SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation

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NOTE

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ANNEX C

Medical radiation exposures

CONTENTS

INTRODUCTION

1. Ionizing radiation is widely used for both the diagnosis and treatment of injuries and disease. As a result of this practice, individuals and populations receive significant exposure to radiation, although they normally receive in return the direct benefits in health care. Nevertheless, there is a continuing need to analyse the frequencies, doses and trends of diagnostic and therapeutic medical radiation procedures worldwide. Such information permits the evaluation of regional differences in medical radiation usage, comparisons with other sources of radiation, the identification of areas of concern, and the estimation of presumed detriment. It can also be used by ministries of health and other bodies involved in optimization and other aspects of radiation protection.

2. The Committee has repeatedly assessed exposures from the medical uses of radiation. The available data have been evaluated and extrapolated to worldwide usage. In the UNSCEAR 1988 Report [U1], the Committee estimated that medical radiation exposures ranged from 0.4 to 1 mSv annually per caput. Exposures from medical radiation, which amount to less than half the exposure to natural background radiation, exceed those from all other man-made sources.

3. The purpose of this Annex is to provide an updated review and assessment of medical radiation exposures worldwide. Within this framework, there are specific objectives, such as to determine temporal and

regional trends in doses and practices; to assess how the introduction of new techniques, radiation protection measures or quality assurance programmes affect these trends; to evaluate the variations in dose for given procedures and for total practices as well as the reasons for such variations; and to examine the age distributions of patients subjected to various procedures. While some of these objectives are descriptive, they could also serve as quantitative inputs for analysis, e.g. risk-benefit analyses.

4. Medical radiation exposures arise from the diagnostic use of x rays and other external radiation sources and internally administered radioisotopes as well as from the therapeutic use of external and sealed internal sources of radiation and radiopharmaceuticals. The basic information needed for assessing medical radiation exposures is the frequency of each type of diagnostic or therapeutic procedure and the doses to all parts of the body. Since there are considerable variations in values from country to country, comprehensive data are required to make the assessment complete and accurate. From data assembled in a consistent manner over time, important trends should be apparent in exposures from medical radiation usage.

5. One impediment to the accurate assessment of medical radiation exposures has been the incompleteness or unavailability of data for many regions of the world. To improve this situation, the Committee sent a questionnaire on medical radiation usage to all States Members of the United Nations. Information was requested on examination and treatment facilities; the number, age- and sex-distribution of patients; and doses from procedures. Not all countries were able to provide the information requested, but the responses received constitute a valuable database for the Committee's evaluation, supplementing published scientific papers and reports and permitting a more complete and accurate analysis of medical radiation exposures. The Committee gratefully acknowledges the response of so many countries to the UNSCEAR Survey of Medical Radiation Usage and Exposures. The countries are listed in Part A of the References.

I. ANALYSIS OF MEDICAL EXPOSURES

6. Ionizing radiation is used for two main purposes in medicine: diagnosis and therapy. Of these, diagnosis is much more common and is experienced by many more people. The doses to persons being examined are usually quite low. Radiation therapy, by contrast, is used mainly to treat cancer patients. While a high dose delivered to a limited, predetermined location is required to kill malignant tissue, it is necessary to restrict the irradiation of surrounding normal tissues.

7. Radiation exposures from medical examinations and treatments are determined by the type and frequency of the procedure and by the doses to tissues in the radiation fields. Because of the great regional differences in the availability of medical radiation services, it is necessary to have an extensive database to evaluate the radiation exposures worldwide. Although more countries are now collecting statistics on medical radiation usage, the Committee is still forced to make rather large extrapolations to determine the total dose to all people. The availability of medical radiation data and the procedures for extrapolation and dose evaluations are discussed in this Chapter.

A. MEDICAL RADIATION USAGE

8. Not all countries are able to provide statistics on medical radiation exposures. To supplement the data that were available, the Committee undertook a survey in 1990-1991 of medical radiation usage and exposures worldwide. Questionnaires were sent to 140 countries, and over 50 responded. The data contained in these responses, combined with data in published papers, cover more medical radiation services and exposures than the data available for previous Reports of the Committee and thus permit improved worldwide dose estimates.

9. An analogous survey, but limited to six common types of x-ray examination in 24 x-ray departments in 10 European countries, was carried out by the Commission of the European Communities [M23]. Hitherto, that survey has served mainly for optimizing x-ray examination procedures rather than for describing the impact on the population of the doses from the examinations [M23, M26]. A survey of x-ray examinations in the USSR is described in a preliminary report [N4]. Two related surveys, one in China [Z6] and one in India [S40], based on sound statistical sampling have been made available to the Committee.

10. The improved database does not obviate the need for extrapolation of the available data, especially for the least developed regions of the world. In the UNSCEAR 1988 Report [U1], a good correlation was shown to exist between the number of x-ray examinations per unit of population and the number of

physicians per unit of population. Accordingly, data on diagnostic x-ray frequencies in a small number of countries could be extrapolated to estimate diagnostic x-ray frequencies in all regions of the world, based on a more widely available statistic, the number of physicians per unit population. Countries were categorized as to level of health care, based on the population per physician [U1]. In countries of health-care level I, there is at least one physician for every 1,000 population; health-care level II, one physician for 1,000-3,000 population; health-care level III, one for 3,000-10,000 population and health-care level IV, one for more than 10,000 population.

11. Although there will in future be greater reliance on the direct reporting of examination or treatment frequencies, the grouping of countries according to level of health care is retained here for the analysis of medical radiation exposures. The use of health-care levels has several advantages: it gives a basis for extrapolating data on medical radiation usage to the entire world; it allows comparing trends for different levels of health care; and it is consistent with the analysis in the UNSCEAR 1988 Report [U1].

12. The World Health Organization (WHO) has carried out two major surveys of physician densities (number of physicians per 1,000 population) [U18, W1]. The first set of data centred on the year 1977 and the second on 1984. The 1977 data were used by the Committee to evaluate medical radiation exposures for the UNSCEAR 1988 Report [U1]. It should be noted that there are uncertainties in the WHO data because physicians are defined differently in different countries.

13. There may well also be questions of the validity of assigning an average health-care level to an entire country, for such a value may obscure wide variations. As an example, Brazil, at level II (it has one physician per 1,035 population), is geographically and demographically heterogeneous, and its level of development varies greatly [C14, D4]. Urban areas such as Brasilia (one physician per 500 population) are typical of level I, while the states of Acre and Maranhao (one physician per 3,000 population) approach level III. Large countries at level I may also contain less-developed areas, and in most countries, there are differences in the availability of medical radiation in urban and rural areas. Since the correlation between medical radiation facilities and number of physicians is not absolute, the availability of medical radiology in a particular country may be better or worse than indicated by its health-care level, particularly during periods of rapid development. Ecuador moved from level II to level I between the two WHO surveys, but the density of equipment and frequencies of examination and treatment are still typical of level II countries.

14. As health care improves, it can be expected that the distribution of the world population in the four health-care categories will shift. In the 1977 survey, the distribution was as follows: 29%, 35%, 23% and 13% in levels I-IV, respectively. In the 1984 survey, it was 27%, 50%, 15% and 8%. The most significant change was the increase in the proportion of people living in countries at level II, as improvements in health care caused countries formerly at levels III and IV to move up. Using the 1984 WHO survey to determine a country's health-care level and taking into account population growth, the number of people in each health-care level in 1990 was as follows: level I, 1,350 million; level II, 2,630 million; level III, 850 million; and level IV, 460 million.

15. Table 1 indicates the level of health care and the population of the 93 countries appearing in subsequent tables or otherwise discussed in this Annex. The table also lists the information obtained by the UNSCEAR Survey of Medical Radiation Usage and Exposures on the number of radiologists and the number of x-ray units, therapy units and nuclear medicine clinics. The availability of medical radiation services in the four health-care levels of the world is summarized in Table 2, which gives the number of radiologists and the number of facilities per 1,000 population. Table 3 lists the numbers of diagnostic examinations and therapeutic treatments. While some of the respondents gave the number of patients, others may have given the number of examinations and procedures. Although the one may be a first approximation of the other, the two quantities can differ by a factor of 3 or more, depending on the procedure.

16. There are some general limitations in data obtained in surveys of medical radiation uses and exposures. Thus, estimates of countrywide values are often based on extensive extrapolations from small samples. Some data are very coarsely rounded, while others may be spuriously precise. Varying definitions (of, for example, "radiologist", "examination" or "x-ray unit") and different ways of categorizing individual procedures contribute to the variations and inexactness of all data. In some cases, national x-ray statistics may be confounded by statistics on ultrasound examinations, entered as "radiological" procedures. These uncertainties underlie the data obtained in the UNSCEAR Survey of Medical Radiation Usage and Exposures. Although the data in the Tables are given to two or sometimes even three significant figures, the statistical precision is obviously almost always less.

17. These uncertainties notwithstanding, a reasonable degree of compilation and analysis seemed feasible. The number of responses from level I countries and the completeness of these responses, should give

adequate statistical reliability. With data available for China and India, the representativeness of data on level II countries is also quite high. For countries with less-developed medical services the precision is lower, but on a worldwide basis, this has little impact on the estimation of the per caput effective dose or the collective dose from medical radiation usage.

18. Medical radiation facilities are very unevenly distributed throughout the world. Table 2 shows that the numbers of facilities per 1,000 population are from 20 to 1,000 times smaller in countries of health-care level IV than of level I, the numbers differing by a factor of up to 50 between different health-care levels. Within health-care levels there is generally a closer relationship between the number of facilities and the size of the population, but even here the variations are notable.

19. The trends observed in medical radiation facilities are uneven. At levels II-IV the availability of facilities has generally been increasing with time. At level I the number of medical and dental x-ray units and therapeutic x-ray units per unit population have decreased somewhat. Since the countries constituting the health-care level may be different for the different periods, some caution must be exercised in attributing real differences.

20. The data in Tables 2 and 3 can be used to estimate the total numbers of medical radiation facilities and usage in the world. These results are given in Table 4. The average normalized quantities have been applied to the total population of each region. The main point to note is that level I, with 25% of the world population, accounts for some 70% of the diagnostic x-ray examinations and for 90% of the patients for therapy and nuclear medicine treatments. There is still a far from equitable distribution of medical radiation services in the world.

B. DOSE EVALUATION

21. Doses to tissues and organs from medical radiation exposures are evaluated in terms of absorbed dose. For x-ray examinations, the dose without backscatter at the entrance side of the patient is specified by the air kerma. The effect of backscatter is included in the specification of the entrance surface dose. To facilitate the summary of results and the comparison with exposures from other sources of radiation, it has been the practice of the Committee to evaluate effective doses from the procedures. Along with its simplifying advantages, this quantity has limitations when applied to medical radiation exposures.

