).
Croatia: Data from one large centre serving about one-fifth of population.
France: Data represent annual number of patients undergoing radiotherapy [S50].
Peru: Survey data from INEN (Cancer Institute, Lima, serving population of about 7 million).
New Zealand: Data from 50% of radiotherapy centres (serving about two-thirds of population).
United Rep. of Tanzania: 98% of the total shown for 'Lung/thorax tumour' are treatments of the oesophagus.
Turkey: On the basis of data from Hacettepe University Hospital.
United States: Value shown for 'Benign' includes the general category of 'Others/Unspecified' [I23].

Table 52
Annual numbers of brachytherapy treatments [a] per 1,000 population by disease category (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	*Head/neck tumour*	*Breast tumour*	*Gynaecological tumour*	*Prostate tumour*	*Total of all brachytherapy treatments*
Health-care level I					
Australia	0.001	0.002	0.055	0	0.064
Belarus	0.021	0.003	0.059	0.001	0.096
Bulgaria	-	-	-	-	0.556
Canada	0.001	0	0.055	0.009	0.070
Cayman Islands	0	0	0	0	0
Croatia	0	0	0.074	0	0.074
Cyprus	0	0	0.018	0	0.018
Czech Republic	0.002	0.010	0.247	0.0005	0.273
Denmark	-	-	0.009	-	-
Ecuador	0	0	0.010	0	0.010
Hungary	-	-	-	-	0.311
Ireland	0.004	0.0008	0.082	-	0.094
Kuwait	0	0	0.015	0	0.015
Luxembourg	0	0	0	0	0
Netherlands	0.008	0.062	0.027	0.003	0.15 [b]
New Zealand	0.005	0.002	0.035	0	0.047
Panama	0.001	0	0.051	0	0.053
Qatar	0	0	0	0	0
Romania	0.002	0.004	0.143	0.0007	0.162
Russian Federation	-	-	-	-	0.440
Slovakia	0.010	0.054	0.154	0.0004	0.258
Slovenia	0.044	0	0.088	0.001	0.140
Sweden	-	-	0.110	-	0.110
United Arab Emirates	0.002	0	0.007	0	0.009
United States [I23]	-	-	-	-	0.115
Uruguay	-	-	-	-	0
Average	0.005	0.011	0.078	0.002	0.20
Health-care level II					
Antigua and Barbuda [B43]	-	-	-	-	0
Bahamas [B43]	-	-	-	-	0
Belize [B43]	-	-	-	-	0
Dominica [B43]	-	-	-	-	0
Grenada [B43]	-	-	-	-	0
Mexico	0.002	0.004	0.0001	0	0.021
Oman	0	0	0	0	0
Pakistan	0	0	0.001	0	0.001
Paraguay	-	-	-	-	0
Peru	0	0	0.036	0	0.036
Saint Kitts and Nevis [B43]	-	-	-	-	0
Saint Lucia [B43]	-	-	-	-	0
Saint Vincent and the Grenadines [B43]	-	-	-	-	0
Tunisia	0.003	0	0.014	0	0.022
Turkey	0.003	0.002	0.028	-	0.037
Average	0.0008	0.0005	0.009	0	0.017
Health-care level III					
Jamaica [B43]	-	-	-	-	0
Morocco	-	-	0.030	-	0.030
Sudan	0	0	0.0009	0	0.0009
Average	0	0	0.016	0	0.015

a Complete courses of treatment.
b These revised data were received by the Committee after completion of the global analysis.

The entries in this Table are qualified as follows:

Australia: Survey data from only 8 of 31 radiotherapy treatment centres (representing about 42% of national practice).
Canada: On the basis of data from the Nova Scotia Cancer Treatment and Research Foundation, the Cross Cancer Institute (Northern Alberta), and the province of Manitoba (collectively representing about 14% of the population).
Croatia: Data from one large centre serving about one-fifth of population.
New Zealand: Data from 50% of radiotherapy centres (serving about two-thirds of population).
Peru: Survey data from INEN (Cancer Institute, Lima, serving population of about 7 million).
Turkey: On the basis of data from Hacettepe University Hospital.

Table 53
Percentage contributions by disease category to annual total numbers of teletherapy treatments [a] (1991-1996)
Based on data and qualifications from Table 51

Country	*Leukaemia*	*Lymphoma*	*Breast tumour*	*Lung/ thorax tumour*	*Gynae-cological tumour*	*Head/neck tumour*	*Brain tumour*	*Skin tumour*	*Bladder tumour*	*Prostate tumour*	*Tumour of rectum*	*Benign disease*	*Total of all teletherapy treatments*
Health-care level I													
Australia	2.8	3.2	17	15	5.4	8.3	2.5	6.7	2.2	8.4	3.7	2.8	100
Belarus	0.2	5.9	17	18	16	12	2.4	7.2	3.8	1.4	4.1	-	100
Bulgaria	2.2	2.7	33	3.6	18	13	1.9	1.9	0.6	-	1.6	16	100
Canada	0.5	9.3	21	26	6.0	4.8	2.2	2.7	1.7	7.1	3.0	2.1	100
Croatia	0.1	3.2	40	9.2	9.8	14	3.0	6.6	0.9	0.6	3.0	0.2	100
Cyprus	0.3	2.0	28	8.3	3.0	1.7	3.3	20	1.7	3.6	3.3	0.7	100
Czech Republic	0.2	0.8	5.6	4.0	4.8	1.6	0.8	1.3	0.6	0.8	2.3	77	100
Denmark	1.9	6.4	18	4.5	10	18	6.4	3.8	5.1	0	3.2	-	100
Ecuador	3.4	6.7	14	2.7	38	9.2	6.7	3.3	1.9	2.5	4.4	0.6	100
Hungary	-	-	-	-	-	-	-	12	-	-	-	33	100
Ireland	0.3	4.3	17	11	5.8	7.9	2.7	4.3	1.2	3.1	4.0	-	100
Japan	-	6.7	-	24	12	8.1	-	10	3.6	-	13	0.3	100
Kuwait	8.0	6.7	27	9.6	7.0	14	4.4	0.3	2.9	4.2	3.1	0	100
Netherlands	-	2.9	30	24	6.6	5.6	1.3	4.5	12	-	4.0	1.1	100
New Zealand	1.0	5.4	23	13	4.5	3.7	2.3	13	2.0	15	6.0	1.4	100
Panama	1.9	1.5	19	11	26	20	7.3	0.9	1.0	7.9	2.7	0.5	100
Romania	0.2	1.2	23	11	25	13	2.6	13	0.8	0.6	2.6	0.3	100

Table 53 (continued)

Country	*Leukaemia*	*Lymphoma*	*Breast tumour*	*Lung/ thorax tumour*	*Gynae-cological tumour*	*Head/neck tumour*	*Brain tumour*	*Skin tumour*	*Bladder tumour*	*Prostate tumour*	*Tumour of rectum*	*Benign disease*	*Total of all teletherapy treatments*
Slovakia	0.2	1.7	19	13	21	11	3.1	5.1	1.6	1.2	5.9	0.1	100
Slovenia	0.4	3.3	9.5	14	7.7	9.9	1.2	4.9	1.1	1.4	2.5	0.7	100
Sweden	-	7.1	30	12	11	5.6	3.8	2.9	3.3	16	5.4	3	100
United Arab Emirates	2.9	4.5	20	8.9	7.1	12	4.7	1.8	4.4	3.3	2.7	1.3	100
United States [I23]	0.1	3.5	25	28	6.8	1.7	2.8	0.7	2.3	14	3.7	0.9	100
Average [b]	0.3	4.1	23	24	7.7	3.7	2.7	3.1	2.7	12	4.7	5.8	100
Health-care level II													
Jordan	6.7	9.6	19	8.9	4.7	8.4	8.2	1.3	3.2	2.2	3.5	1.8	100
Libyan Arab Jamahiriya	2.7	8.0	12	18	6.1	19	15	6.1	8.3	2.4	3.7	-	100
Mexico	4.1	4.1	22	6.3	26	15	5.6	3.0	1.3	3.9	2.2	1.5	100
Pakistan	6.2	7.5	14	7.0	8.8	18	4.0	6.3	3.5	2.7	2.7	1.2	100
Peru	1.3	5.3	9.4	4.6	48	9.2	4.6	1.1	0.7	3.1	1.6	-	100
Turkey	5.7	6.3	17	14	7.5	11	10	1.5	2.5	1.7	3.0	0.6	100
Average [b]	5.1	6.0	17	11	14	13	7.8	2.6	2.3	2.4	2.7	0.9	100
Health-care level III													
Madagascar	0.2	6.6	34	4.7	26	13	0.2	2.5	0.6	1.2	2.8	3.3	100
Morocco	0.3	-	-	-	-	-	-	-	-	-	-	-	100
Sudan	11	5.5	22	-	11	4.2	1.3	2.4	3.7	-	1.8	-	100
Average [b]	1.4	6.0	28	4.7	18	7.8	0.8	2.5	2.3	1.2	2.2	3.3	100
Health-care level IV													
United Rep. of Tanzania	0.7	6.6	5.0	8.6	41	2.9	0	5.1	0.8	1.1	0	4.7	100
Average [b]	0.7	6.6	5.0	8.6	41	2.9	0	5.1	0.8	1.1	0	4.7	100

a Complete courses of treatment.
b Overall averages for sample calculated as total number of each particular type of treatment divided by total number of all treatments.

Table 54
Percentage contributions by disease category to annual total numbers of brachytherapy treatments [a] (1991-1996)
Based on data and qualifications from Table 52

Country / area	*Head/neck tumour*	*Breast tumour*	*Gynaecological tumour*	*Prostate tumour*	*Total of all brachytherapy treatments*
Health-care level I					
Australia	2.1	3.8	86	0	100
Belarus	22	3.7	61	1.4	100
Canada	1.9	0	79	12	100
Croatia	0	0	100	0	100
Cyprus	0	0	100	0	100
Czech Republic	0.6	3.7	91	0.2	100
Ecuador	0	0	100	0	100
Ireland	4.4	0.9	88	-	100
Kuwait	0	0	100	0	100
Netherlands	7.9	59	26	2.4	100
New Zealand	11	4.7	75	0	100
Panama	2.8	0	97	0	100
Romania	1.2	2.5	88	0.4	100
Slovakia	3.9	21	59	0.2	100
Slovenia	32	0	63	0.7	100
Sweden	-	-	100	-	100
United Arab Emirates	23	0	77	0	100
Average [b]	4.3	10	78	2.2	100
Health-care level II					
Mexico	1.0	1.8	0.4	0	100
Pakistan	0	0	96	0	100
Peru	0	0	100	0	100
Tunisia	13	0	63	0	100
Turkey	8.6	4.9	75	-	100
Average [b]	4.5	2.8	52	0	100
Health-care level III					
Morocco	-	-	100	-	100
Sudan	0	0	100	-	100
Average [b]	0	0	100	-	100

a Complete courses of treatment.
b Overall averages for sample calculated as total number of each particular type of treatment divided by total number of all treatments.

Table 55
Distribution by age and sex of patients undergoing teletherapy treatment for a range of conditions (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Leukaemia						
I	Australia	22	18	60	71	29
	Belarus	0	0	100	80	20
	Bulgaria	100	0	0	68	32
	Canada	67	33	0	–	–
	Croatia	0	0	100	0	100
	Cyprus	100	0	0	50	50
	Czech Republic	96	4	0	60	40
	Ecuador	63	34	3	54	46
	Ireland	18	36	45	45	55
	Kuwait	77	23	0	58	42
	New Zealand	36	23	41	62	38
	Panama	40	47	13	67	33
	Romania	5	48	47	50	50
	Slovakia	66	17	17	83	17
	Slovenia	23	26	51	65	35
	United Arab Emirates	62	19	19	88	12
	Average	38	21	41	68	32
II	Jordan	26	38	36	69	31
	Libyan Arab Jamahiriya	73	18	9	64	36
	Mexico	65	20	15	61	39
	Pakistan	41	37	22	66	34
	Peru	55	32	13	18	82
	Turkey	53	37	10	80	20
	Average	52	34	14	72	28
III	Madagascar	100	0	0	50	50
	Morocco	80	–	–	–	–
	Sudan	80	11	9	51	49
	Average	80	11	9	51	49
IV	United Republic of Tanzania	67	11	22	70	30
Lymphoma						
I	Australia	2	21	77	50	50
	Belarus	10	67	23	50	50
	Bulgaria	48	11	41	57	43
	Croatia	3	48	49	55	45
	Cyprus	0	25	75	42	58
	Czech Republic	6	28	66	53	47
	Ecuador	6	39	55	54	46
	Ireland	1	20	78	48	52
	Japan	13	23	64	–	–
	Kuwait	19	31	50	54	46
	Netherlands	–	–	–	55	45
	New Zealand	1	31	68	58	42
	Panama	0	25	75	33	67
	Romania	20	32	48	61	39
	Slovakia	3	20	77	55	45
	Slovenia	5	55	40	57	43
	United Arab Emirates	20	48	32	68	32
	Average	10	26	64	53	47
II	Jordan	13	43	44	68	32
	Libyan Arab Jamahiriya	31	49	20	62	38
	Mexico	3	42	55	57	43
	Pakistan	16	42	42	67	33
	Peru	11	29	60	52	48
	Turkey	26	28	46	60	40

Table 55 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
II	Average	19	34	47	61	39
III	Madagascar	0	60	40	60	40
	Morocco	10	80	10	–	–
	Sudan	14	27	59	64	36
	Average	7	43	50	62	38
IV	United Rep. of Tanzania	30	50	20	62	38
Breast tumour						
I	Australia	0	14	86	0.5	99.5
	Belarus	0	16	84	1.5	98.5
	Bulgaria	0	12	88	0.5	99.5
	Canada	0	16	84	1	99
	Croatia	0	6	94	1	99
	Cyprus	–	–	–	2	98
	Czech Republic	0	5	95	0	100
	Ecuador	0	19	81	1	99
	Ireland	0	8	92	16	84
	Kuwait	0	30	70	0	100
	Netherlands	–	–	–	0.3	99.7
	New Zealand	0	23	77	1	99
	Panama	0	16	84	0	100
	Romania	0	16	84	1.5	98.5
	Slovakia	0	10	90	1	99
	Slovenia	0	10	90	1	99
	United Arab Emirates	0	19	81	9	91
	Average	0	13	87	1.2	98.8
II	Jordan	0	23	77	4	96
	Libyan Arab Jamahiriya	0	31	69	6	94
	Mexico	0	30	70	0.3	99.7
	Pakistan	0	41	59	7	93
	Peru	0	31	69	0	100
	Turkey	0	26	74	2	98
	Average	0	29	71	2	98
III	Madagascar	0	34	66	1	99
	Morocco	–	80	–	–	–
	Sudan	0	40	60	3	97
	Average	0	37	63	2	98
IV	United Rep. of Tanzania	0	2	98	3	97
Lung/thorax tumour						
I	Australia	0	6	94	72	28
	Belarus	0	4	96	94	6
	Bulgaria	0	2	98	94	6
	Canada	0	3	97	61	39
	Croatia	0	1	99	83	17
	Cyprus	0	0	100	80	20
	Czech Republic	0	1	99	87	13
	Ecuador	14	9	77	50	50
	Ireland	0	1	99	66	33
	Japan	0	5	95	–	–
	Kuwait	0	8	92	92	8
	Netherlands	–	–	–	80	20
	New Zealand	0	2	98	68	32
	Panama	0	0	100	69	31
	Romania	1	8	91	85	15
	Slovakia	0	2	98	88	12
	Slovenia	0	3	97	70	30
	United Arab Emirates	0	2	98	80	20
	Average	0	4	96	72	28

Table 55 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
II	Jordan	2	10	88	86	14
	Libyan Arab Jamahiriya	1	13	86	86	14
	Mexico	0	11	89	70	30
	Pakistan	1	28	71	65	35
	Peru	0	11	89	76	24
	Turkey	0	8	92	95	5
	Average	0	11	89	88	12
III	Madagascar	0	45	55	90	10
IV	United Rep. of Tanzania	0	0	100	76	24
Gynaecological tumour						
I	Australia	0	11	89	0	100
	Belarus	0	12	88	0	100
	Bulgaria	0	18	82	0	100
	Canada	0	17	83	0	100
	Croatia	0	15	85	0	100
	Cyprus	0	17	83	0	100
	Czech Republic	0	11	89	0	100
	Ecuador	0	18	82	0	100
	Ireland	0	10	89	1	99
	Japan	0	12	88	0	100
	Kuwait	0	37	63	0	100
	Netherlands	–	–	–	0	100
	New Zealand	1	30	69	0	100
	Panama	0	25	75	0	100
	Romania	1	27	72	0	100
	Slovakia	0	20	80	0	100
	Slovenia	0	32	68	0	100
	United Arab Emirates	0	18	82	0	100
	Average	0	15	85	0	100
II	Jordan	0	23	77	0	100
	Libyan Arab Jamahiriya	0	24	76	0	100
	Mexico	0	34	66	0	100
	Pakistan	2	48	50	0	100
	Peru	1	21	78	0	100
	Turkey	4	8	88	0	100
	Average	2	25	73	0	100
III	Madagascar	1	45	54	0	100
	Sudan	0	23	77	0	100
	Average	1	37	62	0	100
IV	United Republic of Tanzania	0	40	60	0	100
Head/neck tumour						
I	Australia	0	9	91	75	25
	Belarus	3	8	89	79	21
	Bulgaria	1	6	93	81	19
	Canada	0	11	89	66	34
	Croatia	0	4	96	87	13
	Cyprus	0	0	100	80	20
	Czech Republic	0	4	96	73	27
	Ecuador	3	10	87	43	57
	Ireland	1	4	95	67	33
	Japan	0	10	90	–	–
	Kuwait	0	35	65	56	44
	Netherlands	–	–	–	75	25
	New Zealand	0	19	81	63	37
	Panama	4	4	92	69	31
	Romania	3	15	82	79	21
	Slovakia	0	6	94	87	13

Table 55 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Slovenia	1	16	83	88	12
	United Arab Emirates	0	34	66	72	28
	Average	0	10	90	75	25
II	Jordan	10	10	80	76	24
	Libyan Arab Jamahiriya	4	17	79	74	26
	Mexico	0	18	82	96	4
	Pakistan	3	37	60	58	42
	Peru	0	27	73	48	52
	Turkey	4	20	76	76	24
	Average	3	23	74	76	24
III	Madagascar	0	35	65	91	9
	Morocco	10	–	–	–	–
	Sudan	4	17	79	66	34
	Average	1	30	69	83	17
IV	United Rep. of Tanzania	0	1	99	44	56
Brain tumour						
I	Australia	3	23	74	63	37
	Belarus	68	21	11	57	43
	Bulgaria	36	4	60	56	44
	Canada	0	8	92	58	42
	Croatia	4	14	82	50	50
	Cyprus	0	0	100	50	50
	Czech Republic	11	21	68	54	46
	Ecuador	28	34	38	51	49
	Ireland	4	2	75	63	27
	Kuwait	12	41	47	47	53
	Netherlands	–	–	–	60	40
	New Zealand	13	32	55	61	39
	Panama	19	26	55	55	45
	Romania	15	37	48	66	34
	Slovakia	7	35	58	61	39
	Slovenia	1	14	85	50	50
	United Arab Emirates	23	23	54	77	23
	Average	8	19	73	59	41
II	Jordan	28	34	38	56	44
	Libyan Arab Jamahiriya	28	25	47	66	34
	Mexico	26	28	46	53	47
	Pakistan	20	46	34	67	33
	Peru	18	33	49	63	37
	Turkey	11	39	50	58	42
	Average	15	37	48	58	42
III	Madagascar	0	50	50	50	50
	Morocco	10	80	10	–	–
	Sudan	0	33	67	67	33
	Average	0	35	65	65	35
Skin tumour						
I	Australia	0	11	89	71	29
	Belarus	0	7	93	40	60
	Bulgaria	0	0	100	75	25
	Canada	0	10	90	60	40
	Croatia	0	5	95	53	47
	Cyprus	0	0	100	50	50
	Czech Republic	0	5	95	75	25
	Ecuador	3	20	77	55	45
	Ireland	0	3	97	59	41
	Japan	2	25	73	–	–

Table 55 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Kuwait	0	0	100	100	0
	Netherlands	-	-	-	65	35
	New Zealand	0	8	92	64	36
	Panama	14	14	72	57	43
	Slovakia	0	4	96	50	50
	Slovenia	0	7	93	65	35
	United Arab Emirates	10	10	80	90	10
	Average	1	18	81	63	37
II	Jordan	6	6	88	67	33
	Libyan Arab Jamahiriya	8	20	72	50	50
	Mexico	1	12	87	52	48
	Pakistan	6	32	62	70	30
	Peru	0	18	82	53	47
	Turkey	0	18	82	69	31
	Average	3	22	75	64	36
III	Madagascar	0	40	60	60	40
	Morocco	0	100	0	–	–
	Sudan	4	29	67	–	–
	Average	2	34	64	60	40
IV	United Rep. of Tanzania	0	80	20	63	37
Bladder tumour						
I	Australia	0	8	92	67	33
	Belarus	0	3	97	74	26
	Bulgaria	0	0	100	75	25
	Canada	0	6	94	66	34
	Croatia	0	0	100	69	31
	Cyprus	0	0	100	80	20
	Czech Republic	0	1	99	53	47
	Ecuador	0	0	100	85	15
	Ireland	0	0	100	100	0
	Japan	0	13	87	–	–
	Kuwait	0	18	82	73	27
	Netherlands	–	–	–	80	20
	New Zealand	0	1	99	73	27
	Panama	0	0	100	50	50
	Romania	0	0	100	80	20
	Slovakia	0	0	100	92	8
	Slovenia	0	0	100	54	46
	United Arab Emirates	0	4	96	88	12
	Average	0	9	91	75	25
II	Jordan	0	0	100	93	7
	Libyan Arab Jamahiriya	0	6	94	88	12
	Mexico	0	12	88	64	36
	Pakistan	1	31	68	75	25
	Peru	0	9	91	70	30
	Turkey	0	2	98	91	9
	Average	0	10	90	84	16
III	Madagascar	0	50	50	60	40
	Morocco	0	100	0	–	–
	Sudan	0	7	93	70	30
	Average	0	11	89	69	31
IV	United Rep. of Tanzania	0	80	20	64	36
Prostate tumour						
I	Australia	0	12	88	100	0
	Belarus	3	0	97	100	0

Table 55 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Canada	0	0	100	100	0
	Croatia	0	0	100	100	0
	Cyprus	0	0	100	100	0
	Czech Republic	0	0	100	100	0
	Ecuador	0	0	100	100	0
	Ireland	0	0	100	100	0
	Kuwait	0	0	100	100	0
	New Zealand	0	1	99	100	0
	Panama	0	0	100	100	0
	Romania	0	12	88	100	0
	Slovakia	0	0	100	100	0
	Slovenia	0	5	95	100	0
	United Arab Emirates	0	0	100	100	0
	Average	0	4	96	100	0
II	Jordan	0	0	100	100	0
	Libyan Arab Jamahiriya	0	10	90	100	0
	Mexico	0	5	95	100	0
	Pakistan	0	19	81	100	0
	Peru	0	4	96	100	0
	Turkey	0	0	100	100	0
	Average	0	6	94	100	0
III	Madagascar	0	0	100	100	0
IV	United Rep. of Tanzania	0	1	99	100	0
Tumour of the rectum						
I	Australia	0	6	94	70	30
	Belarus	0	8	92	49	51
	Bulgaria	0	5	95	81	19
	Canada	0	11	89	47	53
	Croatia	0	10	90	42	58
	Cyprus	0	0	100	75	25
	Czech Republic	0	2	98	59	41
	Ecuador	0	13	87	44	56
	Ireland	0	2	98	73	27
	Japan	0	5	95	–	–
	Kuwait	0	25	75	67	33
	Netherlands	–	–	–	55	45
	New Zealand	0	10	90	58	42
	Panama	0	0	100	48	52
	Romania	0	7	93	59	41
	Slovakia	0	5	95	61	39
	Slovenia	0	8	92	70	30
	United Arab Emirates	0	20	80	73	27
	Average	0	6	94	57	43
II	Jordan	0	22	78	47	53
	Libyan Arab Jamahiriya	0	35	65	67	33
	Mexico	0	16	84	63	37
	Pakistan	1	36	63	71	29
	Peru	0	13	87	62	38
	Turkey	1	16	83	66	34
	Average	1	19	80	65	35
III	Madagascar	0	33	67	55	45
	Sudan	5	35	60	54	46
	Average	2	34	64	55	45
Benign disease						
I	Australia	1	23	76	43	57
	Bulgaria	2	13	85	34	66
	Croatia	0	75	25	50	50

Table 55 (continued)

Health-care level	*Country / area*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Cyprus	0	100	0	50	50
	Czech Republic	0	0	100	40	60
	Ecuador	100	0	0	100	0
	Japan	4	37	59	–	–
	New Zealand	0	39	61	47	53
	Panama	0	50	50	25	75
	Romania	10	80	10	20	80
	Slovenia	0	0	100	50	50
	United Arab Emirates	14	14	72	57	43
	Average	0	1	99	40	60
II	Jordan	0	48	52	40	60
	Mexico	5	43	52	43	57
	Pakistan	5	54	41	75	25
	Turkey	4	23	73	45	55
	Average	4	39	57	50	50
III	Madagascar	0	60	40	50	50
IV	United Rep. of Tanzania	2	80	18	36	64
Other						
I	Australia (digestive)	0	8	92	75	25
	Cyprus (brain mets.)	0	0	100	80	20
	Cyprus (bone mets.)	0	0	100	60	40
	Czech Republic (colon)	0	1	99	51	49
II	Turkey (opthalmopathy)	37	15	48	69	31
IV	United Republic of Tanzania (Kaposis sarc.)	0	50	50	68	32
All teletherapy treatments						
I	Australia	2	13	85	58	42
	Belarus	4	14	82	48	52
	Bulgaria	6	12	82	30	70
	Croatia	0	9	91	35	65
	Ecuador	7	19	74	25	75
	Ireland	–	–	–	58	42
	Kuwait	9	28	63	45	55
	Netherlands	0	7	93	44	56
	New Zealand	1	14	85	52	48
	Slovakia	1	11	88	45	55
	Sweden	1	8	91	–	–
	United Arab Emirates	5	19	76	55	45
	Average	1	11	88	49	51
II	Jordan	8	24	68	52	48
	Libyan Arab Jamahiriya	10	22	68	61	39
	Mexico	4	26	70	37	63
	Pakistan	8	37	55	60	40
	Average	6	30	64	47	53

The entries in this Table are qualified as follows:

Australia: Survey data from only 8 of 31 radiotherapy treatment centres (representing about 42% of national practice).
Canada: On the basis of data from the Nova Scotia Cancer Treatment and Research Foundation and the province of Manitoba (collectively representing about 8% of the population).
Croatia: Data from one large centre serving about one-fifth of population.
Jordan: Survey data from one hospital.
New Zealand: Data from 50% of radiotherapy centres (serving about two-thirds of population).
Peru: Survey data from INEN (Cancer Institute, Lima, serving population of about 7 million).
United Republic of Tanzania: Data for 'Lung/thorax tumour' include treatments of the oesophagus.
Turkey: Survey data from Hacettepe University Hospital, Çukurova University Hospital, Istanbul University Hospital, Cerrahpaşa Hospital and Gülhane Military Hospital.

Table 56
Distribution by age and sex of patients undergoing brachytherapy treatment for a range of conditions (1991-1996)
Data from UNSCEAR 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/neck tumour						
I	Australia	0	0	100	59	41
	Belarus	0	11	89	70	30
	Czech Republic	0	4	96	73	27
	Ireland	0	0	100	60	40
	Panama	0	25	75	25	75
	Slovakia	0	24	76	81	19
	Slovenia	1	20	79	25	75
	United Arab Emirates	0	20	80	80	20
	Average	0	14	86	61	39
II	Mexico	0	5	95	85	15
	Turkey	0	30	70	84	16
	Average	0	28	72	84	16
III	Morocco	10	–	–	–	–
Breast tumour						
I	Australia	0	0	100	0	100
	Belarus	0	17	83	0	100
	Czech Republic	0	5	95	0	100
	Ireland	0	0	100	0	100
	Slovakia	0	20	80	0	100
	Average	0	15	85	0	100
II	Mexico	0	34	66	0	100
	Turkey	0	24	76	3	97
	Average	0	26	74	2	98
Gynaecological tumour						
I	Australia	0	9	91	0	100
	Belarus	0	10	90	0	100
	Canada	0	13	87	0	100
	Croatia	0	10	90	0	100
	Cyprus	0	17	83	0	100
	Czech Republic	0	11	89	0	100
	Ecuador	0	12	88	0	100
	Ireland	0	0	100	0	100
	Kuwait	0	30	70	0	100
	Panama	0	25	75	0	100
	Slovakia	0	13	87	0	100
	Slovenia	0	6	94	0	100
	United Arab Emirates	0	24	76	0	100
	Average	0	11	89	0	100
II	Mexico	0	48	52	0	100
	Pakistan	0	52	48	0	100
	Peru	0	20	80	0	100
	Turkey	0	2	98	0	100
	Average	0	10	90	0	100
III	Sudan	0	60	40	0	100
Prostate tumour						
I	Belarus	0	0	100	100	0
	Canada	0	0	100	100	0
	Czech Republic	0	0	100	100	0

Table 56 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Slovakia	0	0	100	100	0
	Slovenia	0	0	100	100	0
	Average	0	0	100	100	0
Other brachytherapy treatments						
I	Australia (bile duct)	0	0	100	88	12
	Australia (oesophagus)	0	6	94	50	50
	Czech Republic (bronchus)	0	3	97	87	13
	Czech Republic (skin)	0	5	95	75	25
	Ireland (oesophagus)	0	0	100	–	–
	Ireland (rectum)	0	0	100	–	–
	Slovakia (bronchus)	0	6	94	89	11
	Slovakia (GI tract)	0	4	96	100	0
II	Turkey (genitals)	0	3	97	100	0
All brachytherapy treatments						
I	Australia	0	5	95	42	58
	Belarus	0	13	87	22	78
	Bulgaria	0.5	8	91.5	36	64
	Croatia	0	10	90	0	100
	Ecuador	0	12	88	0	100
	Ireland	0	0	100	20	80
	Kuwait	0	30	70	0	100
	Slovakia	0	14	86	18	82
	United Arab Emirates	0	23	77	18	82
	Average	0	9	91	30	70
II	Mexico	0	49	51	3	97
	Pakistan	0	65	35	38	62
	Average	0	50	50	6	94

The entries in this Table are qualified as follows:

Australia: Survey data from only 8 of 31 radiotherapy treatment centres (representing about 42% of national practice).
Canada: On the basis of data from the Nova Scotia Cancer Treatment and Research Foundation and the province of Manitoba (collectively representing about 8% of the population).
Croatia: Data from one large centre serving about one-fifth of population.
New Zealand: Data from 50% of radiotherapy centres (serving about two-thirds of population).
Peru: Survey data from INEN (Cancer Institute, Lima, serving population of about 7 million).
Turkey: Survey data from Hacettepe University Hospital, Çukurova University Hospital, Istanbul University Hospital, Cerrahpaşa Hospital and Gülhane Military Hospital.

Table 57
Prescribed doses to patients undergoing radiation teletherapy by disease category (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	*Typical dose [a] to target volume (Gy)*											
	Leukaemia	*Lymphoma*	*Breast tumour*	*Lung/thorax tumour*	*Gynaecolo-gical tumour*	*Head/neck tumour*	*Brain tumour*	*Skin tumour*	*Bladder tumour*	*Prostate tumour*	*Tumour of rectum*	*Benign disease*
Health-care level I												
Argentina	14 (10–20)	36 (25–45)	60 (55–65)	66 (45–70)	50 (45–60)	70 (45–75)	65 (40–65)	75 (60–78)	58 (50–64)	70 (50–76)	55 (45–60)	(15–75)
Australia	15 (11–22)	34 (17–46)	53 (26–64)	44 (22–63)	49 (32–57)	56 (28–67)	50 (29–58)	45 (25–62)	49 (27–62)	52 (33–62)	49 (26–54)	15 (6–26)
Belarus	30 (20–40)	40 (30–46)	50 (30–70)	60 (40–70)	40 (40–60)	60 (40–70)	60 (40–70)	65 (60–70)	60 (40–60)	60 (40–60)	75 (40–80)	–
Bulgaria	24 (24–30)	36 (36–44)	50 (40–60)	56 (40–60)	56 (50–60)	60 (60–70)	55 (50–60)	60 (50–70)	60 (50–70)	60 (50–70)	60 (50–70)	5 (1–50)
Canada	25 (12–30)	40 (20–50)	50 (40–60)	40 (17–60)	45 (25–70)	60 (50–70)	50 (20–60)	35 (20–50)	50 (20–70)	60 (50–66)	50 (40–60)	(6–20)
Croatia	30	48 (40–55)	52 (50–60)	60 (52–68)	60 (52–65)	60 (60–70)	60 (50–66)	60 (60–70)	60 (54–66)	60 (60–65)	55 (55–65)	15 (8–40)
Cyprus	18	40 (35–45)	50	(20–60)	45 (45–50)	60 (20–70)	60	50	66 (20–66)	64	54	12 (6–18)
Czech Republic	12 (12–24)	30 (30–40)	50 (50–60)	55 (50–60)	60 (45–65)	60 (45–65)	60 (45–65)	55 (50–60)	60 (55–60)	65 (60–70)	50 (45–60)	6 (4–8)
Denmark	12	40 (35–40)	48 (48–58)	(30–50)	46 [c]	64 (62–68)	54	48	60	–	46 [d]	–
Ecuador	25 (±25%)	40 (±10%)	60 (±16%)	50 (±10%)	50 ((±30%)	50 (±20%)	40 (±30%)	50 (12–72)	50 (±20%)	50 (±10%)	50 ((±20%)	30
Hungary	–	–	–	–	–	–	–	–	–	–	–	4 (1–5)
Ireland	30 (25–30)	(30–60)	45 (40–50)	(40–55)	40	60 (40–66)	40	35 (35–50)	60 (60–70)	66 (66–70)	50 (45–50)	–
Kuwait	18 (18–24)	36 (30–40)	50 (50–65)	60 (55–60)	46 (40–46)	60 (60–66)	60 (55–60)	40 (30–40)	60 (60–64)	60 (60–66)	50 (50–54)	–
Netherlands	–	40 (40–48)	66 (64–68)	64 (60–68)	46 (42–48)	66 (64–70)	60 (60–64)	60 (60–64)	60 (60–64)	–	(45–60)	–
New Zealand	15 (6–28)	40 (8–50)	50 (8–65)	50 (8–60)	45 (27–65)	60 (40–70)	50 (20–66)	40 (18–64)	60 (30–64)	65 (60–68)	45 (18–60)	30 (8–50)
Panama	12 (12–24)	40 (40–45)	50 (50–60)	50 (50–60)	50 (50–70)	60 (60–70)	50 (40–60)	50	50	60 (60–70)	50 (50–60)	15 (15–20)
Romania	(10–40)	(6–45)	–	(2–74)	(18–70)	(2–87)	(16–60)	–	(16–74)	(12–70)	(20–70)	–
Russian Federation	–	(25–60)	(40–70)	(40–70)	(40–60)	(40–70)	–	(40–70)	(40–60)	(40–60)	(40–60)	(0.5–5)
Slovakia	18 (18–24)	36 (35–40)	50 (46–50)	60	60 (60–80)	60 (60–80)	56 (56–60)	60 (60–70)	60	60 (60–66)	50 (50–60)	4 (4–20)
Slovenia	5 (5–12)	30 (20–40)	50 (50–60)	50 (30–60)	50 (50–60)	60 (50–70)	40 (30–50)	60 (50–70)	50 (40–60)	50 (20–60)	50 (20–60)	20 (20–50)
Sweden	–	37 (26 [b])	49 (35 [b])	51 (34 [b])	55 (35 [b])	59 (37 [b])	52 (37 [b])	46 (31 [b])	48 (31 [b])	64 (35 [b])	38 (36 [b])	–
United Arab Emirates	12 (12–24)	40 (35–44)	50 (45–65)	60 (50–60)	45 (40–60)	66 (60–66)	54 (50–60)	50 (50–64)	64 (60–64)	64 (60–66)	45 (40–60)	30 (30–45)
United States [I23]	–	–	(45–50)	–	–	–	–	–	–	(60–72)	–	–
Average	17	39	54	49	50	60	53	48	57	59	49	6
Health–care level II												
Jordan	20 (6–24)	35 (25–40)	50 (42–50)	30 (20–60)	44 (30–50)	60 (40–66)	50 (30–60)	50 (40–55)	66 (30–66)	60 (30–60)	50 (30–50)	10 (10–40)
Libyan Arab Jamahiriya	18 (18–24)	45 (45–50)	50 (50–60)	30 (30–60)	50 (50–60)	66 (60–66)	55 (50–60)	45 (45–50)	60 (60–65)	65 (60–65)	60 (50–60)	–
Mexico	24 (18–24)	40 (35–45)	50 (50–65)	55 (50–65)	80 (50–80)	75 (50–75)	65 (55–65)	65 (55–65)	65 (65–70)	65 (65–70)	65 (65–70)	24 (24–32)
Peru	18 (18–30)	44 (30–50)	60 (45–60)	50 (30–60)	50 (45–55)	60 (50–75)	60 (30–70)	50 (45–55)	60 (55–65)	70 (60–72)	50 (45–55)	–
Tunisia	35	(45–55)	50 (50–75)	(45–65)	(20–60)	75 (55–75)	55	(65–75)	65 (55–65)	65 (55–65)	(35–65)	20
Turkey	22 (10–30)	34 (20–58)	50 (45–70)	59 (45–66)	51 (45–62)	63 (50–70)	55 (45–60)	58 (40–70)	61 (50–66)	61 (50–60)	50 (40–60)	14 (9–25)
Average	22	36	50	57	63	67	57	60	62	64	53	18

Table 57 (continued)

Country	*Typical dose to target volume (Gy)*											
	Leukaemia	*Lymphoma*	*Breast tumour*	*Lung/thorax tumour*	*Gynaecolo-gical tumour*	*Head/neck tumour*	*Brain tumour*	*Skin tumour*	*Bladder tumour*	*Prostate tumour*	*Tumour of rectum*	*Benign disease*
Health-care level III												
Madagascar	24	40	45	45	45	45	45	50	50	45	45	–
Morocco	24 (18-24)	36 (36-40)	50	(30-70)	46	70	60	70	70	70	(50-70)	–
Sudan	30 (20-30)	50 (40-50)	45	45 (40-50)	55 (50-60)	55 (50-60)	–	55 (50-60)	55 (50-60)	25 (20-30)	45 (40-50)	25 (20-30)
Average	29	45	45	45	49	48	45	53	54	45	45	25
Health-care level IV												
United Rep. of Tanzania	30 (20-30)	30 (20-30)	50 (30-50)	30 (30-45)	64 (30-64)	60 (30-60)	45 (30-45)	60 (30-60)	60 (30-60)	60 (30-60)	60 (30-60)	6

a Prescribed dose for complete course of treatment. Range or standard deviation in parentheses. Mean doses for each health-care level are frequency-weighted averages of national values. These doses should not be used to infer deterministic or stochastic risks since these depend *inter alia* strongly on irradiation technique (dose distribution) and fractionation.
b Palliative treatment.
c Plus brachytherapy.
d Plus boost.