22. Earlier assessments by the Committee of medical radiation exposures in the UNSCEAR 1958, 1962 and 1972 Reports [U5, U9, U10] stressed the genetically significant dose. This gave some common measure for the uneven dose distributions from various procedures and also recognized that the age distribution of patients or individuals examined differed from that of the general population. The doses to bone marrow were also evaluated. Doses to additional organs were estimated in the UNSCEAR 1977 Report [U4]. Beginning with the UNSCEAR 1982 Report [U3] and continuing in the UNSCEAR 1988 Report [U1], the effective dose equivalent was evaluated. The Committee's decision to express patient doses in terms of effective dose is based mainly on the potential for comparisons this provides. Effective doses permit, in principle at least, comparisons between time periods, countries, health-care levels, medical methods and sources of radiation.

23. It is not possible to obtain a correct estimate of detriment from multiplication of effective doses to patients by the nominal fatality probability coefficients given by ICRP [I8]. This has several reasons [D13]. In the first place, patients are by their very nature a group which can expect to benefit from medical radiation exposure. Thus, for patients, radiation-induced detriment cannot be computed or regarded as, for example, an occupational hazard. Any analysis would not be fair without consideration of the increase in health obtained from the medical radiation usage. This is usually easily done in individual cases, but there are no general methods to compare overall hazards and benefits.

24. Another difficulty is that patients, because of their health status, may respond differently to the radiation exposures than the base population. Methods of deriving separate risk estimates for patients, which would take account of their health status, have not yet been fully developed [H17, H34]. Furthermore, the age and sex distribution of patients will rarely match that of the population for whom the nominal fatality probability coefficients of ICRP [I8] were derived. Several ways to adjust for different age and sex distributions have been suggested [S47, V9], but these have not been applied to the data in this Annex, since the purpose of using effective dose here is not to provide input for calculations of estimated detriment, but to facilitate comparisons between exposed groups.

25. Most, but not all, of the values given in this Annex were calculated as effective dose equivalents. Therefore, throughout this Annex, a distinction is made between effective dose equivalents, H_E [I1] and effective doses, E [I8]. Typical values are indicated for specific examinations. Average effective doses or effective dose equivalents refer to the arithmetical average among examined patients. Per caput doses refer to the arithmetical average in the entire popula-

tion (including non-examined individuals). Both of these may refer to specific examinations or to total doses for an entire medical radiation practice. When average or per caput doses from different countries are combined, this is normally done on a population-weighted basis.

26. The relationship between E and H_E is discussed in a number of publications [H36, L22, R27, S44, W28, Z7]. The results of dose calculations are included in Table 5. Generally lower values of effective dose compared to effective dose equivalent are obtained for examinations of the chest and skull, for mammography and for computed tomography. Higher values are obtained for examinations of the abdomen and gastro-intestinal tract. The specific values are not always consistent in the various calculations. In particular, Huda et al. [H36] obtained lower E/H_E estimates for the chest and skull and higher estimates for the abdomen than other authors. This difference is mainly attributable to the way the "remainder" dose was computed for H_E [L22, H29]. However, while the range of E/H_E values of Huda et al. [H36] is widest, with individual values ranging from 0.24 to 2.1, their average value for all examinations of 0.9 seems similar to average E/H_E values from other sources. Thus, although E/H_E values for specific types of examination may deviate from unity, the total effective doses for diagnostic x-ray examinations should be fairly similar whether computed with the 1977 or the 1990 weighting factors. This has been verified for a range of typical examinations in several countries. The E/H_E values ranged from 0.93 to 1.13, a variation that is certainly no greater than the variation in effective dose resulting from differences between countries in average patient size [G21, M43]. The average of all E/H_E values is 1.01, supporting the notion that effective doses for entire practices, such as diagnostic x-ray examinations, should be insensitive to the choice of weighting factors, even if individual examinations deviate somewhat more. It should be noted, however, that the correlation between energy imparted and effective dose becomes weaker with the ICRP 1990 [I8] weighting factors [H36].

27. The situation is similar for nuclear medicine examinations [H36, G21, G22, J8]. The average of all E/H_E values is, as for x-ray examinations, around 0.9 (Table 5). E/H_E values exceeding 1 occur mainly when the thyroid is exposed. Values of the effective dose equivalent (H_E) for most radiopharmaceuticals are listed in ICRP Publication 53 [I5]; values of the effective dose (E) for these substances are also available [I14, J9].

28. Since organ doses are in most cases not measured but calculated, the underlying assumptions and models used affect the numerical results for both organ doses and effective doses. The influence of the models for the radiation source, the human body, the radiation transport calculation and the definition of dose equivalent have been investigated in several papers [B2, D2, V7, Z15].

29. When cited papers state exposure only (expressed in C kg^{-1} or in non-SI units), this has been converted to surface air kerma using the relationship that $2.58\ 10^{-4}$ C kg^{-1} is equivalent to $8.7\ 10^{-3}$ Gy. For therapy, effective doses are not easily used for purposes of comparison. Although effective doses to radiotherapy patients are briefly discussed in this Annex, the impact of therapy is primarily described by the number of patients treated and the age- and sex-distribution of these patients.

C. BENEFITS AND RISKS

30. Exposures to patients in medical diagnostic examinations and treatments are made in anticipation of the direct benefits to be received by the patient. Usually the risk to the individual is small in comparison with the benefit, and it is easy to justify the exposure. Risk can be assessed for the exposed populations, although the procedures are not so straightforward. The dose quantities to be used in detriment evaluations were considered in the previous Section. Some general considerations on benefits and risks in medical uses of radiation are presented below.

31. In diagnostic radiography, the dose must be sufficient to obtain the desired information. If too low a dose is chosen, the image may be of unacceptably low quality [G19]. Within a relatively narrow dose band, the amount of information is generally correlated with the dose used. This is, of course, not the case when high doses are simply the result of unsatisfactory technique, for example, too large a field, the incorrect positioning of the patient or incorrect film processing (underdevelopment) in x-ray examinations. Even quite small deviations from satisfactory techniques can remove the correlation [L19]. But to some extent, there is a positive correlation between dose and information for a given technique: doses that are too low permit random noise to blur the images so that they are not clinically useful [G2]. Particularly in fluoroscopy, images may appear to improve in quality with increasing dose to the patient [B4].

32. In therapy, it is necessary that deterministic effects be induced in the target organ. In consequence, the dose to the target organ must usually exceed some threshold. Below this threshold, no benefit at all is likely to result. Above the threshold, the dose imparted to the target volume must be delivered within a

narrow range, since higher doses do not produce an extra benefit but may cause serious injury or death. This description is simplified, since the height of the threshold can be manipulated in various ways, such as with concurrent chemotherapy, but it indicates that the amount of benefit is not linearly correlated with the dose in radiotherapy.

33. The risks associated with the diagnostic uses of ionizing radiation are normally limited to late stochastic effects, which are estimated to occur at a frequency of perhaps 0.01% for an average examination (deterministic skin damage may occur after fluoroscopy in extreme cases). At the individual level, these risks are almost always small compared to the benefit of diagnosis and treatment. They may also help to avert a competing risk; for instance, cardiac fluoroscopy could entail entrance surface doses of several gray, possibly even inducing deterministic skin damage, but might obviate the need for open heart surgery. In contrast, the risks associated with radiotherapy treatment involve deterministic effects, which must be induced to a sufficient extent, and also late stochastic effects, which can occur in about 10% of therapy courses [W10]. In fact, second cancers in radiotherapy patients are important sources of data for the assessment of radiation risks.

34. From a radiation protection point of view, doses should be maintained as low as reasonably achievable. This means that exposures above clinically acceptable minimum doses, must be avoided. There is much potential for reducing the risks associated with medical radiation exposures for diagnostic or therapeutic purposes. While radiation protection is outside the scope of this Annex, the considerations involved influence the doses encountered and therefore merit mention here. The Annex discusses some ways of reducing doses from specific procedures. In particular, quality control programmes are setting targets for facilities whose doses are excessive, thereby reducing average doses.

35. Mass screening programmes continue to come under scrutiny, and in most countries mass lung screening programmes have been reduced or eliminated. Mammography screening programmes, however, are expanding. Nationwide breast screening programmes and policies are in effect in Finland, the Netherlands, Sweden and the United Kingdom. Several other European countries, Australia, New Zealand and several provinces in Canada have decided to start such programmes [V17]. The benefits of such programmes are diminished if the screening procedures subsequently induce breast cancers. Since the frequency of breast cancer increases with age and the radiosensitivity of the breast decreases with age, the relative benefit of screening is much greater in older women. The question of suitable age to start screening and how often to repeat it (in other words, the question of when the benefit outweighs the detriment) has been studied by several authors [A6, A8, D3, D6, I10, M25, V1, W11]. These considerations apply only to mass screening programmes. In clinical examinations of women in whom breast cancer is already suspected, correctly performed mammography will virtually always be beneficial.

36. There is certainly merit in seeking to restrict doses when the radiological procedures are readily available. For most of the developing countries, however, the more important need may be to expand the availability of medical radiation services. Health will improve with such an expansion, and therefore an increased collective dose to the population due to higher examination frequency would be justified. Even here, however, it is important to maintain equipment in proper order and to introduce modern techniques to optimize the radiation exposures that are made for medical purposes.

D. SUMMARY

37. Medical radiation facilities are very unevenly distributed in the world. Four levels of health care have been defined, based on physician densities. Level I comprises countries with fewer than 1,000 persons per physician, level II countries have 1,000-3,000, level III, 3,000-10,000 and level IV, more than 10,000 persons per physician. Some 26% of the world population resides in level I countries, 50% in level II, 16% in level III and 9% in level IV countries. The data provided in response to the UNSCEAR Survey of Medical Radiation Usage and Exposures indicate that in 1990, there were 210,000 radiologists worldwide, 720,000 diagnostic x-ray units, 1.6 billion x-ray examinations performed and 6 million patients undergoing some form of radiotherapy. Some 70% of these medical radiation services were available in countries of health-care level I and the remaining 30% to the three quarters of the world population that live in countries of health-care levels II-IV.

38. Medical irradiation entails benefits to the patient as well as detriment from the radiation exposure. Radiation protection is not in itself a subject of this Annex, but its effect on medical exposure is discussed where relevant. Doses to patients are described in terms of effective dose or effective dose equivalent, depending on which of these quantities were available. The quantity effective dose (or effective dose equivalent) was chosen to facilitate comparisons, but it is not used in any calculations aimed at assessments of detriment to patients. Instead, effective doses have

been supplemented, where possible, with basic data on entrance surface doses or administered activity to facilitate comparisons. For therapy patients, no single type of dose quantity permits a valid determination of radiological impact, so the assessment of this practice is based primarily on the numbers of patients receiving various treatments, with effective dose used as supplementary information.

II. DIAGNOSTIC X RAY EXAMINATIONS

39. Of the medical uses of radiation, the examination of patients with x rays for diagnostic purposes is by far the most frequent practice. Such examinations are performed in all kinds of health care establishments, including hospitals and medical clinics but also, e.g. chiropractic and podiatric clinics in many countries.

40. Although the doses from diagnostic x-ray examinations are generally relatively low, the magnitude of the practice makes for a significant radiological impact. National data on diagnostic medical x-ray examinations, provided in response to the UNSCEAR Survey of Medical Radiation Usage and Exposures and supplemented with published data, are evaluated in this Chapter.