The entries in this Table are qualified as follows:

Argentina: On the basis of data from one large national centre.
Australia: Survey data from only 8 of 31 radiotherapy treatment centres (representing about 42% of national practice).
Canada: On the basis of data from the Nova Scotia Cancer Treatment and Research Foundation and the province of Manitoba (collectively representing about 8% of the population).
Croatia: Data from one large centre serving about one-fifth of population.
Cyprus: Target dose of 50 Gy for breast tumour refers to treatment with ^{60}Co unit; this is supplemented by treatment with x rays (target dose of 14 Gy); target dose of 45 Gy for gynaecological tumour refers to treatment with ^{60}Co unit; this is supplemented by treatment with x rays (target dose of 15 Gy).
Jordan: Survey data from one hospital.
Madagascar: Treatments shown for Breast, Lung/thorax, Gynaecological, Head/neck, Brain, Skin, Bladder, Prostate and Rectum tumours supplemented by additional irradiation with x rays.
New Zealand: Data from 50% of radiotherapy centres (serving about two thirds of population).
Peru: Survey data from INEN (Cancer Institute, Lima, serving population of about 7 million).
United Republic of Tanzania: Data for 'Lung/thorax tumour' include treatments of the oesophagus.
Turkey: Survey data from Hacettepe University Hospital, Çukurova University Hospital, Istanbul University Hospital, Cerrahpaşa Hospital, and Gülhane Military Hospital.
United Arab Emirates: Doses for radical treatments only.
United States: Breast tumours receive an additional 10-20 Gy "boost" with either electrons or brachytherapy.

Table 58
Prescribed doses to patients undergoing radiation brachytherapy by disease category (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	*Typical dose [a] to target volume (Gy)*			
	Head/neck tumour	*Breast tumour*	*Gynaecological tumour*	*Prostate tumour*
Health-care level I				
Argentina	75 (68–78)	–	60 (50–65)	70
Australia	30 (22–45)	10 (10–25)	32 (15–42)	–
Belarus	40 (30–50)	40 (30–40)	45 (30–50)	40 (30–60)
Bulgaria	60 (60–70)	40 (30–40)	70 (30–70)	–
Canada	60	–	45 (11–50)	30 (25–40)
Cyprus	–	–	30	–
Czech Republic	65 (60–70)	12 (10–12)	60 (60–70)	65 (60–70)
Denmark	–	–	35 (plus teletherapy)	–
Ecuador	–	–	35 (±15%)	–
Ireland	30 (30–60)	30	15 (10–20)	–
Kuwait	–	–	36 (30–36)	–
Netherlands	60 (20–30 boost)	(20–24)	(30–60)	60
New Zealand	45 (25–65)	15	70 (15–70)	–
Panama	20 (20–30)	–	20 (20–30)	–
Russia	(30–50)	(20–40)	(20–40)	–
Slovakia	20 (20–30)	15	30 (10–60)	–
Slovenia	–	–	–	–
United Arab Emirates	10 (5–10)	–	20 (15–20)	–
Average	44	16	45	35
Health–care level II				
Mexico	30 (20–40)	15 (10–20)	30 (20–30)	–
Peru	–	–	40 (30–80)	–
Tunisia	(55–75)	–	(20–60)	–
Turkey	21 (18–40)	20 (20–25)	24 (16–24)	–
Average	22	19	29	–
Health–care level III				
Morocco	24	–	24	–
Sudan	–	–	35 (30–40)	–
Average	24	–	24	–

a Prescribed dose for complete treatment. Range or standard deviation in parentheses. Mean doses for each health-care level are frequency-weighted averages of national values. These doses should not be used to infer deterministic or stochastic risks since these depend *inter alia* strongly on irradiation technique (dose distribution) and fractionation.

The entries in this Table are qualified as follows:

Argentina: On the basis of data from one large national centre.
Australia: Survey data from only 8 of 31 radiotherapy treatment centres (representing about 42% of national practice).
Canada: On the basis of data from the Nova Scotia Cancer Treatment and Research Foundation and the province of Manitoba (collectively representing about 8% of the population).
New Zealand: Data from 50% of radiotherapy centres (serving about two-thirds of population).
Peru: Survey data from INEN (Cancer Institute, Lima, serving population of about 7 million).
Turkey: Survey data from Hacettepe University Hospital, Çukurova University Hospital, Istanbul University Hospital, Cerrahpaşa Hospital, and Gülhane Military Hospital.
United Arab Emirates: Doses for radical treatments only.

Table 59
Gonad doses from photon teletherapy treatments for some specific tumour sites
[V6]

Tumour site/disease	*Treatment technique*	*Target dose [a] (Gy)*	*Gonad dose (mGy)*	
			^{60}Co	*4–25 MV*
Brain	2 lateral opposed beams	20–60	10–40	10–30
Breast	2 tangential beams	50	110–170	20–50
Thorax: lung cancer	AP/PA parallel opposed beams	45–55	50–80	30–50
Thorax: Hodgkin's disease	AP/PA mantle fields	36–40	80–100	60–80

a These doses should not be used to infer deterministic or stochastic risks since these depend *inter alia* strongly on irradiation technique (dose distribution) and fractionation.

Table 60
Annual numbers [a] of treatments per 1,000 population assumed in global model for radiotherapy practice (1991-1996)

Disease/site	*Level I*	*Level II*	*Level III*	*Level IV*	*World*	*Contribution to world total (%)*
Teletherapy						
Leukaemia	0.01	0.04	0.01	0.0004	0.021	3
Lymphoma	0.06	0.04	0.03	0.003	0.042	5
Breast tumour	0.35	0.12	0.13	0.003	0.17	21
Lung/thorax tumour	0.36	0.08	0.02	0.004	0.14	17
Gynaecological tumour	0.12	0.10	0.09	0.02	0.09	11
Head/neck tumour	0.06	0.09	0.04	0.001	0.07	8
Brain tumour	0.04	0.05	0.004	0	0.04	5
Skin tumour	0.05	0.02	0.01	0.003	0.02	3
Bladder tumour	0.04	0.02	0.01	0.0004	0.02	2
Prostate tumour	0.18	0.02	0.01	0.0005	0.06	7
Tumour of rectum	0.07	0.02	0.01	0	0.03	4
Benign disease	0.09	0.01	0.02	0.002	0.03	3
Other	0.09	0.10	0.10	0.01	0.09	11
Total	1.5	0.69	0.47	0.05	0.82	100
Brachytherapy						
Head/neck tumour	0.01	0.001	0		0.003	4
Breast tumour	0.02	0.0005	0		0.006	9
Gynaecological tumour	0.16	0.009	0.015		0.05	75
Prostate tumour	0.004	0	0		0.001	2
Other	0.01	0.007	0		0.007	10
Total	0.20	0.02	0.02		0.07	100

a Estimated on the basis of average percentage distributions by treatment type (Tables 53 and 54) and average total frequencies (Tables 51 and 52) observed for each health-care level.

Table 61
Global resources for high-energy radiation therapy
[D27]

Region	*Number of radiation therapy centres*	*Number of ^{60}Co machines*	*Number of clinical accelerators*	*Teletherapy machines [a] per million population*
North America	1 909	202	2 238	8.1
Central America	139	115	30	1.1
Tropical South America	266	219	122	1.2
Temperate South America	139	128	46	3.2
Caribbean	18	23	1	0.8
Western Europe	1 027	410	1 109	3.9
Eastern Europe	327	491	148	1.6
Northern Africa	59	49	35	0.6
Middle Africa	22	25	3	0.1
Southern Africa	21	19	27	0.8
Middle East	92	64	56	0.5
Indian Subcontinent	221	286	46	0.3
South East Asia	81	71	59	0.3
East Asia	1 107	606	948	1.1
Australia and the Pacific Islands	49	5	113	5.2
The World	5 500	2 700	5 000	1.4

a Cobalt-60 unit or linear accelerator.

Table 62
Temporal trends in annual frequency of radiotherapy treatments [a] per 1,000 population
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	Teletherapy				Brachytherapy			
	1970 – 1979	1980 – 1984	1985 – 1990	1991 – 1996 [b]	1970 – 1979	1980 – 1984	1985 – 1990	1991 – 1996 [c]
Health-care level I								
Argentina	–	–	–	–	–	–	0.2	–
Australia	2.0	–	1.5	1.8	0.8	–	0.2	0.06
Belarus	–	–	–	0.5	–	–	–	0.1
Bulgaria	–	–	–	0.2	–	–	–	0.6
Canada	–	1.6	2.9	1.7	–	–	–	0.07
Cayman Islands	–	–	–	0	–	–	–	0
Croatia	–	–	–	2.0	–	–	–	0.07
Cuba	–	–	0.2	2.0 [e]	–	–	0.05	–
Cyprus	–	–	–	0.9	–	–	–	0.02
Czechoslovakia	2.9	4.2	2.7	–	0.2	0.1	0.1	–
Czech Republic	–	–	–	3.5	–	–	–	0.3
Denmark	–	–	1.2	1.5	–	–	0.1	–
Ecuador	(0.03)	–	(0.08)	0.1	(0.006)	–	(0.02)	0.01
Finland	–	–	1.2	–	–	–	–	–
France	–	–	–	1.7	–	–	–	–
Hungary	–	–	–	3.7	–	–	–	0.3
Iceland	–	–	1.2	–	–	–	–	–
Ireland	–	–	–	1.6	–	–	–	0.09
Japan	0.7	–	0.7	0.7	0.2	0.2	–	–
Kuwait	–	–	0.2	0.2	–	–	0.06	0.02
Luxembourg	–	–	–	0	–	–	0.07	0
Malta	–	–	–	–	–	–	0.03	–
Netherlands	–	–	1.8	2.2 [f]	–	–	0.1	0.15 [f]
New Zealand	0.4	0.4	0.6	1.7	0.1	0.08	0.07	0.05
Norway	0.5 [d]	–	3.9	–	0.2	–	0.1	–
Panama	–	–	–	0.3	–	–	–	0.05
Qatar	–	–	–	0	–	–	–	0
Romania	–	1.7	6.8	0.5	–	0.06	–	0.2
Russian Federation	(0.6)	(0.7)	(0.8)	1.0	(0.3)	(0.4)	(0.3)	0.4
Slovakia	–	–	–	0.8	–	–	–	0.3
Slovenia	–	–	–	2.4	–	–	–	0.1
Sweden	0.6	–	0.8	1.3	0.3	0.2	0.1	0.1
Switzerland	–	–	1.8	–	–	–	0.1	–
United Arab Emirates	–	–	–	0.2	–	–	–	0.009
United Kingdom	–	2.4 [d]	–	2.3	–	–	–	–
United States [I23]	(1.5)	(1.7)	(1.9)	2.0	–	–	–	0.1
Uruguay	–	–	–	1.5 [e]	–	–	–	0
Venezuela	–	–	–	1.6 [e]	–	–	–	–
Yugoslavia	–	–	0.6	–	–	–	0.9	–
Average	1.0	2.4 [d]	1.2	1.5	0.26	0.17	0.24	0.2
Health-care level II								
Antigua and Barbuda	–	–	–	0	–	–	–	0
Bahamas	–	–	–	0	–	–	–	0
Barbados	–	–	0.6	3.1 [e]	–	–	0.2	–
Belize	–	–	–	0	–	–	–	0
Bolivia	–	–	–	0.8 [e]	–	–	–	–
Brazil	–	–	–	1.3	–	–	–	–
Chile	–	–	–	2.1 [e]	–	–	–	–
China	–	–	0.2	–	–	–	0.08	–
Colombia	–	–	–	1.6 [e]	–	–	–	–
Dominica	–	–	–	0	–	–	–	0
Dominican Republic	–	–	–	1.9 [e]	–	–	–	–
El Salvador	–	–	–	2.0 [e]	–	–	–	–
Grenada	–	–	–	0	–	–	–	0
Honduras	–	–	–	2.0 [e]	–	–	–	–
India	(0.07)	–	0.1	–	(0.02)	–	0.03	–
Iraq	–	–	0.1	–	–	–	0.009	–
Jordan	–	–	–	0.3	–	–	–	–
Libyan Arab Jamahiriya	–	–	–	0.08	–	–	–	–

Table 62 (continued)

Country / area	*Teletherapy*				*Brachytherapy*			
	1970 – 1979	*1980 – 1984*	*1985 – 1990*	*1991 – 1996* [b]	*1970 – 1979*	*1980 – 1984*	*1985 – 1990*	*1991 – 1996* [c]
Mexico	–	–	–	0.1	–	–	–	0.02
Nicaragua	–	–	–	2.2 [e]	–	–	–	–
Oman	–	–	–	0	–	–	–	0
Pakistan	–	–	–	0.05	–	–	–	0.001
Paraguay	–	–	–	2.2 [e]	–	–	–	0
Peru	0.09	–	0.1	0.1	0.03	–	0.04	0.04
Puerto Rico	–	–	–	1.5 [e]	–	–	–	–
Saint Kitts and Nevis	–	–	–	0	–	–	–	0
Saint Lucia	–	–	–	0	–	–	–	0
Saint Vincent and the Grenadines	–	–	–	0	–	–	–	0
Trinidad and Tobago	–	–	–	1.5 [e]	–	–	–	–
Tunisia	–	–	–	0.1	–	–	–	0.02
Turkey	0.7	0.9	0.7	0.4	–	–	–	0.04
Average	0.1	–	0.2	0.7	0.02	–	0.06	0.02
Health-care level III								
Afghanistan	–	–	–	0	–	–	–	–
Egypt	–	–	0.04	–	–	–	0.0005	–
Guatemala	–	–	–	2.1 [e]	–	–	–	–
Haiti	–	–	–	1.8 [e]	–	–	–	–
Jamaica	–	–	(0.1)	2.1 [e]	–	–	(0.07)	0
Madagascar	–	–	–	0.07	–	–	–	–
Morocco	–	–	–	0.4	–	–	–	0.03
Myanmar	–	0.2	0.2	–	0.01	0.01	0.02	–
Sudan	–	–	0.08	0.05	–	–	0.0003	0.0009
Thailand	–	–	0.09	–	–	0.04	0.04	–
Average	–	–	0.1	0.5	0.02	0.03	0.02	0.02
Health-care level IV								
United Rep. of Tanzania	–	–	–	0.05	–	–	–	–

a Complete course of treatment.
b See qualifications to national data shown in Tables 8 and 51.
c See qualifications to national data shown in Tables 8 and 52.
d Value includes brachytherapy.
e Number of new cancer patients.
f These revised data were received by the Committee after completion of the global analysis.

The entries in this Table are qualified as follows:

Czechoslovakia: Historical data.
Ecuador: Categorized in health-care level II in previous analyses.
India: Categorized in health-care level III for period 1970–1979.
Jamaica: Categorized in health-care level II in previous analyses.
Russian Federation: Historical data were not included in previous analyses.
United States: Historical data from reference [I23] were not included in previous analyses.

Table 63
Temporal trends in the average annual number [a] of the various types of radiotherapy treatments per 1,000 population
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures

Disease/site	*Period*	*Average annual number of treatments per 1,000 population*			
		Health-care level I	*Health-care level II*	*Health-care level III*	*Health-care level IV*
Teletherapy					
Leukaemia	1970–1979	0.010	0.016	0.0007	–
	1980–1984	0.029	–	0.002	–
	1985–1990	0.018	0.004	0.005	–
	1991–1996	0.005	0.007	0.002	0.0004
Lymphoma	1970–1979	0.038	0.015	0.002	–
	1980–1984	0.025	–	0.004	–
	1985–1990	0.045	0.005	0.007	–
	1991–1996	0.060	0.009	0.003	0.003
Breast tumour	1970–1979	0.12	0.016	0.005	–
	1980–1984	0.13	–	0.012	–
	1985–1990	0.16	0.026	0.018	–
	1991–1996	0.40	0.025	0.014	0.003
Lung/thorax tumour	1970–1979	0.11	0.011	0.002	–
	1980–1984	0.14	–	0.023	–
	1985–1990	0.20	0.025	0.009	–
	1991–1996	0.36	0.015	0.003	0.004
Gynaecological tumour	1970–1979	0.11	0.042	–	–
	1980–1984	0.11	–	0.019	–
	1985–1990	0.16	0.041	0.017	–
	1991–1996	0.11	0.021	0.009	0.020
Benign disease	1970–1979	0.40	–	0.004	–
	1980–1984	2.0	–	–	–
	1985–1990	0.48	0.004	0.004	–
	1991–1996	0.09	0.001	0.002	0.002
Total of all teletherapy	1970–1979	1.0	0.1	–	–
	1980–1984	2.4	–	–	–
	1985–1990	1.2	0.2	0.1	–
	1991–1996	1.5	0.7	0.5	0.050
Brachytherapy					
Breast tumour	1970–1979	0.0001	–	–	–
	1980–1984	–	–	–	–
	1985–1990	0.019	0.012	–	–
	1991–1996	0.011	0.0005	–	–
Prostate	1970–1979	0.0005	–	–	–
	1980–1984	–	–	–	–
	1985–1990	0.005	0.00001	–	–
	1991–1996	0.002	0	–	–
Total of all brachytherapy	1970–1979	0.26	0.02	–	–
	1980–1984	0.17	–	–	–
	1985–1990	0.24	0.06	–	–
	1991–1996	0.20	0.02	0.02	–

a Complete courses of treatment. Overall averages calculated from national data as the total number of treatments divided by the total population for each treatment category. Data for 1991-1996 from Tables 51 and 52; since the total population is not the same for each treatment category due to the lack of comprehensive national data for all countries included in the analysis, these average numbers can not be expected to be additive.

Table 64
Chronology of technical advances in teletherapy
[R4, R7]

Date	*Limitation*	*Development*
1950s	Radiation energy	^{60}Co teletherapy equipment; linear accelerators (LINACs)
1960s	Difficulty in planning	Computer-based treatment planning systems
1970s	Lack of anatomical information	Computed tomography
1980s	Lack of flexibility in field shaping	Multileaf collimators for conformal therapy
Early 1990s	Lack of flexibility in beam intensity	Intensity modulated beams for improved conformal therapy
Late 1990s	Lack of real-time verification	Transit dosimetry from electronic portal imaging devices

Table 65
Estimated annual numbers of radiotherapy treatments [a] in the world 1991-1996

Health-care level	*Population (millions)*	*Annual number of teletherapy tretments*		*Annual number of brachytherapy tretments*		*Annual number of all radiotherapy treatments [b]*	
		Millions	*Per 1,000 population*	*Millions*	*Per 1,000 population*	*Millions*	*Per 1,000 population*
I	1 530	2.3	1.5	0.3	0.2	2.6	1.7
II	3 070	2.1	0.7	0.05	0.02	2.2	0.7
III	640	0.3	0.5	0.01	0.02	0.3	0.5
IV	565	0.03	0.05	0.01 [c]	0.02 [c]	0.04	0.07
World	5 800	4.7	0.8	0.4	0.07	5.1	0.9

a Complete courses of treatment.
b Excluding treatments with radiopharmaceuticals.
c Assumed value in the absence of data.

Table 66
Examples of clinically used radionuclides in cancer therapy
[Z3]

Radionuclide	*Pharmaceutical*	*Clinical use*
^{131}I	NaI	Differentiated thyroid carcinomas
^{32}P	NaH_2PO_4	Polycythaemia vera
^{89}Sr	$SrCl_2$	Bone metastases
^{131}I	mIBG	Neural crest tumours
^{153}Sm	EDTMP	Bone metastases
^{186}Re	HEDP	Bone metastases
^{32}P	$CrPO_4$	Intracavitary
^{90}Y	Microspheres	Hepatic tumours
^{90}Y	Antibodies	Various tumours
^{114m}In	Lymphocytes	Lymphoma
^{131}I	Antibodies	Various tumours
^{131}I	Lipiodol	Hepatic tumours

Table 67
Annual numbers of therapeutic treatments with radiopharmaceuticals per 1,000 population (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	*Thyroid malignancy* ^{131}I	*Hyper-thyroidism* ^{131}I	*Polycythaemia vera* ^{32}P	*Bone metastases*			*Synovitis* ^{90}Y	*Total number of all treatments*
				^{89}Sr	*Other*	*Total*		
Health-care level I								
Argentina	0.073	0.12	0	0	0	0	0	0.19
Austria [H60]	0.018	0.18	0.0006	–	–	0.0075	[0.0025]	0.29
Bulgaria	0.010	0.0094	0.0015	0	0	0	[0.0092]	0.030
Canada	0.031	0.24	0.0039	0.0047	0	0.0047	0.018	0.30
Cayman Islands	0	0	0	0	0	0	0	0
Croatia	0.014	0.017	0	0	0	0	0	0.031
Cyprus	0.048	0.020	0	0.012	0	0.012	0	0.080
Czech Republic	[0.047]	[0.055]	[0.0009]	–	–	0.044	[0.10]	0.25
Denmark	0.031	0.43	0	0.0012	0	0.0012	0	0.46
Ecuador	0.011	0.022	0	0.0008	0.0009 (^{32}P)	0.0017	0	0.035
Finland [K59]	0.089	0.28	0.050	0.0010	(^{153}Sm, ^{186}Re)	0.011	0.0084	0.44
France [H60]	–	–	–	–	–	0.0091	–	0.13
Germany	0.086	0.27	0.0025	–	^{186}Re	0.0049	0.017	0.39
Greece [H60]	0.047	0.081	–	–	–	0.017	[0.011]	0.16
Hungary	[0.020]	[0.082]	[0.0010]	0	0	0	[0.0019]	0.11
Ireland	0.0083	0.10	0.0069	0.0028	0	0.0028	–	0.12
Israel [H60]	0.0008	–	–	–	–	0.0002	[0.0002]	0.060
Italy	0.054	0.048	0.0011	0	0	0	0	0.11
Japan	0.0073	0.023	–	–	–	–	–	–
Kuwait	0.039	0.091	0	0.0041	0	0.0041	0	0.13
Lithuania	[0.067]	[0.23]	0	0	0	0	0	0.29
Netherlands	0.030	0.19	0.010	–	^{186}Re	0.013	0.020	0.29 [a]
New Zealand [L28]	0.033	0.10	0.012	0.0083	0.0003(^{32}P)	0.0086	0.0046	0.16
Norway [H60]	0.036	0.20	0.0008	–	–	0.016	[0.0010]	0.26
Panama	0.021	–	0	0	0	0	0	–
Portugal [H60]	0.035	0.030	0.0005	–	–	0.0026	[0.0004]	0.068
Qatar	0	0.044	0	0	0	0	0	0.044
Romania	0.050	0.018	0	0	0	0	0	0.068
Russian Federation	–	–	–	–	–	–	–	0.010
Slovakia	0.078	0.035	0	0	0	0	[0.0009]	0.11
Slovenia	0	0.27	0.0010	0.0070	0	0.0070	0.014	0.30
Spain [H60]	–	–	–	–	–	–	–	0.20
Sweden	0.013	0.32	0.034	0.032	0	0.032	0.0014	0.40
Switzerland [H60]	0.028	0.15	0.0017	–	–	0.013	[0.031]	0.27
United Arab Emirates	0.013	0.011	0	0	0	0	0	0.024
United Kingdom [C27]	0.020	0.20	0.012	0.0092	0	0.0092	0.0070	0.25
United States [I23]	0.039	0.19	–	–	–	–	–	–
Average	0.038	0.15	0.0046	–	–	0.0063	0.098	0.17
Health-care level II								
Antigua and Barbuda [B43]	–	–	–	–	–	–	–	0
Brazil	–	–	–	–	–	–	–	0.033
Dominica [B43]	–	–	–	–	–	–	–	0
Grenada [B43]	–	–	–	–	–	–	–	0
Jordan	0.021	0.047	–	–	–	–		0.13
Mexico	0.0064	0.031	0.00001	0	^{32}P, ^{153}Sm	0.0002	0.0002	0.038
Oman	0	0	0	0	0	0	0	0
Pakistan	0.0034	0.016	0.00004	0	^{131}I	0.0001	0	0.028
Peru	0.0085	0.0085	0	–	^{32}P, ^{153}Sm	0.017	–	0.034
Saint Kitts and Nevis [B43]	–	–	–	–	–	–	–	0
Saintt Lucia [B43]	–	–	–	–	–	–	–	0
St Vincent and the Grenadines [B43]	–	–	–	–	–	–	–	0
Tunisia	0.020	0.022	0	0	0	0	0	0.042
Turkey	0.031	0.014	0.0005	0.0023	0	0.0023	0	0.048
Average	0.011	0.020	0.0001	–	–	0.0017	0.0001	0.036

Table 67 (continued)

Country / area	*Thyroid malignancy* ^{131}I	*Hyper-thyroidism* ^{131}I	*Polycythaemia vera* ^{32}P	*Bone metastases*			*Synovitis* ^{90}Y	*Total number of all treatments*
				^{89}Sr	*Other*	*Total*		
Health-care level III								
Morocco	0.0045	0.030	0	0	0	0	0	0.035
Sudan	0.0008	0.0033	0	0	0.0023 (^{32}P)	0.0023	0	0.0064
Average	0.0027	0.017	0	–	–	0.0011	0	0.021
Health-care level IV								
Ethiopia	0	0.0004	0	0	0	0	0	0.0004
United Rep. of Tanzania	0	0.0002	0	0	0	0	0	0.0002
Average	0	0.0004	0	–	–	0	0	0.0004

a These revised data were received by the Committee after completion of the global analysis.

The entries in this Table are qualified as follows:

Argentina: On the basis of data from a sample of 25% of nuclear medicine centres.
Brazil: Survey data for Paraná State (with a population of 9 million and a social and economic profile above the average for Brazil).
Bulgaria: Data for 'Synovitis' relate to use of ^{198}Au.
Canada: On the basis of data for the province of Ontario (representing about 37% of population).
Cyprus: Survey data relating to 90% of population.
Finland: 'Bone metastases'treatments also conducted using ^{153}Sm (with a frequency of 0.0098 per 1,000 population) and ^{186}Re (with a frequency of 0.0004 per 1,000); total for synovitis also includes use of ^{166}Ho (with a frequency of 0.0002 per 1,000).
Germany: Total for 'Bone metastases' relates to use of ^{89}Sr and ^{186}Re; total for synovitis also includes use of ^{169}Er and ^{186}Re.
Mexico: No information on radionuclide for synovitis.
Netherlands: Total for 'Bone metastases' relates to use of ^{186}Re and ^{89}Sr.
Peru: Total for 'Bone metastases' relates to use of ^{153}Sm, ^{32}P and ^{89}Sr.
Turkey: On the basis of data from Hacettepe University Hospital.
Austria, Czech Republic, France, Greece, Hungary, Israel, Lithuania, Norway, Portugal, Switzerland: No information available on radionuclides used.

Table 68
Percentage contributions by treatment type to annual total numbers of therapeutic administrations of radiopharmaceuticals (1991-1996)
Based on data and qualifications from Table 67

Country / area	*Thyroid malignancy*	*Hyper-thyroidism*	*Polycythaemia vera*	*Bone metastases*	*Synovitis*	*Total of all treatments*
Health-care level I						
Argentina	38	62	0	0	0	100
Austria [H60]	6.3	61	0.2	2.6	0.9	100
Bulgaria	34	31	5.0	0	30	100
Canada	10	80	1.3	1.6	5.9	100
Croatia	45	55	0	0	0	100
Cyprus	60	25	0	15	0	100
Czech Republic	19	22	0.4	18	41	100
Denmark	6.8	93	0	0.3	0	100
Ecuador	31	64	0	4.9	0	100
Finland [K59]	20	64	12	2.5	1.9	100
France [H60]	-	-	-	7.1	-	100
Germany	22	70	0.6	1.3	4.5	100
Greece [H60]	30	52	-	11	7.1	100
Hungary	19	78	0.9	0	1.9	100
Ireland	6.7	85	5.6	2.3	-	100
Israel [H60]	1.3	-	-	0.3	0.3	100
Italy	51	45	1	0	0	100
Kuwait	29	68	0	3.1	0	100
Lithuania	23	77	0	0	0	100
Netherlands	11	72	3.9	5.1	7.7	100
New Zealand [L28]	20	64	7.3	5.3	2.9	100
Norway [H60]	14	78	0.3	6.2	0.4	100
Portugal [H60]	51	43	0.7	3.8	0.6	100
Qatar	0	100	0	0	0	100
Romania	74	26	0	0	0	100
Slovakia	68	30	0	0	0.8	100
Slovenia	0	92	0.3	2.4	4.7	100
Sweden	3.3	81	8.6	8.0	0.3	100
Switzerland [H60]	10	56	0.6	4.8	12	100
United Arab Emirates	55	45	0	0	0	100
United Kingdom [C27]	8.0	80	5.0	3.7	2.8	100
Average [a]	21	68	2.0	3.0	4.4	100
Health-care level II						
Jordan	16	35	-	-	-	100
Mexico	17	82	0.03	0.7	0.7	100
Pakistan	12	58	0.2	0.2	0	100
Peru	25	25	0	50	-	100
Tunisia	47	53	0	0	0	100
Turkey	65	29	1.0	4.8	0	100
Average [a]	29	54	0.3	5.0	0.2	100
Health-care level III						
Morocco	13	87	0	0	0	100
Sudan	13	51	0	36	0	100
Average [a]	13	81	0	5.5	0	100
Health-care level IV						
Ethiopia	0	100	0	0	0	100
United Rep. of Tanzania	14	86	0	0	0	100
Average [a]	3.1	97	0	0	0	100

a Overall averages for sample calculated as total number of each particular type of treatment divided by total number of all treatments.

Table 69
Distribution by age and sex of patients undergoing therapeutic treatments with radiopharmaceuticals (1991–1996)
Data from UNSCEAR 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*
Thyroid malignancy						
I	Argentina	5	49	46	20	80
	Bulgaria	0	43	57	27	73
	Canada	0	43	57	20	80
	Croatia	0	14	86	12	88
	Czech Republic	4	29	67	29	71
	Ecuador	4	50	46	29	71
	Finland	0	–	–	–	–
	Ireland	0	30	70	25	75
	Japan	0	9	91	23	77
	Kuwait	3	64	33	27	73
	Panama	0	38	62	20	80
	Romania	4	30	66	34	66
	Slovakia	0	40	60	–	–
	United Arab Emirates	0	41	59	57	43
	Average	3	37	60	24	76
II	Jordan	2	43	55	12	88
	Mexico	2	46	52	20	80
	Pakistan	11	56	33	48	52
	Peru	0	30	70	30	70
	Turkey	0	51	49	40	60
	Average	2	49	49	36	64
III	Morocco	0	100	0	–	–
	Sudan	0	60	40	65	35
	Average	0	94	6	65	35
IV	United Rep. of Tanzania	0	0	100	0	100
Hyperthyroidism						
I	Argentina	2	46	52	19	81
	Bulgaria	0	81	19	3	97
	Canada	4	39	57	27	73
	Croatia	0	13	87	14	86
	Czech Republic	0	9	91	9	91
	Ecuador	9	58	33	19	81
	Finland	0	–	–	–	–
	Japan	0	23	77	18	82
	Jordan	3	43	54	32	68
	Kuwait	0	60	40	40	60
	Romania	0	35	65	20	80
	Slovakia	0	35	65	–	–
	United Arab Emirates	8	23	69	35	65
	Average	3	37	60	22	78
II	Jordan	3	43	54	32	68
	Mexico	2	49	49	16	84
	Pakistan	14	54	32	39	61
	Peru	0	70	30	20	80
	Average	7	51	42	26	74
III	Morocco	0	100	0	–	–
	Sudan	0	75	25	6	94
	Average	0	98	2	6	94
IV	Ethiopia	0	0	100	8	92
	United Rep. of Tanzania	0	100	0	15	85
	Average	0	19	81	9	91

Table 69 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Polycythaemia vera						
I	Bulgaria	0	0	100	90	10
	Canada	0	0	100	68	32
	Finland	0	–	–	–	–
	Ireland	0	0	100	50	50
	Average	0	0	100	67	33
II	Mexico	0	0	100	100	0
	Pakistan	0	17	83	100	0
	Average	0	15	85	100	0
Bone metastases						
I	Canada	0	0	100	67	33
	Czech Republic	0	0	100	77	23
	Ecuador	0	10	90	65	35
	Kuwait	–	–	–	100	0
	Average	0	0	100	75	25
II	Mexico	0	0	100	70	30
	Pakistan	33	33	34	100	0
	Peru	0	0	100	50	50
	Turkey	0	1	99	51	49
	Average	0	1	99	52	48
III	Sudan	0	30	70	50	50
Synovitis						
I	Bulgaria	0	47	53	63	37
	Canada	0	0	100	50	50
	Czech Republic	36	37	27	73	27
	Slovakia	0	0	100	–	–
	Average	23	26	51	66	34
II	Mexico	0	87	13	83	17
All therapeutic procedures						
I	Argentina	3	47	50	19	81
	Bulgaria	0	54	46	34	66
	Croatia	0	13	87	16	84
	Czech Republic	4	9	87	53	47
	Ecuador	7	53	40	24	76
	Kuwait	1	61	38	38	64
	Slovakia	0	38	62	–	–
	United Arab Emirates	3	33	64	47	53
	Average	3	38	59	28	72
II	Jordan	2	53	45	29	71
	Mexico	2	48	50	17	83
	Pakistan	16	37	47	72	28
	Average	9	43	48	45	55
IV	Ethiopia	0	0	100	8	92
	United Rep. of Tanzania	0	85	15	13	87
	Average	0	19	81	9	91

The entries in this Table are qualified as follows:

Argentina: On the basis of data from a sample of 25% of nuclear medicine centres.
Canada: Data from London Health Sciences Centre, SW Ontario (representing 50% of the services provided to population of about 1 million).
Turkey: Survey data from Gülhane Military Hospital, Hacettepe University Hospital and Samsun Ondokuz Mayis University Hospital.