41. Although the frequencies of examinations and dose data are becoming available for many more countries than in earlier UNSCEAR Reports, it is important to remember the limitations of these data. Often, estimates in the Tables are based on quite small and not necessarily unbiased samples. Minor differences between countries or examinations should therefore not be overinterpreted. In general, values for examinations and procedures are given to two significant figures, while summary data are shown with one significant figure.

A. FREQUENCIES OF EXAMINATIONS

42. Annual numbers of diagnostic medical x-ray examinations reported by different countries span several orders of magnitude. They are shown in relation to the population of the country and its level of health care in Figure I; data for 1985-1990 are used for level I and data for 1980-1990 are used for levels II-IV to encompass a greater number of countries. Countries of health-care level I fall on the upper edge of the distribution; countries of lower health-care levels show fewer examinations at the same relative populations. When the same data (numbers of examinations) are plotted against the number of physicians, a much tighter correlation is evident. Only four countries fall somewhat below the general distribution: Ecuador, Honduras, Myanmar and Peru. It could be that the pattern of examinations is different in these countries, but it is more likely that the number of examinations has been underestimated. For instance, information from private practice is often unavailable. It could also be that the number of physicians has been overestimated; the definition of a physician is not standard, so this possibility should also be considered. On the whole, however, using the number of physicians as the basis for extrapolating from averaged reported data to the number of examinations worldwide seems well founded.

43. The total annual frequencies (number of examinations per 1,000 population) of all diagnostic medical x-ray examinations performed in a country are listed in Table 6 and illustrated in Figure II. The distribution of frequencies at each level is approximately log-normal. The range in level I countries is a factor of 6 (200-1,280 examinations per 1,000 population) and an order of magnitude or more in levels II and III (15-520 and 10-180 examinations per 1,000 population, respectively). Only one value is available for level IV from the present survey (Rwanda: 9 examinations per 1,000 population); this has been supplemented in this Figure by values available for Cote d'Ivoire and Nigeria for 1977 (40 and 25 examinations per 1,000 population). Examination frequencies for individual patients or years may of course deviate considerably from these annual average values. Repeated examinations of small subsets of the population are discussed in Section II.F.3.

44. Most data on examination frequencies were obtained by surveys or registrations that were complete enough to give representative results. In some cases, however, only small samplings were available that may not adequately reflect the availability of medical radiation services in the country. The frequency for Turkey, for example, is based on data from a single urban centre serving only 1% of the population of the country. This very likely explains why it is so different from the frequencies in other countries of health-care level II, and this should be recognized in

deriving the average values. In other cases, samples may be adequate in size but not completely representative. For example, the frequency for Brazil seems to be based on public hospitals only.

45. There are questions about the results for other countries as well. According to the 1984 WHO survey of the number of physicians in various countries [U18], Ecuador has moved from level II to the borderline of level I. The frequency of examinations remains, however, clearly typical of level II, so the classification has not yet been changed in this analysis.

46. There is no question about the health-care level for the United States, but the value for examination frequency in 1985-1990 of 800 per 1,000 population rests on considerable extrapolation. Some information indicates that the estimate could be an underestimate by up to 60% [B10, G8, M2]. Comprehensive statistics on medical radiation are often inadequate for collective dose evaluation. Many countries emphasize the delivery of medical services and pay less attention to the collection of data that might be needed to evaluate the collective radiological impact, which is anyway a secondary consideration. That said, however, estimates of examination frequencies are more broadly based than ever and are contributing to more reliable estimates of worldwide values.

47. The population-weighted frequencies of examinations in 57 countries are summarized in Table 6. Since the values for some larger countries are usually above the median values, slightly higher values are derived for the population-weighted averages. These values are 890 and 120 examinations per 1,000 population in countries of health-care levels I and II, respectively, for 1985-1990 and 64 examinations per 1,000 population in countries of health-care levels III and IV combined. Average frequencies of examination have generally been increasing. Data are not available to show trends in individual countries to any great extent, except at level I. Examinations in Thailand (level III) increased by 50% between the first period and the successive periods, and examinations in China increased by 30% between the second and third periods. At health-care level I, a few countries showed downward trends: Czechoslovakia, Finland, the Netherlands, Norway, Romania and Sweden. Increases were apparent for Canada, Cuba, the Federal Republic of Germany, France, Japan and Malta.

48. Data on specific types of examinations are summarized in Table 7. The average frequencies are the population-weighted values (i.e. the total number of examinations divided by the total population of reporting countries). They are best suited for the evaluation of collective doses. These and other statistical parameters are summarized in Table 8. The standard deviations on the unweighted average values may be used to identify unusually high or low frequencies of examinations. For example, examinations of the chest in the RSFSR of the former Soviet Union, examinations of the abdomen and gastro-intestinal tract and computed tomography in Japan and urography, angiography and mammography in the Federal Republic of Germany exceeded the average values in 1985-1990 by more than two times the standard deviations. There may be medical or other explanations for the greater frequency of specific examinations.

49. The trends in examination frequencies are illustrated in Figure III. These are the population-weighted averages of available data. The composition of the groups may vary from one period to another, thus affecting the comparisons. Countries of health-care level I are well represented. At level II, China and India are represented in the more recent periods, which helps the reliability of results. Too few data are available for countries of health-care levels III and IV to give reliable averages.

50. The main type of examination at all levels is that of the chest. This examination made up 60% of the total in level I countries during 1985-1990 and 70% in all other countries. Examinations of extremities, the remainder of the skeleton and the digestive system (abdomen and gastro-intestinal tract) accounted for just over 10% each of the total in level I countries and just under 10% in other countries. This leaves about 10% for other more specialized examinations in countries of health-care level I and only a few per cent for these examinations in all other countries.

51. Almost all examinations are being performed with increasing frequency, especially in countries of health-care levels II-IV. There are differences between countries with respect to the most prominent trends, however. In countries of health-care level II-IV the largest increase is in examinations of the chest (from 10 to 100 and from 20 to 50 examinations per 1,000 population in levels II and III-IV, respectively). In countries of health-care level I, the most notable increases are in computed tomography and examinations of the skull and abdomen. Mammography examinations increased threefold in level I countries in 1985-1990, compared with earlier periods.

52. A decreasing trend is noted for examinations of the chest in level I countries. This could be the result of the decreasing emphasis on mass screening programmes. Examinations of the extremities, the spine and the gastro-intestinal tract and urography-cholecystography reached stable levels during the last two five-year periods.

53. There are wide variations in examination frequencies between countries, even if they are geographically close and culturally and economically similar. The total frequencies of examinations in European countries differ by a factor of 3. A comparative investigation in France, Italy and the United Kingdom found differences which indicate that medical exposures are not justified in the same way in these countries [C2]. The frequencies of x-ray examinations in the Nordic countries varied by over 50% in 1982 from 500 to 800 per 1,000 population [S14], with the highest frequency in Finland, primarily because more radiological examinations took place outside of hospitals at health centres and private clinics. The frequency of colon examinations is fairly similar in the five Nordic countries, while stomach examinations are more frequent in Norway, primarily because endoscopy is less used. Cholecystography is performed about twice as frequently in Sweden as in other Nordic countries, presumably because there are fewer radiologists who could perform ultrasonographic examinations. Sweden has the highest frequency of mammography, because the Government recommends screening, while Denmark and Norway have no screening apart from minor research projects.

54. Statistics may be less accessible in health care systems where medical care is largely private and thus decentralized. They may also be less reliable; for instance, the increase in the number of x-ray examinations at hospitals in the United States could be due to a shift from private clinics to hospitals, making the change more apparent than real [N1]. While comparisons may be indicative, they must always be treated very cautiously. The definitions, methods of examination, methods of measurement and other conditions may vary greatly between studies. Thus, similarities and differences may be spurious and conclusions may be false, even in the rare cases where a formal analysis of statistical significance seems technically feasible. There may also be regional differences within countries. The frequencies of diagnostic x-ray examinations in the different republics of the former USSR are estimated to have ranged from 500 to over 1,100 per 1,000 population in 1987 [S18]. Thus, even with centrally organized health care systems, differences may occur.

55. Computed tomography is rapidly becoming a very important diagnostic technique. The number of computed tomography scanners in the United States in 1980 was 6.7 per million population, while the figure for Japan was 25 per million in 1984. In the United States, the number of computed tomography scanners in hospitals increased from 3 million in 1980 to 12.3 million in 1990 [M2]. In New Zealand, there were about 5 per million in early 1988, expected to be 20 per million within a few years [P11]. A study in Manitoba, Canada, showed the number of computed tomography scans steadily increasing, from 200 per month in 1977 to 1,500 per month in 1987 [H4]. The number of computed tomography scanners in the United Kingdom has increased from 1 scanner in 1972 to over 200 in 1990 [S42]. The relative frequency of such examinations in the United Kingdom is now estimated to be over 20 per 1,000 population [S42], contributing 20% of the collective effective dose from x-ray examinations [S43].

56. The data in Table 8 show an unweighted average value of 22 computed tomography examinations per 1,000 population in countries of health-care level I, with more than 30 per 1,000 population in Australia and the Federal Republic of Germany, 50 per 1,000 population in Belgium and 97 per 1,000 population in Japan. In the UNSCEAR 1988 Report [U1], the average frequency of computed tomography examinations in countries of health-care level I was estimated to be 9 per 1,000 population. An upward revision would, therefore, seem justified. The procedure is used at negligible frequency in all countries of health-care levels II-IV: some 2 examinations per 1,000 population, at most, with many countries reporting none of these examinations.

B. AGE- AND SEX-DISTRIBUTIONS

57. The age- and sex-distribution of patients in diagnostic x-ray examinations, and the population-weighted averages of these for each of the health-care levels, are given in Table 9. Broadly speaking, patients subjected to x-ray examinations are older than randomly chosen members of the public. This does not necessarily mean that x-ray examinations of children are rare. Many examinations are in fact rather frequent in children (in particular, those of the chest, the extremities, the skull, the pelvis/hips and the abdomen, and urography).

58. For level II-IV countries, the fraction of the patients that are children is larger than for level I countries. This difference is statistically significant. However, the frequency of child examinations may still be lower than in level I countries, since the total examination frequency is much lower. Although the detail is not given in Table 9, reports indicate that the examination of infants and young children is not infrequent. The per caput effective dose equivalent to children in the Federal Republic of Germany in 1983 was estimated to be 30% of the effective dose equivalent to an adult [M15].

59. These general conclusions from Table 9 are in agreement with observations in the UNSCEAR 1988

Report [U1], where it was also pointed out that the greater proportion of children in the populations of countries of health-care levels II-IV is reflected in a higher share (compared to level I countries) of children among examined patients. The differences in population age structure appear to be sufficient to explain the differences in patient age. The average ages for countries contributing data for Table 9 could be roughly calculated to be 34 years at level I, 27 years at level II and 24 years at level III. Similarly, the roughly calculated average ages for patients are 44, 36 and 38 years. Thus, the average person in a level II or III country is 7-10 years younger than the average person in a level I country, and the average patient in level II or III countries is 6-8 years younger than the average patient in a level I country.