Table 70
Average [a] activities administered (MBq) in therapeutic treatments with radiopharmaceuticals (1991-1996)
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country / area	Thyroid malignancy	Hyperthyroidism	Polycythaemia vera	Bone metastases			Synovitis	
	^{131}I iodide	^{131}I iodide	^{32}P phosphate	^{89}Sr chloride	^{32}P phosphate	Other	^{90}Y	Other
Health-care level I								
Argentina	4 477 (±1258)	433 (±122)	–	–	–	–	–	–
Bulgaria	3 300 (3 000–5 500)	185	(74–370)	–	–	–	–	–
Canada	(5 500–7 400)	(300–1 500)	185	–	–	–	300	–
Croatia	4 706 (3 452–5 960)	726 (±510)	–	–	–	–	–	–
Denmark	–	420	–	–	–	–	–	–
Ecuador	3 700 (± 50%)	370 (±50%)	–	150	5	–	–	–
Finland [K59]	4 334 (3 500–5 550)	321 (148–425)	154 (110–222)	148	–	1 300 [d], 2 564 (1 295–3 000) [f]	168 (148–185)	555 [b]
Germany	(1 000–8 000)	(200–2 000)	(150–200)	150	–	1 300 [d]	168	(15–30) [c], (35–185) [d]
Ireland	3 700 (1 110–7 400)	400 (185–500)	148 (111–185)	150	–	–	–	–
Italy	5550 (2 500–11 100)	555 (185–1 110)	185	–	–	–	–	–
Japan	3 330	160	–	–	–	–	–	–
Kuwait	7 400	106	–	148	–	–	–	–
Netherlands	5 500 (8 000 max.)	500 (1800 max.)	(250–400)	150	–	1 300 [d]	185	–
New Zealand [L28]	3 303 (1 000–7 000)	381 (150–1 000)	174 (120–259)	150	–	–	185	–
Panama	5 550 (2 934–8 166)	463 (±131)	–	–	–	–	–	–
Slovakia	3 700 (2 600–5 550)	260 (185–370)	–	–	–	–	–	–
Slovenia	–	350 (185–550)	37	150	–	–	185	–
Sweden	6 800 (4 000–7 400)	525 (240–1 500)	200 (160–400)	150 (125–150)	–	–	170 (110–220)	–
United Arab Emirates	3 700 (2 275–5 550)	422 (200–462)	–	–	–	–	–	–
United Kingdom [C27]	–	–	166	136	–	–	200	–
Average	4 760	415	170	140	–	–	250	–
Health-care level II								
Jordan	3 700 (±20%)	550 (±20%)	–	–	–	–	–	–
Mexico	3 700 (1 840–5 560)	370 (185–555)	148 [e] (111–185)	–	185	46 [f] (37–555)	–	–
Peru	5 550 (5 000–6 000)	260 (200–300)	–	148	444	3 885 (3 500–4 000) [f]	–	–
Turkey	3 238	185	148	111	–	–	–	–
Average	3 510	340	148	111	–	–	–	–

Table 70 (continued)

Country / area	*Thyroid malignancy*	*Hyperthyroidism*	*Polycythaemia vera*	*Bone metastases*			*Synovitis*	
	^{131}I iodide	*^{131}I iodide*	*^{32}P phosphate*	*^{89}Sr chloride*	*^{32}P phosphate*	*Other*	*^{90}Y*	*Other*
Health-care level III								
Morocco	3 700 (3 330–4 440)	296 (222–444)	–	–	–	–	–	–
Sudan	3 710	300	–	–	291	–	–	–
Average	3 700	300	–	–	–	–	–	–
Health-care level IV								
Ethiopia	–	185 (111–370)	–	–	–	–	–	–
United Rep. of Tanzania	3 500	350 (±2%)	–	–	–	–	–	–
Average	3 500	220	–	–	–	–	–	–

a Range or standard deviation in parentheses.
b Data relate to use of ^{166}Ho.
c Data relate to use of ^{169}Er.
d Data relate to use of ^{186}Re.
e Data relate to use of ^{90}Y.
f Data relate to use of ^{153}Sm.

The entries in this Table are qualified as follows:

Argentina: On the basis of data from a sample of 25% of nuclear medicine centres.
Canada: Data from London Health Sciences Centre, SW Ontario (representing 50% of the services provided to population of about 1 million).
Turkey: Survey data from Gülhane Military Hospital, Hacettepe University Hospital, and Samsun Ondokuz Mayis University Hospital.

Table 71
Annual numbers [a] of radiopharmaceutical treatments per 1,000 population assumed in global model for radionuclide therapy practice (1991-1996)

Disease	*Level I*	*Level II*	*Level III*	*Level IV*	*World*	*% Contribution to world total*
Thyroid malignancy	0.035	0.010	0.003	0.00001	0.015	23
Hyperthyroidism	0.11	0.019	0.017	0.00035	0.042	65
Polycythaemia vera	0.003	0.0001	0	0	0.001	1
Bone metastases	0.005	0.002	0.001	0	0.002	4
Synovitis	0.007	0.0001	0	0	0.002	3
Total	0.17	0.036	0.021	0.0004	0.065	100

a Estimated on the basis of average percentage distributions by treatment type (Table 68) and average total frequencies (Tables 67) observed for each health-care level.

Table 72
Temporal trends in annual frequency of radiopharmaceutical treatments per 1,000 population
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures

Country	*1970–1979*	*1980–1984*	*1985–1990*	*1991–1996*
Health-care level I				
Argentina	–	–	0.16	0.19
Australia	0.15	0.15	0.14	–
Austria	–	–	–	0.29
Belgium	4	–	0.31	–
Bulgaria	–	–	–	0.03
Canada	–	–	0.88	0.30
Cayman Islands	–	–	–	0
Croatia	–	–	–	0.031
Cyprus	–	–	–	0.080
Czechoslovakia [a]	0.073	0.12	0.18	–
Czech Republic	–	–	–	0.25
Denmark	0.13	0.18	0.21	0.46
Ecuador [b]	(0.007)	–	(0.0065)	0.035
Finland	0.32	0.36	–	0.44
France	–	–	–	0.13
Germany	–	–	–	0.39
Greece	–	–	–	0.16
Hungary	–	–	–	0.11
Ireland	–	–	–	0.12
Israel	–	–	–	0.060
Italy	–	–	–	0.11
Japan	0.049	0.025	0.030	–
Kuwait	–	–	0.018	0.13
Lithuania	–	–	–	0.29
Luxembourg	–	–	0.19	–
Malta	–	–	0.075	–
Netherlands	–	–	–	0.29 [d]
New Zealand	0.16	0.18	0.17	0.16
Norway	0.059	–	0.12	0.26
Portugal	–	–	–	0.068
Qatar	–	–	–	0.044
Romania	–	0.051	0.052	0.068
Russian Federation [c]	(0.02)	(0.02)	(0.00)	0.010
Slovakia	–	–	–	0.11
Slovenia	–	–	–	0.30
Spain	–	–	–	0.20
Sweden	0.34	–	0.43	0.4
Switzerland	1.55	–	–	0.27
United Arab Emirates	–	–	–	0.024
United Kingdom	–	0.20	–	0.25
Yugoslavia [a]	–	–	0.11	–
Average	0.086	0.093	0.10	0.17

Table 72 (continued)

Country	*1970–1979*	*1980–1984*	*1985–1990*	*1991–1996*
Health-care level II				
Antigua and Barbuda	–	–	–	0
Barbados	–	–	0.15	–
Brazil	–	–	–	0.033
China	–	–	0.035	–
Dominica	–	–	–	0
Grenada	–	–	–	0
India	–	–	0.0036	–
Iraq	–	–	0.013	–
Jordan	–	–	–	0.13
Mexico	–	–	–	0.038
Oman	–	–	–	0
Pakistan	–	–	–	0.028
Peru	–	–	0.011	0.034
Saint Kitts and Nevis	–	–	–	0
Saint Lucia	–	–	–	0
Saint Vincent and the Grenadines	–	–	–	0
Tunisia [e]	(0.35)	–	(0.042)	0.042
Turkey	–	–	0.008	0.048
Average	0.044	–	0.021	0.036
Health-care level III				
Egypt	0.064	0.061	0.062	–
Jamaica [b]	(0.17)	–	(0.005)	–
Morocco	–	–	–	0.035
Myanmar	0.014	0.011	0.005	–
Sudan	0.001	0.003	0.006	0.0064
Thailand	0.008	0.011	0.013	–
Average	0.025	0.025	0.025	0.021
Health-care level IV				
Ethiopia	–	–	–	0.0004
United Rep. of Tanzania	–	–	–	0.0002
Average	–	–	–	0.0004

a Historical data.
b Categorized in health-care level II in previous analyses.
c Historical data were not included in previous analyses.
d These revised data were received by the Committee after completion of the global analysis.
e Categorized in health-care level III in previous analyses.

Table 73
Temporal trends in the average annual number [a] of the various types of radionuclide therapy treatments per 1,000 population
Data from UNSCEAR Surveys of Medical Radiation Usage and Exposures

Disease/site	*Period*	*Average annual number of treatments per 1,000 population*			
		Health-care level I	*Health-care level II*	*Health-care level III*	*Health-care level IV*
Thyroid malignancy	1970–1979	0.059	0.023	0.010	–
	1980–1984	0.033	–	0.009	–
	1985–1990	0.063	0.0004	0.011	–
	1991–1996	0.038	0.011	0.003	0
Hyperthyroidism	1970–1979	0.088	–	0.023	–
	1980–1984	0.10	–	0.024	–
	1985–1990	0.022	0.0004	0.020	–
	1991–1996	0.15	0.020	0.017	0.0004
Polycythaemia vera	1970–1979	0.014	–	–	–
	1980–1984	0.024	–	0.001	–
	1985–1990	0.016	0.0001	0.002	–
	1991–1996	0.005	0.0001	0	0
Total of all radionuclide therapy	1970–1979	0.086	0.044	0.025	–
	1980–1984	0.093	–	0.025	–
	1985–1990	0.10	0.021	0.025	–
	1991–1996	0.17	0.036	0.021	0.0004

a Overall averages calculated from national data as the total number of treatments divided by the total population for each treatment category. Data for 1991–1996 from Table 67; since the total population is not the same for each treatment category due to the lack of comprehensive national data for all countries included in the analysis, these average numbers can not be expected to be additive.

Table 74
Estimated annual numbers of therapeutic treatments with radiopharmaceuticals in the world 1991–1996

Health-care level	*Population (millions)*	*Annual number of treatments*	
		Millions	*Per 1,000 population*
I	1 530	0.3	0.2
II	3 070	0.1	0.04
III	640	0.01	0.02
IV	565	0.0002	0.0004
World	5 800	0.4	0.065

Table 75
Distributions of effective doses to volunteers from administrations of radiopharmaceuticals during participation in research studies in Germany
[B78]

Year	*No of research studies*		*Range of effective dose (mSv)*	*Fraction of population by volunteer category (%)*		
	PET	*Other*		*Healthy persons*	*Patients*	*All*
1997	17 [a]	19 [b]	≤ 1	50.5	0	3.6
			> 1 – 6	16.7	8.1	8.7
			>6 – 10	3.0	17.9	16.8
			>10 – 20	23.8	68.3	65.1
			>20 – 50	6.0	5.0	5.1
			>50	0	0.7	0.7
1998	28 [c]	15 [d]	≤ 1	11.6	6.8	7.2
			> 1 – 6	41.3	30.4	31.4
			>6 – 10	0	4.1	3.8
			>10 – 20	41.3	44.2	44.0
			>20 – 50	5.8	14.1	13.3
			>50	0	0.4	0.3

a Distribution by radionuclide: 13 ^{18}F, 2 ^{15}O, 2 ^{11}C, and 1 ^{68}Ga. Distribution by speciality: 4 neurology/psychiatry, 12 oncology and 1 cardiology.
b Distribution by radionuclide: 8 ^{99m}Tc, 7 ^{123}I, 2 ^{131}I, and 1 ^{81m}Kr. Distribution: 6 neurology/psychiatry, 9 oncology, 1 cardiology and 3 other.
c Distribution by radionuclide: 14 ^{18}F, 6 ^{15}O, 8 ^{11}C, and 1 ^{13}N. Distribution: 18 neurology/psychiatry, 6 oncology , 3 cardiology and 2 other.
d Distribution by radionuclide: 13 ^{99m}Tc, 1 ^{123}I, 1 ^{201}Tl, and 1 ^{81m}Kr. Distribution: 4 neurology/psychiatry, 5 oncology, 2 cardiology and 4 other.

Table 76
Guidelines for notification of incidents in the United Kingdom involving radiation equipment used for medical exposure
[H62]

Type of diagnostic examination	*Guideline multiplying factor* [a]
Barium enemas, barium meals, IVUs, angiography and other such procedures involving fluoroscopy (including digital radiology) and CT	3
Nuclear medicine: intended effective dose > 5mSv	3
Lumbar spine, abdomen, pelvis, mammography and all other examinations not otherwise included	10
Nuclear medicine: intended effective dose in the range 0.5–5 mSv	10
Extremities, skull, chest, dental examinations and other simple examinations such as elbow, knee and shoulder	20
Nuclear medicine: intended effective dose < 0.5 mSv	20
Type of treatment	*Guideline multiplying factor* [a]
Beam therapy, brachytherapy	1.1 (whole course) 1.2 (any fraction)
Radionuclide therapy	1.2 (any administration)

a For application to the ratio of suspected dose to intended dose, when deciding whether the patient exposure from an incident was ‘much greater than intended’.

Table 77
Estimated annual global practice and doses to the world population [a] from medical uses of radiation [b] (1991–1996)

Medical radiation use	*Number of procedures (millions)*					*Effective dose per caput (mSv)*					*Collective effective dose (10^3 man Sv)*				
	Level I	*Level II*	*Level III*	*Level IV*	*World*	*Level I*	*Level II*	*Level III*	*Level IV*	*World*	*Level I*	*Level II*	*Level III*	*Level IV*	*World*
Diagnosis															
Medical x-ray examinations	1 410	470	13	11	1 910	1.2	0.14	0.02	0.02	0.4	1 900	425	14	13	2 300
Dental x-ray examinations	475	42	0.1	0.1	520	0.01	0.001	<0.0001	<0.0001	0.002	9	4	0.01	0.01	14
Nuclear medicine procedures	29	3	0.2	0.01	32	0.08	0.008	0.006	0.0003	0.03	120	23	4	0.2	150
Total	1 900	520	13	11	2 500	1.3	0.15	0.03	0.02	0.4	2 000	450	18	13	2 500
Therapy [c]															
Radiotherapy treatments	2.6	2.2	0.3	0.04	5.1										
Nuclear medicine treatments	0.3	0.1	0.01	0.0002	0.4										
Total	2.9	2.3	0.3	0.04	5.5										

a World population estimated to be 5,800 million in 1996 with following distribution between health-care levels of global model: 1,530 million (26%) in level I; 3,070 million (53%) in level II; 640 million (11%) in level III; and 565 million (10%) in level IV.

b Since, as discussed in Section I.C, many of these exposures are received by patients nearing the end of their lives and the doses are not distributed evenly amongst the population, these doses should not be used for the assessment of detriment.

c Complete courses of treatment.

Table 78
Trends in annual global use of radiation for diagnosis

UNSCEAR Report	*Annual use of medical x rays*				*Annual use of dental x rays*				*Annual use of radiopharmaceuticals*				*Annual per caput dose from global practice* [a] *(mSv)*
	Number of exams (millions)	*Frequency per 1,000 population*	*Collective dose (10^3 man Sv)*	*Per caput dose (mSv)*	*Number of exams (millions)*	*Frequency per 1,000 population*	*Collective dose (10^3 man Sv)*	*Per caput dose (mSv)*	*Number of exams (millions)*	*Frequency per 1,000 population*	*Collective dose (10^3 man Sv)*	*Per caput dose (mSv)*	
1958 [U13]	–	[c]	–	–	–	[i]	–	–	–	–	–	–	[o]
1962 [U12]	–	[d]	–	–	–	[j]	–	–	–	[k]	–	–	[p]
1972 [U8]	[b]	[e]	–	–	–	–	–	–	–	[l]	–	–	[q]
1977 [U7]	–	[f]	–	–	–	–	–	–	–	–	–	–	[r]
1982 [U6]	–	300–900[g]	–	1[h]	–	–	–	–	–	10–40[m]	–	[n]	0.4
1988 [U4]	1 380	280	1 800	0.35	340	70	17	0.003	23.5	4.7	74	0.015	0.4
1993 [U3]	1 600	300	1 600	0.3	–	–	18	0.003	24	4.5	160	0.03	0.3
2000 [Present]	1 910	330	2 300	0.4	520	90	14	0.002	32.5	5.6	150	0.03	0.4

a Includes diagnostic uses of x rays and radiopharmaceuticals.
b Annual increases by a few percent noted for technically developed countries.
c Range of 380–1,270 per 1,000 in survey data from 9 developed countries.
d Range of 260–410 per 1,000 in survey data from 12 countries.
e Range of 39–1,240 per 1,000 in survey data from 12 countries.
f Range of 35–1,660 per 1,000 in survey data from 11 countries.
g Survey data (excluding mass surveys) for industrialized countries; 100–200 per 1,000 in developing countries.
h Estimate for industrialized countries; lower value for developing countries where examinations are less frequent.
i Range of 21–400 per 1,000 in survey data from 4 developed countries.
j Range of 10–400 per 1,000 in survey data from 10 developed countries.
k Range of 0.1–1.7 per 1,000 in survey data from 8 countries.
l Range of 1.7–10.1 per 1,000 in survey data from 7 countries.
m Range for industrialized countries; 0.2–2 per 1,000 in developing countries.
n Range of 0.02–0.15 mSv for industrialized countries.
o GSD same order as from natural sources (estimated range 0.2–2 mGy per year). Per capita mean marrow dose similar to that from natural sources (2.3 mGy per year).
p Relative to risk from natural radiation: 0.3 for hereditary effects and 0.4–0.8 for risk of leukaemia.
q Limited survey data (relative to annual doses from natural sources): GSD in range 0.1 – 0.5, per caput marrow dose in range 0.3 – 2.
r 0.5–1 mSv in countries with developed radiological facilities; 0.01 mSv in countries with limited facilities. Globally, 0.2 relative to dose from natural sources.

Table 79
Trends in annual global use of radiation for therapy

UNSCEAR Reports	*Teletherapy and brachytherapy*		*Radiopharmaceuticals*	
	Annual number of treatments [a] (millions)	*Annual frequency per 1,000 population*	*Annual number of treatments (millions)*	*Annual frequency per 1,000 population*
1988 [U4]	4.3	0.9	0.7	0.14
1993 [U3]	4.9	0.9	0.2	0.04
2000 [Present]	5.1	0.9	0.4	0.065

a Complete courses of treatment.

References

PART A

Responses to UNSCEAR Survey of Medical Radiation Usage and Exposures

Country	*Respondent*
Argentina	A. Curti. Nuclear Regulatory Authority, Buenos Aires
Australia	D. Webb. Australian Radiation Laboratory, Yallambie
Bahrain	Response submitted by the Permanent Mission of the State of Bahrain to the United Nations in Geneva
Belarus	G. Chijz. Ministry of Health, Minsk
Belgium	J. Van Dam. Katholieke Universtitet Leuven
Brazil	J. Tilly. Federal Centre of Technological Education of Paraná, Curitiba
Bulgaria	G. Vasilev. National Centre of Radiobiology and Radiation Protection, Sofia
Canada	S. Vlahovich. Radiation Protection Bureau, Ottawa
Cayman Islands	R Namburi. Cayman Islands Government Hospital, Grand Cayman Island
China	D. Li. China Atomic Energy Authority, Beijing
China (Taiwan Province)	C.-N. Guan. Atomic Energy Council, Taipei
Costa Rica	P. Mora. University of Costa Rica, San José
Croatia	S. Gigić. Ministry of Health, Zagreb
Cyprus	C. Stelios. Medical Physics Department, Nicosia General Hospital
Czech Republic	Z. Prouza. State Office for Nuclear Safety, Prague
Denmark	O Hjardemaal and K. Ennow. National Institute of Radiation Hygiene, Brønshøj
Ecuador	S. Moreno. Comision Ecuatoriana de Energia Atomica, Quito
Ethiopia	S. Demena and D. Walelign. Nuclear Medicine Unit, Addis Ababa University
Finland	R. Havukainen. Finnish Centre for Radiation and Nuclear Safety, Helsinki
France	J.F. Lacronique. Office de Protection contre les Rayonnements Ionisants, Le Vesinet
Germany	B. Bauer. Federal Office for Radiation Protection, Institute of Radiation Hygiene, Munich
Greece	P. Dimitriou. Greek Atomic Energy Commission, Attikis
Hungary	P. Vittay. National Institute for Radiology and Radiation Physics, Budapest
Ireland	D. Fenton. Radiological Protection Institute of Ireland, Dublin
Italy	F. Dobici and J. Wells. National Agency for the Environment Protection, Rome
Japan	T. Maruyama. National Institute of Radiological Sciences, Chiba
Jordan	O. AL-Taleb. Nuclear Medicine Department, Al-Bashir Hospital, Amman
Kuwait	J. Al-Mudaires. Ministry of Health, Dahayat Abdulla Al-Salem
Lebanon	N. Khoury and M. Nasreddine. Lebanese Atomic Energy Commission, Beirut
Libyan Arab Jamahiriya	D. Abouhadra. Scientific Research, IAEA Division, Tripoli
Lithuania	B. Švykaitė. Radiation Protection Centre, Vilnius

Country	*Respondent*
Luxembourg	C. Back. Division de la Radioprotection, Direction de la Santé, Luxembourg
Madagascar	Institut National des Sciences et Techniques Nucleaires, Antanana Rivo
Malaysia	Kwan-Hoong. Ng. University of Malaya Medical Centre, Kuala Lumpur
Mexico	C. Medina Villegas. Instituto Mexicano de Seguro Social, Mexico City M. Verdejo. Secretaría de Salud
Morocco	Y. Charif. Centre National de Radioprotection, Sale
Netherlands	L.W. Meinders. Inspectorate for Health Care, Rijswijk
New Zealand	J. Le Heron and V. Smyth. National Radiation Laboratory, Christchurch
Norway	G. Saxebøl. Norwegian Radiation Protection Authority, Østerås
Oman	Director General of Health Affairs, Ministry of Health, Muscat
Pakistan	Head, Regulation Enforcement Division, Directorate of Nuclear Safety and Radiation Protection, Islamabad
Panama	E. Gibbs. Departmento de Salud Radiologica, Caja de Seguro Social, Panama
Peru	L. Pinillos Ashton and R. Morales. Instituto de Enfermedades Neoplasicas, Lima
Philippines	B. San Juan. Radiation Health Service, Department of Health, Manila
Poland	J. Jankowski and M.A. Staniszewska. Nofer Institute of Occupational Medicine, Lódź
Qatar	A.M. Ismail. Hamed Medical Corporation, Doha
Romania	C. Milu. Institute of Hygiene and Public Health, Bucharest C. Diaconescu. Institute of Public Health and Medical Research, Iassy
Russian Federation	S.A. Kalnitsky and Y.O. Yakubovsky-Lipsky. St Petersburg Institute of Radiation Hygienne G.P. Zharkova. Institute of Biophysics, Moscow
Slovakia	P. Gaál. State Health Institute of the Slovak Republic, Bratislava
Slovenia	M. Križman. Slovenian Nuclear Safety Administration, Ljubljana
Spain	E. Vañó and M. Bezares. Ministry of Health, Madrid
Sudan	O.I. Elamin. Sudan Atomic Energy Commission, Khartoum
Sweden	W. Leitz. Swedish Radiation Protection Institute, Stockholm
Switzerland	J. Marti. Swiss Federal Office of Public Health, Berne
Tanzania	W. Muhogora. National Radiation Commission, Arusha
Tunisia	S. Mtimet. Centre National de Radio Protection, Tunis
Turkey	G. Buyan, N. Tuğrul, B. Okyar, M. Vural, E. Uğur, I. Ingeç. Turkish Atomic Energy Authority, Ankara
United Arab Emirates	R. Cheesman. Federal Radiology Department, Ministry of Health, Abu Dhabi
United Kingdom	P. Shrimpton. National Radiological Protection Board, Chilton
United States of America	R. Burkhart. Food and Drug Administration, Rockville

PART B

A1 Atherton, J.V. and W. Huda. Energy imparted and effective doses in computed tomography. Med. Phys. 23(5): 735-741 (1996).

A2 Angerstein, W., B. Bauer and I. Barth. Frequency of x-ray examinations in former East- and West Germany: methods and results. Eur. Radiol. 4: 561-565 (1994).

A3 Atherton, J.V. and W. Huda. Effective doses to pediatric patients undergoing CT examinations. Med. Phys. 23(6): 1058 (1996).

A4 Amols, H.I., L.E. Reinstein and J. Weinberger. Dosimetry of a radioactive coronary balloon dilatation catheter for treatment of neointimal hyperplasia. Med. Phys. 23(10): 1783-1788 (1996).

A5 Adelman, S.L. Europium-152 as a potential substitute for cobalt-60 in radiation therapy. Med. Phys. 23(8): 1443-1445 (1996).

A6 Allen, B.J., D.E. Moore and B.V. Harrington. Progress in Neutron Capture Therapy for Cancer. Plenum Press, New York, 1992.

A7 Alm Carlsson, G. and C.A. Carlsson. Relations between effective dose equivalent and mean absorbed dose (energy imparted) to patients in diagnostic radiology. Phys. Med. Biol. 31: 911-921 (1986).

A8 Althof, V.G.M., J.C.J. de Boer, H. Huizenga et al. Physical characteristics of a commercial electronic portal imaging device. Med. Phys. 23(11): 1845-1855 (1996).

A9 Alecu, R. and M. Alecu et al. *In-vivo* rectal dose measurements with diodes to avoid misadministrations during intracavitary high dose rate brachytherapy for carcinoma of the cervix. Med. Phys. 26(5): 768-770 (1999).

A10 Agosteo, S., A.F. Para, F. Gerardi et al. Photoneutron dose in soft tissue phantoms irradiated by 25 MV x-rays. Phys. Med. Biol. 38: 1509-1528 (1993).

A11 Allen, P.D. and M.A. Chaudhri. Charged photoparticle production in tissue during radiotherapy. Med. Phys. 24(6): 837-839 (1997).

A12 Aird, E.G.A., J.E. Burns, M.J. Day et al. Central axis depth dose data for use in radiotherapy: 1996. Report of a BIR/ IPSM Working Party. Br. J. Radiol. (Suppl.) 25: (1996).

A13 Adeyemi, A. and J. Lord. An audit of radiotherapy patient doses measured with *in vivo* semiconductor detectors. Br. J. Radiol. 70: 399-408 (1997).

A14 Annuaire de la Cancerologie/Radiotherapie et des Imageries Medicales en France. ACRIM 1995, 15ème édition (A. Laugier, ed.). Riv Atelier, Paris, 1995.

A15 Aldrich, J.E., B.C. Lentle and C. Vo. Radiation doses from medical diagnostic procedures in Canada. Advisory Committee on Radiological Protection, Report ACRP-9. Atomic Energy Control Board of Canada, Ottawa (1997).

A16 Asiamah, S.D, E.K. Osei, C. Schandorf et al. Radiation dose due to nuclear medicine practice in Ghana. Health Phys. 75(2): 207-208 (1998).

A17 Agosteo, S., C. Birattari, M. Caravaggio et al. Secondary neutron and photon dose in proton therapy. Radiother. Oncol. 48: 293-305 (1998).

A18 Aird, E.G.A. Clinical electron therapy. Br. J. Radiol. 71: 1113-1115 (1998).

A19 Adam, A. The definition of interventional radiology (or, "When is a barium enema an interventional procedure?"). Eur. Radiol. 8: 1014-1015 (1998).

A20 Administration of Radioactive Substances Advisory Committee. Notes for guidance on the clinical administration of radiopharmaceuticals and use of sealed radioactive sources. NRPB, Chilton (1998).

A21 Almazan, C., A. Granados and G. Oliva. Spanish strive for efficient use of MRI. Diagn. Imag. Eur. 12(7): 30-43 (1996).

A22 Agard, E.T. Healthful radiation. Health Phys. 72(1): 97-99 (1997).

A23 Ashford, R.L., C.J. Fullerton and N.J. Hughes. The role of radiology in podiatry. Radiography 4: 189-194 (1998).

A24 Alm Carlsson, G., D.R. Dance, J. Persliden et al. Use of the concept of energy imparted in diagnostic radiology. Appl. Radiat. Isot. 50(1): 39-62 (1999).

A25 Archer, B.R. and L.K. Wagner. Management of patient dose during fluoroscopy. Med. Phys. 26(6): 1175 (1999).

A26 Aldrich, J.E., Vancouver Hospital. Communication to the UNSCEAR Secretariat (1999).

A27 Asai, Y., Y. Tanabe, Y. Ozaki et al. Optimum tube voltage for chest radiographs obtained by psychophysical analysis. Med. Phys. 25(11): 2170-2175 (1998).

A28 Arfelli, F., V. Bonvicini, A. Bravin et al. A linear array silicon pixel detector: images of a mammographic test object and evaluation of delivered doses. Phys. Med. Biol. 42: 1565-1573 (1997).

A29 Arfelli, F., V. Bonvicini, A. Bravin et al. Mammography of a phantom and breast tissue with synchrotron radiation and a linear-array silicon detector. Radiology 208: 709-715 (1998).

A30 Adams, E.J., D.S. Brettle, A.P. Jones et al. Estimation of fetal and effective dose for CT examinations. Br. J. Radiol. 70: 272-278 (1997).

A31 Axelsson, B., C. Khalil, M. Lidegran et al. Estimating the effective dose to children undergoing heart investigations - a phantom study. Br. J. Radiol. 72: 378-383 (1999).

A32 Almén, A. and S. Mattsson. Dose distribution in children at chest radiography. Radiat. Prot. Dosim. 57(1-4): 463-467 (1995).

A33 Asahina, H. Selenium-based flat panel x-ray detector for digital fluoroscopy and radiography. Toshiba Med. Rev. 69 (August): 1-7 (1999).

A34 Aberle, D.R. Future directions of research in thoracic imaging. Radiology 206: 11-13 (1998).

A35 Alvarez, R.E. Active energy selective image detector for dual-energy computed radiography. Med. Phys. 23(10): 1739-1748 (1996).

A36 Arfelli, F., M. Assante, V. Bonvicini et al. Low-dose phase contrast x-ray medical imaging. Phys. Med. Biol. 43: 2845-2852 (1998).

A37 Antolak, J.A. and E.A. Strom. Fetal dose estimates for electron-beam treatment to the chest wall of a pregnant patient. Med. Phys. 25(12): 2388-2391 (1998).

A38 Atkins, H.L. Overview of nuclides for bone pain palliation. Appl. Radiat. Isot. 49(4): 277-283 (1998).

A39 Ando, A., I. Ando, N. Tonami et al. ^{177}Lu-EDTMP: a potential therapeutic bone agent. Nucl. Med. Commun. 19: 587-591 (1998).

A40 Almeida, P., B. Bendriem, O. de Dreuille et al. Dosimetry of transmission measurements in nuclear medicine: a study using anthropomorphic phantoms and thermoluminescent dosimeters. Eur. J. Nucl. Med. 25(10): 1435-1441 (1998).

A41 Areberg, J., K. Norrgren and S. Mattsson. Absorbed doses to patients from ^{191}Pt-, ^{193m}Pt- and ^{195m}Pt-cisplatin. Appl. Radiat. Isot. 51: 581-586 (1999).

A42 Adelstein, S.J., R.W. Howell, J.L. Humm et al. On the conceptual basis for dose quantities in nuclear medicine. ICRU News 98(1) (June): 4-10 (1998).

B1 Berger, H. TIPS controls bleeding in variceal haemorrhage. Diagn. Imag. Int. 6: 34-37 (1994).

B2 Bacal, M., C. Gaudin, A. Bourdier et al. A compact radiological x-ray source. Nature 384: 421 (1996).

B3 Betsou, S., E.P. Efstathopoulos, D. Katritsis et al. Patient radiation doses during cardiac catheterization procedures. Br. J. Radiol. 71: 634-639 (1998).

B4 Blake, G. New technology for bone density measurements. RAD Magazine 20(224): 29-30 (1994).

B5 Blake, P. Intracavitary brachytherapy. RAD Magazine 20(226): 19-20 (1994).

B6 Bell, M.R., P.B. Berger, K.K. Menke et al. Balloon angioplasty of chronic total coronary artery occlusions. Cathet. Cardiovasc. Diagn. 25: 10-15 (1992).

B7 Brahmavar, S., C. Miller and L. Tidwell. Entrance skin exposures and fluoroscopy times in cardiac catheterisation, electrophysiology and special x-ray patient procedures. Med. Phys. 22(6): 947 (1995).

B8 Berthelsen, B. and A. Cederblad. Radiation doses to patients and personnel involved in embolization of intracerebral arteriovenous malformations. Acta Radiol. 32: 492-497 (1991).

B9 Bernhardt, J., R. Veit and B. Bauer. Erhebungen zur effektiven Dosis und zur Kollektivdosis bei der Röntgendiagnostik in den alten Bundesländern. Veröffentlichungen der Strahlenschutzkommission, Bd 30. Gustav Fischer Verlag (1995).

B10 Bakalyar, D.M., M.D. Castellani, R.D. Safian. Radiation exposure to patients undergoing diagnostic and interventional cardiac catheterization procedures. Cathet. Cardiovasc. Diagn. 42(2): 121-125 (1997).

B11 Boer, A. den, P.J. de Feyter, W.A. Hummel et al. Reduction of radiation exposure while maintaining high-quality fluoroscopic images during interventional cardiology using novel x-ray tube technology with extra beam filtering. Circulation 89: 2710-2714 (1994).

B12 Bulling, S.M. and J.J. Nicoll. Level and distribution of the radiation dose to the population from a mammography screening programme in New Zealand. Radiat. Prot. Dosim. 57(1-4): 455-458 (1995).

B13 Burattini, E., E. Cossu, C. di Maggio et al. Mammography with synchrotron radiation. Radiology 195: 239-244 (1995).

B14 Broadhead, D.A., C.-L. Chapple and K. Faulkner. The impact of digital imaging on patient doses during barium studies. Br. J. Radiol. 68: 992-996 (1995).

B15 Bardiès, M. and M.J. Myers. Computational methods in radionuclide dosimetry. Phys. Med. Biol. 41(10): 1933-1940 (1996).

B16 Bolster, A.A. and T.E. Hilditch. The radiation dose to the urinary bladder in radio-iodine therapy. Phys. Med. Biol. 41(10): 1993-2008 (1996).

B17 Bergeron, P., R. Carrier, D. Roy et al. Radiation doses to patients in neurointerventional procedures. Am. J. Neuroradiol. 15: 1809-1812 (1994).

B18 Bentel, G.C., C.E. Nelson and K.T. Noell. Treatment Planning and Dose Calculation in Radiation Oncology (4th edition). Pergamon Press, New York, 1989.

B19 British Institute of Radiology. Recommendations for brachytherapy dosimetry. Report of a Joint Working Party of the BIR and the Institute of Physical Sciences in Medicine. British Institute of Radiology, London (1993).

B20 Butson, M.J., A.R. Rozenfeld, J.N. Mathur et al. A new radiotherapy surface dose detector: the MOSFET. Med. Phys. 23(5): 655-658 (1996).

B21 Bentzen, S.M. and J. Overgaard. Clinical normal-tissue radiobiology. Chapter 2 in: Current Radiation Oncology, Volume 2 (J.S. Tobias and P.R.M. Thomas, eds.). Arnold, London, 1996.

B22 Beteille, D., R. Setzkorn, H. Prévost et al. Laser heating of thermoluminescent plates: application to intraoperative radiotherapy. Med. Phys. 23(8): 1421-1424 (1996).

B23 Biggs, D.S. and E.S. Thomson. Radiation properties of a miniature x-ray device for radiosurgery. Br. J. Radiol. 69: 544-547 (1996).

B24 Brandan, M.E., M.A. Pérez-Pastenes, P. Ostrosky-Wegman et al. Mean dose to lymphocytes during radio-therapy treatments. Health Phys. 67(4): 326-329 (1994).

B25 Bruggmoser, G. and R.F. Mould. Brachytherapy review. Freiburg Oncology Series Monograph No. 1. Albert-Ludwigs-University, Freiburg (1994).

B26 Butson, M.J., J.N. Mathur and P.E. Metcalfe. Radiochromic film as a radiotherapy surface-dose detector. Phys. Med. Biol. 41: 1073-1078 (1996).

B27 Breen, S.L. and J.J. Battista. Radiation dosimetry in human bone using electron paramagnetic resonance. Phys. Med. Biol. 40: 2065-2077 (1995).

B28 Brettle, D.S., A. Workman, R.P. Ellwood et al. The imaging performance of a storage phosphor system for dental radiography. Br. J. Radiol. 69: 256-261 (1996).

B29 Boal, T. and L. Wilkinson. The use of dose constraints in diagnostic radiology. Radiat. Prot. Aust. 12(2): 50-53 (1994).

B30 Bauml, A., B. Bauer, J.-H. Bernhardt et al. (eds.). Proceedings of joint WHO/ISH Workshop on Efficacy and Radiation Safety in Interventional Radiology, Munich, October 1995. BfS-ISH-178/97 (1997).

B31 Bauer, B., C. Tsavachidis and R. Veit. Aktuelle Erhebungen zur Strahlenexposition durch die Röntgendiagnostik in Deutschland. Strahlenschutz Forsch. Prax. 37: 103-116 (1995).

B32 Bruckenberger, E. Situation der nuklearmedizinischen Therapie 1991 in Deutschland. Nuklearmedizin 33(6): 56-59 (1994).

B33 Borras, C. (ed.). Organization, development, quality assurance and radiation protection in radiology services: imaging and radiation therapy. Pan American Health Organisation, Washington (1997).

B34 Blyth, C., A.S. McLeod and D.I. Thwaites. A pilot study of the use of *in vivo* diode dosimetry for quality assurance in radiotherapy. Radiography 3: 131-142 (1997).

B35 Beddoe, A.H. Boron neutron capture therapy. Br. J. Radiol. 70: 665-667 (1997).

B36 Blomquist, M., A. Sätherberg, M. Karlsson et al. Scanned intensity modulations for 50 MV photons. Phys. Med. Biol. 43: 1185-1197 (1998).

B37 Bågesund, M., A. Tilikidis and G. Dahllöf. Absorbed doses in the head and oral cavity during total body irradiation. Oral Oncol. 34: 72-74 (1998).

B38 Ban, N., S. Sawai, Y. Aoki et al. Dose evaluation of patients receiving total-body irradiation for the pre-treatment of bone marrow transplantation. Radiat. Prot. Dosim. 71(1): 61-64 (1997).

B39 Bailey, D.L. Transmission scanning in emission tomography. Eur. J. Nucl. Med. 25(7): 774-787 (1998).

B40 Bahador, B. Trends in Diagnostic Imaging to 2000. FT Pharmaceuticals and Healthcare Publishing, London, 1996.
B41 Bourland, D. Medical physics in Kenya. Med. Phys. World 14(1): 19 (1998).
B42 Bourland, D. Medical physics in Zimbabwe. Med. Phys. World 14(1): 16 (1998).
B43 Borras, C., PAHO. Communication to the UNSCEAR Secretariat (1998).
B44 Banu, H., M.N. Alam, M.I. Chowdhury et al. Assessment of occupational and patient dose from diagnostic and therapeutic radiation exposure using thermoluminescent dosimetry. Health Phys. 74(4): 478-480 (1998).
B45 Behrman, R.H. and G. Yasuda. Effective dose in diagnostic radiology as a function of x-ray beam filtration for a constant exit dose and constant film density. Med. Phys. 25(5): 780-790 (1998).
B46 Bridge, L.R. and J.E. Ison. An evaluation of correction factors applied to dose-area product meter readings for the use of sinus cones. Br. J. Radiol. 70: 1280-1282 (1997).
B47 Badr, I., S.M. Thomas, A.D. Cotterill et al. X-ray pelvimetry - which is the best technique? Clin. Radiol. 52: 136-141 (1997).
B48 Boothroyd, A., E. McDonald, B.M. Moores et al. Radiation exposure to children during cardiac catheterization. Br. J. Radiol. 70: 180-185 (1997).
B49 Belli, A.-M. and T.M. Buckenham. Arteriography: developments in diagnostic and interventional techniques. Imaging 7: 107-113 (1995).
B50 Bouhnik, H., J.J. Bard, J. Chavaudra et al. Évaluation des doses délivrées au cours d'examens radiologiques. J. Radiol. 72(8-9): 403-420 (1991).
B51 Boal, T.J., K.W. Dessent and M. Facci. A survey of fluoroscopic equipment in Victoria. Australas. Phys. Eng. Sci. Med. 21(4): 161-169 (1998).
B52 Boone, J.M., D.E. Pfeiffer, K.J. Strauss et al. A survey of fluoroscopic exposure rates: AAPM Task Group No. 11 Report. Med. Phys. 20(3): 789-794 (1993).
B53 Brennan, P.C. and M. Nash. Increasing FFD: an effective dose-reducing tool for lateral lumbar spine investigations. Radiography 4: 251-259 (1998).
B54 Broadhead, D.A., C.-L. Chapple, K. Faulkner et al. The impact of cardiology on the collective effective dose in the North of England. Br. J. Radiol. 70: 492-497 (1997).
B55 Bernhardt, J., R. Veit and B. Bauer. Erhebungen zur Strahlenexposition der Patienten bei der Röntgen-diagnostik. Z. Med. Phys. 5: 33-39 (1995).
B56 Broadhead, D.A., C.-L. Chapple and K. Faulkner. Reference doses during fluoroscopic procedures. Radiat. Prot. Dosim. 80(1-3): 143-144 (1998).
B57 Broadhead, D.A., C.-L. Chapple, K. Faulkner et al. Local reference doses during cardiology procedures. Radiat. Prot. Dosim. 80(1-3): 149-150 (1998).
B58 Bauer, B. and R. Veit. Initiatives, achievements and perspectives in quality assurance and radiation protection in diagnostic radiology, both on the legal and practical level in Germany. Radiat. Prot. Dosim. 57(1-4): 43-46 (1995).
B59 Beaconsfield, T., R. Nicholson, A. Thornton et al. Would thyroid and breast shielding be beneficial in CT of the head? Eur. Radiol. 8(4): 664-667 (1998).
B60 Berland, L.L. and J.K. Smith. Multidetector-array CT: once again, technology creates new opportunities. Radiology 209: 327-329 (1998).
B61 Becker, C.R., M. Schätzl, U.J. Schoepf et al. Technical foundations and scanner characteristics of electron beam computed tomography. Der Radiologe 38(12): 987-992 (1998).
B62 Becker, C.R., A. Knetz, T.F. Jakobs et al. Detection and quantification of coronary artery calcification with electron-beam and conventional CT. Eur. Radiol. 9(4): 620-624 (1999).
B63 Becker, C.R., M. Schätzl, H. Feist et al. Radiation dose for investigation of the chest and abdomen; comparison of sequential, spiral and electron beam computed tomography. Der Radiologe 38(9): 726-729 (1998).
B64 Baadegaard, N. and L.C. Jensen. Organ doses in CT calculated by Monte Carlo technique based on measured CT-beam-profiles. Proceedings of World Congress on Medical Physics and Biomedical Engineering, 14-19 September 1997, Nice (1997).
B65 Busch, H.P., K.J. Lehmann, P. Drescher et al. New chest imaging techniques: a comparison of five analogue and digital methods. Eur. Radiol. 2: 335-341 (1992).
B66 Burch, A. and D.A. Goodman. A pilot survey of radiation doses received in the United Kingdom Breast Screening Programme. Br. J. Radiol. 71: 517-527 (1998).
B67 Boone, J.M. Glandular breast dose for monoenergetic and high-energy x-ray beams: Monte Carlo assessment. Radiology 213: 23-37 (1999).
B68 Beemsterboer, P.M.M., P.G. Warmerdamm, R. Boer et al. Radiation risk of mammography related to benefit in screening programmes: a favourable balance? J. Med. Screen 5: 81-87 (1998).
B69 Bezakova, E., P.J. Collins and A.H. Beddoe. Absorbed dose measurements in dual energy x-ray absorptiometry (DXA). Br. J. Radiol. 70: 172-179 (1997).
B70 Boal, T.J., I. Cardillo and P.F. Einsiedel. Paediatric doses from diagnostic radiology in Victoria. Australas. Phys. Eng. Sci. Med. 21(2): 57-67 (1998).
B71 Bradford, C.D., W.W. Peppler and J.T. Dobbins. Performance characteristics of a Kodak computed radiography system. Med. Phys. 26(1): 27-37 (1999).
B72 Blakely, E.A., F.Q.H. Ngo, S.B. Curtis et al. Heavy-ion radiobiology: cellular studies. Adv. Radiat. Biol. 11: 295-389 (1984).
B73 Bonnett, D.E. Current developments in proton therapy: a review. Phys. Med. Biol. 38: 1371-1392 (1993).
B74 Brenner, D.J., C.-S. Leu, J.F. Beatty et al. Clinical relative biological effectiveness of low-energy x-rays emitted by miniature x-ray devices. Phys. Med. Biol. 44: 323-333 (1999).
B75 Brady, L.W. and S.H. Levitt. Radiation oncology in the 3rd millennium. Radiology 209: 593-596 (1998).
B76 Becker, W. Nuclear medicine goes therapy? Nuklearmedizin 38(2): 3-5 (1999).
B77 Britton, K.E. Towards the goal of cancer-specific imaging and therapy. Nucl. Med. Commun. 18: 992-1007 (1997).
B78 Bundesamtes für Strahlenschutz. Jahresbericht 1999 (In press).
B79 Botwood, N., C. Lewanski and C. Lowdell. The risks of treating keloids with radiotherapy. Br. J. Radiol. 72: 1222-1224 (1999).
B80 Buscombe, J.R., J.B. Cwikla, D.S. Thakrar et al. Scintigraphic imaging of breast cancer: a review. Nucl. Med. Commun. 18: 698-709 (1997).
B81 Bengel, F.M. and M. Schwaiger. Nuclear medicine studies of the heart. Eur. Radiol. 8(9): 1698-1706 (1998).
B82 Boyd, R.E. The gel generator: a viable alternative source of ^{99m}Tc for nuclear medicine. Appl. Radiat. Isot. 48(8): 1027-1033 (1997).
B83 Britten, A.J. and J.N. Gane. Gamma camera imaging of positron emitting isotopes. p. 174-195 in: Current Topics in Radiography - 2 (A. Paterson and R. Price, eds.). W.B. Saunders, London, 1996.

B84 Blower, P.J. and I. Gardin. A place for cellular dosimetry in risk assessment. Nucl. Med. Commun. 18: 989-991 (1997).

B85 Bray, D., W.H. Thomson and L.K. Harding. Is extravasated ^{99m}Tc a problem? Nucl. Med. Commun. 18: 229 (1997).

B86 Blok, D., R.I.J. Feitsma, P. Vermeij et al. Peptide radiopharmaceuticals in nuclear medicine. Eur. J. Nucl. Med. 26(11): 1511-1519 (1999).

B87 Britton, K.E. Where next and how? Highlights lecture of the European Association of Nuclear Medicine and the World Federation of Nuclear Medicine and Biology Congress, Berlin 1998. Eur. J. Nucl. Med. 25(12): 1671-1684 (1998).

B88 Bailey, K.M. Nuclear medicine in Latin America. J. Nucl. Med. 40(9): 9N-12N (1999).

B89 Brugmans, M., RIVM (Netherlands). Data from the Radiology Information System of NvvR. Communication to the UNSCEAR Secretariat (1999).

C1 Cowen, A.R., A. Workman and J.S. Price. Physical aspects of photostimulable phosphor computed radiography. Br. J. Radiol. 66: 332-345 (1993).

C2 Centre for Devices and Radiological Health. FDA draws attention to concerns about radiation risk from fluoroscopy. Radiological Health Bulletin XXVI No. 8 (1992).

C3 Chamberlain, C.C. and S.A. Baran. The reduction of patient dose in interventional radiography. Health Phys. 66 (Suppl.): S103 (1994).

C4 Centre for Devices and Radiological Health. FDA amends diagnostic X-ray equipment performance standard. Radiological Health Bulletin XXVIII No. 2 (1994).

C5 Conway, B.J., O.H. Suleiman, F.G. Rueter et al. National survey of mammographic facilities in 1985, 1988 and 1992. Radiology 191: 323-330 (1994).

C6 Carmichael, J.H.E., C. Maccia, B.M. Moores et al. European guidelines on quality criteria for diagnostic radiographic images. EUR 16260 EN (1996).

C7 Colmanet, S.F. and D.L. Samuels. Diagnostic radiopharmaceutical dose estimate to the Australian population. Health Phys. 64(4): 375-380 (1993).

C8 Coleman, R.E. Clinical PET: a technology on the brink. J. Nucl. Med. 34(12): 2269-2271 (1993).

C9 Calkins, H., L. Niklason, J. Sousa et al. Radiation exposure during radiofrequency catheter ablation of accessory atrioventricular connections. Circulation 84: 2376-2382 (1991).

C10 Compston, J.E., C. Cooper and J.A. Kanis. Bone densito-metry in clinical practice. Br. Med. J. 310: 1507-1510 (1995).

C11 Camm, A.J., J. Reid, M. Raphael et al. Radiation hazards to the cardiologist. Br. Heart J. 70: 489-498 (1993).

C12 Chettle, D.R. and J.H. Fremlin. Techniques of *in vivo* neutron activation analysis. Phys. Med. 29(9): 1011-1043 (1984).

C13 Czajka, J., V.E. Rushton, A.C. Shearer et al. Sensitometric and image quality performance of "rapid" intraoral film processing techniques. Br. J. Radiol. 69: 49-58 (1996).

C14 Corbett, R.H. and G. Hart. A burning question? Br. J. Radiol. 69: 482 (1996).

C15 Cozzi, L. and A. Fogliata-Cozzi. Quality assurance in radiation oncology: A study of feasibility and impact on action levels of an *in vivo* dosimetry program during breast cancer irradiation. Radiother. Oncol. 47: 29-36 (1998).

C16 Carswell, H. Interventionalists fight restenosis with radiation. Diagn. Imag. Int. 13(3): 37-50 (1997).

C17 Calandrino, R., G.M. Cattaneo, C. Fiorino et al. Detection of systematic errors in external radiotherapy before treatment delivery. Radiother. Oncol. 45: 271-274 (1997).

C18 Carter, J. A literature review of the cost-effectiveness of nuclear medicine. King's Fund Centre, London (1995).

C19 Chadwick, B.L. and P.H.M. Dummer. Factors affecting the diagnostic quality of bitewing radiographs: a review. Br. Dent. J. 184: 80-84 (1998).

C20 Cook, J.V., K. Shah, S. Pablot et al. Guidelines on best practice in the x-ray imaging of children; a manual for all x-ray departments. Queen Mary's Hospital for Children, Carshalton, UK (1998).

C21 Carstens, G.J., M.B. Horowitz, P.D. Purdy et al. Radiation dermatitis after spinal arteriovenous malformation embolization: case report. Neuroradiology 38 (Suppl.1): S160-S164 (1996).

C22 Coulden, R.A. and L.P. Readman. Coronary angiography: an analysis of radiographic practice in the UK. Br. J. Radiol. 66: 327-331 (1993).

C23 Chu, R.Y.L., C. Parry, W. Thomson et al. Patient doses in abdominal aortogram and aortogram femoral runoff examinations. Health Phys. 75(5): 487-491 (1998).

C24 Castellano, I.A., J.G. McNeil, N.C. Thorp et al. Assessment of organ radiation doses and associated risk for digital bifemoral arteriography. Br. J. Radiol. 68: 502-507 (1995).

C25 Coleridge Smith, P.D. Imaging in venous disease. Imaging 7: 148-157 (1995).

C26 Curto, T.L. and S.S. Siegelman. Radiology in Europe: Part I. France, Belgium and Switzerland. Radiology 192(3): 41A-48A (1994).

C27 Clarke, S.E.M., D.G. Clarke and N. Prescod. Radionuclide therapy in the United Kingdom in 1995. Nucl. Med. Commun. 20: 711-717 (1999).

C28 Cela, M. Albania seeks progress after years of darkness. Diagn. Imag. Eur. 15(3): 7 (1999).

C29 Calicchia, A., L. Chiacchiararelli, C. de Felice et al. Evaluation of effective dose in hysterosalpingography. Radiat. Prot. Dosim. 80(1-3): 159-161 (1998).

C30 Canevaro, L.V., M.T. Carlos, J.C. Borges et al. Assessment of doses to patients submitted to fluoroscopic gastrointestinal tract examinations. Radiat. Prot. Dosim. 80(1-3): 155-158 (1998).

C31 Calzado, A., S. Ruiz Sanz, M. Melchor et al. A comparison of measured and calculated organ doses from CT examinations. Radiat. Prot. Dosim. 57(1-4): 381-385 (1995).

C32 Chan, C.-Y., Y.-C. Wong, L.-F. Chau et al. Radiation dose reduction in paediatric cranial CT. Pediatr. Radiol. 29: 770-775 (1999).

C33 Collie, D.A., A.R. Wright, J.R. Williams et al. Comparison of spiral-acquisition computed tomography and conventional computed tomography in the assessment of pulmonary metastatic disease. Br. J. Radiol. 67: 436-444 (1994).

C34 Crawley, M.T. and A.T. Rogers. A comparison of computed tomography practice in 1989 and 1991. Br. J. Radiol. 67: 872-876 (1994).

C35 Carlsson, C.A. Imaging modalities in x-ray computerized tomography and in selected volume tomography. Phys. Med. Biol. 44: R23-R56 (1999).

C36 Caon, M., G. Bibbo and J. Pattison. A comparison of radiation dose measured in CT dosimetry phantoms with calculations using EGS4 and voxel-based computational models. Phys. Med. Biol. 42: 219-229 (1997).

C37 Caon, M., G. Bibbo and J. Pattison. An EGS4-ready tomographic computational model of a 14-year-old female torso for calculating organ doses from CT examinations. Phys. Med. Biol. 44: 2213-2225 (1999).

C38 Cardillo, I., T.J. Boal and P.F. Einsiedel. Patient doses from chest radiography in Victoria. Australas. Phys. Eng. Sci. Med. 20(2): 92-101 (1997).

C39 Chotas, H.G., C.E. Floyd and C.E. Ravin. Technical evaluation of a digital chest radiography system that uses a selenium detector. Radiology 195: 264-270 (1995).

C40 Chevalier, M., P. Morán, M. Pombar et al. Breast dose measurements on a large group of patients: results from a 4 year period. Radiat. Prot. Dosim. 80(1-3): 187-190 (1998).

C41 Cowen, A.R. A tutorial on digital mammography imaging equipment. Part 1: advances in image acquisition and display. Radiography 4: 159-171 (1998).

C42 Cowen, A.R. A tutorial on digital mammography imaging equipment. Part 2: developments in digital support technologies. Radiography 4: 239-249 (1998).

C43 Calicchia, A., M. Gambaccini, P.L. Indovina et al. Niobium/molybdenum k-edge filtration in mammography: contrast and dose evaluation. Phys. Med. Biol. 41: 1717-1726 (1996).

C44 Chapple, C.-L., D.A. Broadhead and K. Faulkner. Reference doses for paediatrics from fluoroscopic procedures. Radiat. Prot. Dosim. 80(1-3): 203-206 (1998).

C45 Chapple, C.-L. and K. Faulkner. The assessment and clinical implementation of additional beam filtration in paediatric radiology. p. 113-115 in: Proceedings of 6th SRP International Symposium, Southport, 14-18 June 1999 (M.C. Thorne, ed.). Society for Radiological Protection, London, 1999.

C46 Colin, C., P. Vergnon, L. Guibaud et al. Comparative assessment of digital and analog radiography: diagnostic accuracy, cost analysis and quality of care. Eur. J. Radiol. 26: 226-234 (1998).

C47 Chotas. H.G., J.T. Dobbins and C.E. Ravin. Principles of digital radiography with large-area, electronically readable detectors: a review of the basics. Radiology 210: 595-599 (1999).

C48 Chapman, D., W. Thomlinson, R.E. Johnston et al. Diffraction enhanced x-ray imaging. Phys. Med. Biol. 42: 2015-2025 (1997).

C49 Chisholm, R. Radiology guidelines. Clin. Radiol. 52: 409-411 (1997).

C50 Chissov, V.M. et al. (eds.). Malignant Neoplasms in Russia, 1980-1995. Moscow, 1998.

C51 Coderre, J.A. and G.M. Morris. The radiation biology of boron neutron capture therapy. Radiat. Res. 151(1): 1-18 (1999).

C52 Cho, P.S., K.L. Lindsley, J.G. Douglas et al. Digital radiotherapy simulator. Comput. Med. Imaging Graph. 22: 1-7 (1998).

C53 Cremonesi, M., M. Ferrari, E. Sacco et al. Radiation protection in radioguided surgery of breast cancer. Nucl. Med. Commun. 20: 919-924 (1999).

C54 Cosgriff, P.S. Quality assurance in renography: a review. Nucl. Med. Commun. 19: 711-716 (1998).

D1 Diaconescu, C., O. Iacob and D. Davidescu. An update on the frequency of medical x-ray examinations in Romania - 1990. Jurnal de Medicinã Preventivã 1(1): 9-13 (1993).

D2 DePuey, E.G. An update on radiopharmaceuticals for myocardial perfusion imaging. J. Nucl. Med. 35(4): 17N-20N (1994).

D3 Department of Health, United Kingdom. Quality assurance in radiotherapy: a quality management system for radiotherapy. Department of Health, London (1994).

D4 Dische, S. Advances in basic science: have they benefitted patients with cancer? Br. J. Radiol. 64: 1081-1091 (1991).

D5 Dimbylow, P.J. (ed.). Voxel phantom development. Proceedings of an International Workshop held at the National Radiological Protection Board, Chilton, UK (1995).

D6 Diaconescu, C., O. Iacob, T. Bostaca et al. Darkroom and photographic processing of exposed film: a national update. Jurnal de Medicinã Preventivã 4(4): 17-22 (1996).

D7 Drexler, G., W. Panzer, L. Widenmann et al. The calculation of dose from external photon exposures using reference human phantoms and Monte Carlo methods. Part III: Organ doses in x-ray diagnosis. GSF-Bericht 11/90 (1990).

D8 Davis, D.R., A.B. Miller and S.M. Love. Should screening mammography be performed for women 40-49 years of age? Med. Imag. Int. (July/August): 14-19 (1995).

D9 Diaconescu, C. and O. Iacob. Dental radiology: collective dose and risks. Jurnal de Medicinã Preventivã 2(1-2): 41-44 (1994).

D10 Dinsmore, M., K.J. Harte, A.P. Sliski et al. A new miniature x-ray source for interstitial radiosurgery: device description. Med. Phys. 23(1): 45-52 (1996).

D11 Dale, R.G. Dose-rate effects in targeted radiotherapy. Phys. Med. Biol. 41(10): 1871-1884 (1996).

D12 Duke, P.R. and J.A. Hanson. Compton scatter densitometry with polychromatic sources. Med. Phys. 11: 624-633 (1984).

D13 Derreumaux, S., J. Chavaudra, A. Bridier et al. A European quality assurance network for radiotherapy: dose measure-ment procedure. Phys. Med. Biol. 40: 1191-1208 (1995).

D14 Das, I.J. and K.R. Kase. Higher energy: is it necessary, is it worth the cost for radiation oncology? Med. Phys. 19(4): 917-925 (1992).

D15 Dobelbower, R.R. and M. Abe. Intraoperative Radiation Therapy. CRC Press, Florida, 1989.

D16 Dorn, R.V. Boron neutron capture therapy (BNCT): a radiation oncology perspective. Int. J. Radiat. Oncol. Biol. Phys. 28(5): 1189-1201 (1994).

D17 Dunscombe, P., P. McGhee and E. Lederer. Anthropomorphic phantom measurements for the validation of a treatment planning system. Phys. Med. Biol. 41: 399-411 (1996).

D18 Duch, M.A., M. Ginjaume, H. Chakkor et al. Thermoluminescence dosimetry applied to *in vivo* dose measurements for total body irradiation techniques. Radiother. Oncol. 47: 319-324 (1998).

D19 Das, I.J., C.-W. Cheng, D.A. Fein et al. Patterns of dose variability in radiation prescription of breast cancer. Radiother. Oncol. 44: 83-89 (1997).

D20 Dale, R.G. and B. Jones. The clinical radiobiology of brachytherapy. Br. J. Radiol. 71: 465-483 (1998).

D21 Donahue, B.R. and A.D. Steinfeld. Neutron therapy for pancreatic cancer: thirty years of unrealized promise. Radiology 200: 608-609 (1996).

D22 Duke, K. Radiotherapy in Nepal. Synergy (February): 20-21 (1998).

D23 de Wilde, J., C. Double and D. Bhachu. Report on MRI safety workshop, Washington, 1996. Diagn. Imag. Rev. 1(2): 5-9 (1997).

D24 Duncan, G., W. Duncan and E.J. Maher. Patterns of palliative radiotherapy in Canada. Clin. Oncol. 5: 92-97 (1993).

D25 Damilakis, J., K. Perisinakis, M. Koukourakis et al. Maximum embryo absorbed dose from intravenous urography: interhospital variations. Radiat. Prot. Dosim. 72(1): 61-65 (1997).

D26 Dearnaley, D.P., V.S. Khoo, A.R. Norman et al. Comparison of radiation side-effects of conformal and conventional radiotherapy in prostate cancer: a randomized trial. Lancet 353: 267-272 (1999).

D27 Directory of Radiotherapy Centres (DIRAC), IAEA. Communication to the UNSCEAR Secretariat (1999).

D28 Diaconescu, C., O. Iacob and D. Davidescu. 1995 review of dignostic x-ray exposures in Romania. Jurnal de Medicinã Preventivã 5(4): 31-38 (1997).

D29 Dzik-Jurasz, A.S.K. and E.A. Mumcuoglu. Does 100 mm photofluorography always have a dose advantage over conventional film-screen radiography in barium meals? Br. J. Radiol. 70: 168-171 (1997).

D30 Dewerd, L.A. and L.K. Wagner. Characteristics of radiation detectors for diagnostic radiology. Appl. Radiat. Isot. 50(1): 125-136 (1999).

D31 Dehen, L., C. Vilmer, C. Humiliere et al. Chronic radiodermatitis following cardiac catheterisation: a report of two cases and a brief review of the literature. Heart 81(3): 308-312 (1999).

D32 Dula, K., R. Mini, P.F. van der Stelt et al. Hypothetical mortality risk associated with spiral computed tomography of the maxilla and mandible. Eur. J. Oral Sci. 104(5-6): 503-510 (1996).

D33 Dean, L.M. and G.A. Taylor. Pediatric applications of spiral CT. p. 159-166 in: Spiral CT: Principles, Techniques and Clinical Applications (E.K. Fishman and R.B. Jeffrey, eds.). Raven Press, New York, 1995.

D34 Dixon, A.K. and P. Dendy. Spiral CT: how much does radiation dose matter? Lancet 352(9134): 1082-1083 (1998).

D35 Diederichs, C.G., H. Bruhn, M. Funke et al. Spiral-CT with reduced radiation dosage. RoeFo - Fortschr. Geb. Roentgenstr. Neuen Bildgebenden Verfahr. 164(3): 183-188 (1996).

D36 Daly, B. and P.A. Templeton. Real-time CT fluoroscopy: evolution of an interventional tool. Radiology 211: 309-315 (1999).

D37 Dixon, A.K. The appropriate use of computed tomography. Br. J. Radiol. 70: S98-S105 (1997).

D38 Dilmanian, F.A., X.Y. Wu, E.C. Parsons et al. Single- and dual-energy CT with monochromatic synchrotron x-rays. Phys. Med. Biol. 42: 371-387 (1997).

D39 Diederichs, C.G., W.G. Engelke, B. Richter et al. Must radiation dose for CT of the maxilla and mandible be higher than that for conventional panoramic radiography? Am. J. Neuroradiol. 17(9): 1758-1760 (1996).

D40 Dance, D.R., C.L. Skinner and G. Alm Carlsson. Breast dosimetry. Appl. Radiat. Isot. 50(1): 185-203 (1999).

D41 DeBruhl, N.D., L.W. Bassett, N.W. Jessop et al. Mobile mammography: results of a national survey. Radiology 201: 433-437 (1996).

D42 Doll, R. and R. Wakeford. Risk of childhood cancer from fetal irradiation. Br. J. Radiol. 70: 130-139 (1997).

D43 Dalla Palma, L., G. Grisi, R. Cuttin et al. Digital vs conventional radiography: cost and revenue analysis. Eur. Radiol. 9(8): 1682-1692 (1999).

D44 Dunn, M.A. and A.T. Rogers. X-ray film reject analysis as a quality indicator. Radiography 4: 29-31 (1998).

D45 Dale, R.G. and B. Jones. Enhanced normal tissue doses caused by tumour shrinkage during brachytherapy. Br. J. Radiol. 72: 499-501 (1999).

D46 Dutreix, J., M. Tubiana and B. Pierquin. The hazy dawn of brachytherapy. Radiother. Oncol. 49: 223-232 (1998).

D47 Deloar, H.M., T. Fujiwara and M. Shidahara. Internal absorbed dose estimation by a TLD method for ^{18}F-FDG and comparison with the dose estimates from whole body PET. Phys. Med. Biol. 44: 595-606 (1999).

E1 Elliot, A.T. and R.A. Shields. UK nuclear medicine survey, 1989/90. Nucl. Med. Commun. 14: 360-364 (1993).

E2 Erdi, A.K., Y.E. Erdi, E.D. Yorke et al. Treatment planning for radio-immunotherapy. Phys. Med. Biol. 41(10): 2009-2026 (1996).

E3 Edyvean, S., M.A. Lewis and J.F. Carden. CTDI: confusion and clarification. Br. J. Radiol. 65 (Congress Suppl.): 150 (1992).

E4 European Commission. European guidelines on quality criteria for computed tomography. EUR 16262 (1999).

E5 Edwards, C.R., M.H. Grieveson, P.J. Mountford et al. A survey of current *in vivo* radiotherapy dosimetry practice. Br. J. Radiol. 70: 299-302 (1997).

E6 Edwards, C.R., S. Green, J.E. Palethorpe et al. The response of a MOSFET, p-type semiconductor and LiF TLD to quasi-monoenergetic x-rays. Phys. Med. 42: 2383-2391 (1997).

E7 Ertl, A., M. Zehetmayer, A. Schöggl et al. Shuttle dose at the Vienna Leksell Gamma Knife. Phys. Med. Biol. 43: 1567-1578 (1998).

E8 Ertl, A., M. Zehetmayer, A. Schöggl et al. Dosimetry studies with TLDs for stereotactic radiation techniques for intraocular tumours. Phys. Med. Biol. 42: 2137-2145 (1997).

E9 Ekestubbe, A., A. Thilander, K. Gröndahl et al. Absorbed doses from computed tomography for dental implant surgery: comparison with conventional tomography. Dento-Maxillo-Facial Radiol. 22: 13-17 (1993).

E10 European Commission. Guidance on diagnostic reference levels (DRLs) for medical exposures. Radiation Protection 109 (1999).

E11 Elliot, A.T., F.M. Elliot and R.A. Shields. UK nuclear medicine survey, 1992-3. Nucl. Med. Commun. 17: 3-7 (1996).

E12 Ernst, E. Chiropractors' use of x-rays. Br. J. Radiol. 71: 249-251 (1998).

E13 Eklund, S., A. Thilander, W. Leitz et al. The impact of anatomic variations on absorbed radiation doses in mammography. Radiat. Prot. Dosim. 49(1/3): 167-170 (1993).

E14 European Commission. Guidance for protection of unborn children and infants irradiated due to parental medical exposures. Radiation Protection 110 (1998).

E15 Espenan, G.D., J.A. Nelson, D.R. Fisher et al. Experiences with high dose radiopeptide therapy: the health physics perspective. Health Phys. 76(3): 225-235 (1999).

E16 European Association of Nuclear Medicine. A radio-pharmaceutical schedule for imaging in paediatrics. Eur. J. Nucl. Med. 17: 127-129 (1990).

E17 Ell, P.J., D.C. Costa and J.H. McKillop. Nuclear medicine: neurology and psychiatry. J. Royal Coll. Phys. London 32(6): 529-536 (1998).

F1 Furhang, E.E., C.-S. Chui and G. Sgouros. A Monte Carlo approach to patient-specific dosimetry. Med. Phys. 23(9): 1523-1529 (1996).

F2 Flower, M.A. and S.L. Fielding. Radiation dosimetry for ^{131}I-mIBG therapy of neuroblastoma. Phys. Med. Biol. 41(10): 1933-1940 (1996).

F3 Fraass, B.A. The development of conformal radiation therapy. Med. Phys. 22(11): 1911-1921 (1995).

F4 Faulkner, K., H.G. Love, J.K. Sweeney et al. Radiation doses and somatic risk to patients during cardiac radiological procedures. Br. J. Radiol. 59: 359-363 (1986).

F5 Fischer, von H., C. Przetak, G. Teubert et al. Die Strahlenexposition des Radiologen bei Angiographien: Dosismessungen ausserhalb der Bleischürze. Fortschr. Röntgenstr. 162(2): 152-156 (1995).

F6 Faulkner, K. Communication to the UNSCEAR Secretariat (1995).

F7 Flioni-Vyza, A., S. Xenofos, G. Panayiotakis et al. Analysis of the results of a QC project on mammography in Greece. Radiat. Prot. Dosim. 57(1-4): 329-332 (1995).

F8 Ftacnikova, S. and P. Ragan. Radiation dose to the population of Slovak Republic from diagnostic nuclear medicine. Health Phys. 69(1): 16-20 (1995).

F9 Food and Drug Administration. Avoidance of serious x-ray-induced skin injuries to patients during fluoroscopically-guided procedures. Public Health Advisory Notice, 30 September 1994.

F10 Frischbier, H.-J., W. Hoeffken, B.-P. Robra et al. Mammographie in der Krebsfrüherkennung. Ergebnisse der Deutschen Mammographie-Studie. Ferdinand Enke Verlag, Stuttgart, 1994.

F11 Ferro de Carvalho, A. and J. Vaz Carreiro. Appendix 10; Radiation protection of the patient in Portugal. Radiat. Prot. Dosim. 57(1-4): 64-66 (1995).

F12 Friedman, W.A., J.M. Buatti, F.J. Bova et al. Linac Radiosurgery; A Practical Guide. Springer-Verlag, New York, 1998.

F13 Frederiksen, N.L., B.W. Benson and T.W. Sokolowski. Effective dose and risk assessment from film tomography used for dental implant diagnostics. Dento-Maxillo-Facial Radiol. 23: 123-127 (1994).

F14 Farjardo, L.C., R.A. Geise and E.R. Ritenour. A survey of films for use as dosimeters in interventional radiology. Health Phys. 68(4): 595-599 (1995).

F15 Feygelman, V.M., W. Huda and K.R. Peters. Effective dose equivalents to patients undergoing cerebral angiography. Am J. Neuroradiol. 13(3): 845-849 (1992).

F16 Fernández, J.M., E. Vaño and E. Guibelalde. Patient doses in hysterosalpingography. Br. J. Radiol. 69: 751-754 (1996).

F17 Faulkner, K., D.A. Broadhead and R.M. Harrison. Patient dosimetry measurement methods. Appl.Radiat. Isot. 50(1): 113-123 (1999).

F18 Faulkner, K., N.W. Marshall, A.R. Lecomber et al. Establishment of reference doses for examinations using digital fluoroscopy. Radiat. Prot. Dosim. 80(1-3): 129-134 (1998).

F19 Ford, N.L., D.R. Elfstrom, M.J. Yaffe et al. A comparison of image quality measurements among mammography facilities in Ontario. Med. Phys. 26(7): 1423 (1999).

F20 Faulkner, K. and K. Cranley. An investigation into variations in the estimation of mean glandular dose in mammography. Radiat. Prot. Dosim. 57(1-4): 405-407 (1995).

F21 Farmer, S. Computed radiography - influences on sensitivity and latitude. p. 288-297 in: Current Topics in Radiography-2 (A. Paterson and R. Price, eds.). W.B. Saunders, London, 1996.

F22 Farajollahi, A.R. and D. Sutton. Evaluation of a new ultraviolet-emitting rare-earth film-screen combination. Br. J. Radiol. 70: 629-634 (1997).

F23 Franken, Y. and Chr.J. Huyskens. Balancing the use of radiation in endovascular brachytherapy. p. 105-108 in: Proceedings of 6th SRP International Symposium, Southport, 14-18 June 1999 (M.C. Thorne, ed.). Society for Radiological Protection, London, 1999.

F24 Faraggi, M., I. Gardin, J.-L. Stievenart et al. Comparison of cellular and conventional dosimetry in assessing self-dose and cross-dose delivered to the cell nucleus by electron emissions of ^{99m}Tc, ^{123}I, ^{111}In, ^{67}Ga and ^{201}Tl. Eur. J. Nucl. Med. 25(3): 205-214 (1998).

F25 Forbes, E., S.E.M. Clarke, M. Buxton-Thomas et al. The development of regional nuclear medicine audit in South Thames. Nucl. Med. Commun. 18: 693-697 (1997).

F26 Freifelder, R. and J.S. Karp. Dedicated PET scanners for breast imaging. Phys. Med. Biol. 42: 2463-2480 (1997).

G1 Guibelalde, E., J.M. Fernández, E. Vañó et al. Image quality and patient dose for different screen-film combinations. Br. J. Radiol. 67: 166-173 (1994).

G2 Gordon, I. Effect of nuclear medicine on paediatric imaging. Br. J. Radiol. 66: 971-985 (1993).

G3 Galt, J.R. New instrumentation for cardiovascular nuclear medicine. J. Nucl. Med. 35(4): 20N-22N (1994).

G4 Gray, J.E. Fluoroscopy systems control, evaluation and performance. Proceedings of Workshop on Fluoroscopy organised by the American College of Radiology and the Food and Drug Administration, Washington (1992).

G5 Guglielmi, G., C.C. Glüer, S. Majumdar et al. Current methods and advances in bone densitometry. Eur. Radiol. 5: 129-139 (1995).

G6 Gaze, M.N. The current status of targeted radiotherapy in clinical practice. Phys. Med. Biol. 41(10): 1895-1903 (1996).

G7 Godden, T.J. Therapeutic uses of unsealed radionuclides. Chapter 2 in: Radiation Protection in Nuclear Medicine and Pathology, Report 63 (K.E. Goldstone, P.C. Jackson, M.J. Myers et al., eds.). Institute of Physical Sciences in Medicine, York, 1991.

G8 Greenfield, M.A. Current status of physical measurements of the skeleton. Med. Phys. 19(6): 1349-1357 (1992).

G9 Girolami, B., M. Larsson, M. Preger et al. Photon beams for radiosurgery produced by laser Compton backscattering from relativistic electrons. Phys. Med. Biol. 41: 1581-1596 (1996).

G10 Griffin, T.W. Fast neutron radiation therapy. CRC Crit. Rev. Oncol./Hematol. 13: 17-31 (1992).

G11 Gentry, J.R. and L.A. DeWerd. TLD measurements of *in vivo* mammographic exposures and the calculated mean glandular dose across the United States. Med. Phys. 23(6): 899-903 (1996).

G12 Gkanatsios, N.A., W. Huda and K. Peters. Patient doses in interventional neuroradiology. Med. Phys. 25(7) Part 1: A166 (1998).

G13 Gkanatsios, N.A. and W. Huda. Computation of energy imparted in diagnostic radiology. Med. Phys. 24(4): 571-579 (1997).

G14 Gfirtner, H., F.-E. Stieve and J. Wild. A new Diamentor for measuring kerma-area product and air-kerma simultaneously. Med. Phys. 24(12): 1954-1959 (1997).