60. The sex distributions do not deviate widely from the distribution of males and females in the population. The excess of women undergoing cholecystography in countries of health-care level I is well known and may possibly be related to diet. Likewise, the excess of women in level I countries having lower gastro-intestinal tract examinations was recognized in the UNSCEAR 1988 Report [U1]. The excess of women in countries of health-care level I having pelvis/hip examinations is probably associated with femoral fractures and hip joint replacements in older women. The data indicate consistently fewer female patients in level II and level III countries than in level I countries, which, if correct, may reflect an uneven distribution of medical care in different countries.

C. DOSES IN EXAMINATIONS

61. Estimates of doses to patients in diagnostic x-ray examinations, derived largely from the UNSCEAR Survey of Medical Radiation Usage and Exposures, are listed in Table 10. The primary quantity shown is average entrance surface dose, ESD, per examination. The dose-area product, DAP, was reported in one or two cases, but these values are not included in the Table. Both quantities are readily measurable. When reported in response to the UNSCEAR Survey of Medical Radiation Usage and Exposures, effective doses (or effective dose equivalents) are also listed in Table 10. Effective dose can be calculated from ESD or DAP if the projection, tube kilovoltage and beam filtration are known [B23, G23, H27, J3, R23, R24, R28, S45] and, if necessary, corrected for patient size and anatomy [L24, L25, S46]. A reasonable approximation of effective dose without such detailed information is possible from DAP [L23] but difficult from ESD. In the absence of such data, effective doses were not calculated.

62. Population-weighted average values of effective dose equivalent for specific examinations are summarized in Table 11 and illustrated in Figure IV. In line with earlier studies, average doses are comparatively high for gastro-intestinal tract examinations, about 4-7 mSv at health-care level I. Angiography and computed tomography also confer relatively high doses, about 4-7 mSv. Urography doses are about 3 mSv. Cholecystography and lumbosacral spinal examinations give doses of 1.5-2 mSv. Effective dose equivalents from examinations of the abdomen or of the pelvis/hip are of about 1 mSv. Fluoroscopic chest examinations are also associated with doses around 1 mSv, while chest radiography gives average doses of 0.14 mSv, and fluorographic mass miniature examinations, 0.5 mSv. Examinations of the skull or extremities cause average effective dose equivalents of 0.05-0.15 mSv. The average for mammography, 1 mSv, may be spuriously high due to a very high value (9.5 mSv) reported from Czechoslovakia (values of about 0.5 mSv are reported from several countries).

63. The average effective dose equivalents in countries of health-care level I, illustrated in Figure IV, indicate that, for the same examination, the doses were consistently higher in 1970-1979 than in 1980-1990. This does not necessarily mean, however, that per caput effective dose equivalents are decreasing, since the spectrum of examination changes as well. Computed tomography was already mentioned above as one example of the developments that affect collective doses appreciably.

64. Comparison of the average doses from examination in countries of health-care levels I and II in 1980-1990 is also illustrated in Figure IV (earlier data are not available for level II, and data are altogether insufficient for levels III and IV). No consistent difference is apparent: reported doses for level II are about twice those for level I for examinations of the lumbosacral spine, pelvis and hip, 20% higher than level I doses for upper gastro-intestinal tract examinations, similar to level I doses for cholecystography and for skull examinations; half the level I doses for urography and for examinations of the extremities; and less than half the level I doses for examinations of the chest, abdomen and the lower gastro-intestinal tract. While based on only two countries (China and India), the averages for level II refer to a large population. Nevertheless, apparent differences between health-care levels should be interpreted very cautiously. Some reported differences between China and India are bigger than the apparent differences between the averages of different health-care levels. It seems highly likely that dose differences of similar magnitude occur within these large countries. Conditions in China or India may also be quite different from conditions in other countries of

level II or in countries of level III or IV, where the more frequent use of fluoroscopy may cause higher doses.

65. Numerous factors of technique contribute to the dose variation observed. Several such factors are listed in Table 12, which compiles both general information [N5] and information originally aimed at mammography [R18, S56] but relevant also in a general context. Patient size is not listed in Table 12, since it is not a controllable factor of technique, but it contributes appreciably to variation [L24, L25, V3], also between countries. For instance, the weight of the reference Japanese adult male is 61.5 kg and the female 51.5 kg [T5], compared with 70 kg (male) and 60 kg (female) of the ICRP reference man [I2].

66. Variations in dose for specific procedures are discussed in more detail below. These include (a) fluoroscopy, because of its significant impact on procedures and per caput doses; (b) computed tomography, because of its rapid growth; (c) chest examinations, since they are so frequent; (d) mammography, with a view to its use in screening programmes; (e) chiropractic examinations, since they are not well known; and (f) neonatal and child examinations, because these patients may be more radiosensitive than adults.

1. Fluoroscopy

67. Traditional fluoroscopy (in which a fluorescent screen receives an image) and photofluorography (in which the image on the screen is recorded photographically or electronically) often cause high absorbed doses in the patient. There are two reasons for this: dose rates may be high and exposure times may be long. There are wide variations in patient exposures, even for the same type of examination, between patients, between equipment and between radiologists (see, e.g. [R1]). Modern equipment with image intensifiers may mean that fluoroscopy and photofluorography do not cause relatively higher doses. The imaging properties of image intensifiers have improved, and the input screen size can now be large. Based on these technical developments, a dose reduction of about one half was possible with large-screen image intensifier photofluorography instead of screen/film radiography (with full-size images) in posterior/anterior (PA) projection in scoliosis examinations [M5]. A Swiss study of older and newer fluoroscopy units for chest screening purposes revealed a 30-fold range in dose rates. Entrance surface doses ranging from 0.1 mGy for the most modern unit to 2.2 mGy for an old mobile unit were observed, the lower value being one third of the entrance surface dose observed in the same study for screen/film radiography [M37]. Nonetheless, modern equipment may also have a potential for high doses, but for somewhat different reasons. For instance, high-level fluoroscopic boost options for image enhancement can contribute to high doses and may be easily activated, e.g. by a simple foot pedal [C12].

68. Thus, fluoroscopy can cause a high dose to an examined patient. Furthermore, its widespread use in countries of health-care levels II-IV contributes to high collective patient doses [U1]. But where the Basic Radiology System developed by the World Health Organization [W3] is installed, there seems to be a potential for substantial dose reductions, which are not yet reflected in reported data (see Table 10). Trials at a Swedish hospital [H7] indicate that doses for common examinations could be reduced by 80% [C2] or even more in comparison with older fluorographic systems. Trials in Colombia [W3], which show doses less than half of those observed in the United States, seem to corroborate these results. Furthermore, the effective dose equivalents for specific examinations (see Table 10) do not appear to be consistently higher in level II countries than in level I countries. For levels III and IV, information is insufficient to draw any conclusion, but higher doses may be suspected, owing to, for one thing, the absence of stable voltage in many countries [B18].

69. Interventional radiology describes procedures in which the physician utilizes radiology for guidance before, during or after surgery or in relation to other examinations or treatments. Some examples are the placement of catheters for drainage, stone extraction, recanalization, the dilatation or occlusion of vessels and the infusion of pharmaceuticals, as well as the needle biopsy of various lesions. The dilatation of vessels by percutaneous transluminal angioplasty may be peripheral (PTA) or cardiac (PTCA). Most of these procedures require lengthy periods of fluoroscopy and may impart high doses to patients and staff. On the other hand, the frequency of these often life-saving procedures is low. The total frequency of interventional radiology in Nordic countries varies from 0.3 to 0.8 per 1,000 population [S14]. Of these, the higher values are obtained in countries with a high frequency of percutaneous nephrostomy. PTCA, with potentially very high doses, is practised at a rate of 0.03 to 0.05 procedures per 1,000 population [S14]. The number of PTCA procedures in the United States increased to an estimated 400,000 in 1990 [K29].

70. Average effective dose equivalents in interventional radiology were determined by Diaz-Romero et al. [D18] for 1,389 patients at Tenerife, Canary Islands. The results included an adjustment factor of 0.85 to take account of the age distribution of patients (see Section I.B and [H4]). After recalcula-

tion to remove the adjustment factor, the effective dose equivalents (H_E) ranged from 1.9 mSv (for nephro-urinary procedures) to 15 mSv (for abdominal arteriography). Some specific dose data and other information are given below for cardiac, cerebral and nephro-urogenital interventional radiology, as well as for other types of fluoroscopy. Gonad doses for some interventional radiology procedures are available [V14]. Fluoroscopically guided fallopian tube recanalization as a treatment for infertility has been attracting interest recently. Average absorbed ovarian doses of 8.5 ± 5.6 mGy (corresponding to an effective dose equivalent of about 2 mSv) were recorded by Hedgpeth et al. [H45].

71. The greatest radiation dose to individual patients in fluoroscopy is associated with the imaging of the heart (interventional or otherwise). Skin doses in cardiac angiography often approach 1 Gy, and during coronary angioplasty skin doses between 1 and 5 Gy were recorded for 31 patients in an Australian study [H1]. A maximum skin dose of 43 Gy (for 1 hour of fluoroscopy and 2 minutes of digital subtraction angiography) is quoted in Finland [P12], corresponding to an effective dose equivalent of about 1,400 mSv. This was a unique case, and typical skin doses were around 1 Gy (corresponding to an effective dose equivalent of about 10 mSv). In a French study, Moroni et al. [M30] highlighted some special situations with very long exposure times in angiography or catheterization, such as the sampling of pancreatic hormone to detect mute cancer or hepatic embolizations. Entrance surface doses of 2 Gy and gonad doses (outside the primary beam) of 3.2 mGy were observed in single examinations. A study in the United Kingdom [T9] reported that entrance surface doses of up to 1 Gy were in the normal range for digital subtraction angiography (including the associated fluoroscopy).

72. Some variations are difficult to assess. Patient doses differed significantly between cardiologists in one hospital in the Netherlands, but not in another one [K1]. Digital subtraction angiography (DSA) with pulsed high dose-rate fluoroscopy should permit patient doses to be reduced to about one third of the dose in conventional angiography. To some extent, however, this may be offset by more liberal use of the procedure [J6, P2]. The range of entrance surface doses and organ absorbed doses in angiography enumerated in two reviews [S37, V14] are summarized in Table 13. For cerebral angiography during the embolization of arteriovenous malformations, effective dose equivalents to patients of 6-43 mSv were recorded [B29] for entrance surface doses of 170-1,400 mGy, a range exceeding that given in Table 13. In another study [F3], effective dose equivalents in cerebral angiography ranged from 2.7 to 23 mSv (average: 10.6 mSv). Of this dose, fluoroscopy contributed 67%, cut films 26% and DSA 7%. Absorbed doses to organs in the head in conventional and DSA in the Federal Republic of Germany were given in [G17]. DSA caused lower orbital doses; conventional angiography produced lower doses in the cervical marrow, the cerebellum and the parotid glands.

73. While imaging of the heart causes high individual doses, the collective dose is mainly influenced by the much more frequent fluoroscopic examinations of the gastro-intestinal tract. In the United States, these cause average effective dose equivalents per examination of 2.4 mSv (upper gastro-intestinal tract examination) and 4.1 mSv (barium enema). Due to the frequent use of these examinations, they produce annual collective effective dose equivalents of 18,500 and 19,900 man Sv, respectively. Together, this is over 40% of the annual collective dose due to diagnostic x rays in the United States [N1]. Fluoroscopy time in gastro-intestinal tract examinations is an important source of dose variation [H33]. Screening time can be reduced significantly with no loss of examination quality [H14]. This, coupled with radiation protection attention [B4, S54], means that decreasing doses per examination are to be expected. Of course, examinations causing very low doses have little impact even if they are frequent. Fluoroscopy of the extremities produces absorbed doses of a few milligray [C11] and effective dose equivalents of 0.1 mSv or less.

74. In Japan, effective dose equivalents per examination of the upper gastro-intestinal tract were found to be 2.1 mSv for radiography and 2.8 mSv for fluoroscopy, with a total of 5 mSv when both procedures were utilized. Owing to the frequent use of these examinations, they cause annual collective effective dose equivalents of about 35,200 man Sv (radiography) and about 43,400 man Sv (fluoroscopy). This is about 43% of the total annual collective effective dose equivalent from all x-ray diagnostic examinations in Japan [M4]. Suleiman et al. [S34] reported the following absorbed doses for upper gastro-intestinal tract examinations in the United States, apparently indicating somewhat lower effective dose equivalents than in Japan: thyroid, 0.2-3.5 mGy, lung, 0.9-4.2 mGy, red bone marrow, 0.8-5.4 mGy and uterus, 0.2-1.0 mGy (all numbers refer to the sum of radiography and fluoroscopy). In another survey in the United States, enteroclysis caused entrance surface doses three times higher than dedicated peroral small bowel study (123 ± 60 mGy as opposed to 46 ± 21 mGy) [T14].

75. In extracorporeal shock-wave lithotripsy, fluoroscopic x-ray imaging is used to localize renal stones. One estimate from the United States of a likely surface air kerma was about 225 mGy [L1]. Other estimates, also from the United States, gave surface

doses of 10-300 mGy, with average female gonadal doses of about 1 mGy [B1, G13]. The dose increased with increasing stone burden and patient weight, and stones in the ureter resulted in higher average doses than renal stones [C8]. The introduction of a radiation control programme in the United States permitted exposure reductions of between 20% and 60% [G5]. An investigation in Canada produced similar values, with an average entrance surface dose of 140 mGy, corresponding to an effective dose equivalent of about 0.8 mSv [H5]. Average surface doses of 30-34 mGy were observed in Taiwan [C20]. The authors attributed their relatively low doses to, among other things, small average patient size, which permitted low current for spot films.

76. An alternative to extracorporeal lithotripsy is percutaneous lithotomy. In this procedure, fluoroscopy is used to localize the renal stones for extraction. A Swedish study reported an average effective dose equivalent to the patient of 4.2 mSv (range: 0.60-8.3 mSv) [G4]. In Finland, percutaneous nephrostomy (which is a part of percutaneous lithotripsy) generated entrance surface doses to patients of 160 mGy [V13]. Thus, the newer technique of extracorporeal lithotripsy does not seem to cause higher radiation exposure; if anything it does the reverse [V13]. An investigation in the United Kingdom [R3] gave similar results. Extracorporeal renal stone lithotripsy has been much more successful than the corresponding technique for gallstones [M33]. Although gallstones are more frequent, only a limited number of patients are suited to such treatments [Z5], so the frequency of this procedure is not expected to increase markedly.

77. Numerous suggestions for reducing doses in fluoroscopy have been made. During placement of feeding tubes, a procedure that is not diagnostic and does not require an image of high quality, order-of-magnitude dose reductions (from entrance surface doses of about 300 mGy) were achieved by removing the anti-scatter grid and increasing the iris of the video camera [R20]. Similar reductions were possible for nasoenteral tube placements [R13]. This is of significance, since many of the patients in question are exposed to these procedures repeatedly. A broader overview of measures to reduce doses in fluoroscopy has been published [I13].

2. Computed tomography

78. In computed tomography (CT), the conditions of exposure are quite different from those in conventional x-ray imaging. This has required the development of specific techniques for assessing patient dose from computed tomography. Usually, the dose in a single CT slice is estimated using either the computed tomography dose index (CTDI) or the multiple-scan average dose (MSAD) [C23, C24]. CTDI is defined as the integral along the axial, z, direction of a single-slice dose profile, D(z), divided by the nominal slice width. MSAD is the average dose across the central slice from several contiguous slices. These two parameters are related, and, under certain conditions, are identical for 7 mm thick slices. For thicker slices, MSAD underestimates CTDI, by 10%-15% for a 10 mm slice [C23]. Entries under ESD in Table 10 are actually such slice doses, as indicated in a footnote. From slice doses, organ doses and, ultimately, effective doses can be estimated [J7, S43, Z16]. Studies in the Nationwide Evaluation of X-ray Trends (NEXT) programme in the United States in 1990 [C23] indicated MSADs in examinations of the head of, usually, 34-55 mGy, although doses as high as 140 mGy were encountered.

79. The dose per examination by computed tomography varies with the type of examination. On average, the effective dose equivalent to patients undergoing such examinations was 3.2 mSv in a study in Manitoba, Canada, in 1987 [H4]. Since there were 18.2 examinations per 1,000 inhabitants in Manitoba, computed tomography contributed 0.06 mSv to the annual per caput dose from medical exposure. Effective doses, as well as effective dose equivalents, in 1989 for specific examinations and for all computed tomography in the United Kingdom were compiled by Shrimpton et al. [S43]. On average, the effective dose is lower than the effective dose equivalent by a factor of 0.7, with ratios for specific examinations ranging from 0.5 to 1.5. Only for the cervical spine is the ratio greater than unity. Their results, and associated data on examination frequency [S42], are summarized in Table 14. Absorbed organ doses recorded in the same project are given by Jones and Shrimpton [J7]. Detailed information on eye lens and gonadal doses during computed tomography were given by Rosenkranz et al. [R2].

80. In computed tomography, the absorbed dose for a given examination varied by a factor of 3 in New Zealand [P11], and a factor of 5 in Sweden [M1] and the United Kingdom [C9]. In Japan, the effective dose equivalent for the same examination varied by a factor of up to 3.5, depending on the scanner unit [N8]. Table 15 summarizes some of the dose data obtained in that study. Panzer et al. [P3] noted even greater variation, by a factor of up to 10, with 122 scanners in the Federal Republic of Germany. Researchers in the USSR found that some dose variability was unavoidable due to the clinical situation [A1], but apparently some of the variation could be removed. This would be important, since the general use of computed tomography is increasing at the same time as doses per examination are also increasing [H4]. Siddle et al.

discussed variation between scanner units [S29] and between procedures [S30] in Australia in connection with the risk of causing cataracts in the eye lens. They concluded that while neither scanner variation nor procedure variation led to doses approaching the threshold for cataracts in their studies, a potential for such doses does exist. A low-dose technique for computed tomography orbital volume measurements reduces lens doses from over 100 to 11 mGy [M24].

81. In some cases, the dose from a computed tomography examination is lower than the dose from similar examinations with conventional techniques. For instance, conventional myelography of the lumbar spine gives effective doses equivalents that are five to nine times higher than those for computed tomography of the same region (H_E = 9-18 mSv compared to 1-2 mSv), while effective dose equivalents are similar for the two techniques for cervical spine myelography (about 2 mSv) [H28]. However, patient doses from computed tomography examinations are typically an order of magnitude higher than those from conventional x-ray diagnostic examination, as reported in the Federal Republic of Germany [P10] and in the United Kingdom [S43].

82. Fetal doses in computed tomography examinations of pregnant patients were evaluated by Felmlee et al. [F6] and Panzer et al. [P9]. Both articles provide the necessary formulae for dose calculation. Felmlee et al. concluded that clinically required head scans can be performed with little or no dose to the fetus, and that the prudent use of body scans can be considered.

83. Several European countries are at present collaborating on quality assurance measures to reduce the variability in doses from comparable computed tomography scans [C9]. Such efforts at reduction are expected to reduce average doses (or rather, since both the number of examinations and the dose per examination are increasing for other reasons, as detailed above, to limit the rate of increase). Equipment failure can, of course, increase doses; as an example, the accidental loss of filtration increased entrance surface doses in head and body scans by some 25% [Y2].

3. Chest examinations

84. Individual doses are usually low in radiographic chest examinations. Digital computed radiography could permit even smaller doses than screen/film radiography (although some effort might be required to achieve acceptable image quality) [J10, K24, L19, M34]. As an example of doses in conventional chest radiography, the effective dose equivalent averaged over all chest x-ray units in Manitoba, Canada, and over all projections in 1987 was 0.07 mSv [H24]. The authors stressed that lateral projections (taken in addition to posterior/anterior or anterior/posterior in 70% of the Manitoba examinations) contributed most to the effective dose equivalent for a chest examination. For posterior/anterior only, the average entrance surface dose was 0.12 mGy, corresponding to an effective dose equivalent of about 0.02 mSv. For lateral projections, an average entrance surface dose of 0.59 mGy (corresponding to an effective dose equivalent of about 0.06 mSv) was calculated based on phantom measurements [H6].

85. A collaborative study in Sweden and the United States [L6] found that the entrance surface air kerma for posterior/anterior chest projections was 0.16 mGy in Sweden and 0.14 mGy in the United States (all Swedish facilities and 75% of United States facilities use scatter suppression, mostly grids and in a few cases air gap). These similar average doses are the result of quite different underlying conditions. Since grids typically increase the dose by a factor of 2 or 3, an even higher dose could have been expected in Sweden. Slower screen/film systems in Sweden would act in the same direction. On the other hand, in Sweden, higher tube voltage, more appropriate total filtration, the absence of single-phase units, overprocessing and a mandatory quality assurance programme all act in the direction of lower doses. As a rough approximation, the air kerma values divided by 0.75 correspond to entrance surface doses with backscatter. Using this approximation, the entrance surface doses are 0.16 ÷ 0.75 = 0.21 mGy in Sweden and 0.14 ÷ 0.75 = 0.19 mGy in the United States. Thus, they are of the same order of magnitude as the doses in Manitoba. As usual, there was considerable variation around the averages. In Sweden, the air kerma values ranged from 0.022 to 0.58 mGy, a 26-fold difference [L6], while in the United States they ranged from 0.004 to 0.70 mGy, a 175-fold difference [R14].

86. Studies within the Nationwide Evaluation of X-ray Trends (NEXT) programme of chest examinations in United States hospitals in 1984 and private practices in 1986 [R14] showed no overall difference in doses (an entrance surface air kerma of 0.14 mGy in both cases). Fewer private practices use scatter suppression grids. For each technique (with or without grid), doses were slightly higher in private practices. One of the causes of higher doses may be that 41% of the private practices, as opposed to 17% of the hospitals, underprocessed their films.

87. In spite of low doses, chest examinations contribute 5,100 man Sv annually in the United States, over 5% of the collective effective dose equivalent from medical x-ray usage, reflecting the fact that this is the most frequent type of x-ray examination apart

from dental x-ray examinations [N1]. Some countries conduct extensive chest screening programmes, often with photofluoroscopy rather than radiography. For conventional equipment, photofluorography causes doses at least some five times higher than radiography in chest examinations [U1], and depending on the type of fluoroscopy, the duration etc., it can cause doses 10 times higher [U1].