G15 Gallen, C.C., E.C. Hirschkoff and D.S. Buchanan. Magnetoencephalography and magnetic source imaging. Neuroimaging Clin. North Am. 5(2): 227-249 (1995).

G16 Gambaccini, M., A. Taibi, A. Del Guerra et al. MTF evaluation of a phosphor-coated CCD for x-ray imaging. Phys. Med. Biol. 41: 2799-2806 (1996).

G17 Gkanatsios, N.A., W. Huda, K.R. Peters et al. Evaluation of an on-line patient exposure meter in neuroradiology. Radiology 203: 837-842 (1997).

G18 Geise, R.A., B.A. Schueler, W. Lien et al. Suitability of laser stimulated TLD arrays as patient dose monitors in high dose x-ray imaging. Med. Phys. 24(10): 1643-1646 (1997).

G19 Gordon, A.T. and T.J. McMillan. A role for molecular radiobiology in radiotherapy? Clin. Oncol. 9: 70-78 (1997).

G20 Gaze, M.N., C.G. Kelly, G.R. Kerr et al. Pain relief and quality of life following radiotherapy for bone metastases: a randomized trial of two fractionation schedules. Radiother. Oncol. 45: 109-116 (1997).

G21 Gabel, D. Present status and perspectives of boron neutron capture therapy. Radiother. Oncol. 30: 199-205 (1994).

G22 Green, S. Developments in accelerator based boron neutron capture therapy. Radiat. Phys. Chem. 51(4-6): 561-569 (1998).

G23 Georg, D., F. Julia, E. Briot et al. Dosimetric comparison of an integrated multileaf-collimator versus a conventional collimator. Phys. Med. Biol. 42: 2285-2303 (1997).

G24 Gleckler, M., J.D. Valentine and E.B. Silberstein. Calculating lens dose and surface dose rates from ^{90}Sr opthalmic applicators using Monte Carlo modelling. Med. Phys. 25(1): 29-36 (1998).

G25 Ganz, J.C. Gamma Knife Surgery. Second edition. Springer, Vienna, 1997.

G26 Goldstein, A. Exposure and dose in panoramic radiology. Med. Phys. 25(6): 1033-1040 (1998).

G27 Green, S., J.E. Palethorpe, D.E. Peach et al. Development of a calibration facility for test instrumentation in diagnostic radiology. Radiat. Prot. Dosim. 67(1): 41-46 (1996).

G28 Gregan, A.C.M., D. Peach and J.M. McHugo. Patient dosimetry in hysterosalpingography: a comparative study. Br. J. Radiol. 71: 1058-1061 (1998).

G29 Geleijns, J., J.J. Broerse, M.P. Chandie Shaw et al. A comparison of patient dose for examinations of the upper gastrointestinal tract at 11 conventional and digital x-ray units in the Netherlands. Br. J. Radiol. 71: 745-753 (1998).

G30 Geleijns, J., J.J. Broerse, M.P. Chandie Shaw et al. Patient dose due to colon examination: dose assessment and results from a survey in the Netherlands. Radiology 204: 553-559 (1997).

G31 Geiser, W.R., W. Huda and N.A. Gkanatsios. Effect of patient support pads on image quality and dose in fluoroscopy. Med. Phys. 24(3): 377-382 (1997).

G32 Granger, W.E., D.R. Bednarek and S. Rudin. Primary beam exposure outside the fluoroscopic field of view. Med. Phys. 24(5): 703-707 (1997).

G33 Ginsberg, G.M., T. Schlesinger, A. Ben-Shlomo et al. An economic evaluation of the use of rare earth screens to reduce the radiation dose from diagnostic x-ray procedures in Israel. Br. J. Radiol. 71: 406-412 (1998).

G34 Geise, R.A. and T.J. O'Dea. Radiation dose in interventional fluoroscopic procedures. Appl. Radiat. Isot. 50(1): 173-184 (1999).

G35 Gfirtner, H., E. Giesse and Th. Schmidt. Dosimetric methods for and influence of exposure parameters on the establishment of reference doses for examinations using fluoroscopy. Radiat. Prot. Dosim. 80(1-3): 121-128 (1998).

G36 Geleijns, J., J.J. Broerse, W.A. Hummel et al. Reference dose rates for fluoroscopy guided interventions. Radiat. Prot. Dosim. 80(1-3): 135-138 (1998).

G37 Goddard, C.C. and A. Al-Farsi. Radiation doses from CT in the Sultanate of Oman. Br. J. Radiol. 72: 1073-1077 (1999).

G38 Geleijns, J., J.G. van Unnik, J. Zoetelief et al. Comparison of two methods for assessing patient dose from computed tomography. Br. J. Radiol. 67: 360-365 (1994).

G39 Gosch, D., R. Kloeppel, S. Lieberenz et al. Radiation exposure in computed tomography. Radiat. Prot. Dosim. 80(1-3): 167-169 (1998).

G40 Giacomuzzi, von S.M., B. Erckert, T. Schöpf et al. The Smart-Scan-technique in spiral computed tomography; a new method for dose reduction. Fortschr. Röntgenstr. 165(1): 10-16 (1996).

G41 Grampp, S., C.B. Henk and H. Imhof. Clinical application of densitometry. Der Radiologe 39(3): 222-227 (1999).

G42 Gilsanz, V. Bone density in children: a review of the available techniques and indications. Eur. J. Radiol. 26: 177-182 (1998).

G43 González, L., E. Vañó, S. Oliete et al. Report of an image quality and dose audit according to Directive 97/43/Euratom at Spanish private radiodiagnostics facilities. Br. J. Radiol. 72: 186-192 (1999).

G44 Grätz, M., L. Kiernan and K. Herrlin. Time-gated imaging in planar and tomographic x-ray imaging. Med. Phys. 26(3): 438-446 (1999).

G45 Gahbauer, R., N. Gupta, T. Blue et al. BNCT: status and dosimetry requirements. Radiat. Prot. Dosim. 70(1-4): 547-554 (1997).

G46 Gershkevitsh, E., I. Rosenberg, D.P. Dearnaley et al. Bone marrow doses and leukaemia risk in radiotherapy of prostate cancer. Radiother. Oncol. 53: 189-197 (1999).

G47 Gadd, R., P.J. Mountford and J.W. Oxtoby. Effective dose to children and adolescents from radiopharmaceuticals. Nucl. Med. Commun. 20: 569-573 (1999).

G48 Groth, S. and A. Padhy. The role of the IAEA in nuclear medicine. Eur. J. Nucl. Med. 26: 73-75 (1999).

G49 Glass, D. and A.M. Peters. Current trends in nuclear medicine. p. 259-269 in: Current Topics in Radiography - 2 (A. Paterson and R. Price, eds.). W.B. Saunders, London, 1996.

G50 Goris, M.L. and H.W Strauss. Predictions for nuclear medicine in the next decade. Radiology 208: 3-5 (1998).

G51 Graham, M.C., K.S. Pentlow, O. Mawlawi et al. An investigation of the physical characteristics of ^{66}Ga as an isotope for PET imaging and quantification. Med. Phys. 24(2): 317-326 (1997).

G52 Green, S., J.E. Palethorpe, D. Peach et al. Performance assessment of patient dosimetry services and x-ray quality assurance instruments used in diagnostic radiology. Appl. Radiat. Isot. 50(1): 137-152 (1999).

H1 Hendee, W.R. and J.H. Trueblood (eds.). Digital Imaging. American Association of Physicists in Medicine, Medical Physics Monograph No. 22. Medical Physics Publishing, Madison, 1993.

H2 Haywood, J. Radiotherapy accidents in Europe - a preliminary report. Scope 2(1): 45-46 (1993).

H3 Hughes, J.S. and M.C. O'Riordan. Radiation exposure of the UK population - 1993 review. NRPB-R263 (1993).

H4 Hansen, V.N., P.M. Evans and W. Swindell. The application of transit dosimetry to precision radiotherapy. Med. Phys. 23(5): 713-721 (1996).

H5 Huda, W. and N.A. Gkanatsios. Effective dose and energy imparted in radiology. Med. Phys. 28(4): 1311-1316 (1997).

H6 Huyskens, C.J. and W.A. Hummel. Data analysis on patient exposures in cardiac angiography. Radiat. Prot. Dosim. 57(1/4): 475-480 (1995).

H7 Hagekyriakou, J. and M.A. Chaudhri. Radiation exposures to patients during cardiac angiography and coronary angioplasty. p. 732-735 in: Radiation Protection in Practice. Proceedings of the 7th International Congress of the International Radiation Protection Association, Sydney, 1988.

H8 Hoffman, E., A. Gerth and G. Steinbeck. Communication to the UNSCEAR Secretariat (1995).

H9 Hart, D. and J.C. Le Heron. The distribution of medical x-ray doses amongst individuals in the British population. Br. J. Radiol. 65: 996-1002 (1992).

H10 Hart, D. and B.F. Wall. Potentially higher patient radiation doses using digital equipment for barium studies. Br. J. Radiol. 68: 1112-1115 (1995).

H11 Hart, D., M.C. Hillier, B.F. Wall et al. Doses to patients from medical x-ray examinations in the UK - 1995 review. NRPB-R289 (1996).

H12 Huda, W. and R.L. Morin. Patient doses in bone mineral densitometry. Br. J. Radiol. 69: 422-425 (1996).

H13 Heijmen, B.J.M., K.L. Pasma, M. Kroonwijk et al. Portal dose measurement in radiotherapy using an electronic portal imaging device (EPID). Phys. Med. Biol. 40: 1943-1955 (1995).

H14 Heydarian, M., P.W. Hoban and A.H. Beddoe. A comparison of dosimetry techniques in stereotactic radiosurgery. Phys. Med. Biol. 41: 93-110 (1996).

H15 Hart, D., D.G. Jones and B.F. Wall. Normalised organ doses for medical x-ray examinations calculated using Monte Carlo techniques. NRPB-SR262 (1994).

H16 Hart, D., D.G. Jones and B.F. Wall. Normalised organ doses for paediatric x-ray examinations calculated using Monte Carlo techniques. NRPB-SR279 (1996).

H17 Hendrick, R.E., L.W. Bassett, G.D. Dodd et al. American College of Radiology Mammography Quality Control Manual. ACR, Reston, Va., 1994.

H18 Huda, W., G. Sandison, R.F. Palser et al. Radiation doses and detriment from chest x-ray examination. Phys. Med. Biol. 34: 1477-1492 (1989).

H19 Hokkanen, J., J. Heikkonen and P. Holmberg. Theoretical calculations of dose distributions for beta-ray eye applicators. Med. Phys. 24(2): 211-213 (1997).

H20 Hanson, G., J. Stjernsward, M. Nofal et al. An overview of the situation in radiotherapy with emphasis on developing countries. Int. J. Radiat. Oncol. Biol. Phys. 19: 1257-1261 (1990).

H21 Huda, W. and N.A. Gkanatsios. Radiation dosimetry for extremity radiographs. Health Phys. 75(5): 492-499 (1998).

H22 Hufton, A.P., S.M. Doyle and H.M.L. Carty. Digital radiography in paediatrics: radiation dose considerations and magnitude of possible dose reduction. Br. J. Radiol. 71: 186-199 (1998).

H23 Huda, W. and K.R. Peters. Radiation-induced temporary epilation after a neuroradiologically guided embolization procedure. Radiology 193: 642-644 (1994).

H24 Heyne, J.P., C. Schleicher, J. Soldner et al. Radiation exposure of the ocular lens and thyroid gland in digital subtraction angiography of brain-supplying arteries. RoeFo Fortschr. Geb. Roentgenstr. Neuen Bildgebenden Verfahr. 167(5): 479-485 (1997).

H25 Hoskins, P.R., I. Gillespie and H.M. Ireland. Patient dose measurements from femoral angiography. Br. J. Radiol. 69: 1159-1164 (1996).

H26 Holmes, D.R., M.A. Wondrow, J.E. Gray et al. Effect of pulsed progressive fluoroscopy on reduction of radiation dose in the cardiac catheterization laboratory. J. Am. Coll. Cardiol. 15(1): 159-162 (1990).

H27 Hidajat, N., Th. Vogel, G. Biamino et al. Radiation exposure in interventional radiology as demonstrated by chemoembolisation of hepatocellular carcinoma and laser angioplasty of the pelvic arteries. Fortschr. Roentgenstr. 164(3): 249-256 (1996).

H28 Hamed, A.A., N. Elshirbiny and M.H. Nassef. Study of radiation exposure dependence on the physical parameters of medical diagnostic x ray machines. Radiat. Prot. Dosim. 82(4): 277-283 (1999).

H29 Hering, E.R., T.J. van W. Kotze and G.J. Maree. An estimation of the genetically significant dose from diagnostic radiology for the South African population, 1990-1991. Health Phys. 74(4): 419-428 (1998).

H30 Hanson, G. WHO and rational reduction of patient dose. Radiat. Prot. Dosim. 57(1-4): 27-32 (1995).

H31 Hjardemaal, O. An overview of radiation protection and QA in diagnostic radiology at national level in Denmark. Radiat. Prot. Dosim. 57(1-4): 37-39 (1995).

H32 Hernandez, J.M.M. Medical physics in Cuba. Med. Phys. World 11(1): 6 (1995).

H33 Hiles, P.A., S.A. Scott, S.E. Brennen et al. All Wales CT dose and technique survey. Report by the Medical Imaging Sub-committee of the Welsh Scientific Advisory Committee. Welsh Office, Cardiff (1996).

H34 Hidajat, N., T. Vogel, R.J. Schroder et al. Calculated organ doses and effective dosage for computerized tomography examination of the thorax and abdomen: are these doses realistic? RoeFo - Fortschr. Geb. Roentgenstr. Neuen Bildgebenden Verfahr. 164(5): 382-387 (1996).

H35 Hidajat, N., R.J. Schroder, T. Vogel et al. The efficacy of lead shielding in patient dosage reduction in computed tomography. RoeFo - Fortschr. Geb. Roentgenstr. Neuen Bildgebenden Verfahr. 165(5): 462-465 (1996).

H36 Hopper, K.D., S.H. King, M.E. Lobell et al. The breast: in-plane x-ray protection during diagnostic thoracic CT-shielding with bismuth radioprotective garments. Radiology 205: 853-858 (1997).

H37 Hentschel, D., K. Klingenbeck-Regn, S. Popescu et al. Reduced patient dose and improved image quality in computed tomography examinations with on-line anatomically adapted tube current modulation. Radiat. Prot. Dosim. 80(1-3): 287-289 (1998).

H38 Huda, W., J.V. Atherton, D.E. Ware et al. An approach for the estimation of effective radiation dose at CT in pediatric patients. Radiology 203: 417-422 (1997).

H39 Heiken, J.P., J.A. Brink and M.W. Vannier. Spiral (helical) CT. Radiology 189: 647-656 (1993).

H40 Hidajat, N., R.-J. Schröder, T. Vogel et al. Dose distribution in conventional CT and spiral CT and the question of dose reduction in spiral CT. Der Radiologe 38(5): 438-443 (1998).

H41 Hu, H. Multi-slice helical CT: scan and reconstruction. Med. Phys. 26(1): 5-18 (1999).

H42 Hidajat, N., J. Mäurer, R.-J. Schröder et al. Relationships between physical dose quantities and patient dose in CT. Br. J. Radiol. 72: 556-561 (1999).

H43 Hill, A.L. Half value layer measurements to facilitate patient dose assessment for newer CT scanners using published normalized dose data. Br. J. Radiol. 72: 792-798 (1999).

H44 Hansell, D.M. Thoracic imaging - then and now. Br. J. Radiol. 70: S153-S161 (1997).

H45 Higashida, Y., Y. Murakami, A. Yoshida et al. Basic imaging properties of a new screen-film system for chest radiography. Med. Phys. 23(8): 1351-1357 (1996).

H46 Huda, W., R.M. Slone, C.J. Belden et al. Mottle on computed radiographs of the chest in pediatric patients. Radiology 199: 249-252 (1996).

H47 Heesewijk, J.P.M. van and J.C. de Valois. Clinical evaluation of a new digital chest imaging system. Eur. Radiol. 5: 83-87 (1995).

H48 Heggie, J.C.P. Survey of doses in screening mammo-graphy. Australas. Phys. Eng. Sci. Med. 19(4): 207-216 (1996).

H49 Hartley, L.D., B.J. Cobb and D.E. Hutchinson. Estimating mean glandular dose using propriety mammography phantoms. Appl. Radiat. Isot. 50(1): 205-213 (1999).

H50 Holje, G., O. Jarlman and L. Samuelsson. Radiation doses and image imformation in digital pelvimetry with a phosphorous screen. Acta Radiol. 38: 181-184 (1997).

H51 Hintenlang, K.M. Predicted radiation dose and risk associated with pediatric diagnostic x-ray procedures. Med. Phys. 26(6): 1021 (1999).

H52 Hansson, B., T. Finnbogason and B. Axelsson. Dose distribu-tions and image quality in paediatric colon examinations: assessment of effective dose and conversion coefficients. Radiat. Prot. Dosim. 80(1-3): 307-310 (1998).

H53 Hejazi, S. and D.P. Trauernicht. System considerations in CCD-based x-ray imaging for digital chest radiography and digital mammography. Med. Phys. 24(2): 287-297 (1997).

H54 Hricak, H., D. Adams, C. D'Orsi et al. Radiology: a partner in clinical care. Radiology 209: 297-302 (1998).

H55 Hendee, W.R. Realizing the true potential of medical imaging. Radiology 209: 604-605 (1998).

H56 Hashizume, T., H. Matsuzawa, T. Maruyama et al. Population doses from beam therapy in Japan, 1978. Part 2: Estimation of genetically significant dose, *per caput* mean bone marrow dose and leukemia significant dose. Nippon Acta Radiol. 40: 466-475 (1980).

H57 Hashizume, T., H. Matsuzawa, T. Maruyama et al. Population doses from beam therapy in Japan, 1978. Part 3: Estimation of malignancy significant dose and fatal malignant risk. Nippon Acta Radiol. 41: 158-167 (1981).

H58 Hounsell, A.R. and J.M. Wilkinson. Electron contamination and build-up doses in conformal radiotherapy fields. Phys. Med. Biol. 44: 43-55 (1999).

H59 Hesse, B.M., L. Spies and B.A. Groh. Tomotherapeutic portal imaging for radiation treatment verification. Phys. Med. Biol. 43: 3607-3616 (1998).

H60 Hoefnagel, C.A., S.E.M. Clarke, M. Fischer et al. Radionuclide therapy practice and facilities in Europe. Eur. J. Nucl. Med. 26: 277-282 (1999).

H61 Howell, R.W., S.M. Goddu and D.V. Rao. Proliferation and the advantage of longer-lived radionuclides in radioimmunotherapy. Med. Phys. 25(1): 37-42 (1998).

H62 Health and Safety Executive. Fitness of equipment used for medical exposure to ionising radiation. Guidance Note PM77 (2nd ed.). HSE, London (1998).

H63 Hofer, K.G. Dosimetry and biological effects of incorporated Auger emitters. Radiat. Prot. Dosim. 79(1-4): 405-410 (1998).

H64 Hawkins, R.A. and C.K. Hoh. PET FDG studies in oncology. Nucl. Med. Biol. 21(5): 739-747 (1994).

I1 International Standards Organisation. Quality systems - model for quality assurance in production and installation. ISO 9002 (1987).

I2 IAEA/WHO/ILO/CEC/PAHO. Manual on radiation protection in hospitals and in general practice. (2000, to be published).

I3 International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Annals of the ICRP 21(1-3). Pergamon Press, Oxford, 1991.

I4 International Atomic Energy Agency. Radiation doses in diagnostic radiology and methods for dose reduction. IAEA-TECDOC 796 (1995).

I5 International Atomic Energy Agency. International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. Safety Series 115. IAEA, Vienna (1996).

I6 Iacob, O. and C. Diaconescu. Collective effective dose from diagnostic nuclear medicine procedures. Jurnal de Medicinã Preventivã 3(1-2): 37-43 (1995).

I7 International Commission on Radiological Protection. Recommendations of the ICRP. ICRP Publication 26. Annals of the ICRP 1(3). Pergamon Press, Oxford, 1977.

I8 International Atomic Energy Agency. Cobalt-60 teletherapy: a compendium of international practice. IAEA, Vienna (1984).

I9 International Atomic Energy Agency. Radiotherapy in developing countries. Proceedings Series. IAEA, Vienna (1987).

I10 International Atomic Energy Agency. Dosimetry in radiotherapy. Proceedings Series. IAEA, Vienna (1988).

I11 International Commission on Radiation Units and Measurements. Measurement of absorbed dose in a phantom irradiated by a single beam of X or gamma rays. ICRU Report 23 (1973).

I12 International Commission on Radiation Units and Measurements. Determination of absorbed dose in a patient irradiated by beams of X or gamma rays in radiotherapy procedures. ICRU Report 24 (1976).

I13 International Commission on Radiation Units and Measurements. Radiation dosimetry: electron beams with energies between 1 and 50 MeV. ICRU Report 35 (1984).

I14 International Commission on Radiation Units and Measurements. Dose and volume specification for reporting intracavitary therapy in gynaecology. ICRU Report 38 (1985).

I15 International Commission on Radiation Units and Measurements. Use of computers in external beam radiotherapy procedures with high-energy photons and electrons. ICRU Report 42 (1987).

I16 International Commission on Radiation Units and Measurements. Prescribing, recording and reporting photon beam therapy. ICRU Report 50 (1993).

I17 International Commission on Radiological Protection. Radiological protection and safety in medicine. ICRP Publication 73. Annals of the ICRP 26(2). Pergamon Press, Oxford, 1996.

I18 Iacob, O., C. Diaconescu, C. Cotrutz et al. Patient exposure during fluoroscopic x-ray examinations. Jurnal de Medicinã Preventivã 2(3-4): 35-39 (1994).

I19 International Commission on Radiological Protection. Radiation dose to patients from radiopharmaceuticals. Addendum 1 to Publication 53. ICRP Publication 62. Annals of the ICRP 22(3). Pergamon Press, Oxford, 1991.

I20 International Atomic Energy Agency. Absorbed dose determination in photon and electron beams: an international code of practice. Technical Reports Series No. 277 (second edition). IAEA, Vienna (1997).

I21 International Commission on Radiation Units and Measurements. Dose and volume specification for reporting interstitial therapy. ICRU Report 58 (1997).

I22 International Commission on Radiological Protection. Radiological protection in biomedical research. ICRP Publication 62. Annals of the ICRP 22(3). Pergamon Press, Oxford, 1991.

I23 Institute of Medicine. Radiation in Medicine; A Need for Regulatory Reform. National Academy Press, Washington, 1996.

I24 International Atomic Energy Agency. Tomography in nuclear medicine. Proceedings Series. IAEA, Vienna (1996).

I25 International Atomic Energy Agency. Accidental overexposure of radiotherapy patients in San José, Costa Rica. IAEA, Vienna (1998).

I26 Itoh, S., M. Ikeda, T. Isomura et al. Screening helical CT for mass screening of lung cancer: application of low-dose and single-breath-hold scanning. Radiat. Med. 16(2): 75-83 (1998).

I27 Iinuma, T.A., Y. Tateno, Y. Umegaki et al. Proposed system for ultrafast computed tomography. J. Comput. Assist. Tomogr. 1(4): 494-499 (1977).

I28 Iacob, O. and C. Diaconescu. An attempt to establish the reference dose levels in diagnostic radiology. Jurnal de Medicinã Preventivã 7(3): 31-38 (1999).

I29 Ishigaki, T., T. Endo, M. Ikeda et al. Subtle pulmonary disease: detection with computed radiography versus conventional chest radiography. Radiology 201: 51-60 (1996).

I30 Iwai, K., K.-I. Ejima, Y. Arai et al. Nationwide survey of dental radiographic examination in Japan, 1994. Dent. Radiol. 38(3): 164-173 (1998).

I31 Iacob, O., C. Diaconescu and E. Botezatu. An update of exposures from natural and artificial ionizing radiation sources in Romania. Jurnal de Medicinã Preventivã 6(3): 7-16 (1998).

I32 Ingal, V.N., E.A. Beliaevskaya, A.P. Brianskaya et al. Phase mammography - a new technique for breast investigation. Phys. Med. Biol. 43: 2555-2567 (1998).

I33 International Commission on Radiation Units and Measurements. Clinical proton dosimetry. Part 1: beam production, beam delivery and measurement of absorbed dose. ICRU Report 59 (1998).

I34 International Atomic Energy Agency. Modern trends in radiopharmaceuticals for diagnosis and therapy. IAEA-TECDOC-1029. IAEA, Vienna (1998).

I35 International Commission on Radiation Units and Measurements. Methods of assessment of absorbed dose in clinical use of radionuclides. ICRU Report 32 (1979).

I36 Iacob, O. and C. Diaconescu. Exposure from diagnostic nuclear medicine procedures in Romania. Jurnal de Medicinã Preventivã 5(4): 39-46 (1997).

I37 International Commission on Radiological Protection. Radiation dose to patients from radiopharmaceuticals. ICRP Publication 53. Annals of the ICRP 18(1-4). Pergamon Press, Oxford, 1987.

I38 International Commission on Radiological Protection. Summary of the current ICRP principles for protection of the patient in nuclear medicine. ICRP Publication 68. Annals of the ICRP 24(4). Pergamon Press, Oxford, 1994.

I39 International Commission on Radiological Protection. Radiation dose to patients from radiopharmaceuticals. Addendum to Publication 53. ICRP Publication 80. Annals of the ICRP 28(3). Pergamon Press, Oxford, 1998.

I40 International Atomic Energy Agency. Lessons learned from accidental exposures in radiotherapy. Safety Report Series No. 17. IAEA, Vienna (2000).

J1 Jones, G., H. Lukka and B. O'Brien. High dose rate *versus* low dose rate brachytherapy for squamous cell carcinoma of the cervix: an economic analysis. Br. J. Radiol. 67: 1113-1120 (1994).

J2 Jones, A.P. Factors affecting patient dose. Chapter 4 in: Safety in Diagnostic Radiology. IPSM Report No. 72. IPSM, York, 1995.

J3 Jones, D.G. and P.C. Shrimpton. Normalised organ doses for x-ray computed tomography calculated using Monte Carlo techniques. NRPB-SR250 (1993).

J4 Jankowski, J., M.A. Staniszewska, A. Bednarek et al. A comparison of patient doses in lumbar spine radiography from various x-ray units in Poland. Pol. J. Med. Phys. Eng. 1(2): 83-87 (1995).

J5 Johnston, R.E., D. Washburn, E. Pisano et al. Mammographic phantom studies with synchrotron radiation. Radiology 200: 659-663 (1996).

J6 Jones, D.G. A realistic anthropomorphic phantom for calculating organ doses arising from external photon irradiation. Radiat. Prot. Dosim. 72(1): 21-29 (1997).

J7 Janicki, C., D.M. Duggan, C.W. Coffey et al. Radiation dose from a phosphorus-32 impregnated wire mesh vascular stent. Med. Phys. 24(3): 437-445 (1997).

J8 Jarritt, P.H. and P.D. Acton. PET imaging using gamma camera systems: a review. Nucl. Med. Commun. 17: 758-766 (1996).

J9 Jolesz, F.A. Image-guided procedures and the operating room of the future. Radiology 204: 601-612 (1997).

J10 Johnston, D. An investigation into current radiation dose levels for patients undergoing common diagnostic x-ray examinations in Irish hospitals and the establishment of national reference dose levels. M.Med.Sc. Thesis, University College, Dublin (1999).

J11 Japan Radioisotope Association (Medical and Pharmaceutical Committee). The present state of nuclear medicine practice in Japan - a report of the 3rd nationwide survey in 1992. Radioisotopes 42: i-xxi (1993).

J12 Jansen, J.Th.M., J. Geleijns, D. Zweers et al. Calculation of computed tomography dose index to effective dose conversion factors based on measurement of the dose profile along the fan shaped beam. Br. J. Radiol. 69: 33-41 (1996).

J13 Jessen, K.A., P.C. Shrimpton, J. Geleijns et al. Dosimetry for optimisation of patient protection in computed tomography. Appl. Radiat. Isot. 50(1): 165-172 (1999).

J14 Jergas, M. and G. Schmid. Conventional radiology of osteoporosis and radiographic absorptiometry. Der Radiologe 39(3): 174-185 (1999).

J15 Jónsson, Á., K. Herrlin, K. Jonsson et al. Radiation dose reduction in computed skeletal radiography. Acta Radiol. 37: 128-133 (1996).

J16 Jones, D., National Accelerator Centre, South Africa. Communication to the UNSCEAR Secretariat (1999).

J17 Jones, B., P.L. Pryce, P.R. Blake et al. High dose rate brachytherapy practice for the treatment of gynaecological cancers in the UK. Br. J. Radiol. 72: 371-377 (1999).

J18 Jani, S.K. Physics of vascular brachytherapy. J. Invas. Cardiol. 11(8): 517-523 (1999).

J19 Jones, D.G. A realistic anthropomorphic phantom for calculating specific absorbed fractions of energy deposited from internal gamma emitters. Radiat. Prot. Dosim. 79(1-4): 411-414 (1998).

J20 Johnson, T.K., D. McClure and S. McCourt. MABDOSE. I: Characterisation of a general purpose estimation code. Med. Phys. 26(7): 1389-1395 (1999).

J21 Johnson, T.K., D. McClure and S. McCourt. MABDOSE. II: Validation of a general purpose estimation code. Med. Phys. 26(7): 1396-1403 (1999).

J22 Jansen, H.M., R.A. Dierckx, J.M. Hew et al. Positron emission tomography in primary brain tumours using cobalt-55. Nucl. Med. Commun. 18: 734-740 (1997).

J23 Jones, T. Strategy for creating accurate functional imaging with PET and its relevance to SPECT. p. 81-88 in: Tomography in Nuclear Medicine. Proceedings Series. IAEA, Vienna, 1996.

K1 Kaiser, W.A. MRM promises earlier breast cancer diagnosis. Diagn. Imag. Int. 11/12: 44-50 (1992).

K2 Khaw, B.A., H.W. Strauss and J. Narula. "Magic bullets": from muskets to smart bombs. J. Nucl. Med. 34(12): 2264-2268 (1993).

K3 Kutcher, G.J., L. Coia, M. Gillin et al. Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40. Med. Phys. 21(4): 581-618 (1994).

K4 Kohn, M.M., B.M. Moores, H. Schibilla et al. European guidelines on quality criteria for diagnostic radiographic images in paediatrics. EUR 16261 EN (1996).

K5 Karppinen, J., T. Parviainen, A. Servomaa et al. Radiation risk and exposure of radiologists and patients during coronary angiography and percutaneous transluminal coronary angioplasty (PTCA). Radiat. Prot. Dosim. 57(1/4): 481-485 (1995).

K6 Kruger, D.G., C.C. Abreu, E.G. Hendee et al. Imaging characteristics of x-ray capillary optics in digital mammography. Med. Phys. 23(2): 187-196 (1996).

K7 Kusama, T., M. Kai, E. Yabuuchi et al. Dose estimates for patients receiving radiation from various instruments used for measuring bone mass and density. Radiat. Prot. Dosim. 58(2): 149-151 (1995).

K8 Kubo, H.D. and B.C. Hill. Respiration gated radiotherapy treatment: a technical study. Phys. Med. Biol. 41: 83-91 (1996).

K9 Kanai, T. and E. Takada (eds.) Proceedings of NIRS International Seminar on the Application of Heavy Ion Accelerator to Radiation Therapy of Cancer. NIRS-M-103 (1994).

K10 Klevenhagen, S.C., R.J. Aukett, R.M. Harrison et al. The IPEMB code of practice for the determination of absorbed dose for x-rays below 300 kV generating potential (0.035 mm Al - 4 mm Cu HVL; 10-300 kV generating potential). Phys. Med. Biol. 41: 2605-2625 (1996).

K11 Knox, H.H. and R.M. Gagne. Alternative methods of obtaining the computed tomography dose index. Health Phys. 71(2): 219-224 (1996).

K12 Kaul, A., B. Bauer, J. Bernhardt et al. Effective doses to members of the public from the diagnostic application of ionizing radiation in Germany. Eur. Radiol. 7: 1127-1132 (1997).

K13 Kumamoto, Y. and T. Maruyama. Application of age- and gender-specific probability coefficients to the barium meal examination in Japan. Health Phys. 68: 827-831 (1995).

K14 Kubo, H.D., G.P. Glasgow, T.D. Pethel et al. High dose-rate brachytherapy treatment delivery: Report of the AAPM Radiation Therapy Committee Task Group 59. Med. Phys. 25(4): 375-403 (1998).

K15 Karlsson, M.G., M. Karlsson and B. Zackrisson. Intensity modulation with electrons: calculations, measurements and clinical applications. Phys. Med. Biol. 43: 1159-1169 (1998).

K16 Krasikova, R.N. and G.E. Kodina. Radionuclides and radiopharmaceuticals for single-photon emission tomography, positron emission tomography and radiotherapy in Russia. Eur. J. Nucl. Med. 26(7): 774-788 (1999).

K17 Kase, K.R., X.S. Mao, W.R. Nelson at al. Neutron fluence and energy spectra around the Varian Clinac 2100C/ 2300C medical accelerator. Health Phys. 74(1): 38-47 (1998).

K18 Kalmykov, L., N. Pilipenko and V. Korneeva. Collective doses and radiation risks due to medical diagnostic exposures in Ukraine. Radiat. Prot. Dosim. 69(4): 275-280 (1997).

K19 Kyriou, J.C., M. Fitzgerald, A. Pettett et al. A comparison of doses and techniques between specialist and non-specialist centres in the diagnostic x-ray imaging of children. Br. J. Radiol. 69: 437-450 (1996).

K20 Kalifa, G., Y. Charpak, C. Maccia et al. Evaluation of a new low-dose digital x-ray device: first dosimetric and clinical results in children. Pediatr. Radiol. 28: 557-561 (1998).

K21 Kuan, H., J. Manzione, J. Ferretti et al. Monitoring and reducing patient radiation exposure during interventional procedures by direct portal film dosimetry. Med. Phys. 25(7): A167 (1998).

K22 Knautz, M.A., D.C. Abele and T.L. Reynolds. Radiodermatitis after transjugular intrahepatic portosystemic shunt. South. Med. J. 90(3): 352-356 (1997).

K23 Kicken, P.J., G.J. Kemerink, P.J. Vaessen et al. An automated measurement system for characterisation of patient exposure during angiography. Radiat. Prot. Dosim. 43(1-4): 165-199 (1992).

K24 Kron, T. Applications of thermoluminescence dosimetry in medicine. Radiat. Prot. Dosim. 85(1-4): 333-340 (1999).

K25 Kezerashvili, M., D.R. Bednarek and S. Rudin. Automatic system for measuring dose-area product (DAP) in ROI fluoroscopy. Phys. Med. Biol. 42: 613-623 (1997).

K26 Kemerink, G.J., P.J.H. Kicken, F.W. Schulz et al. Patient dosimetry in abdominal arteriography. Phys. Med. Biol. 44: 1133-1145 (1999).

K27 Kicken, P.J.H., M. Zankl and G.J. Kemerink. Patient dosimetry in arteriography of the lower limbs. Part II: dose conversion coefficients, organ doses and effective dose. Radiat. Prot. Dosim. 81(1): 37-45 (1999).

K28 Kicken, P.J.H., G.J. Kemerink and J.M.A. van Engelshoven. Patient dosimetry in arteriography of the lower limbs. Part I: quantification of exposure. Radiat. Prot. Dosim. 81(1): 25-36 (1999).

K29 Krasovec, M. and R.M. Trueb. Temporary roentgen epilation after embolization of a cerebral arteriovenous malformation. Hautarzt 49(4): 307-309 (1998).

K30 Kalender, W.A. Computed tomography: influence of exposure parameters and the establishment of reference dose values. Radiat. Prot. Dosim. 80(1-3): 163-166 (1998).

K31 Kalender, W.A., H. Wolf, C. Suess et al. Dose reduction in CT by on-line tube current control: principles and validation on phantoms and cadavers. Eur. Radiol. 9: 323-328 (1999).

K32 Kearney, S.E., P. Jones, K. Meakin et al. CT scanning of the paranasal sinuses - the effect of reducing mAs. Br. J. Radiol. 70: 1071-1074 (1997).

K33 Kalender, W.A. Technical foundations of spiral CT. Semin. Ultrasound, CT, MRI 15(2): 81-89 (1994).

K34 Kalender, W.A. Grundlagen und Technik der Spiral-CT. Der Radiologe 39(9): 809-819 (1999).

K35 Kuntz, R., M. Skalej and A. Stefanou. Image quality of spiral CT versus conventional CT in routine brain imaging. Eur. J. Radiol. 26: 235-240 (1998).

K36 Kalender, W.A., K. Wedding, A. Polacin et al. Basic principles of vascular imaging by spiral CT. Aktuelle Radiol. 4: 287-297 (1994).

K37 Kauczor, H.-U., P. Mildenberger and M. Thelen. Helical computed tomography angiography: technical considerations and clinical applications. Radiography 3: 3-15 (1997).

K38 Katada, K., R. Kato, H. Anno et al. Guidance with real-time CT fluoroscopy: early clinical experience. Radiology 200: 851-856 (1996).

K39 Kato, R., K. Katada, H. Anno et al. Radiation dosimetry at CT fluoroscopy: physician's hand dose and development of needle holders. Radiology 201: 576-578 (1996).