88. Entrance surface doses in chest radiography have been studied in Hunan Province, China (health-care level II) [Y1]. For photofluorography, the average dose was 6.1 mGy, while for full-size image radiography, the dose was 0.6 mGy. The average entrance surface dose during fluoroscopy was 9.6 mGy.

4. Mammography

89. Mammography is used in two contexts: for clinical examinations in order to investigate suspected breast cancers and for the mass screening of healthy women in order to detect such cancers. The preferred dose quantity in mammography is the mean absorbed dose in glandular tissue [I11, N14]. A summary of recent results of dose studies in mammography in countries of health-care level I is given in Table 16. The average of mean glandular doses ranged from 0.6 to 4.8 mGy per film. Reported effective dose equivalents spanned an even wider range: results of the UNSCEAR Survey of Medical Radiation Usage and Exposures gave an average effective dose equivalent of about 1 mSv and a range of 0.03-9.5 mSv. Since mammography is probably subject to more quality control and standardization than many other examinations, at least in countries where there are mammography screening programmes in effect [K16, L10, N12, P15, T11, Z8], the degree of variation is remarkable.

90. For a state-of-the-art screening programme, 1 mGy may be a representative breast dose (2-3 mGy if an anti-scatter grid is used). The dose varies with breast thickness [T20, W32] and composition [A15]. There are, as noted in the UNSCEAR 1988 Report [U1], considerable performance variations between systems, e.g. in Italy [C1] and the United States [K2, P1]. One source of variation is lack of a quality assurance programme. In the report from Italy cited in Table 16 [R19], it is observed that with the criteria used by the authors, 24% of the centres surveyed used too high a dose, 24% had a poor image quality and 14% had both high doses and poor images, illustrating the potential for quality assurance. To meet this need, the Commission of the European Communities has introduced European guidelines for quality assurance in mammography screening [C19]. In Washington State, United States, 30%-70% of 131 mammography centres were not in compliance with various quality assurance recommendations [F7]. This subject is further discussed in Section II.F.4. An important difference exists between xeromammographic systems (typical mean absorbed breast dose: 4 mGy) and screen/film systems (typical value 1 mGy) [H42, L17, R18]. The screen/film value is, in fact, an average of results without anti-scatter grids (0.6 mGy) and with grids (1.3 mGy); the latter, in turn, is an average of moving grid (1.1 mGy) and stationary grid (1.5 mGy) [D17].

91. In a study in Italy, low-dose plates permitted the surface air kerma to be reduced by 15%, to 4.4 mGy; a further 15% reduction was possible with an increased film-focus distance [C1]. In the United States, 15 new mammographic units of 8 different models were tested, using identical screen/film combinations with and without grids [K2]. The mean glandular dose varied between 0.4 and 2.2 mGy with a grid, 0.4 and 2.1 mGy without a grid, at 28 kVp. In another study in the United States, four different screen/film systems were tested [P1]. The mean glandular dose varied from 0.6 to 3.2 mGy at 25 kVp and from 0.5 to 1.8 mGy at 30 kVp. Five different types of film were tested in a study in the United States of the effects of prolonged exposure, delayed processing and increased film darkening [K21]. Each of these increased dose, by 20%-30%, and optimal viewing density was different for each film type. The Nationwide Evaluation of X-ray Trends (NEXT) programme, also in the United States, observed average mean glandular doses of 0.93 mGy in 1985 and 1.6 mGy in 1988 for screen/film mammography [R12]. For xeromammography, the values were 3.9 mGy in 1984 and 4.3 mGy in 1988. In 1985, 36% of facilities had an unacceptable image quality, but by 1988 this proportion had dropped to 13%.

5. Chiropractic examinations

92. X-ray examinations are also performed in connection with chiropractic, either at the chiropractic office or by a collaborating medical radiologist. The main types of examination are cervical spine, thoracic spine and lumbar spine. In the province of Manitoba, Canada, the entrance surface doses for these three types of examinations were 0.6, 1.8 and 3.5 mGy, respectively, corresponding to effective dose equivalents of 0.03, 0.24 and 0.41 mSv per examination and collective effective dose equivalents of 0.4, 0.8 and 6.2 man Sv for a population of 1 million [H8]. This averaged 0.22 mSv per patient and gave a per caput effective dose equivalent of 0.007 mSv. These values agree closely with corresponding values for the United States [N1] and indicate that chiropractic examinations do not make a significant contribution to either individual or the collective radiation dose.

93. Nevertheless, these averages do not reflect the extent of the dose variation encountered among chiropractic offices. In the Manitoba study, the ratio of maximum to minimum dose was as great as 23 [H8]. This is similar in magnitude to the variations found in medical diagnostic radiology [S23]. In its response to the UNSCEAR Survey of Medical Radiation Usage and Exposures, the National Radiation Laboratory of New Zealand pointed out that entrance surface doses may be difficult to interpret, because chiropractors use a complex system of plane and wedge filters and diaphragms to obtain even irradiation of contrasting tissue regions. According to the Laboratory, the filter and diaphragm systems lead to doses lower than those obtained in approximately equivalent medical procedures.

6. Neonatal and child examinations

94. The pattern of diagnostic examinations is such that children may get higher doses than adults. For instance, a study in the Netherlands reported the highest doses per examined patient for persons under age 5 years or between ages 25 and 50 years. The reason was that the most frequent examinations were abdomen, lumbar spine, intravenous pyelogram and computed tomography of the head, all of which cause doses in the middle to upper range [V16]. Furthermore, the exposure conditions and field sizes must be adapted, otherwise the effective dose from examinations of infants would be higher than that to an adult. This also applies to high-dose procedures, such as interventional cardiac catheterization, which is used on infants with a variety of congenital heart diseases [W16]. Phantoms [V11] and tables are available for the determination of absorbed organ doses to children in various x-ray examinations [T12]. With theoretical methods, Zankl et al. [Z2, Z15] obtained organ doses for an infant and a child for the most common radiographic examinations and demonstrated the strong dependence of organ doses on body size [V3]. Lindskoug [L11] provided tables of suitable exposure parameter settings.

95. Fetal doses in computed tomography were discussed above in Section II.C.2. Fetal absorbed doses in Japan during screening of the upper gastrointestinal tract ranged from 0.3 to 5.5 mGy [O2]. To the extent that pelvimetry is performed by x rays instead of ultrasound, doses (including possible fetal doses) are decreasing where computed tomography scanners are available, but not using their computed tomography feature. Pelvimetry with Scan Projection Tomography (a non-tomographic survey view with the scanner) causes doses about one tenth of those with conventional x rays [G9, W33].

96. For premature infants, chest examinations can be medically very important. Weingärtner et al. [W2] stressed the importance of suitable equipment and careful patient referral for x-ray imaging for this sensitive group of patients. Faulkner et al. [F4] listed various ways to reduce doses per film but also pointed out that neonates may be subjected to large numbers of examinations during their stay in hospital. They also mentioned that the average dose to the infant patient is determined mainly by the number of examinations, which depends on clinical symptoms. In the UNSCEAR 1988 Report [U1], other examinations of neonates (barium, computed tomography, angiocardiography) were discussed.

97. Ruiz et al. [R22] studied entrance surface doses to children of different age groups from frequent simple examinations of the abdomen, hip and pelvis, skull, spine and chest. The ranges of doses they observed in the Madrid area to children less than 1 year of age (AP projection) were 0.8-1.7 mGy (abdomen), 0.8-1.3 mGy (pelvis), 1.1-3.2 mGy (skull) and 0.1-0.5 mGy (chest). The variations observed, as well as the fact that skull doses for some examinations exceeded suggested reference values for adults [M38], were said to demonstrate the need for quality assurance programmes. Similar data collected from the United Kingdom [C22] showed that some skull doses exceeded the CEC reference dose values.

98. A study covering 11 member States of the European Community [S19], which considered typical x-ray examinations performed on infants (abdomen, skull, chest, spine, pelvis), showed large variations in entrance surface doses, far greater than the known and expected variations for corresponding examinations of adults. The maximum entrance surface doses for the abdomen, skull, chest and spine were almost 50 times higher than the minimum doses, and for the pelvis, a 76-fold difference was found. The study had been standardized on the size of the infant so that no additional variation was introduced. It should be possible to remove some of the dose variation, which would presumably lead to lower average doses to infants in future x-ray examinations.

99. Most of the patients subjected to scoliosis radiography are females between 10 and 16 years of age, and many of them are examined repeatedly, perhaps 20 times in all, for prolonged periods, so that considerable doses result from the total course of examinations. It is likely, however, that technical improvements will reduce doses per examination. As an example, the filtration systems common in chiropractic practice can reduce doses to scoliosis patients significantly [A2]. Computed radiography seems to reduce doses by about an order of magnitude, both with large-screen image intensifiers [M5] and with photostimulable phosphor imaging plates [K12, K22]. A disadvantage is that neither

technique permits the entire cervical, thoracic and lumbar spine of a tall teenager to be shown on a single image [M5, K22]. One study in Sweden found that the effective dose equivalent with state-of-the-art technique was 0.07 mSv for one examination. Other techniques gave up to 10 times higher doses. Published figures indicated that certain techniques could give doses a further order of magnitude higher [H39].

100. Several authors have examined the utility of filtration in paediatric radiology. For abdominal examinations of 10-year-old children, niobium filtration neither impaired the image quality substantially nor reduced doses significantly [J4]. Rare earth (erbium, hafnium) filters have been received with mixed reviews for paediatric radiology (and for general radiology; they are discussed below with respect to dental examinations). Although they do permit dose reductions of 20%-25% with unimpaired image quality, the cost is high [D12, S39, W15]. Adams [A9] advocated rare earth filters but also pointed out that a number of other items in a quality assurance programme are at least as important. A more advanced technical development, computed radiography using photostimulable phosphor imaging plates, permits dose reductions of 30%-50%, compared to screen/film systems, in various examinations of children, infants and premature babies [B24]. An added benefit is that the findings can be highlighted using image post-processing.

101. In computed tomography, paediatric body scans using ceramic detectors allow 50% dose reductions compared to xenon detectors, with a negligible reduction of image quality [P17]. Naidich et al. [N9] addressed the potential for low-dose computed tomography of children, comparing a 10 mA setting to the more routine 140 mA (at 120 kVp) for lung examinations. In spite of increased image noise and loss of low-contrast detail, the low-dose examination produced images of acceptable quality.

D. DENTAL X-RAY EXAMINATIONS

102. Although the effective dose to a patient from an oral radiographic examination is low, the frequency of examinations is high enough to warrant study of dose distributions. Country-by-country frequencies of dental examinations are listed in Table 17, and the entrance surface doses and effective doses or effective dose equivalents per examination, mainly for intraoral films, are listed in Table 18. Representative frequencies of dental examination were estimated in the UNSCEAR 1988 Report [U1] to be 250 and 4 per 1,000 population in countries of health-care levels I and II, respectively. Since then many additional studies have been performed, providing a wider basis for estimates. The population-weighted average examination frequency for countries of health-care levels I, II and III for 1985-1990 were, according to Table 17, 350, 2.5 and 1.7 per 1,000 population, respectively. Some data were collected on age- and sex-distributions, but these appear too scattered to warrant formal analysis. It is noted, however, that dental examinations of children are rather frequent.