K40 Klingenbeck-Regn, K., S. Schaller, T. Flohr et al. Subsecond multi-slice computed tomography: basics and applications. Eur. J. Radiol. 31: 110-124 (1999).

K41 Kalender, W.A., B. Schmidt, M. Zankl et al. A PC program for estimating organ dose and effective dose values in computed tomography. Eur. Radiol. 9: 555-562 (1999).

K42 Katoh, T., A. Hayami, Y. Harata et al. Variation of organ doses with tube potential and total filtration in dental radiography. Radiat. Prot. Dosim. 49(1/3): 117-119 (1993).

K43 Kruger, R. and B. Schueler. A mean glandular dose patient survey of 6006 women undergoing mammography. Med. Phys. 26(6): 1071 (1999).

K44 Kimme-Smith, C. New digital mammography systems may require different x-ray spectra and, therefore, more general normalized glandular dose values. Radiology 213: 7-10 (1999).

K45 Keddache, S., A. Thilander-Klang, B. Lanhede et al. Storage phosphor and film-screen mammography: performance with different mammographic techniques. Eur. Radiol. 9(4): 591-597 (1999).

K46 Kallergi, M. Digital mammography: from theory to practice. Cancer Control JMCC 5(1): 72-79 (1998).

K47 Krol, A., A. Ikhlef, J.C. Kieffer et al. Laser-based microfocused x-ray source for mammography: feasibility study. Med. Phys. 24(5): 725-732 (1997).

K48 Kimme-Smith, C., C. Lewis, M. Beifuss et al. Establishing minimum performance standards, calibration intervals, and optimal exposure values for a whole breast digital mammography unit. Med. Phys. 25(12): 2410-2416 (1998).

K49 Klein, R., H. Aichinger, J. Dierker et al. Determination of average glandular dose with modern mammography units for two large groups of patients. Phys. Med. Biol. 42: 651-671 (1997).

K50 Kicken, P.J.H., D. Koster and G.J. Kemerink. Exposure conditions of patients in vascular radiology. Radiat. Prot. Dosim. 86(2): 129-137 (1999).

K51 Kotre, C.J. and I.P. Burch. Phase contrast enhancement of x-ray mammography: a design study. Phys. Med. Biol. 44: 2853-2866 (1999).

K52 Kheddache, S., R. Kullenberg and E. Kivilo-Carlsson. Dose reduction in pelvimetry using a digital technique. Radiat. Prot. Dosim. 80(1-3): 275-278 (1998).

K53 Kamm, K.F. The future of digital imaging. Br. J. Radiol. 70: S145-S152 (1997).

K54 Kofler, J.M., M.L. Mohlke and T.J. Vrieze. Techniques for measuring radiographic repeat rates. Health Phys. 76(2): 191-194 (1999).

K55 Kopp, J., W. Maier and C. Losereit. Radiation exposure of patients by using modern digital fluoroscopy systems. Radiat. Prot. Dosim. 57(1-4): 487-488 (1995).

K56 Kleuker, U., P. Suortti, W. Weyrich et al. Feasibility study of x-ray diffraction computed tomography for medical imaging. Phys. Med. Biol. 43: 2911-2923 (1998).

K57 Kanai, T., M. Endo, S. Minohara et al. Biophysical characteristics of HIMAC clinical irradiation system for heavy-ion radiation therapy. Int. J. Radiat. Oncol. Biol. Phys. 44(1): 201-210 (1999).

K58 Kroonwijk, M., K.L. Pasma, S. Quint et al. In vivo dosimetry for prostate cancer patients using an electronic portal imaging device (EPID); demonstration of internal organ motion. Radiother. Oncol. 49: 125-132 (1998).

K59 Korpela, H. Use of radiopharmaceuticals in Finland in 1997. STUK-B-STO38 (1999).

K60 Knapp, F.F., R.H. Spencer and M. Stabin. Use of rhenium-188 liquid-filled balloons for inhibition of coronary restenosis after PTCA - a new opportunity for nuclear medicine. Nucl. Med. Commun. 20(7): 673 (1999).

K61 Knapp, F.F. The development and use of radionuclide generators in nuclear medicine - recent advances and future perspectives. p. 485-495 in: Modern Trends in Radiopharmaceuticals for Diagnosis and Therapy. IAEA-TECDOC 1029 (1998).

K62 Kori, S.H., J.A. LaPerriere, M.B. Kowalski et al. Management of bone pain secondary to metastatic disease. Cancer Control JMCC 4(2): 153-157 (1997).

K63 Kemp, G., A. Van Aswegen, A. Roodt et al. The use of ^{186}Re(Sn)-HEDP for pain relief in the palliative treatment of bone cancer. p. 627-633 in: Modern Trends in Radiopharmaceuticals for Diagnosis and Therapy. IAEA-TECDOC 1029 (1998).

K64 Keeling, D.H. and P. Maltby. Maladministrations and misadministrations. Nucl. Med. Commun. 15: 63-65 (1994).

K65 Kuikka, J.T., K.E. Britton, V.U. Chengazi et al. Future developments in nuclear medicine instrumentation: a review. Nucl. Med. Commun. 19: 3-12 (1998).

L1 Labbe, M.S., M.Y. Chiu, M.S. Rzeszotarski et al. The x-ray fovea, a device for reducing x-ray dose in fluoroscopy. Med. Phys. 21(3): 471-481 (1994).

L2 Lacy, J.L., M.S. Verani, M.E. Ball et al. First-pass radionuclide angiography using a multiwire gamma camera and Tantalum-178. J. Nucl. Med. 29(3): 293-301 (1988).

L3 Leung, K.C. and C.J. Martin. Effective doses for coronary angiography. Br. J. Radiol. 69: 426-431 (1996).

L4 Lindsay, B.D., J.O. Eichling, H.D. Ambos et al. Radiation exposure to patients and medical personnel during radiofrequency catheter ablation for supraventricular tachycardia. Am. J. Cardiol. 70: 218-223 (1992).

L5 Lunar Corporation. Increasing worldwide use of bone densitometry. Lunar News (December): 1-2 (1995).

L6 Lai, S.-Y., J. Sabol and P.-S. Weng. Assessment of the population effective doses from the diagnostic use of radiopharmaceuticals in Taiwan. Radiat. Prot. Dosim. 62(4): 255-261 (1995).

L7 Liniecki, J. Pediatrics and radiological risk. Probl. Med. Nukl. 8(16): 123-140 (1994).

L8 Lewington, V.J. Cancer therapy using bone-seeking isotopes. Phys. Med. Biol. 41(10): 2027-2042 (1996).

L9 Lewis, M.K., G.M. Blake and I. Fogelman. Patient dose in dual x-ray absorptiometry. Osteoporosis Int. 4: 11-15 (1994).

L10 Ling, C.C. and Z. Fuks. Conformal radiation treatment: a critical appraisal. Eur. J. Cancer 31A(5): 799-803 (1995).

L11 Lang, E.K. The future of vascular and interventional radiology. Radiology 204(3): 63A-65A (1997).

L12 Lee, C.D. Teleradiology. Radiology 201: 15 (1996).

L13 Laugier, A. (ed.). Annuaire de la Cancerologie/ Radiotherapie et des Imageries Medicales en France (ACRIM 1995), 15th edition. ISSN 1242.3327 (1995).

L14 Larsson, J.P., J. Persliden, M. Sandborg et al. Transmission ionization chambers for measurements of air collision kerma integrated over beam area. Factors limiting the accuracy of the calibration. Phys. Med. Biol. 41: 2381-2398 (1996).

L15 Law, J., D.R. Dance, K. Faulkner et al. The Commissioning and Routine Testing of Mammographic X-ray Systems. IPSM Report 59, 2nd edition. IPSM, York, 1994.

L16 Le Heron, J. and J. Poletti. Reference doses for patients in diagnostic radiology. Radiat. Prot. Aust. 12(2): 45-49 (1994).

L17 Lecomber, A.R. and K. Faulkner. Organ absorbed doses in intraoral dental radiography. Br. J. Radiol. 66: 1035-1041 (1993).

L18 Lovelock, D.J. Radiation incidents in dentistry. p. 6-11 in: Radiation Incidents (K. Faulkner, R.M. Harrison, eds.). British Institute of Radiology, London, 1996.

L19 Le Heron, J.C., NRL (New Zealand). Communication to the UNSCEAR Secretariat (1997).

L20 Leitz, W., B. Axelsson and G. Szendrö. Computed tomography dose assessment - a practical approach. Radiat. Prot. Dosim. 57(1-4): 377-380 (1995).

L21 Last, A. Radiotherapy in patients with cardiac pacemakers. Br. J. Radiol. 71: 4-10 (1998).

L22 Li, A.N., N.L. Eigler, F. Litvack et al. Characterization of a positron emitting V48 nitinol stent for intracoronary brachytherapy. Med. Phys. 25(1): 20-28 (1998).

L23 Liu, W.H., M. Kai, K. Ohta et al. Diagnostic medical x ray examination frequencies in Taiwan. Radiat. Prot. Dosim. 67(3): 193-197 (1996).

L24 Leer, J.W.H., P. van Houtte and J. Davelaar. Indications and treatment schedules for irradiation of benign diseases: a survey. Radiother. Oncol. 48: 249-257 (1998).

L25 Lien, W. and R.A. Geise. Temperature response of two photographic films and TLDs suitable for patient dosimetry of high dose fluoroscopic procedures. Health Phys. 73(3): 483-487 (1997).

L26 Layng, H.F. Scanora®: a new perspective in dental radiology. Radiography 4: 33-40 (1998).

L27 Larsson, J.P., J. Persliden and G. Alm Carlsson. Ionization chambers for measuring air kerma integrated over beam area: deviations in calibration values using simplified calibration methods. Phys. Med. Biol. 43: 599-607 (1998).

L28 Laban, J.A. and V.G. Smythe. Survey of the use of nuclear medicine in New Zealand. NRL Report 1999/1 (1999).

L29 Lavoie, C. and C. Don. *In vivo* measurement method of ovarian dose during barium enema examinations. Br. J. Radiol. 70: 291-295 (1997).

L30 Lloyd, P., D. Lowe, D.S. Harty et al. The secondary radiation grid: its effect on fluoroscopic dose-area product during barium enema examinations. Br. J. Radiol. 71: 303-306 (1998).

L31 LaFrance, M. and R. Breton. Radiation exposure to breast in CT scanning. Med. Phys. 26(6): 1173 (1999).

L32 Lehmann, K.J., G. Weisser, K.W. Neff et al. First results of computerised tomographic angiography using electron beam tomography. Eur. Radiol. 9(4): 625-629 (1999).

L33 Launders, J.H., A.R. Cowen, R.F. Bury et al. A case study into the effect of radiographic factors on image quality and dose for a selenium based digital chest radiography system. Radiat. Prot. Dosim. 80(1-3): 279-282 (1998).

L34 Leppek, R., S.S. Bertrams, W. Höltermann et al. Radiation exposure due to bedside chest radiography during intensive care; cumulative dose and additional morbidity risk of long term therapy. Der Radiologe 38(9): 730-736 (1998).

L35 Leitz, W.K., L.G. Månsson, B.R.K. Hedberg-Vikström et al. In search of optimum chest radiography techniques. Br. J. Radiol. 66: 314-321 (1993).

L36 Launders, J.H., S.M. Kengyelics and A.R. Cowen. A comprehensive physical image quality evaluation of a selenium based digital x-ray imaging system for thorax radiography. Med. Phys. 25(6): 986-997 (1998).

L37 Lecomber, A.R. and K. Faulkner. Dose and risk in dental radiography. Radiat. Prot. Dosim. 80(1-3): 249-252 (1998).

L38 Leitz, W. Reference (target) levels for mammography in Sweden. Radiat. Prot. Dosim. 80(1-3): 181-182 (1998).

L39 Laib, A. and P. Rüegsegger. Local x-ray tomography for *in vivo* bone structure examinations. Med. Phys. 26(3): 447-552 (1999).

L40 Lunar Corporation. Worldwide densitometry market. Lunar News (Autumn): 33 (1998).

L41 Lowe, A., A. Finch, D. Boniface et al. Diagnostic image quality of mobile neonatal chest x-rays and the radiation exposure incurred. Br. J. Radiol. 72: 55-61 (1999).

L42 Levine, M.S. and I. Laufer. The gastrointestinal tract: do's and don't's of digital imaging. Radiology 207: 311-316 (1998).

L43 Luhta, R. and J.A. Rowlands. Feasibility of a large area x-ray sensitive vidicon for medical fluoroscopy: signal and noise factors. Med. Phys. 24(5): 609-620 (1997).

L44 Lewis, R. Medical applications of synchrotron radiation x-rays. Phys. Med. Biol. 42: 1213-1243 (1997).

L45 Levin, C.V., B. El Gueddari and A. Meghzifene. Radiation therapy in Africa: distribution and equipment. Radiother. Oncol. 52: 79-84 (1999).

L46 Lanson, J.H., M. Essers, G.J. Meijer et al. In vivo dosimetry during conformal radiotherapy; requirements for and findings of a routine procedure. Radiother. Oncol. 52: 51-59 (1999).

L47 Li, X.A., C.-M. Ma, D. Salhani et al. Dosimetric evaluation of a widely used kilovoltage x-ray unit for endocavitary radiotherapy. Med. Phys. 25(8): 1464-1471 (1998).

L48 Lin, J.-D., P.-F. Kao and T.-C. Chao. The effects of radioactive iodine in thyroid remnant ablation and treatment of well differentiated thyroid carcinoma. Br. J. Radiol. 71: 307-313 (1998).

L49 Lampinen, J.S. and S. Rannikko. Patient specific doses used to analyse the optimum dose delivery in barium enema examinations. Br. J. Radiol. 72: 1185-1195 (1999).

L50 Lewellen, T.K., R.S. Miyaoka and W.L. Swan. PET imaging using dual-headed gamma cameras: an update. Nucl. Med. Commun. 20: 5-12 (1999).

L51 Loevinger, R., T.F. Budinger and E.E. Watson. MIRD Primer for Absorbed Dose Calculations. Society of Nuclear Medicine, New York, 1988.

L52 Liu, A., L.E. Williams and A.A. Raubitschek. A CT assisted method for absolute quantitation of internal radioactivity. Med. Phys. 23(11): 1919-1928 (1996).

L53 Ljungberg, M., S.-E. Strand and M.A. King (eds.). Monte Carlo Calculations in Nuclear Medicine. IOPP, Bristol, 1998.

L54 Link, J.M. Advances in nuclear medicine instrumentation: considerations in the design and selection of an imaging system. Eur. J. Nucl. Med. 25(10): 1453-1466 (1998).

L55 Långström, B., M. Bergström, P. Hartvig et al. Radiopharmaceuticals for PET studies. p. 359-376 in: Tomography in Nuclear Medicine. Proceedings Series. IAEA, Vienna, 1996.

L56 Lubberink, M., V. Tolmachev, S. Beshara et al. Quantification aspects of patient studies with ^{52}Fe in positron emission tomography. Appl. Radiat. Isot. 51: 707-715 (1999).

L57 Laugier, A. (ed.). Radiothérapie sans frontières: Pakistan - Albanie. La Lettre de la Cancérologie-Radiothérapie No. 3: 91-93 (1998).

M1 Mettler, F.A., J.E. Briggs, R. Carchman et al. Use of radiology in United States general short-term hospitals: 1980-1990. Radiology 189: 377-380 (1993).

M2 McManus, J. Southeast Asia strives to update its radiology. Diagn. Imag. Int. 10(1): 31-35 (1994).

M3 Marshall, N.W., K. Faulkner, H.P. Busch et al. A comparison of radiation dose in examination of the abdomen using different radiological imaging techniques. Br. J. Radiol. 67: 478-484 (1994).

M4 Marshall, N.W., K. Faulkner, H.P. Busch et al. An investigation into the radiation dose associated with different imaging systems for chest radiology. Br. J. Radiol. 67: 353-359 (1994).

M5 Mori, H., K. Hyodo, E. Tanaka et al. Small-vessel radiography in situ with monochromatic synchrotron radiation. Radiology 201: 173-177 (1996).

M6 Milano, F., B. Lazzari and M. Rosselli del Turco. Mammography dose reference levels in practice. Radiat. Prot. Dosim. 80(1-3): 195-198 (1998).

M7 Maccia, C., X. Nadeau, R. Renaud et al. Quality control in mammography: the pilot campaign of breast screening in the Bas-Rhin region. Radiat Prot. Dosim 57(1-4): 323-328 (1995).

M8 Maccia, C., E. Neofotistou, R. Padovani et al. Patient doses in interventional radiology. p. 39-44 in: Radiation Protection in Interventional Radiology (K. Faulkner and D. Teunen, eds.). British Institute of Radiology, London, 1995.

M9 Marshall, N.W., J. Noble and K. Faulkner. Patient and staff dosimetry in neuroradiological procedures. Br. J. Radiol. 68: 495-501 (1995).

M10 Mohammadi, H., F. Tabeie and M. Saghari. Trends of population absorbed dose from diagnostic nuclear medicine procedures in Iran: 1985-1989. Health Phys. 68(4): 503-508 (1995).

M11 Maccia, C., B.M. Moores and B.F. Wall.. The 1991 CEC trial on quality criteria for diagnostic radiographic images: detailed results and findings. EUR 16635 (1996).

M12 Miller, D.W. A review of proton beam radiation therapy. Med. Phys. 22(11): 1943-1954 (1995).

M13 McKenzie, A.L. Would the two most serious radiotherapy accidents in the UK have occurred under ISO 9000? p. 40-44 in: Radiation Incidents (K. Faulkner, R.M. Harrison, eds.). British Institute of Radiology, London, 1996.

M14 Morgan, H.M., S.C. Lillicrap and A.L. McKenzie. Leakage radiation in radiotherapy - what is an acceptable level in the electron mode? Br. J. Radiol. 66: 548-551 (1993).

M15 Maryanski, M.J., G.S. Ibbott, P. Eastman et al. Radiation therapy dosimetry using magnetic resonance imaging of polymer gels. Med. Phys. 23(5): 699-705 (1996).

M16 McNutt, T.R., T.R. Mackie, P. Reckwerdt et al. Calculation of portal dose using the convolution/superposition method. Med. Phys. 23(4): 527-535 (1996).

M17 Mayles, W.P.M., S. Heisig and H.M.O. Mayles. Treatment verification and *in vivo* dosimetry. Chapter 10 in: Radiotherapy Physics in Practice (J.R. Williams and D.I. Thwaites, eds.). OUP, Oxford, 1993.

M18 Mould, R.F., J.J. Battermann, A.A. Martinez et al. (eds.). Brachytherapy from Radium to Optimisation. Nucleotron International BV, Netherlands, 1994.

M19 Martinez-Siemel, M.S., F.A. Mettler, J.J. Sell et al. Performance of radiologic and nuclear medicine examinations in the 6 months before death. Radiology 200: 817-819 (1996).

M20 Murphy, M.J. and R.S. Cox. The accuracy of dose localisation for an image-guided frameless radiosurgery system. Med. Phys. 23(11): 2043-2049 (1996).

M21 Mini, R.L. Dosisbestimmungen in der Medizinischen Röntgendiagnostik. Verlag Max Huber, Kerzers, 1992.

M22 Maree, G.J. Determination of the genetically-significant dose from diagnostic radiology for the South African population, 1990-1991. Ph.D Thesis, University of Cape Town (1995).

M23 Mettler, F.A., M. Davis, R.D. Moseley et al. The effect of utilising age and sex dependent factors for calculating detriment from medical irradiation. Radiat. Prot. Dosim. 15: 269-271 (1986).

M24 Martin, R.C., R.R. Laxson, J.H. Miller et al. Development of high-activity ^{252}Cf sources for neutron brachytherapy. Appl. Radiat. Isot. 48(10-12): 1567-1570 (1997).

M25 Merrick, M.V. Essentials of Nuclear Medicine. 2nd edition. Springer-Verlag, London, 1998.

M26 Miah, F.K., M.F. Ahmed, Z. Begum et al. Dose distribution over different parts of cancer patients during radiotherapy treatments in Bangladesh. Radiat. Prot. Dosim. 77(3): 199-203 (1998).

M27 Mozzo, P., C. Procacci, A. Tacconi et al. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur. Radiol. 8: 1558-1564 (1998).

M28 Martin, C.J., D.G. Sutton, A. Workman et al. Protocol for measurement of patient entrance surface dose rates for fluoroscopic x-ray equipment. Br. J. Radiol. 71: 1283-1287 (1998).

M29 Morrison, J.J., R. Sinnatamby, G.A. Hackett et al. Obstetric pelvimetry in the UK: an appraisal of current practice. Br. J. Obstet. Gynaecol. 102: 748-750 (1995).

M30 Mooney, R. and P.S. Thomas. Dose reduction in a paediatric x-ray department following optimization of radiographic technique. Br. J. Radiol. 71: 852-860 (1998).

M31 McDonald, S., C.J. Martin, C.L. Darragh et al. Dose-area product measurements in paediatric radiography. Br. J. Radiol. 69: 318-325 (1996).

M32 McParland, B.J., W. Gorka, R. Lee et al. Radiology in the neonatal intensive care unit: dose reduction and image quality. Br. J. Radiol. 69: 929-937 (1996).

M33 Maruyama, T. et al. Organ or tissue doses, effective doses and collective effective doses from x-ray diagnosis in Japan. Radioisotopes 45: 761-773 (1996).

M34 McParland, B.J. A study of patient radiation doses in interventional radiological procedures. Br. J. Radiol. 71: 175-185 (1998).

M35 Merkle, E.M., J. Vogel, A.J. Aschoff et al. Radiation exposure from interventional radiology of the biliary system: how much is due to fluoroscopy? Radiat. Prot. Dosim. 71(3): 219-222 (1997).

M36 McParland, B.J. Entrance skin dose estimates derived from dose-area product measurements in interventional radiological procedures. Br. J. Radiol. 71: 1288-1295 (1998).

M37 Muhogora, W.E., A.M. Nyanda, U.S. Lema et al. Typical radiation doses to patients from some common x ray examinations in Tanzania. Radiat. Prot. Dosim. 82(4): 301-305 (1999).

M38 Murphy, J.M., A.D. Quinn, J. Upton et al. Organ dosimetry in small bowel enemas. Radiography 4: 125-128 (1998).

M39 Martin, C.J., D.G. Sutton and P.F. Sharp. Balancing patient dose and image quality. Appl. Radiat. Isot. 50(1): 1-19 (1999).

M40 Moores, B.M. The role of phantoms in standardisation of the radiological process. Radiat. Prot. Dosim. 49(1-3): 19-26 (1993).

M41 Mini, R.L. Dosimetric methods for the establishment of reference dose levels in conventional and computed radiography. Radiat. Prot. Dosim. 80(1-3): 221-224 (1998).

M42 McParland, B.J. and D.B. Lewall. Reductions in fluoroscopy screening times resulting from physician credentialling and practice surveillance. Br. J. Radiol. 71: 461 (1998).

M43 Massoumzadeh, P., S. Rudin and D. Bednarek. Filter material selection for region of interest imaging. Med. Phys. 25(2): 161-171 (1998).

M44 Mini, R.L. Strahlenexposition in der Röntgendiagnostik. p. 51-74 in: Strahlenexposition in der medizinischen Diagnostik (S. Hähnel, ed.). Veröffentlichungen der Strahlenschutzkommission, Band 30. Gustav Fischer Verlag, Stuttgart, 1995.

M45 Mini, R.L. and P. Schneeberger. Registrierung des Dosisflächenproduktes bei Kontrastmitteluntersuchungen in der Röntgenradiologie. p. 99-110 in: Die Messung des Dosisflächenproduktes in der diagnostischen Radiologie als Methode zur Ermittlung der Strahlenexposition (W. Löster, G. Drexler and F-E. Stieve, eds.). H. Hoffmann GmbH Verlag, Berlin, 1995.

M46 Mini, R.L., B. Schmid, P. Schneeberger et al. Dose-area product measurements during angiographic x ray procedures. Radiat. Prot. Dosim. 80(1-3): 145-148 (1998).

M47 Macnamara, A. and P. Hoskins. Patient radiation dose during lithotripsy. Br. J. Radiol. 72: 495-498 (1999).

M48 Marshall, N.W., K. Faulkner, H.P. Busch et al. A comparison of two methods for estimating effective dose in abdominal radiology. Radiat. Prot. Dosim. 57(1-4): 367-369 (1995).

M49 Moran, B., J. Upton, M. Rafferty et al. An initial report on the investigation of high patient doses for the lateral lumbosacral projection in the lumbar spine examination. Radiat. Prot. Dosim. 57(1-4): 423-427 (1995).

M50 Magri, S., M. Arisi, S. Camerini et al. Intensive Care Unit: evaluation of the radiological activity and criteria for reduction of patient and worker exposure. Radiat. Prot. Dosim. 57(1-4): 417-421 (1995).

M51 Mini, R.L., P. Vock, R. Mury et al. Radiation exposure of patients who undergo CT of the trunk. Radiology 195: 557-562 (1995).

M52 Maclennan, A.C. Radiation dose to the lens from coronal CT scanning of the sinuses. Clin. Radiol. 50: 265-267 (1995).

M53 Maclennan, A.C. and D.M. Hadley. Radiation dose to the lens from computed tomography scanning in a neuroradiology department. Br. J. Radiol. 68: 19-22 (1995).

M54 Maclennan, A.C. Radiation dose to the lens from CT brain scans in general radiology departments. Br. J. Radiol. 68: 219 (1995).

M55 Maclennan, A.C. Radiation dose to the lens from CT of petrous bones. Br. J. Radiol. 68: 1136 (1995).

M56 Mayo, J.R., K.P. Whittall, A.N. Leung et al. Simulated dose reduction in conventional chest CT: validation study. Radiology 202: 453-457 (1997).

M57 McGhee, P.L. and S. Humphreys. Radiation dose associated with spiral computed tomography. Can. Assoc. Radiol. J. 45: 124-129 (1994).

M58 McNitt-Gray, M.F. and C.H. Cagnon. Radiation dose in spiral CT: the relative effects of collimation and pitch. Med. Phys. 26(3): 409-414 (1999).

M59 McCollough, C.H. and F.E. Zink. Performance evaluation of a multi-slice CT system. Med. Phys. 26(11): 2223-2230 (1999).

M60 McCollough, C.H. and R.L. Morin. The technical design and performance of ultrafast computed tomography. Radiol. Clin. North Am. 32(3): 521-536 (1994).

M61 McCollough, C.H., Mayo Clinic. Communication to the UNSCEAR Secretariat (1999).

M62 McCollough, C.H., F.E. Zink and R.L. Morin. Radiation dosimetry for electron beam CT. Radiology 637-643 (1994).

M63 McCollough, C.H. and H.H. Liu. Breast dose during electron-beam CT: measurement with film dosimetry. Radiology 196: 153-157 (1995).

M64 Matson, M.B., J.M. Jarosz, D. Gallacher et al. Evaluation of head examinations produced with a mobile CT unit. Br. J. Radiol. 72: 631-636 (1999).

M65 McLean, D., J.E. Gray, S.J. Swensen et al. Technical aspects of twin screen-film chest radiography: cost effective lung and mediastinal imaging. Eur. J. Radiol. 27: 53-60 (1998).

M66 Moeckli, R., F.R. Verdun, F.O. Bochud et al. Comparison of subjective and objective evaluation of screen-film systems for chest radiography. Radiat. Prot. Dosim. 80(1-3): 265-268 (1998).

M67 Morishita, J., H. MacMahon, K. Doi et al. Evaluation of an asymmetric screen-film system for chest radiography. Med. Phys. 21(11): 1769-1775 (1994).

M68 Metzger, R.L. and K.A. Van Riper. Fetal dose assessment from invasive special procedures by Monte Carlo methods. Med. Phys. 26(8): 1714-1720 (1999).

M69 Morgan, H.M., J.T. Shakeshaft and S.C, Lillicrap. Gamma-ray scattering for mandibular bone density measurement. Br. J. Radiol. 72: 1069-1072 (1999).

M70 Matsuura. N., W. Zhao, Z. Huang et al. Digital radiology using active matrix readout: amplified pixel detector array for fluoroscopy. Med. Phys. 26(5): 672-681 (1999).

M71 McBride, M. A computerised method of patient positioning in diagnostic radiography. Radiography 4: 225-226 (1998).

M72 McNeil, E.A., D.E. Peach and D.H. Temperton. Comparison of entrance surface doses and radiographic techniques in the West Midlands (UK) with the CEC criteria, specifically for lateral lumbar spine radiographs. Radiat. Prot. Dosim. 57(1-4): 437-440 (1995).

M73 Mühl, D. Erhebung über die Häufigkeit von Röntgenuntersuchungen bei einzelnen Patienten im Städtischen Krankenhaus München-Schwabing. M.D. Dissertation, Universität München (1991).

M74 Mazonakis, M., J. Damilakis, N. Theoharopoulos et al. Brain radiotherapy during pregnancy: an analysis of conceptus dose using anthropomorphic phantoms. Br. J. Radiol. 72: 274-278 (1999).

M75 Mesa, A.V., A. Norman, T.D. Solberg et al. Dose distributions using kilovoltage x-rays and dose enhancement from iodine contrast agents. Phys. Med. Biol. 44: 1955-1968 (1999).

M76 Ma, C.-M., E. Mok, A. Kapur et al. Clinical implementation of a Monte Carlo treatment planning system. Med. Phys. 26(10): 2133-2143 (1999).

M77 Mitsuhashi, N., K. Hayakawa, M. Yamakawa et al. Cancer in patients aged 90 years or older: radiation therapy. Radiology 211: 829-833 (1999).

M78 Mausner, L.F., K.L. Kolsky, V. Joshi et al. Radionuclide development at BNL for nuclear medicine therapy. Appl. Radiat. Isot. 49(4): 285-294 (1998).

M79 McDevitt, M.R., G. Sgouros, R.D. Finn et al. Radio-immunotherapy with alpha-emitting nuclides. Eur. J. Nucl. Med. 25(9): 1341-1351 (1998).

M80 Mirzadeh, S. Generator-produced alpha-emitters. Appl. Radiat. Isot. 49(4): 345-349 (1998).

M81 Monsieurs, M.A., H.M. Thierens, C. Van de Wiele et al. Estimation of risk based on biological dosimetry for patients treated with radioiodine. Nucl. Med. Commun. 20: 911-917 (1999).

M82 McDougall, I.R. Cancer deaths after ^{131}I therapy for thyrotoxicosis. Nucl. Med. Commun. 20: 407-409 (1999).

M83 Maisey, M. Radionuclide imaging in cancer management. J. Royal Coll. Phys. London 32(6): 525-529 (1998).

M84 Macapinlac, H.A., A.M. Scott, S.M. Larson et al. Gallium-67-citrate imaging in nuclear oncology. Nucl. Med. Biol. 21(5): 731-738 (1994).

M85 Mattsson, S., L. Jacobsson and E. Vestergren. The basic principles in assessment and selection of reference doses: considerations in nuclear medicine. Radiat. Prot. Dosim. 80(1-3): 23-27 (1998).

M86 McCready, R. and R. A'Hern. A more rational basis for determining the activities used for radionuclide imaging? Eur. J. Nucl. Med. 24: 109-110 (1997).

M87 Mattsson, S., L. Johansson, B. Nosslin et al. Dosimetry for radiopharmaceuticals. Radiat. Prot. Dosim. 79(1-4): 343-349 (1998).

M88 Mountford, P.J. Risk assessment of the nuclear medicine patient. Br. J .Radiol. 70: 671-684 (1997).

M89 Mountford, P.J. and M.J. O'Doherty. Exposure of critical groups to nuclear medicine patients. Appl. Radiat. Isot. 50(1): 89-111 (1999).

M90 Mountford, P.J. Radiation, conception and pregnancy. Nucl. Med. Commun. 20: 979-981 (1999).

M91 Medley, C.M.T. and G.C. Vivian. Radionuclide developments. Br. J. Radiol. 70: S133-S144 (1997).

M92 Meyer, G.-J., S.L. Waters, H.H. Coenen et al. PET radiopharmaceuticals in Europe: current use and data relevant for the formulation of summaries of product characteristics (SPCs). Eur. J. Nucl. Med. 22(12): 1420-1432 (1995).

N1 National Radiological Protection Board. Medical exposure: guidance on the 1990 recommendations of ICRP. Doc. NRPB 4(2): 43-74 (1993).

N2 National Radiological Protection Board. Patient dose reduction in diagnostic radiology. Doc. NRPB 1(3): (1990).

N3 National Radiological Protection Board. Guidelines on radiology standards for primary dental care. Doc. NRPB 5(3): (1994).

N4 Nessi, R., D. Minorati, S. Dova et al. Digital panoramic radiography: a clinical survey. Eur. Radiol. 5: 391-394 (1995).

N5 National Council on Radiation Protection and Measurements. Dose limits for individuals who receive exposure from radionuclide therapy patients. NCRP Commentary No. 11 (1995).

N6 Neofotistou, V. Illustrating the need for education and training in radiation safety in interventional radiology. p. 95-100 in: Efficacy and Radiation Safety in Interventional Radiology (A. Bäuml, B. Bauer, J.-H. Bernhardt et al., eds.). BfS-ISH-178/97 (1997).

N7 Norbash, A.M., D.D. Busick and M.P. Marks. Patient skin dose reduction in interventional and neuroradiology procedures through supplemental beam filtration and attention to technical factors. Health Phys. 68 (Suppl. 1): S24 (1995).

N8 Niepel, J. Equipment for interventional radiology. p. 5-8 in: Radiation Protection in Interventional Radiology (K. Faulkner and D. Teunen, eds.). British Institute of Radiology, London, 1995.

N9 National Radiological Protection Board. National protocol for patient dose measurements in diagnostic radiology. NRPB, Chilton (1992).

N10 Nahum, A.E. Microdosimetry and radiocurability: modelling targeted therapy with ß-emitters. Phys. Med. Biol. 41(10): 1957-1972 (1996).

N11 Nishizawa, K., K. Sakurai, K. Iwai et al. Effective dose to patients from bone densitometry. Jpn. J. Med. Phys. 15: 1-8 (1995).

N12 Njeh, C.F., K. Apple, D.H. Temperton et al. Radiological assessment of a new bone densitometer - the Lunar EXPERT. Br. J. Radiol. 69: 335-340 (1996).

N13 National Council on Radiation Protection and Measurements. Sources and magnitude of occupational and public exposures from nuclear medicine procedures. NCRP Report No. 124 (1996).

N14 Nath, R., L.L. Anderson, G. Luxton et al. Dosimetry of interstitial brachytherapy sources: recommendations of the AAPM Radiation Therapy Committee Task Group No 43. Med. Phys. 22(2): 209-234 (1995).

N15 Ng, K.-H., P. Rassiah, H.-B. Wang et al. Doses to patients in routine x-ray examinations in Malaysia. Br. J. Radiol. 71: 654-660 (1998).

N16 Nishizawa, K., T. Maruyama, M. Takayama et al. Estimation of effective dose from CT examination. Nippon Acta Radiol. 55: 763-768 (1995).

N17 Nath, R., L.L. Anderson, J.A. Meli et al. Code of practice for brachytherapy physics: report of the AAPM Radiation Therapy Committee Task Group No 56. Med. Phys. 24(10): 1557-1598 (1997).

N18 Nisbet, A. and D.I. Thwaites. A dosimetric intercomparison of electron beams in UK radiotherapy centres. Phys. Med. Biol. 42: 2393-2409 (1997).

N19 Norman, A. and A.R. Kagan. Radiation doses in radiation therapy are not safe. Med. Phys. 24(11): 1710-1713 (1997).

N20 Niemierko, A. Reporting and analyzing dose distributions: a concept of equivalent uniform dose. Med. Phys. 24(1): 103-110 (1997).

N21 Nuclear Regulatory Commission. Human factors evaluation of remote afterloading brachytherapy. NUREG/CR-615-Vol.1-3 (1995).

N22 Novotný, J., J. Novotný, L. Hobzová et al. Transportation dose and doses to extracranial sites during stereotactic radiosurgery with the Leksell Gamma Knife. Stereotact. Funct. Neurosurg. 66: 170-183 (1996).

N23 Napier, I.D. Reference doses for dental radiography. Br. Dent. J. 186(8): 392-396 (1999).

N24 Nordic Radiation Protection Authorities. Nordic guidance levels for patient doses in diagnostic radiology. Report on Nordic Radiation Protection Co-operation, No. 5. Swedish Radiation Protection Institute, Stockholm (1996).

N25 Nawfel, R.D., P.F. Judy and C. Krinopol. Fluoroscopy time and patient skin dose from radio frequency cardiac catheter ablation procedures. Med. Phys. 23(8): 1500 (1996).

N26 Ng, K.-H., B.J.J. Abdullah and S. Sivalingham. Medical radiation exposures for diagnostic radiology in Malaysia. Health Phys. 77(1): 33-36 (1999).

N27 Ng, K.-H., D.A. Bradley and H.M. Warren-Forward (eds.). Subject Dose in Radiological Imaging. Elsevier, Amsterdam, 1998.

N28 Nic an Ghearr, F.A. and P.C. Brennan. The PA projection of the abdomen: a dose reducing technique. Radiography 4: 195-203 (1998).

N29 Neofotistou, V., A. Karoussou, H. Lobotesi et al. Patient dosimetry during interventional cardiology procedures. Radiat. Prot. Dosim. 80(1-3): 151-154 (1998).