103. In the UNSCEAR 1988 Report [U1], the average effective dose equivalent for a procedure involving about two dental film exposures was estimated to be 0.03 mSv. The population-weighted average effective dose equivalent per examination for countries of health-care level I in 1985-1990, calculated from the data of Table 18, was about 0.03 mSv (the weighted per caput effective dose equivalent is about 0.01 mSv). For countries of health-care levels II-IV, the effective dose equivalent per examination is probably much higher; according to Table 18, the average dose per examination was 0.2 mSv at level II (based mainly on Brazil) and 0.32 mSv at level III (based on Myanmar). These averages correspond, however, to per caput effective dose equivalents of only 0.001 mSv at level II and 0.0003 mSv at level III, due to the low examination frequencies.

104. For dental x-ray examinations, the collective effective dose equivalent in Sweden was estimated to be 79 man Sv in 1984 [S1], while a similar estimate for Finland in 1981-1985 was 15 man Sv [H2]. The population of Sweden, 8.3 million in 1984, is twice that of Finland. However, individual doses were slightly higher in Finland. The results mainly reflect differences in examination frequency; the examination frequency in Sweden is rather high, 1.9 films per inhabitant in 1986, due to a national dental service programme that provides relatively frequent examinations.

105. In contrast, the dental x-ray collective effective dose equivalent of 2,000 man Sv in France in 1984 [B5] cannot be explained just by the larger population of France (54.9 million in 1984) or by the examination frequency (0.5 films per inhabitant in 1984 [B5]). Instead, the difference arises from the average doses per examination, which are at least 2-3 times higher than in the Nordic countries [B5]. Benedittini et al. [B5] noted that the bitewing entrance surface air kerma was halved in the United States between 1973 and 1981, and that the value of 6.9 mGy in France in 1984 was comparable to the value of 5.7 mGy in the United States in 1973. According to the authors, an important explanatory factor is that there is no nationwide quality assurance programme for dental radiography in France, while quality assurance programmes have been implemented in the United States [B5].

106. Doses due to intraoral examinations span an order of magnitude, with effective dose equivalents for a complete mouth examination ranging from 0.02 to 0.28 mSv, according to a survey in the Netherlands [V2]. For rotational panoramic radiography of an adult female, Gibbs et al. estimate the effective dose equivalent to be 0.01-0.03 mSv [G12]. A later study in the Netherlands [V10] found a fourfold difference in average entrance surface doses for various bitewing radiography techniques (2.5-9 mGy), and a 35-fold range for individual measurements (0.9-31 mGy). A review of recent studies in countries of health-care level I found effective dose equivalents for single intraoral exposures from 0.001 to 0.05 mSv and for panoramic exposures from 0.007 to 0.08 mSv [S33]. A similar review [W30] that calculated effective doses using ICRP 1990 weighting factors found a range of values for full-mouth examinations of 0.03-0.14 mSv, average 0.08 mSv, and a range for panoramic examination of 0.003-0.016 mSv, average 0.007 mSv.

107. With such small effective doses, treatment courses involving several examinations over a longer period will also cause relatively small doses. Sewerin [S11] estimated the total effective dose equivalent to a patient during a seven-year treatment with osseo-integrated implants, with concomitant x-ray examinations, to be about 1.7 mSv. The study assumed, however, that two-dimensional imaging is sufficient in pre-operative examinations. Often, cross-sectional information is requested, using computed tomography of the skull, which gives doses that are higher by several orders of magnitude [C10]. The extent to which computed radiography is needed in this situation is somewhat controversial [M36, S32], but given its increasing availability, computed tomography will presumably be used more often in the future. The doses in computed tomography of the mouth region can be higher than in conventional dental x-ray examinations [K13, S55] and similar to those in other computed tomography examinations of the head and neck.

108. The average organ doses encountered in various dental x-ray examinations in France are summarized in Table 19 [B5]. The doses were determined by means of a phantom and are presented here because of the detailed anatomical subdivision. A few doses are in the range one to several milligray, but most are less than 0.2 mGy. Absorbed doses to the thyroid and the eye lens in a study in the United States [T13] were quite similar to those in Table 19. According to another study in France [P14], entrance surface doses were about 15 mGy for intraoral films and about 10 mGy for panoramic examination. Since image quality is slightly inferior with panoramic examinations and since rectangular collimation, lead-backed film and lead aprons are likely to reduce the thyroid doses from intraoral films [B26], panoramic examination is not expected to supplant intraoral films. Nonetheless, the frequency of panoramic examinations merits study. In a number of countries, they are used to screen orthodontal anomalies in children [W19].

109. Computation and interpretation of the effective dose or effective dose equivalent are not entirely straightforward for oral radiology [H38, S3]. This was particularly problematic before the ICRP recommendations of 1990 [I8] were published, since most of the organs exposed belonged to the "remainder" group, for which the ICRP 1977 recommendations [I1] provided only average weighting factors. As an illustration, when the effective dose equivalent [I1] was calculated for a single bitewing film with 60-70 kVp machines in New Zealand, the result was 0.067 mSv. When effective dose was calculated from the same data according to the ICRP recommendations of 1990 [I8], which provide specific weighting factors for some additional organs, the result was only 0.005 mSv, about 7% of the former value [W12].

110. Maruyama [M31] obtained a similar result in Japan: effective doses calculated with 1990 weighting factors [I8] were 53%-86% of the effective dose equivalents calculated with 1977 [I1] weighting factors. However, this calculation was quite sensitive to whether the skin was considered a target organ. If it was, the trend was reversed, and the effective doses were about twice the effective dose equivalents [M31]. Velders et al. [V12] in the Netherlands obtained bitewing effective dose equivalents of 2-11 μSv for various parameter combinations and effective doses of 1-4 μSv.

111. Several reviews in the United Kingdom, the United States and elsewhere summarize recent developments in dental x-ray exposure reduction [B27, H44, K3, K4, K25, T2, T3, T7]. For instance, in panoramic radiography, exposures were reduced 34%-79% with rare earth intensifying screens and heavy metal filtration, and image quality was the same or better [K3, S10]. However, the advantages of rare earth and other thin K-edge filters are not uncontested. Byrne et al. [B25] in Canada found a surface air kerma reduction for intraoral films of about 15% (as opposed to the filter manufacturer's claim of 40%), but thyroid dose was actually increased. MacDonald-Jankowski et al. in the United Kingdom confirmed the surface air kerma reduction but noted the possible disadvantages (unsharp images due to movement and x-ray tube wear) of the associated prolongation of exposure time [M35]. In a subsequent study [M42], the authors concluded that while thin K-edge filters reduced entrance surface dose and, to a certain extent, total dose to the head, orbital dose might be increased.

112. White et al. [W31] regarded niobium filtration, with a 20%-30% dose reduction, compatible with acceptable images on D-speed film. With faster (E-speed) film, niobium filtration significantly degraded the quality of the image. Other theoretical and practical studies suggest the limitations of niobium filtration [J12, M21].

113. Exposure varies widely with technique, also in less frequently performed examinations. Correctly performed [B28], video fluorographic examination of velopharyngeal function causes one tenth of the dose obtained with cinefluorography, which causes entrance surface doses in the 6-30 mGy range [I3].

E. WORLDWIDE EXPOSURES

114. The collective effective dose equivalent from diagnostic medical x-ray examinations performed worldwide is presented in Table 20. Estimates of the frequencies of each examination and the average doses have been combined to determine the collective dose for each health-care level and for the entire world. The average frequencies of examinations given in Table 7 have been used to indicate the relative frequencies, with the total corresponding to the population-weighted average for all examinations (Table 8). The data for level IV are insufficient for separate analysis and are instead included with those of level III.

115. The average doses per examination were derived from data in Table 10 and listed in Table 11. Where estimates of dose were not available for level II countries, they were assumed to be the same as for level I countries. Moreover, for lack of data, the doses in level III-IV are assumed to be the same as doses in level II. The data for level II are the population-weighted data reported for China and India, which may be expected to be representative. However, some doses are less than the more widely based averages for level I; recognizing that the values in level II are unlikely to be lower than those in level I and in order not to underestimate the collective dose, the higher values (i.e. level I values) have been assumed also for level II. This applies to examinations of the chest (radiographic and fluoroscopic), extremities, skull, abdomen and lower gastro-intestinal tract and to urography.

116. The estimate of the collective dose from all diagnostic x-ray examinations performed in one year on the world population of 1990 is 1,600,000 man Sv. The corresponding estimate in the UNSCEAR 1988 Report [U1] was 1,760,000 man Sv. The difference may well be no more than a sampling effect. The results for level I are little changed. The per caput effective dose (and effective dose equivalent) is 0.9 mSv, compared to 1.0 mSv in the earlier analysis. However, the value of 0.9 mSv includes data of 1980 for the United States, which probably underestimate the present examination frequency [M2]. For level II, the estimated per caput effective dose has been reduced, from 0.2 mSv to 0.1 mSv. Few data had been available for the earlier analysis, but the situation is much improved now that data from both China and India are available. For levels III and IV the previous range of 0.03-0.07 mSv, again based on very few data, has now been set at 0.04 mSv. There is still uncertainty in the collective doses from levels II-IV, but their significance is less than that of level I, which alone contributes 78% of the estimated worldwide collective dose.

117. Previous uncertainties regarding the use of fluoroscopy in developing countries are lessened now that data are available for China. While chest photofluoroscopy is still a common examination, accounting for 43% of all examinations in the country (Table 7), the effective dose per examination is now reported to be 0.3 mSv (although 1.0 mSv has been used in Table 20), compared with 3.4 mSv reported previously [U1]. Assuming that the higher dose still prevails would increase the estimated collective dose worldwide to 1,940,000 man Sv.

118. Specific examinations contribute to the total collective dose from diagnostic medical x-ray examinations as shown in Table 21. The examinations are listed in decreasing order of their contribution to the worldwide collective dose. The most prominent contributors in level I are upper gastro-intestinal tract, computed tomography, chest mass miniature, spine and lower gastro-intestinal tract. The doses are relatively high for the examinations of the gastro-intestinal tract, and together upper and lower gastro-intestinal tract examinations contribute more than 30% of the collective dose in level I and 19%-22% in levels II-IV. The importance of chest fluoroscopy in level II countries is apparent (it contributed 42% of the total collective dose). The relative frequency of this examination in levels III and IV was less than in levels I and II, but it was also the highest contributor to the total collective dose at this level. Other examinations of the chest were important in level II (mass miniature) and levels III and IV (radiography). Examinations of the abdomen and pelvis/hip were more important in levels II-IV than in level I, but computed tomography contributed much less to the total collective dose at the lower health-care levels.