N30 Nishizawa, K., K. Iwai, T. Matsumoto et al. Estimation of the exposure and a risk-benefit analysis for a CT system designed for a lung cancer mass screening unit. Radiat. Prot. Dosim. 67(2): 101-108 (1996).

N31 Nishizawa, K., A. Yoshino-Tonari, M. Matsumoto et al. Dose evaluation and effective dose estimation in radiological studies of the paranasal sinuses. Radiat. Prot. Dosim. 82(4): 271-276 (1999).

N32 Nadas, S., B. Duvoisin, S. Raimond et al. Dose délivrée aux organes critiques lors d'investigations radiologiques d'une sinusite chronique. J. Radiol. 75(4): 217-219 (1994).

N33 Nitta, N., M. Takahashi, K. Murata et al. Ultra-low-dose spiral (helical) CT of the thorax: a filtering technique. Nippon Igaku Hoshasen Gakkai Zasshi 56(1): 63-65 (1996).

N34 Nawfel, R., P. Judy, S. Hooton et al. Patient and personnel exposure during CT fluoroscopy. Med. Phys. 25(7 Part 1): A156 (1998).

N35 Naik, K.S., L.M. Ness, A.M.B. Bowker et al. Is computed tomography of the body overused? An audit of 2068 attendances in a large acute hospital. Br. J. Radiol. 69: 126-131 (1996).

N36 Njeh, C.F., J.P. Wade and K.E. Goldstone. The use of lead aprons in chest radiography. Radiography 3: 143-147 (1997).

N37 Ng, K.H., R.J. Aus, L.A. DeWerd et al. Entrance skin exposure and mean glandular dose: effect of scatter and field gradient at mammography. Radiology 205: 395-398 (1997).

N38 Niklason, L.T., B.T. Christian, L.E. Niklason et al. Digital tomosynthesis in breast imaging. Radiology 205: 399-406 (1997).

N39 Njeh, C.F., T. Fuerst, D. Hans et al. Radiation exposure in bone mineral density assessment. Appl. Radiat. Isot. 50(1): 215-236 (1999).

N40 Njeh, C.F., S.B. Samat, A. Nightingale et al. Radiation dose and *in vitro* precision in paediatric bone mineral density measurement using dual x-ray absorptiometry. Br. J. Radiol. 70: 719-727 (1997).

N41 National Radiological Protection Board. Guidelines on patient dose to promote optimisation of protection for diagnostic medical exposures. Doc. NRPB 10(1): 1-43 (1999).

N42 Niroomand-Rad, A., C.R. Blackwell, B.M. Coursey et al. Radiochromic film dosimetry: recommendations of AAPM Radiation Therapy Committee Task Group 55. Med. Phys. 25(11): 2093-2115 (1998).

N43 Nisbet, A., D.I. Thwaites, A.E. Nahum et al. An experimental evaluation of recent electron dosimetry codes of practice. Phys. Med. Biol. 43: 1999-2014 (1998).

N44 Nisbet, A., D.I. Thwaites and M.E. Sheridan. A dosimetric intercomparison of kilovoltage x-rays, megavoltage photons and electrons in the Republic of Ireland. Radiother. Oncol. 48: 95-101 (1998).

N45 Nath, R., H. Amols, C. Coffey et al. Intravascular brachytherapy physics: report of the AAPM Radiation Therapy Committee Task Group No 60. Med. Phys. 26(2): 119-152 (1999).

N46 National Council on Radiation Protection and Measurements. Misadministration of radioactive material in medicine - scientific background. NCRP Commentary No.7. NCRP, Bethesda (1991).

N47 Nibbering, P.H., M.M. Welling, P.J. Van den Broek et al. Radiolabelled antimicrobial peptides for imaging of infections. Nucl. Med. Commun. 19: 1117-1121 (1998).

O1 O'Donoghue, J.A. and T.E. Wheldon. Targeted radiotherapy using Auger electron emitters. Phys. Med. Biol. 41(10): 1973-1992 (1996).

O2 Ott, R.J. Imaging technologies for radionuclide therapy. Phys. Med. Biol. 41(10): 1885-1894 (1996).

O3 Okkalides, D. and M. Fotakis. Patient effective dose resulting from radiographic examinations. Br. J. Radiol. 67: 564-572 (1994).

O4 Ortiz, P., IAEA. Communication to the UNSCEAR Secretariat (1998).

O5 Oldham, M., I. Baustert, C. Lord et al. An investigation into the dosimetry of a nine-field tomotherapy irradiation using BANG-gel dosimetry. Phys. Med. Biol. 43: 1113-1132 (1998).

O6 Olerud, H.M. and G. Saxebøl. Diagnostic radiology in Norway from 1983 to 1993 - examination frequency and collective effective dose to patients. Radiat. Prot. Dosim. 74(4): 247-260 (1997).

O7 O'Dea, T.J. and R.A. Geise. Potential for radiation induced skin damge in neurological procedures: a review of 426 cases using automated dosimetry. Med. Phys. 24(6): 969-970 (1997).

O8 Oresgun, M., J. Le Heron, C. Maccia et al. Radiation protection and quality assurance in diagnostic radiology - an IAEA coordinated research project in Asia and Eastern Europe. Appl. Radiat. Isot. 50(1): 271-276 (1999).

O9 O'Driscoll, D., E.A. McNeil, J. Ferrando et al. Effective dose to the patient undergoing superior vena cava stent. Br. J. Radiol. 71: 1302-1305 (1998).

O10 Olerud, H.M., J.B. Olsen, A. Widmark et al. A Norwegian survey of image quality, doses and film processing in mammography, with reference to two technical phantoms. Radiat.Prot. Dosim. 67(3): 199-210 (1996).

O11 Oestmann, J.-W. The role and impact of reference doses in diagnostic radiology: problems and perspectives. Radiat. Prot. Dosim. 80(1-3): 21-22 (1998).

O12 Olerud, H.M. Analysis of factors influencing patient doses from CT in Norway. Radiat. Prot. Dosim. 71(2): 123-133 (1997).

O13 Ohnesorge, B., T. Flohr, S. Schaller et al. Principles and applications of multi-slice CT. Der Radiologe 39(11): 923-931 (1999).

O14 O'Dea, T.J., R.A. Geise and E.R. Ritenour. The potential for radiation-induced skin damage in interventional neuroradiological procedures: a review of 522 cases using automated dosimetry. Med. Phys. 26(9): 2027-2033 (1999).

O15 Osei, E.K. and K. Faulkner. Fetal doses from radiological examinations. Br. J. Radiol. 72: 773-780 (1999).

O16 Osei, E.K. and K. Faulkner. Fetal position and size data for dose estimation. Br. J. Radiol. 72: 363-370 (1999).

O17 Osei, E.K., K. Faulkner and C.J. Kotre. Radiation dose to the fetus in diagnostic radiology. p. 101-104 in: Proceedings of 6th SRP International Symposium, Southport, 14-18 June 1999 (M.C. Thorne, ed.). Society for Radiological Protection, London, 1999.

O18 Ortiz, P., C. Maccia, R. Padovani et al. Results of the IAEA-CEC coordinated research programme on radiation doses in diagnostic radiology and methods for reduction. Radiat. Prot. Dosim. 57(1-4): 95-99 (1995).

O19 Order, S.E. and S.S. Donaldson. Radiation Therapy of Benign Disease; A Clinical Guide (2nd edition). Springer-Verlag, Berlin, 1998.

O20 O'Duffy, E.K. and P.J. Ell. The practice of medical and surgical synovectomy: a UK survey. Nucl. Med. Commun. 20: 21-24 (1999).

O21 O'Doherty, M.J. Therapy and nuclear medicine. J. Royal Coll. Phys. London 32(6): 536-539 (1998).

O22 O'Donoghue, J.A. Dosimetric aspects of radioimmunotherapy. Nucl. Med. Commun. 18(10): 977 (1997).

P1 Parkin, G.J.S. Digital mammography - the technique of the future. RAD Magazine 20(230): 18 (1994).

P2 Peters, A.M. Recent advances and future projections in clinical radionuclide imaging. Br. J. Radiol. 63: 411-429 (1990).

P3 Pukkila, O. and K. Karila. Interventional Radiology - A New Challenge for Radiation Protection. Nordic Society for Radiation Protection, Ronneby, 1990.

P4 Priestman, T.J., J.A. Bullimore, T.P. Godden et al. The Royal College of Radiologists' fractionation survey. Clin. Oncol. 1: 39-46 (1989).

P5 Poletti, J.L. Patient doses from CT in New Zealand and a simple method for estimating effective dose. Br. J. Radiol. 69: 432-436 (1996).

P6 Persliden, J. and M. Sandborg. Conversion factors between energy imparted to the patient and air collision kerma integrated over beam area in paediatric radiology. Acta Radiol. 34: 92-98 (1993).

P7 Pass, B., R.E. Wood, F.-F. Liu et al. High radiation doses from radiotherapy measured by electron spin resonance in dental enamel. Radiat. Prot. Dosim. 76(4): 239-247 (1998).

P8 Perkins, A.C. Nuclear Medicine, Science and Safety. John Libbey, London, 1996.

P9 Perkins, A.C. Peroperative nuclear medicine. Eur. J. Nucl. Med. 20(7): 573-575 (1993).

P10 Perkins, A.C. and J.G. Hardy. Intra-operative nuclear medicine in surgical practice. Nucl. Med. Commun. 17: 1006-1015 (1996).

P11 Perkins, A.C., P. Yeoman, A.J. Hindle et al. Bedside nuclear medicine investigations in the intensive care unit. Nucl. Med. Commun. 18: 262-268 (1997).

P12 Perris, A. Communication to the UNSCEAR Secretariat (1998).

P13 Poletti, J.L. Radiation injury to skin following a cardiac interventional procedure. Australas. Radiol. 41(1): 82-83 (1997).

P14 Park, T.H., J.O. Eichling, K.B. Schechtman et al. Risk of radiation induced skin injuries from arrhythmia ablation procedures. PACE, Pac. Clin. Electrophysiol. 19(9): 1363-1369 (1996).

P15 Pattee, P.L., P.C. Johns and R.J. Chambers. Radiation risk to patients from percutaneous transluminal coronary angioplasty. J. Am. Coll. Cardiol. 22: 1044-1051 (1993).

P16 Petroff, V. Russia sees glimmer of hope after grave crisis. Diagn. Imag. Eur. 13(8): 31-33 (1997).

P17 Petoussi-Henss, N., M. Zankl and G. Drexler et al. Calculation of backscatter factors for diagnostic radiology using Monte Carlo methods. Phys. Med. Biol. 43: 2237-2250 (1998).

P18 Peet, D.J. and M.D. Pryor. Evaluation of a MOSFET radiation sensor for the measurement of entrance surface dose in diagnostic radiology. Br. J. Radiol. 72: 562-568 (1999).

P19 Petoussi-Hens, N., W. Panzer, M. Zankl et al. Dose-area product and body doses. Radiat. Prot. Dosim. 57(1-4): 363-366 (1995).

P20 Padovani, R., R. Novario and G. Bernardi. Optimisation in coronary angiography and percutaneous transluminal coronary angioplasty. Radiat. Prot. Dosim. 80(1-3): 303-306 (1998).

P21 Pitman, A.G., R.S. Budd and A.F. McKenzie. Radiation dose in computed tomography of the pelvis: comparison of helical and axial scanning. Australas. Radiol. 41(4): 329-335 (1997).

P22 Poletti, J.L. Doses to patients from CT scanning in New Zealand. NRL Report 1992/5 (1992).

P23 Price, R., P. Halson and M. Sampson. Dose reduction during CT scanning in an anthropomorphic phantom by the use of a male gonad shield. Br. J. Radiol. 72: 489-494 (1999).

P24 Prokop, M., C.M. Schaefer-Prokop, A. Chavan et al. Individual adaption of settings in CT based on patient diameter: a technique for constant image quality and selective dose reduction. Radiology 209 (Suppl. P): 246 (1998).

P25 Prassopoulos, P., V. Raptopoulos, R. Chuttani et al. Development of virtual CT cholangiopancreatoscopy. Radiology 209: 570-574 (1998).

P26 Pellet, S., F. Giczi, L. Ballay et al. Hungarian patient dose survey for photofluorography applied in a mass chest screening programme. Radiat. Prot. Dosim. 80(1-4): 115-116 (1998).

P27 Parry, C.K., R.Y.L. Chu, B.G. Eaton et al. Measurement of skin entrance exposure with a dose-area product meter at chest radiography. Radiology 201: 574-575 (1996).

P28 Pages, J. and R. van Loon. The European protocol on dosimetry in mammography: applicability and results in Belgium. Radiat. Prot. Dosim. 80(1-3): 191-193 (1998).

P29 Panayiotakis, G., S. Skiadopoulos, E. Solomou et al. Evaluation of an anatomical filter-based exposure equalization technique in mammography. Br. J. Radiol. 71: 1049-1057 (1998).

P30 Prevrhal, A. and H.K. Genant. Quantitative computed tomgraphy. Der Radiologe 39(3): 194-202 (1999).

P31 Perlmutter, N., R.J. Arthur, G. Beluffi et al. The quality criteria for diagnostic radiographic images in paediatrics. Radiat. Prot. Dosim. 80(1-3): 45-48 (1998).

P32 Persliden, J., H.B.L. Pettersson and K. Fälth-Magnusson. Intestinal biopsy in children with coeliac disease: a Swedish national study of radiation dose and risk. Radiat. Prot. Dosim. 57(1-4): 459-462 (1995).

P33 Peer, S., R. Peer, M. Walcher et al. Comparative reject analysis in conventional film-screen and digital storage phosphor radiography. Eur. Radiol. 9(8): 1693-1696 (1999).

P34 Perez, C.A. and L.W. Brady (eds.). Principles and Practice of Radiation Oncology (3rd edition). Lippincott Williams and Wilkins, 1997.

P35 Poffenbarger, B.A. and E.B. Podgorsak. Viability of an isocentric cobalt-60 teletherapy unit for stereotactic radiosurgery. Med. Phys. 25(10): 1935-1943 (1998).

P36 Pasma, K.L., M. Kroonwijk, J.C.J. de Boer et al. Accurate portal dose measurement with a fluoroscopic electronic portal imaging device (EPID) for open and wedged beams and dynamic multileaf collimation. Phys. Med. Biol. 43: 2047-2060 (1998).

P37 Park, K.B., Y.M. Kim, B.C. Shin et al. Therapeutic application of a new holmium-166 chitosan complex in malignant and benign diseases. p. 569-580 in: Modern Trends in Radiopharmaceuticals for Diagnosis and Therapy. IAEA-TECDOC-1029 (1998).

P38 Peters, A.M. The use of nuclear medicine in infections. Br. J. Radiol. 71: 252-261 (1998).

P39 Peters, A.M. Nuclear medicine imaging in infection and inflammation. J. Royal Coll. Phys. London 32(6): 512-519 (1998).

P40 Pennell, D.J., E. Prvulovich, A. Tweddel et al. Nuclear cardiology in the UK: British Nuclear Cardiology Society survey in 1994. Nucl. Med. Commun. 19: 305-313 (1998).

P41 Prvulovich, E. Nuclear cardiology. J. Royal Coll. Phys. London 32(6): 520-525 (1998).

P42 Petoussi-Hens, N. and M. Zankl. Voxel anthropomorphic models as a tool for internal dosimetry. Radiat. Prot. Dosim. 79(1-4): 415-418 (1998).

P43 Pauwels, E.K.J., W.H. Thomson, J.A.K. Blokland et al. Aspects of fetal thyroid dose following iodine-131 administration during early stages of pregnancy in patients suffering from benign thyroid disorders. Eur. J. Nucl. Med. 26(11): 1453-1457 (1999).

P44 Perkins, A.C. and M. Frier. Bad blood and biologicals: the need for new radiopharmaceutical source materials. Nucl. Med. Commun. 20: 1-3 (1999).

P45 Pötter, R., B. Pokrajac and E. Minar. Endovascular radiotherapy in peripheral arteries - Vienna experience. p. 46-48 in: Vascular Brachytherapy - New Perspectives (P.C. Levendag, ed.). Remedica Publishing, London, 1999.

R1 Royal College of Radiologists. Making the Best Use of a Department of Clinical Radiology, 4th edition. RCR, London, 1998.

R2 Royal College of Radiologists Working Party. Influence of Royal College of Radiologists' guidelines on referral from general practice. Br. Med. J. 306: 110-111 (1993).

R3 Raylman, R. and R.L. Wahl. Magnetically enhanced radionuclide therapy. J. Nucl. Med. 35(1): 157-163 (1994).

R4 Robison, R.F. The race for megavoltage: x-rays versus telegamma. Acta Oncol. 34(8): 1055-1074 (1995).

R5 Rudin, S., L.R. Guterman, W.E. Granger et al. Application of region-of-interest imaging techniques to neurointerventional radiology. Radiology 199: 870-873 (1996).

R6 Raylman, R.R. and R.L. Wahl. Magnetically enhanced protection of bone marrow from beta particles emitted by bone-seeking radionuclides: theory of application. Med. Phys. 22(8): 1285-1292 (1995).

R7 Read, G. Equipment requirements for conformal radiotherapy. RAD Magazine (September): 35-36 (1996).

R8 Raaijmakers, C.P.J., E.L. Nottelman, M.W. Konijnenberg et al. Dose monitoring for boron neutron capture therapy using a reactor-based epithermal neutron beam. Phys. Med. Biol. 41: 2789-2797 (1996).

R9 Rosenstein, M. Handbook of selected tissue doses for projections common in diagnostic radiology. HHS (FDA) 89-8031 (1988).

R10 Rosenstein, M., T.J. Beck and G.G. Warner. Handbook of selected organ doses for projections common in paediatric radiology. HEW (FDA) 79-8079 (1979).

R11 Rannikko, S., K.T.K. Karila and M. Toivonen. Patient and population doses of x-ray diagnostics in Finland. STUK-A144 (1997).

R12 Ruiz Cruces, R., M. Pérez-Martinez, A. Martín-Palanca et al. Patient dose in radiologically guided interventional vascular procedures: conventional versus digital systems. Radiology 205: 385-393 (1997).

R13 Raylman, R.R. and R.L. Wahl. Evaluation of ion-implanted-silicon detectors for use in intraoperative positron-sensitive probes. Med. Phys. 23(11): 1889-1895 (1996).

R14 Reddy, M.S. and M.K. Jeffcoat. Digital subtraction radiography. Dent. Clin. North Am. 37(4): 553-565 (1993).

R15 Rueter, F.G., B.J. Conway, J.L. McCrohan et al. Assessment of skin entrance kerma in the United States: the nationwide evaluation of x ray trends (NEXT). Radiat. Prot. Dosim. 43(1-4): 71-73 (1992).

R16 Rosenthal, L.S., M. Mahesh, T.J. Beck et al. Predictors of fluoroscopy time and estimated radiation exposure during radiofrequency catheter ablation procedures. Am. J. Cardiol. 82(4): 451-458 (1998).

R17 Ruiz Cruces, R., J. García-Granados, F.J. Diaz Romero et al. Estimation of effective dose in some digital angiographic and interventional procedures. Br. J. Radiol. 71: 42-47 (1998).

R18 Roser, H.W. and J. Roth. Medical exposures of patients: medical radiation exposure versus radiation protection. p. 89-92 in: Proceedings of 6th SRP International Symposium, Southport, 14-18 June 1999 (M.C. Thorne, ed.). Society for Radiological Protection, London, 1999.

R19 Rylands-Monk, F. Status of women grows but top jobs elude them. Diagn. Imag. Eur. 14(3): 19-24 (1998).

R20 Rinck, P.A. Helping means more than a handout. Diagn. Imag. Eur. 12(4): 17-18 (1996).

R21 Rinck, P.A. Statistics lead to frustration, falsehoods. Diagn. Imag. Eur. 13(8): 17-18 (1997).

R22 Reiff, K.J. Flat panel detectors - closing the (digital) gap in chest and skeletal radiology. Eur. J. Radiol. 31:125-131 (1997).

R23 Rassow, S. From the entrance dose to the calculation of organ doses. Radiat. Prot. Dosim. 80(1-3): 327-329 (1998).

R24 Rosenthal, L.S., T.J. Back, J. Williams et al. Acute radiation dermatitis following radiofrequency catheter ablation of atrioventricular nodal reentrant tachycardia. PACE, Pac. Clin. Electrophysiol. 20(7): 1834-1839 (1997).

R25 Ridley, E.L. East European rads economize with ultrasound. Diagn. Imag. Eur. 11(8): 15 (1995).

R26 Reid. L.C., G. Needham, C.J. Martin et al. Optimizing dose reduction in CT scanning of the paranasal sinuses: a randomized control trial of recommended versus lowest achievable dose protocols. Radiography 4: 261-268 (1998).

R27 Rogalla, P., B. Stöver, I. Scheer et al. Low-dose spiral CT: applicability to paediatric chest imaging. Paediatr. Radiol. 28: 565-569 (1998).

R28 Remy-Jardin, M. and J. Remy. Spiral CT angiography of the pulmonary circulation. Radiology 212: 615-636 (1999).

R29 Rankin, S.C. CT angiography. Eur. Radiol. 9: 297-310 (1999).

R30 Rogalla, P., C. Enzweiler, E. Schmidt et al. Thoracic diagnostics with electron beam tomography. Der Radiologe 38(12): 1029-1035 (1998).

R31 Royal College of Radiologists. The Use of Computed Tomography in the Initial Investigation of Common Malignancies. RCR, London, 1994.

R32 Ravin, C.E. and H.G. Chotas. Chest radiography. Radiology 204: 593-600 (1997).

R33 Ranschaert, E. Belgian radiologists face unsure future. Diagn. Imag. Eur. 15(8): 57 (1999).

R34 Rezentes, P.S., A. de Almeida and G.T. Barnes. Mammography grid performance. Radiology 210: 227-232 (1999).

R35 Roebuck, D.J. Risk and benefit in paediatric radiology. Pediatr. Radiol. 29: 637-640 (1999).

R36 Rothenberg, L.N., R. Nath, R.R. Price et al. A perspective on the new millennium. Radiology 209: 600-603 (1998).

R37 Ravin, C.E. Future directions in pulmonary imaging. Radiology 206: 9-10 (1998).

R38 Rieppo, P.-K. and J.A Rowlands. X-ray imaging with amorphous selenium: theoretical feasibility of the liquid crystal light valve for radiography. Med. Phys. 24(8): 1279-1291 (1997).

R39 Ruchala, K.J., G.H. Olivera, E.A. Schloesser et al. Megavoltage CT on a tomotherapy system. Phys. Med. Biol. 44: 2597-2621 (1999).

R40 Rhodes, B.A., C.R. Lambert, M.J. Marek et al. Re-188 labelled antibodies. Appl. Radiat. Isot. 47(1): 7-14 (1996).

R41 Ryu, Y.H., T.S. Chung, J.D. Lee et al. Detection of malignant melanoma by Tc-99m HMPAO. Clin. Nucl. Med. 20(6): 528-530 (1995).

R42 Reiners, C. and M. Lassmann. Assessment of patient exposure in nuclear medicine. Radiat. Prot. Dosim. 80(1-3): 243-248 (1998).

R43 Russell, J.R., M.G. Stabin, R.B. Sparks et al. Radiation absorbed dose to the embryo/fetus from radiopharmaceuticals. Health Phys. 73(5): 756-769 (1997).

R44 Russell, J.R., M.G. Stabin and R.B. Sparks. Placental transfer of radiopharmaceuticals and dosimetry in pregnancy. Health Phys. 73(5): 747-755 (1997).

S1 Sanford, L. The continuing story of film technology. Radiogr. Today 58: 27-29 (1992).

S2 Shrimpton, P.C. Low-down on LODOX. Radiol. Prot. Bull. 186: 29-30 (1997).

S3 Steele, H.R. and D.H. Temperton. Patient doses received during digital substraction angiography. Br. J. Radiol. 66: 452-456 (1993).

S4 Stephens, T. Major PACS arise at European hospitals. Diagn. Imag. Int. 12: 39-48 (1993).

S5 Shrimpton, P.C. and B.F. Wall. The increasing importance of x-ray computed tomography as a source of medical exposure. Radiat. Prot. Dosim. 57(1/4): 413-415 (1995).

S6 Shrimpton, P.C., D. Hart and B.F. Wall. A decade of diagnostic reference levels in the UK. p. 132-135 in: Proceedings of 6th SRP International Symposium, Southport, 14-18 June 1999 (M.C. Thorne, ed.). Society for Radiological Protection, London, 1999.

S7 Shope, T.B., R.M. Gagne and G.C. Johnson. A method for describing the doses delivered by transmission x-ray computed tomography. Med. Phys. 8(4): 488-495 (1981).

S8 Shrimpton, P.C., D.G. Jones, M.C. Hillier et al. Survey of CT practice in the UK. Part 2: Dosimetric aspects. NRPB-R249 (1991).

S9 Stern, S.H., M. Rosenstein, L. Renaud et al. Handbook of selected tissue doses for fluoroscopic and cineangiographic examination of the coronary arteries. HHS (FDA) 95-8289 (1995).

S10 Shrimpton, P.C. Computed tomography - a spiralling challenge in radiological protection. p. 26-34 in: Current Topics in Radiography - 2 (A. Paterson and R. Price, eds.). W.B. Saunders, London, 1996.

S11 Stern, S.H., M.J. Dennis, G. Williams et al. Simulation of the upper gastrointestinal fluoroscopic examination for calculation of absorbed dose in tissue. Health Phys. 69(3): 391-395 (1995).

S12 Sjögren, R. and M. Karlsson. Electron contamination in clinical high energy photon beams. Med. Phys. 23(11): 1873-1881 (1996).

S13 Smith, A.R. Rationale for and history of heavy charged particle radiation therapy. Med. Phys. 23(6): 1120 (1996).

S14 Schmidt, Th., M. Wucherer and E. Zeitler. Basics for estimation of the radiation exposure in interventional procedures. Aktuelle Radiol. 8: 11-17 (1998).

S15 Schueler, B.A., P.R. Julsrud, J.E. Gray et al. Radiation exposure and efficacy of exposure-reduction techniques during cardiac catheterization in children. Am. J. Roentgenol. 162: 173-177 (1994).

S16 Servomaa, A., T. Parviainen and T. Komppa. Patient doses and radiation risks in film-screen mammography in Finland. Radiat. Prot. Dosim. 57(1-4): 449-454 (1995).

S17 Short, C. and S. Griffiths. Radiotherapy: developments, contradictions and dilemmas. Radiography 2: 177-189 (1996).

S18 Säbel, M. and H. Aichinger. Recent developments in breast imaging. Phys. Med. Biol. 41: 315-368 (1996).

S19 Sandborg, M., D.R. Dance, G. Alm Carlsson et al. A Monte Carlo study of grid performance in diagnostic radiology: task dependent optimization for digital imaging. Phys. Med. Biol. 39: 1659-1676 (1994).

S20 Sandborg, M., D.R. Dance, G. Alm Carlsson et al. Monte Carlo study of grid performance in diagnostic radiology: task dependent optimization for screen-film imaging. Br. J. Radiol. 67: 76-85 (1994).

S21 Smiddy, P.F., A.D. Quinn, P.J. Freyne et al. Dose reduction in double contrast barium enema by use of low fluoroscopic current. Br. J. Radiol. 69: 852-854 (1996).

S22 Seegenschmiedt, M.H., M. Keilholz, A. Katalinic et al. Heel spur: radiation therapy for refractory pain - results with three treatment concepts. Radiology 200(1): 271-276 (1996).

S23 Speller, R.D., G.J. Royle and J.A. Horrocks. Instrumentation and techniques in bone density measurements. J. Phys., E Sci. Instrum. 2: 202-214 (1989).

S24 Silverman, C.L. and S.L. Goldberg. Total body irradiation in bone marrow transplantation and advanced lymphomas: a comprehensive overview. Chapter 14 in: Current Radiation Oncology, Volume 2 (J.S. Tobias and P.R.M. Thomas, eds.). Arnold, London, 1996.

S25 Syed, A.M.N. and A.A. Puthawala. Current brachytherapy techniques. Chapter 4 in: Current Radiation Oncology, Volume 2 (J.S. Tobias and P.R.M. Thomas, eds.). Arnold, London, 1996.

S26 Stout, R. Intraluminal radiotherapy and its use in lung cancer. RAD Magazine (April): 33-34 (1996).

S27 Stovall, M., C.R. Blackwell, J. Cundiff et al. Fetal dose from radiotherapy with photon beams: report of AAPM Radiation Therapy Committee Task Group No 36. Med. Phys. 22(1): 63-82 (1995).

S28 Sutcliffe, J.F. A review of *in vivo* experimental methods to determine the composition of the human body. Phys. Med. Biol. 41: 791-833 (1996).

S29 Servomaa, A., S. Rannikko, T. Parviainen et al. Quality control and patient dose from x ray examinations in some hospitals in Estonia. Radiat. Prot. Dosim. 57(1/4): 297-300 (1995).

S30 Shrimpton, P.C. and S. Edyvean. CT scanner dosimetry. Br. J. Radiol. 71: 1-3 (1998).

S31 Stasi, M., V.C. Borca and C. Fiorino. Measurements of exit dose profiles in ^{60}Co beams with a conventional portal film system. Br. J. Radiol. 70: 1283-1287 (1997).

S32 Symonds-Tayler, J.R.N., M. Partridge and P.M. Evans. An electronic portal imaging device for transit dosimetry. Phys. Med. Biol. 42: 2273-2283 (1997).

S33 Saunders, M., S. Dische, A. Barrett et al. Continuous hyperfractionated accelerated radiotherapy (CHART) versus conventional radiotherapy in non-small-cell lung cancer: a randomised multicentre trial. Lancet 350: 161-165 (1997).

S34 Sharrock, C. and G. Read. The present status of CRT. RAD Magazine 24 (274): 37-38 (1998).

S35 Solberg, T.D., K.S. Iwamoto and A. Norman. Calculation of radiation dose enhancement factors for dose enhancement therapy of brain tumours. Phys. Med. Biol. 37: 439-443 (1992).

S36 Scott, B.B. Gastroenterology in the Trent Region in 1992 and a review of changes since 1975. Gut 36: 468-472 (1995).

S37 Smith-Morris, M. (ed.). The Economist Book of Vital World Statistics. Hutchison Business Books, London, 1990.

S38 Schandorf, C. and G.K. Tetteh. Analysis of the status of x-ray diagnosis in Ghana. Br. J. Radiol. 71: 1040-1048 (1998).

S39 Schandorf, C. and G.K. Tetteh. Analysis of dose and dose distribution for patients undergoing selected x-ray diagnostic procedures in Ghana. Radiat. Prot. Dosim. 76(4): 249-256 (1998).

S40 Shrimpton, P.C., K.A. Jessen, J. Geleijns et al. Reference doses in computed tomography. Radiat. Prot. Dosim. 80 (1-3): 55-59 (1998).

S41 Smith, T. and I. Gordon. An update of radio-pharmaceutical schedules in children. Nucl. Med. Commun. 19: 1023-1036 (1998).

S42 Schiepers, C. and C.K. Hoh. Positron emission tomography as a diagnostic tool in oncology. Eur. Radiol. 8(8): 1481-1494 (1998).

S43 Shamsaldin, A., E. Grimaud, C. Hardiman et al. Dose distribution throughout the body from radiotherapy for Hodgkin's disease in childhood. Radiother. Oncol. 335: 85-90 (1998).

S44 Suleiman, O.H., R. Antonsen, B.J. Conway et al. Assessing patient exposure in fluoroscopy. Radiat. Prot. Dosim. 49 (1-3): 141-143 (1993).

S45 Smith, T., I. Gordon and J.P. Kelly. Comparison of radiation dose from intravenous urography and ^{99m}Tc DMSA scintigraphy in children. Br. J. Radiol. 71: 314-319 (1998).

S46 Shope, T.B. Radiation-induced skin injuries from fluoroscopy. Radiographics 16(5): 1195-1199 (1996).

S47 Semin, S. and Z. Amato. The number and distribution of computerised tomography scanners in Turkey. Eur. Radiol. 9(7): 1457-1458 (1999).

S48 Schlesinger, T., Israel. Communication to the UNSCEAR Secretariat (1998).

S49 Staniszewska, M.A. and J. Jankowski. An update of the frequency and type of diagnostic x-ray examinations in Poland. Int. J. Occup. Med. Environ. Health 12(2): 127-134 (1999).

S50 Songy, B., Conseil Scientifique de l'OPRI. Communication to the UNSCEAR Secretariat (1997).

S51 Schultz, F., W. Teeuwisse, J. Broerse et al. Dosimetric consequences of implementation of digital radiology for hysterosalpingography. Med. Phys. 25(7) Part 1: A156 (1998).

S52 Seymour, R. Patient dose reduction by audit of grid usage in barium enemas. Br. J. Radiol. 70: 489-491 (1997).

S53 Suleiman, O.H., B.J. Conway, P. Quinn et al. Nationwide survey of fluoroscopy: radiation dose and image quality. Radiology 203: 471-476 (1997).

S54 Stieve, F.-E., G. Hagemann and H.-St. Stender. Relationship between medical requirements and technical parameters of good imaging performance and acceptable dose. Radiat. Prot. Dosim. 49(1-3): 3-18 (1993).

S55 Saure, D., G. Hagemann and H.S. Stender. Image quality and patient dose in diagnostic radiology. Radiat. Prot. Dosim. 57(1-4): 167-170 (1995).

S56 Servomaa, A. and M. Tapiovaara. Organ dose calculation in medical x ray examinations by the program PCXMC. Radiat. Prot. Dosim. 80(1-3): 213-219 (1998).

S57 Saxebøl, G., H.M. Olerud, O. Hjardemaal et al. Nordic guidance levels for patient doses in diagnostic radiology. Radiat. Prot. Dosim. 80(1-3): 99-101 (1998).

S58 Stamm, G. and H.-D. Saure. Entrance surface dose and its correlation with patient parameters. Radiat. Prot. Dosim. 80(1-3): 235-238 (1998).

S59 Sassi, S.A. and A.J. Britten. Moving segments region of interest attenuator for x-ray fluoroscopy. Med. Phys. 26(1): 19-26 (1999).

S60 Stieve, F.-E. Trends in x ray diagnosis and nuclear medicine. Radiat. Prot. Dosim. 57(1-4): 13-20 (1995).

S61 Shrimpton, P.C., B.F. Wall and D. Hart. Diagnostic medical exposures in the UK. Appl. Radiat. Isot. 50(1): 261-269 (1999).

S62 Suleiman, O.H., B.J. Conway, F.G. Rueter et al. The United States experience in patient dose and image quality. Radiat. Prot. Dosim. 57(1-4): 101-104 (1995).

S63 Suleiman, O.H., S. Stern and D.C. Spelic. Patient dosimetry activities in the United States: the nationwide evaluation of x-ray trends (NEXT) and tissue dose handbooks. Appl. Radiat. Isot. 50(1): 247-259 (1999).

S64 Sandborg, M., D.R. Dance, G. Alm Carlsson et al. Results from an optimisation of grid design in diagnostic radiology. Radiat. Prot. Dosim. 57(1-4): 211-215 (1995).

S65 Sajben, F.P., S.B. Schoelch and D.J. Barnette. Fluoroscopic-induced radiation dermititis. Cutis 64(1): 57-59 (1999).

S66 Sovik, E., N.E. Klow, J. Hellesnes et al. Radiation-induced skin injury after pertcutaneous transluminal coronary angioplasty: case report. Acta Radiol. 37(3 Pt 1): 305-306 (1996).

S67 Servomaa, A., M. Heikkilä, T. Komppa et al. Patient dose and radiation risk in computed tomographic examinations in Finland. Abstract PS32-1.13. Phys. Med. Biol. 39a(Part 2): 832 (1994).

S68 Szendrö, G., B. Axelsson and W. Leitz. Computed tomography practice in Sweden: quality control, techniques and patient dose. Radiat. Prot. Dosim. 57(1-4): 469-473 (1995).

S69 Smith, A.N. and G.A. Shah. A survey of routine head CT protocols in Australia. Br. J. Radiol. 70: 372-374 (1997).

S70 Smith, A.N., G.A. Shah and T. Kron. Variation of patient dose in head CT. Br. J. Radiol. 71: 1296-1301 (1998).

S71 Seifert, H., G. Glass, H.-K. Leetz et al. The radiation exposure of the patient from stable-xenon computed tomography. Br. J. Radiol. 68: 301-305 (1995).

S72 Starck, G., L. Lönn, A. Cederblad et al. Radiation dose reduction in CT: application to tissue area and volume determination. Radiology 209: 397-403 (1998).

S73 Stöver, B. and P. Rogalla. CT investigations in children: technique and indications. Der Radiologe 39(6): 455-462 (1999).

S74 Scheck, R.J., E.M. Coppenrath, A. Bäuml et al. Radiation dose and image quality in spiral computed tomography: results of a multicentre study at eight radiological institutions. Radiat. Prot. Dosim. 80(1-3): 283-286 (1998).

S75 Silverman, S.G., K. Tuncali, D.F. Adams et al. CT fluoroscopy-guided abdominal interventions: techniques, results, and radiation exposure. Radiology 212: 673-681 (1999).

S76 Schoepf, T., W.A. Recheis, R. Napp et al. Radiation dose from electron-beam CT. Radiology 201(P): 326 (1996).

S77 Shah, G.A. and A.J. Buxton. Survey of dose associated with chest radiography in the Hunter Valley region of Australia. Radiography 5: 23-27 (1999).

S78 Schultz, F.W., J. Geleijns and J. Zoetelief. Effective doses for different techniques used for PA chest radiography. Radiat. Prot. Dosim. 57(1-4): 372-376 (1995).

S79 Simpson, P.D., C.J. Martin, C.L. Darragh et al. A study of chest radiography with mobile x-ray units. Br. J. Radiol. 71: 640-645 (1998).

S80 Schultz, F.W., J. Geleijns and J. Zoetelief. Calculation of dose conversion factors for posterior-anterior chest radiography of adults with a relatively high-energy x-ray spectrum. Br. J. Radiol. 67: 775-785 (1994).

S81 Suzuki, S., Y. Asada, S. Fujii et al. Estimation of patient dose in mammographic screening examinations. Health Phys. 68(2): 275 (1995).

S82 Suleiman, O.H., D.C. Spelic, J.L. Mc.Crohan et al. Mammography in the 1990s: the United States and Canada. Radiology 210: 345-351 (1999).

S83 Sobol, W.T. and X. Wu. Parametrization of mammography normalized average glandular dose tables. Med. Phys. 24(4): 547-554 (1997).

S84 Sabol, J.M., I.C. Soutar and D.B. Plewes. Practical application of a scan-rotate equalization geometry to mammography. Med. Phys. 23(12): 1987-1996 (1996).

S85 Sharp, C., J.A. Shrimpton and R.F. Bury. Diagnostic medical exposures: advice on exposure to ionising radiation during pregnancy. NRPB, Chilton (1998).

S86 Seely, J.F., C.N. Boyer and G.E Holland. Dual-energy bone densitometry using a single 100 ns x-ray pulse. Med. Phys. 25(10): 2027-2036 (1998).

S87 Swanpalmer, J., R. Kullenberg and T. Hansson. Measurement of bone mineral using multiple-energy x-ray absorptiometry. Phys. Med. Biol. 43: 379-387 (1998).

S88 Schultz, F.W., J. Geleijns, H.C. Holscher et al. Radiation burden to paediatric patients due to micturating cystourethrography examinations in a Dutch children's hospital. Br. J. Radiol. 72: 763-772 (1999).

S89 Seifert, H., R. Kubale, Th. Hagen et al. A study of dose reduction using digital luminescence radiography for lateral skull radiography. Br. J. Radiol. 69: 311-317 (1996).

S90 Speller, R., G. Royle, M.-G. Scannavini et al. Impact of new digital x- and gamma ray imaging systems upon patient doses. Appl. Radiat. Isot. 50(1): 153-163 (1999).

S91 Strickland, N.H. Some cost-benefit considerations for PACS: a radiological perspective. Br. J. Radiol. 69: 1089-1098 (1996).

S92 Siewerdsen, J.H., L.E. Antonuk, Y. El-Mohri et al. Signal, noise power spectrum, and detective quantum efficiency of indirect-detection flat-panel imagers for diagnostic radiology. Med. Phys. 25(5): 614-628 (1998).

S93 Seifert, H., Th. Hagen, K. Bartylla et al. Patient doses from standard and spiral CT of the head using a fast twin-beam system. Br. J. Radiol. 70: 1139-1145 (1997).

S94 Shakeshaft, J.T., H.M. Morgan and P.D. Simpson. *In vivo* dosimetry using diodes as a quality control tool - experience of 2 years and 2000 patients. Br. J. Radiol. 72: 891-895 (1999).

S95 Sätherberg, A. and L. Johansson. Photonuclear production in tissue for different 50 MV bremsstrahlung beams. Med. Phys. 25(5): 683-688 (1998).

S96 Stern, R.L. Peripheral dose from a linear accelerator equipped with multileaf collimation. Med. Phys. 26(4): 559-563 (1999).

S97 Swedish Council on the Technology Assessment in Health Care. Radiotherapy for cancer - Volume 1. Acta Oncol. 35 (Suppl. 6): (1997).

S98 Swedish Council on the Technology Assessment in Health Care. Radiotherapy for cancer - Volume 2. Acta Oncol. 35 (Suppl. 7): (1997).

S99 Schulz, R.J. Further improvements in dose distributions are unlikely to affect cure rates. Med. Phys. 26(6): 1007-1009 (1999).

S100 Solberg, T.D., J.J. DeMarco, F.E. Holly et al. Monte Carlo treatment planning for stereotactic radiosurgery. Radiother. Oncol. 49: 73-84 (1998).

S101 Shrimpton, P.C. Trends in radiopharmaceuticals. Radiol. Prot. Bull. 206: 19-21 (1998).

S102 Sgouros, G. Yttrium-90 biodistribution by yttrium-87 imaging: a theoretical feasibility analysis. Med. Phys. 25(8): 1487-1490 (1998).

S103 Schwarz, von E.-R. and B. Bauer. Bedeutsame Ereignisse nach # 36 StrlSchV aus den Jahresberichten des BMU. p. 103-221: Seminar für Mitarbeiter Regionaler Strahlenschutz-zentren 1993. Institut für Strahlenschutz, Germany, 1993.

S104 Schneebaum, S., E. Even-Sapir, M. Cohen et al. Clinical applications of gamma-detection probes: radioguided surgery. Eur. J. Nucl. Med. 26(13): S26-S35 (1999).

S105 Stabin, M.G., M. Tagesson, S.R. Thomas et al. Radiation dosimetry in nuclear medicine. Appl. Radiat. Isot. 50(1): 73-87 (1999).

S106 Stabin, M.G. MIRDOSE: the personal computer software for use in internal dose assessment in nuclear medicine. J. Nucl. Med. 37: 538-546 (1996).

S107 Stabin, M.G. Fetal dose calculation workbook. Report ORISE 97-0961. Radiation Internal Dose Information Center, Oak Ridge TN (1997).

S108 Sisterson, J.M. World wide proton therapy experience in 1997. p. 959-962 in: CP475, Application of Accelerators in Research and Industry (J.L. Duggan and I.L. Morgan, eds.). AIP Press, New York, 1999.

T1 Tidwell, A., S. Brahmavar, R. Breton et al. Radiation exposures using pulsed fluoroscopy: patient and physician. Paper Presented at the Annual Meeting of American Association of Physicists in Medicine, Anaheim, July 1994.

T2 Technology Marketing Group. Communication to the UNSCEAR Secretariat (1994).

T3 Truscott, J.G., R. Milner, P.C. Holland et al. A portable system for measuring bone mineral density in the pre-term neonatal forearm. Br. J. Radiol. 69: 532-538 (1996).

T4 Trott, N.G. Radionuclides in brachytherapy: radium and after. Br. J. Radiol. (Suppl.): 21 (1987).

T5 Thomadsen, B. Why HDR? Differences compared to LDR brachytherapy. Med. Phys. 23(6): 1046 (1996).

T6 Thwaites, D.I., D.T. Burns, S.C. Klevenhagen et al. The IPEMB code of practice for electron dosimetry for radiotherapy beams of initial energy from 2 to 50 MeV based on an air kerma calibration. Phys. Med. Biol. 41: 2557-2603 (1996).

T7 Thomas, G.O., J.R. Croft, M.K. Williams et al. IRID: specifications for the ionising radiations incident database. NRPB, Chilton (1996).

T8 Thwaites, J.H., M.W. Rafferty, N. Gray et al. A patient dose survey for femoral arteriogram diagnostic radiographic examinations using a dose-area product meter. Phys. Med. Biol. 41: 899-907 (1996).

T9 Tapiovaara, M., M. Lakkisto and A. Servomaa. PCXMC: a PC-based Monte Carlo program for calculating patient doses in medical x-ray examinations. STUK-A139 (1997).

T10 Thompson, V., M. Bidmead and C. Mubata. Comparison of portal imaging and megavoltage verification films for conformal pelvic irradiation. Br. J. Radiol. 69: 1191-1195 (1996).

T11 Teirstein, P.S., V. Massullo, S. Jani et al. Catheter-based radiotherapy to inhibit restenosis after coronary stenting. N. Engl. J. Med. 336: 1697-1703 (1997).

T12 Taylor, S.J. and H.R. Rogers. Measurements of patient dose received from transmission scanning using ^{153}Gd line sources. Nucl. Med. Commun. 19: 369 (1998).

T13 Thurston, M.O. and C.M. Mojzisik. History and development of radioimmunoguided surgery. Seminars in Colon & Rectal Surgery 6(4): 185-191 (1995).

T14 Tyndall, D.A. Order of magnitude absorbed dose reductions in cephalometric radiography. Health Phys. 56(4): 533-538 (1989).

T15 Tanner, R.J., B.F. Wall, P.C. Shrimpton et al. Frequency of medical and dental x-ray examinations in the UK – 1987/98. NRPB-R320 (2000).

T16 Teunen, D. Round table on initiatives, achievements and perspectives with regard to the Council Directive of 3 September 1984 laying down basic measures for the radiation protection of persons undergoing medical examination or treatment. Radiat. Prot. Dosim. 57(1-4): 33-71 (1995).

T17 Thomson, J.E.M. and D.R.C. Tingey. Radiation doses from computed tomography in Australia. ARL/TR123 (1997).

T18 Thomas, C.G., M. Hale and C. Daniels. Absorbed dose distributions in helical versus conventional CT scanning. Med. Phys. 22(5): 674 (1995).

T19 Thomas. P.J., C.H. McCollough and E.L. Ritman. An electron-beam CT approach for transvenous coronary arteriography. J. Comput. Assist. Tomogr. 19(3): 383-389 (1995).

T20 Thilander-Klang, A.C., P.H.R. Ackerholm, I.C. Berlin et al. Influence of anode-filter combinations on image quality and radiation dose in 965 women undergoing mammography. Radiology 203: 348-354 (1997).

T21 Thomas, S.M., N.R. Bees and E.J. Adam. Trends in the use of pelvimetry techniques. Clin. Radiol. 53(4): 293-295 (1998).

T22 Tapiovaara., M.J., M. Sandborg and D.R. Dance. A search for improved technique factors in paediatric fluoroscopy. Phys. Med. Biol. 44: 537-559 (1999).

T23 Ting, J.Y., A.H. Wolfson, X. Wu et al. Bladder and rectal doses from external-beam boosts after gynaecologic brachytherapy. Radiology 209: 825-830 (1998).

T24 Thomson, W.H., D. Bray and L.K. Harding. Clearance of ^{99m}Tc radiopharmaceuticals from extravasated sites. Nucl. Med. Commun. 18: 332 (1997).

T25 Tanaka, E. Instrumentation for PET and SPECT studies. p. 19-29 in: Tomography in Nuclear Medicine. Pro-ceedings Series. IAEA, Vienna, 1996.

U3 United Nations. Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, 1993 Report to the General Assembly, with scientific annexes. United Nations sales publication E.94.IX.2. United Nations, New York, 1993.

U4 United Nations. Sources, Effects and Risks of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, 1988 Report to the General Assembly, with annexes. United Nations sales publication E.88.IX.7. United Nations, New York, 1988.

U6 United Nations. Ionizing Radiation: Sources and Biological Effects. United Nations Scientific Committee on the Effects of Atomic Radiation, 1982 Report to the General Assembly, with annexes. United Nations sales publication E.82.IX.8. United Nations, New York, 1982.

U7 United Nations. Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, 1977 Report to the General Assembly, with annexes. United Nations sales publication E.77.IX.1. United Nations, New York, 1977.

U8 United Nations. Ionizing Radiation: Levels and Effects. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, with annexes. United Nations sales publication E.72.IX.17 and 18. United Nations, New York, 1972.

U12 United Nations. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. Official Records of the General Assembly, Seventeenth Session, Supplement No. 16 (A/5216). New York, 1962.

U13 United Nations. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. Official Records of the General Assembly, Thirteenth Session, Supplement No. 17 (A/3838). New York, 1958.

U14 Uppelschoten, J.M., S.L. Wanders and J.M.A. de Wong. Single-dose radiotherapy (6 Gy): palliation in painful bone metastases. Radiother. Oncol. 36: 198-202 (1995).

U15 Unger, F. Interventions on the coronaries: PTCA versus CABG. J. Interven. Cardiol. 9(1): 3-7 (1996).

U16 Uemura, K. Brain studies using SPECT and PET. p. 233-257 in: Tomography in Nuclear Medicine. Proceedings Series. IAEA, Vienna, 1996.

V1 Vañó, E., A. Velasco, P. Morán et al. Evolution of diagnostic radiology in a big hospital during a 5 year period, and the derived collective dose. Br. J. Radiol. 66: 892-898 (1993).

V2 Vaidyanathan, G. and M.R. Zalutsky. Targeted therapy using alpha emitters. Phys. Med. Biol. 41(10): 1915-1931 (1996).

V3 Vañó, E., L. Gonzalez, J.M. Fernández et al. Patient dose values in interventional radiology. Br. J. Radiol. 68: 1215-1220 (1995).

V4 Voordeckers, M., H. Goossens, J. Rutten et al. The implementation of *in vivo* dosimetry in a small radio-therapy department. Radiother. Oncol. 47: 45-48 (1998).

V5 Vatnitsky, S.M., R.W.M. Schulte, R. Galindo et al. Radiochromic film dosimetry for verification of dose distributions delivered with proton-beam radiosurgery. Phys. Med. Biol. 42: 1887-1898 (1997).

V6 van der Giessen, P.H. Dose outside the irradiated volume in radiotherapy: gonadal or fetal dose and its associated risks. Doctoral Thesis, University of Leiden (1997).

V7 van der Giessen, W.J. and P.W. Serruys. β-particle - emitting stents radiate enthusiasm in the search for effective prevention of restenosis. Circulation 94: 2358-2360 (1996).

V8 Vañó, E., Madrid. Communication to the UNSCEAR Secretariat (1997).

V9 Vrtar, M. Medical physics in Algeria. Med. Phys. World 13(2): 23 (1997).

V10 Vañó, E., E. Guibelalde, J.M. Fernández et al. Patient dosimetry in interventional radiology using slow films. Br. J. Radiol. 70: 195-200 (1997).

V11 Vañó, E., L. Arranz, J.M. Sastre et al. Dosimetric and radiation protection considerations based on some cases of patient skin injuries in interventional cardiology. Br. J. Radiol. 71: 510-516 (1998).

V12 Vetter, S., K. Faulkner, E.-P. Strecker et al. Dose reduction and image quality in pulsed fluoroscopy. Radiat. Prot. Dosim. 80(1-3): 299-301 (1998).

V13 Vehmas, T. Hawthorne effect: shortening of fluoroscopy times during radiation measurement studies. Br. J. Radiol. 70: 1053-1055 (1997).

V14 Verdun, F.R., P. Capasso, J.-F. Valley et al. Dose evaluation in fluoroscopy. Radiat. Prot. Dosim. 80(1-3): 139-141 (1998).

V15 Van Unnik, J.G., J.J. Broerse, J. Geleijns et al. Survey of CT techniques and absorbed dose in various Dutch hospitals. Br. J. Radiol. 70: 367-371 (1997).

V16 Verdun, F.R., R.A. Meuli, F.O. Bochud et al. Image quality and dose in spiral computed tomography. Eur. Radiol. 6: 485-488 (1996).

V17 Verdun, F.R., F. Bochud, C. Depeursinge et al. Subjective and objective evaluation of chest imaging systems. Radiat. Prot. Dosim. 49(1/3): 91-94 (1993).

V18 Vlasbloem, H. and L.J. Schultze Kool. AMBER: a scanning multiple-beam equalization system for chest radiography. Radiology 169: 29-34 (1988).

V19 Verdun, F.R., R. Moeckli, J.-F. Valley et al. Survey on image quality and dose levels used in Europe for mammography. Br. J. Radiol. 69: 762-768 (1996).

V20 Veit, R. and M. Zankl. Variation of organ doses in paediatric radiology due to patient diameter, calculated with phantoms of varying voxel size. Radiat. Prot. Dosim. 49(1/3): 353-356 (1993).

V21 Varchenya, V., D. Gubatova, V. Sidorin et al. Children's heterogeneous phantoms and their application in röntgenology. Radiat. Prot. Dosim. 49(1/3): 77-78 (1993).

V22 van der Putten, W. All changed utterly: implications for image quality, display and dose, changing from conventional to digital radiography. Radiat. Prot. Dosim. 80(1-3): 269-274 (1998).

V23 Vañó, E., L. Gonzalez, E. Guibelalde et al. Some results from a diagnostic radiology optimisation programme in the Madrid area. Radiat. Prot. Dosim. 57(1-4): 289-292 (1995).

V24 Veit, R., M. Zankl, N. Petoussi et al. Tomographic anthropomorphic models. Part 1: Construction technique and description of models of an 8 week old baby and a 7 year old child. GSF-Bericht 3/89 (1989).

V25 Vetter, R.J. and K.L. Classic. Radiation dose to patients who participate in medical research studies. p. 97-100 in: Proceedings of 6th SRP International Symposium, Southport, 14-18 June 1999 (M.C. Thorne, ed.). Society for Radiological Protection, London, 1999.

V26 Van Eijck, C.H.J. and E.P. Krenning. Nuclear medicine imaging of breast cancer. Nucl. Med. Commun. 17: 925-927 (1996).

V27 van Leeuwen, F.E., W.J. Klokman, M. Stovall et al. Roles of radiotherapy and smoking in lung cancer following Hodgkin's disease. J. Natl. Cancer Inst. 87: 1530-1537 (1995).

W1 Wild, R. A decade of ultrasound. Radiology Now 10(1): 6 (1993).

W2 Whitehouse, G.H. and B.S. Worthington (eds). Techniques in Diagnostic Imaging. Blackwell Scientific Publications, Oxford, 1990.

W3 World Health Organization. A rational approach to radiodiagnostic investigations. Technical Report Series 689 (1983).

W4 World Health Organization. Rational use of diagnostic imaging in paediatrics. Technical Report Series 757 (1987).

W5 World Health Organization. Effective choices for diagnostic imaging in clinical practice. Technical Report Series 795 (1990).

W6 Wilkins, S.W., T.E. Gureyev, D. Gao et al. Phase-contrast imaging using polychromatic hard x-rays. Nature 384: 335-338 (1996).

W7 Wandtke, J.C. Bedside chest radiography. Radiology 190: 1-10 (1994).

W8 Workman, A. and A.R. Cowen. Improved image quality utilising dual plate computed radiography. Br. J. Radiol. 68: 182-188 (1995).

W9 World Health Organization. Efficacy and radiation safety in interventional radiology. (2000, to be published).

W10 Wright, D.J., L. Godding and C. Kirkpatrick. Digital radiographic pelvimetry - a novel, low dose, accurate technique. Br. J. Radiol. 68: 528-530 (1995).

W11 Wall, B.F., NRPB. Communication to the UNSCEAR Secretariat (1996).

W12 World Health Organization. World health, 48th Year, No. 3 (1995).

W13 World Health Organization. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis. Technical Report Series 843 (1994).

W14 World Health Organization. Quality assurance in radiotherapy. WHO, Geneva (1988).

W15 Walker, S.J. Extra-corporeal radiotherapy for primary bone sarcomas. Radiography 2: 223-227 (1996).

W16 Wilson, D.L., P. Xue and R. Aufrichtig. Perception of fluoroscopy last-image hold. Med. Phys. 21(12): 1875-1883 (1994).

W17 Weber, J., W. Scheid and H. Traut. Biological dosimetry after extensive diagnostic x-ray exposure. Health Phys. 68(2): 266-269 (1995).

W18 Wilson, E. and S. Ebdon-Jackson. Secretary of States' POPUMET Inspectorate: the first 6 years. p. 12-15 in: Radiation Incidents (K. Faulkner, R.M. Harrison, eds.). British Institute of Radiology, London, 1996.

W19 Walker, S.J. The management of treatment incidents: an analysis of incidents in radiotherapy. p. 29-35 in: Radiation Incidents (K. Faulkner, R.M. Harrison, eds.). British Institute of Radiology, London, 1996.

W20 World Health Organization. Progress towards health for all: Statistics for member states 1994. WHO, Geneva (1994).

W21 World Health Organization. The World Health Report 1997: Conquering suffering, enriching humanity. WHO, Geneva (1997).

W22 World Health Organization. Radiotherapy in Cancer Management - A Practical Manual. Chapman & Hall Medical, London, 1997.

W23 Wheldon, T.E. The radiobiological basis of total body irradiation. Br. J. Radiol. 70: 1204-1207 (1997).

W24 Weaver, K., C.H. Siantar, W. Chandler et al.. A source model for efficient brachytherapy computations with Monte Carlo. Med. Phys. 23(12): 2079-2084 (1996).

W25 Weeks, K.J., V.N. Litvinenko and J.M.J. Madey. The Compton backscattering process and radiotherapy. Med. Phys. 24(3): 417-423 (1997).

W26 Weeks, K.J. and P.G. O'Shea. Production of radioisotopes by direct electron activation. Med. Phys. 25(4): 488-492 (1998).

W27 Wu, V.W.C., J.S.T. Sham and R.W.L. Li. Dose analysis of radiotherapy techniques for nasopharyngeal carcinoma. Radiography 3: 229-240 (1997).

W28 World Health Organization. Use of ionizing radiation and radionuclides on human beings for medical research, training, and nonmedical purposes. Technical Report Series 611 (1977).

W29 Waksman, R., S.B. King, I.R. Crocker et al. Vascular Brachytherapy. Nucleotron BV, Veenendaal, 1996.

W30 Wagner, L.K., R.G. Lester and L.R. Saldana. Exposure of the Pregnant Patient to Diagnostic Radiations; A Guide to Medical Management (2nd edition). Medical Physics Publishing, Madison, Wisconsin, 1997.

W31 Wagner, L.K., P.J. Eifel and R.A. Geise. Potential biological effects following high x-ray dose interventional procedures. J. Vasc. Int. Radiol. 5: 71-84 (1994).

W32 Williams, J.R. The interdependence of staff and patient doses in interventional radiology. Br. J. Radiol. 70: 498-503 (1997).

W33 Ward, P. Radiology under siege in troubled nations. Diagn. Imag. Eur. 14(1): 19-26 (1998).

W34 Webb, D.V., S.B. Solomon and J.E.M. Thomson. Background radiation levels and medical exposures in Australia. Radiat. Prot. Australasia 16(2): 25-32 (1999).

W35 Wise, K.N., M. Sandborg, J. Persliden et al. Sensitivity of coefficients for converting entrance surface dose and kerma-area product to effective dose and energy imparted to the patient. Phys. Med. Biol. 44: 1937-1954 (1999).

W36 Waligórski, M.P.R. What can solid state detectors do for clinical dosimetry in modern radiotherapy? Radiat. Prot. Dosim. 85(1-4): 361-366 (1999).

W37 Warren-Forward, H.M., M.J. Haddaway, D.H. Temperton et al. Dose-area product readings for fluoroscopic and plain film examinations, including an analysis of the source of variation for barium enema examinations. Br. J. Radiol. 71: 961-967 (1998).

W38 Wall, B.F. and P.C. Shrimpton. The historical development of reference doses in diagnostic radiology. Radiat. Prot. Dosim. 80(1-3): 15-20 (1998).

W39 White, D.R. The design and manufacture of anthropomorphic phantoms. Radiat. Prot. Dosim. 49(1-3): 359-369 (1993).

W40 Williams, J.R. and M.K. Catling. An investigation of x-ray equipment factors influencing patient dose in radiography. Br. J. Radiol. 71: 1192-1198 (1998).

W41 Warren-Forward, H.M. and L. Duggan. Patient radiation doses from interventional procedures. p. 136 in: Proceedings of 6th SRP International Symposium, Southport, 14-18 June 1999 (M.C. Thorne, ed.). Society for Radiological Protection, London, 1999.

W42 Walderhaug, T.P. and G. Einarsson. Analysis of kerma area product measurements of barium enema examinations. Radiat. Prot. Dosim. 80(1-3): 231-234 (1998).

W43 Wagner, L.K. and J.J. Pollock. Real-time portal monitoring to estimate dose to skin of patients from high dose fluoroscopy. Br. J. Radiol. 72: 846-855 (1999).

W44 Wade, J.P., J.C. Weyman and K.E. Goldstone. CT standard protocols are of limited value in assessing actual patient dose. Br. J. Radiol. 70: 1146-1151 (1997).

W45 Waite, D.W, H.B. Whittet, G.A. Shun-Shin. Computed tomography dacryocystography. Br. J. Radiol. 66: 711-713 (1993).

W46 Ware, D.E., W. Huda, P.J. Mergo et al. Radiation effective doses to patients undergoing abdominal CT examinations. Radiology 210: 645-650 (1999).

W47 Wong, T.H., W.T. Lai and S.K. Yu. An objective way to standardise the mAs for CT of the paediatric brain. Br. J. Radiol. 72 (Suppl.): 58 (1999).

W48 Wang, G. and M.W. Vannier. Optimal pitch in spiral computed tomography. Med. Phys. 24(10): 1635-1639 (1997).

W49 Wise, K.N. An EGS4 based mathematical phantom for radiation protection calculations using standard man. Health Phys. 67(5): 548-553 (1994).

W50 Warren-Forward, H.M., M.J. Haddaway, I.W. McCall et al. Influence of dose reduction recommendations on changes in chest radiography techniques. Br. J. Radiol. 69: 755-761 (1996).

W51 Warren, R.M.L and S. Duffy. A comparison of the effectiveness of 28 kV (grid) versus 25 kV (no grid) mammographic techniques for breast screening. Br. J. Radiol. 70: 1022-1027 (1997).

W52 Williams, M.B., E.D. Pisano, M.D. Schnall et al. Future directions in imaging of breast diseases. Radiology 206: 297-300 (1998).

W53 Westmore, M.S., A. Fenster and I.A. Cunningham. Tomographic imaging of the angular-dependent coherent-scatter cross section. Med. Phys. 24(1): 3-10 (1997).

W54 Wynn-Jones, J. and S.Groves-Phillips. Telemedicine and teleradiology in primary care: a GP's perspective. p. 250-258 in: Current Topics in Radiography - 2 (A. Paterson and R. Price, eds.). W.B. Saunders, London, 1996.

W55 Weatherburn, G.C., S. Bryan and M. West. A comparison of image reject rates when using film, hard copy computed radiography and soft copy images on picture archiving and communication systems (PACS) workstations. Br. J. Radiol. 72: 653-660 (1999).

W56 Weatherburn, G.C. and S. Bryan. The effect of a picture archiving and communication systems (PACS) on patient radiation doses for examination of the lateral lumbar spine. Br. J. Radiol. 72: 534-545 (1999).

W57 Wall, B.F. and D. Hart. Revised radiation doses for typical x-ray examinations. Br. J. Radiol. 437-439 (1997).

W58 Wade, J.P., K.E. Goldstone and P.P. Dendy. Patient dose measurement and dose reduction in East Anglia (UK). Radiat. Prot. Dosim. 57(1-4): 445-448 (1995).

W59 Wright, D.J. and M.L. Ramsdale. The use of national and locally set reference dose levels in a regional programme for dose reduction in diagnostic radiology. Radiat. Prot. Dosim. 80(1-3): 103-107 (1998).

W60 Weinreich, R., L. Wyer, N. Crompton et al. I-124 and its applications in nuclear medicine and biology. p. 399-418 in: Modern Trends in Radiopharmaceuticals for Diagnosis and Therapy. IAEA-TECDOC-1029 (1998).

W61 Wang, S.J., W.Y. Lin, M.N. Chen et al. Rhenium-188 microspheres: a new radiation synovectomy agent. Nucl. Med. Commun. 19: 427-433 (1998).

W62 Wilhelm, A.J., G.S. Mijnhout and E.J.F. Franssen. Radiopharmaceuticals in sentinel lymph-node detection - an overview. Eur. J. Nucl. Med. 26(13): S36-S42 (1999).

W63 Wells, C.P., R.J. Burwood and E.K. Forbes. South Thames nuclear medicine survey 1996-97. Nucl. Med. Commun. 18: 1098-1108 (1997).

W64 Wahl, R.L., R.A. Hawkins, S.M. Larson et al. Proceedings of a National Cancer Institute workshop: PET in oncology: a clinical research agenda. Radiology 193: 604-606 (1994).

W65 Wagner, H.N. F-18 FDG in oncology: its time has come. Appl. Radiol. 26(6): 29-31 (1997).

X1 Xu, G., T. Chao and K. Eckerman. Organ dose calculations using Monte Carlo method and realistic voxel phantom. Med. Phys. 26(6): 1175 (1999).

Y1 Young, I.R. Review of modalities with a potential future in radiology. Radiology 192: 307-317 (1994).

Y2 Young, K.C. Comparison of dose measurement protocols in mammography. Radiat. Prot. Dosim. 57(1/4): 401-403 (1995).

Y3 Yu, C.X. Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy. Phys. Med. Biol. 40: 1435-1449 (1995).

Y4 Yaffe, M.J. and J.A. Rowlands. X-ray detectors for digital radiography. Phys. Med. Biol. 42: 1-39 (1997).

Y5 Yan, D., F. Vicini, J. Wong et al. Adaptive radiation therapy. Phys. Med. Biol. 42: 123-132 (1997).

Y6 Yu, C.X., D.A. Jaffray and J.W. Wong. The effects of intra-fraction organ motion on the delivery of dynamic intensity modulation. Phys. Med. Biol. 43: 91-104 (1998).

Y7 Yang, J.M., T.R. Mackie, R. Reckwerdt et al. An investigation of tomotherapy beam delivery. Med. Phys. 24(3): 425-436 (1997).

Y8 Young, L.A., I.J. Kalet, J.S. Rasey et al. ^{125}I brachytherapy k-edge dose enhancement with $AgTPPS_4$. Med. Phys. 25(5): 709-718 (1998).

Y9 Yeh, S.-H., W.-J. Hsu, H.-L. Yin et al. Evaluation of dose distribution and a pilot study of population doses for diagnostic x ray exposure in Taiwan in 1997. Radiat. Prot. Dosim. 85(1-4): 421-424 (1999).

Y10 Yakoumakis, E., I.A.Tsalafoutas, P. Sandilos et al. Patient doses from barium meal and barium enema examinations and potential for reduction through proper set-up of equipment. Br. J. Radiol. 72: 173-178 (1999).

Y11 Yakoumakis, E., C. Tierris, I. Tsalafoutas et al. Quality control in dental radiology in Greece. Radiat. Prot. Dosim. 80(1-3): 89-93 (1998).

Y12 Young, K.C., M.L. Ramsdale and A. Rust. Auditing mammographic dose and image quality in the UK breast screening programme. Radiat. Prot. Dosim. 80(1-3): 291-294 (1998).

Y13 Young, K.C., M.L. Ramsdale and F. Bignell. Review of dosimetric methods for mammography in the UK Breast Screening Programme. Radiat. Prot. Dosim. 80(1-3): 183-186 (1998).

Y14 Young, K.C., M.L. Ramsdale and A. Rust. Dose and image quality in mammography with an automatic beam quality system. Br. J. Radiol. 69: 555-562 (1996).

Y15 Young, K.C., M.L. Ramsdale, A. Rust et al. Effect of automatic kV selection on dose and contrast for a mammographic x-ray system. Br. J. Radiol. 70: 1036-1042 (1997).

Y16 Yanch, J.C., S. Shortkroff, R.E. Shefer et al. Boron neutron capture synovectomy: treatment of rheumatoid arthritis based on the $^{10}B(n, \alpha)^{7}Li$ nuclear reaction. Med. Phys. 26(3): 364-375 (1999).

Y17 Yasuda, T., J. Beatty, P.J. Biggs et al. Two-dimensional dose distribution of a miniature x-ray device for stereotactic radiosurgery. Med. Phys. 25(7): 1212-1216 (1998).

Y18 Yamaguchi, H., S. Hongo, H. Takeshita et al. Computational models for organ doses in diagnostic nuclear medicine. Radiat. Prot. Dosim. 49(1/3): 333-337 (1993).

Z1 Zeides des Plantes, B.G. MR proves its value in general medicine. Diagn. Imag. Int. 3/4: 25-46 (1993).

Z2 Zoetelief, J., M. Fitzgerald, W. Leitz et al. European protocol on dosimetry in mammography. EUR 16263 EN (1996).

Z3 Zweit, J. Radionuclides and carrier molecules for therapy. Phys. Med. Biol. 41(10): 1905-1914 (1996).

Z4 Zavgorodni, S.F. A model for dose estimation in therapy of liver with intraarterial microspheres. Phys. Med. Biol. 41(11): 2463-2480 (1996).

Z5 Zankl, M., W. Panzer and G. Drexler. The calculation of dose from external photon exposures using reference human phantoms and Monte Carlo methods. Part VI: Organ doses from computed tomographic examinations. GSF-Bericht 30/91 (1991).

Z6 Zankl, M., W. Panzer and G. Drexler. Tomographic anthropomorphic models. Part II: Organ doses from computed tomographic examinations in paediatric radiology. GSF-Bericht 30/93 (1993).

Z7 Zhu, Y., A.S. Kirov, V. Mishra et al. Quantitative evaluation of radiochromic film response to two-dimensional dosimetry. Med. Phys. 24(2): 223-231 (1997).

Z8 Zhu, T.C. and J.R. Palta. Electron contamination in 8 and 18 MV photon beams. Med. Phys. 25(1): 12-19 (1998).

Z9 Zheng, J.Z. An overview of radiological protection in medical uses of ionizing radiation in China. Health Phys. 70 (Suppl.): S46 (1996).

Z10 Ziqiang, P. Radiation risk - a Chinese perspective. Health Phys. 73(2): 295-300 (1997).

Z11 Zweers, D., J. Geleijns, N.J.M. Aarts et al. Patient and staff radiation dose in fluoroscopy-guided TIPS procedures and dose reduction, using dedicated fluoroscopy exposure settings. Br. J. Radiol. 71: 672-676 (1998).

Z12 Zorzetto, M., G. Bernadi, G. Morocutti et al. Radiation exposure to patients and operators during diagnostic catheterization and coronary angioplasty. Cathet. Cardiovasc. Diagn. 40(4): 348-351 (1997).

Z13 Zhang, L., D. Jia, H. Chang et al. The main characteristics of occupational exposure for Chinese medical diagnostic x ray workers. Radiat. Prot. Dosim. 77(1/2): 83-86 (1998).

Z14 Zonca, G., A. Brusa, M. Bellomi et al. Absorbed dose to the skin in radiological examinations of upper and lower gastrointestinal tract. Radiat. Prot. Dosim. 57(1-4): 489-492 (1995).

Z15 Zankl, M. Computational models employed for dose assessment in diagnostic radiology. Radiat. Prot. Dosim. 49(1-3): 339-344 (1993).

Z16 Zankl, M. Methods for assessing organ doses using computational models. Radiat. Prot. Dosim. 80(1-3): 207-212 (1998).

Z17 Zoetelief, J., J. Geleijns, P.J.H. Kicken et al. Diagnostic reference levels derived from recent surveys on patient dose for various types of radiological examination in the Netherlands. Radiat. Prot. Dosim. 80(1-3): 109-114 (1998).

Z18 Zoetelief, J. and J. Geleijns. Patient doses in spiral CT. Br. J. Radiol. 71: 584-586 (1998).

Z19 Zoetelief, J., M. Fitzgerald, W. Leitz et al. Dosimetric methods for and influence of exposure parameters on the establishment of reference doses in mammography. Radiat. Prot. Dosim. 80(1-3): 175-180 (1998).

Z20 Zoetelief, J. and J.Th. Jansen. Calculation of air kerma to average glandular tissue dose conversion factors for mammography. Radiat. Prot. Dosim. 57(1-4): 397-400 (1995).

Z21 Zoetelief, J., J.Th.M. Jansen and N.J.P de Wit. Determination of image quality in relation to absorbed dose in mammography. Radiat. Prot. Dosim. 49(1/3): 157-161 (1993).

Z22 Zankl, M., W. Panzer, N. Petoussi-Henss et al. Organ doses for children from computed tomographic examinations. Radiat. Prot. Dosim. 57(1-4): 393-396 (1995).Z23 Zhao, W., I. Blevis, S. Germann et al. Digital radiology using active matrix readout of amorphous selenium: construction and evaluation of a prototype real-time detector. Med. Phys. 24(12): 1834-1843 (1997).

Z24 Zankl, M., R. Veit, G. Williams et al. The construction of computer tomographic phantoms and their application in radiology and radiation protection. Radiat. Environ. Biophys. 27: 153-164 (1988).

Z25 Zankl, M., N. Petoussi, R. Veit et al. Organ doses for a child in diagnostic radiology: comparison of a realistic and a MIRD-type phantom. p. 196-198 in: Optimization of Image Quality and Patient Exposure in Diagnostic Radiology (B.M. Moores, B.F. Wall, H. Eriskat et al. eds.). BIR Report 20. BIR, London (1989).

Z26 Zaret, B.L. and F.J. Wackers. Nuclear cardiology: Part 1. N. Engl. J. Med. 329(11): 775-783 (1993).

Z27 Zaret, B.L. and F.J. Wackers. Nuclear cardiology: Part 2. N. Engl. J. Med. 329(11): 855-863 (1993).

Z28 Zaidi, H. Relevance of accurate Monte Carlo modeling in nuclear medical imaging. Med. Phys. 26(4): 574-608 (1999).

Z29 Zheng, J.Z., Q.H. He, S.T. Li et al. General situation on medical uses of ionizing radiation in P.R. China. Chin. J. Radiol. Med. Prot. 20 (Suppl.): (2000).