119. Doses from all diagnostic x-ray examinations have been evaluated in a number of countries. The resulting effective dose equivalents, provided in responses to the UNSCEAR Survey of Medical Radiation Usage and Exposures or available in published

are summarized in Table 22. In a few cases, effective doses or effective dose equivalents for all examinations were calculated from data provided for specific examinations in Tables 7 and 10. Table 22 indicates that the latest annual effective dose equivalent per caput attributable to x-ray examinations in countries of health-care level I ranged from 0.3 to 2.2 mSv.

120. The population-weighted per caput effective dose equivalent in health-care level I countries, based on Table 22, for 1980-1990 is 1 mSv. This is the same value as that given in the UNSCEAR 1988 Report [U1] for available data reported for 1976-1984. The data for Canada, Czechoslovakia and the United States in Table 22 are for 1980. Updated values might have increased the 1980-1990 average somewhat, especially in view of the increasing trends in computed tomography [M2]. Thus, the weighted average for 1982-1990 is 1.2 mSv. The unweighted average and median values of data for level I reported in Table 22 are both about 0.8 mSv. This agrees with the fact that relatively high doses are reported from Japan and the former USSR (RSFSR only), both of which have large populations.

121. The reported estimates of effective dose or effective dose equivalent from diagnostic medical x-ray examinations are less extensive for levels II-IV than for level I. An overall range of 0.02-0.2 mSv is evident from the data in Table 22. The values at the lower end of the range were underestimated when fluoroscopy was not included. The estimates at the upper end of the range were made before 1980. It can only be said that the estimates of collective dose based on the frequencies of examinations and average doses in Table 20 appear reasonable. The per caput doses in that analysis were 0.1 mSv in level II and 0.04 mSv in levels III-IV.

122. The estimated annual per caput and collective effective dose (equivalent) from diagnostic x-ray examinations, taking results of the different sampling methods used into account, are summarized in Table 23. The collective dose totals are the values rounded subsequent to calculation. The values for the medical examinations for levels II-IV are those determined in Table 20. The per caput effective doses and the collective dose from dental examinations were determined from average frequencies and doses cited in Section II.D. These doses are less by a factor of 100 than those from medical examinations. The total collective dose from diagnostic x-ray examinations worldwide is just over 1.6 million man Sv.

F. TRENDS

123. It is anticipated that both the total number of diagnostic x-ray examinations and the frequency of examinations per unit population will increase worldwide for simple demographic reasons, at least up to the year 2000 and probably to 2025 [U1]. There are three main reasons for this expectation:

(a) population growth. Even if the relative frequency of examinations per unit population remained constant, the absolute number of examinations would grow by 60% from 1988 to 2025 as a result of population increase;

(b) growing urbanization. In general, urban populations have more access to health care and a much higher frequency of radiological examinations than rural ones, and the percentage of the urban population is expected to rise from 41% to 65% between 1988 and 2025;

(c) ageing of the population, particularly in Europe. Since the older population accounts for a disproportionately high utilization of medical radiation procedures, the ageing of populations leads to increasing examination frequencies. However, in Africa and Latin America, the proportion of young persons will increase. Although the frequency of examinations increases as the population ages, an older population would be less at risk for stochastic effects because of the time periods required for their induction.

124. In general terms, these factors governing long-term trends in examination frequencies and doses are likely to remain valid. For specific countries and groups of countries, over a shorter period and for specific examinations, trends may be more complex and difficult to discern, analyse or forecast.

125. It was mentioned above that according to the UNSCEAR Survey of Medical Radiation Usage and Exposures, the total frequency of all x-ray examinations at health-care level I increased from 810 per 1,000 population in the mid-1970s to 890 per 1,000 population in 1985-1990, representing a 4% increase in the population-weighted average per 5-year period. The unweighted average increased by 2% per 5-year period (not statistically significant). This observation is supported by independent estimates that there should be at least a slowing in the rate of increase of frequencies in the future compared to the 1970s [S7, S14]. The composition of the examination types changes, however: there are, for example, fewer chest examinations and more computed tomography in recent years.

126. Trends in individual countries deviate from the average. Increasing total frequencies of x-ray examinations are evident in France (+18% per five-year period), the Federal Republic of Germany (+10%), Japan (+13%), Malta (+69%), United King-

dom (+10%) and particularly in Cuba (+342%). Some differences may reflect changes in survey methods that give more complete results rather than real changes in examination frequencies. Decreasing total frequencies of examinations are reported in Finland (-10% per 5-year period), Norway (-16%) and Romania (-16%). The Netherlands [B21, B22] and also the Russian Federation show first increasing, then decreasing trends, with peak examination frequencies in the early 1980s. In Japan, the increase is due chiefly to radiographic examinations; the increased use of fluoroscopy has been relatively moderate since 1970, with a slight decline since 1987 [M32].

127. In countries of health-care levels II-IV, the frequency of examinations appears to be increasing, with a 1985-1990 population-weighted frequency of about 100 per 1,000 population. Unweighted averages increased by some 25% per 5-year period, and the trend appears to be statistically significant. In the few countries that could supply data for more than one time period, trends are less scattered than at health-care level I. Very clear increases occur in Ecuador and in India. Decreasing examination frequencies were reported for Brazil and Nicaragua.

128. One reason for slower rates of increase or slight decreases in examination frequencies in countries of health-care level I is that newer modalities, such as magnetic resonance tomography, endoscopy and ultrasonography, are replacing some x-ray examinations. X-ray examinations continue, however, to be the most important imaging method, accounting for 79% of diagnostic images in Europe in 1988 and a projected 77% in 1993 [H40]. Hill [H40] expects the relative use of computed tomography and of nuclear medicine examinations to remain constant, at 2% each. This prediction appears low for computed tomography considering its rapid increase, which more than offsets the decrease of other examinations in the United Kingdom [S42], even if a constant percentage may mean an increased number in some countries. Finally, Hill expects the share of ultrasound examinations to increase from 17% to 19% and that of magnetic resonance imaging to remain constant, at 1% [H40], although the interpretation of these percentages is hampered by the omission of endoscopy.

129. Broadly, the UNSCEAR Survey of Medical Radiation Usage and Exposures shows that doses per examination are decreasing for most procedures in countries of health-care level I (not enough information is available from other countries to draw conclusions about trends). This generalization is supported by independent reports from, for example, Australia [H37], the Federal Republic of Germany [G7], Japan [M4], Sweden [V4], the United States [S6] and the USSR [S18]. The decrease from the 1930s to the 1980s may be by a factor of 5-15, and that 1970 to 1980, by a factor of 1.5-3 [G7, H15, V19].

130. The trends for specific procedures or countries are more complicated. Table 10 indicates decreasing doses per procedure in Australia, Finland and Sweden; decreasing doses for gastro-intestinal tract imaging (important, since they are at the upper end of the dose range) but not for other examinations in Czechoslovakia; and no strong change in Romania. Trends in computed tomography doses cannot be discerned directly from Table 10, but as was shown in Section II.C.2, these doses are increasing. Hence, the total dose for all x-ray examinations per examined patient may be unchanged or only slightly decreased. This agrees with the impression of doses per examined patient in Table 11. The population-weighted annual per caput effective dose equivalent is 0.93 mSv for 1985-1990 from analyses of frequencies and doses (Table 20) and 1.2 mSv for 1982-1990 from available estimates from countries (Table 22), indicating that there has been no significant change for countries of health-care level I from the estimate of 1 mSv given in the UNSCEAR 1988 Report [U1].

131. The rapid development of more powerful yet cheaper computers is revolutionizing all imaging methods, with and without ionizing radiation. As an example, data obtained in computed tomography (or magnetic resonance tomography or nuclear medicine) can now be assembled into three-dimensional pictures that can easily be rotated by the analyst [F12, F13, T17, W17]. This may permit lower doses per examination; with pelvic trauma, for example, a three-dimensional examination obviates the need for plain radiographs to supplement a computed tomographic examination [S9], eliminating an average entrance surface dose of 23 mGy per examination. Thus, new information is obtained, and more uses of these techniques become possible.

132. The transition to digital systems in industrialized countries is likely to continue. At present 15%-30% of examinations are digital [B9, O3]. Digital radiography uses large image intensifiers or photostimulable phosphor imaging plates. Chest examinations using digital techniques can produce substantial savings of time and money for film, chemicals and archiving [K23]. While the quality of the image with a large image intensifier is not as good as with full-size images on film, the difference can be small enough to be clinically negligible. If fluoroscopy is not used, an image intensifier can reduce patient exposure to one third that of full-size images on film [K23, M16] or, in situations such as peripheral angiography, to one tenth [P21].

133. The alternative technology of imaging plates with photostimulable phosphor [T10] seems to have been more widely adopted in Japan than large image intensifier computed radiography. Worldwide, about 1,000 such systems had been installed by the end of 1991, 700 of them in Japan [B9]. This system also permits substantial dose reductions, partly because it separates the two functions of detection and display, which are combined in conventional radiographical film [W5]. For chest radiography, exposure was 20%-44% of the standard exposure with a screen/film combination [R17, S24, S25] or even 15% in paediatric chest imaging [K19]. In examinations of the upper gastro-intestinal tract, exposure was 32% of that with a screen/film combination [S26]. For urethrocystography the dose-area product was reduced from 13 mGy cm^2 to 1.3 mGy cm^2 [Z9]. As the technology improves, digital imaging is also becoming a method of choice in difficult situations like cardiac imaging [D15].

134. Digital computed radiography with imaging plates not only gives a potential for lower doses per image but also permits more sophisticated experiments in dose reduction. Using stacked imaging plates, such experiments can also be made in the course of actual diagnosis on patients without undue exposure [R17]. However, persistent anecdotal evidence (see, e.g. [J5, F8]) indicates that some of the dose reduction per image in computed radiography may be offset by a tendency of radiologists to obtain more images per patient than they would have done with conventional screen/film systems. Also, while over- or under-exposure shows up in conventional radiology as incorrect blackening of the film, considerable over-exposure can go undetected in a digital system unless exposure is specifically monitored [B9, W5].

135. The use of rare earth intensifying screens is one of the more important technical developments leading to lower doses per examination. While such screens are by no means new, having been available since the early 1970s, they are not yet utilized in all relevant situations. For instance, sample studies indicate that fewer than 50% of the radiographic examinations in the United Kingdom were carried out with rare earth screens in 1986 [N5]. Other factors remaining constant, a complete transition to rare earth screens would reduce the collective effective dose from x-ray examinations in the United Kingdom by 3,000 man Sv [N5]. It seems highly likely that rare earth screens will continue to be more widely used, reducing the doses per examination.

136. The ICRP recommendations of 1990 [I8] suggest that dose constraints or investigation levels should be considered for some common diagnostic procedures. While this is not to be construed as advocating the introduction of limits for medical exposures, it is likely that implementation [C16, N5] of the recommendations would truncate the upper end of the dose range for many examinations. Since doses per examination vary by a factor of 10 or more, even in a single hospital [H37, O7], such a truncation could be expected to reduce average doses.

137. National recommendations are also likely to lead to reduced doses. Screen/film speed is the overriding cause of patient dose variation in the United Kingdom, and fluoroscopy time in gastro-intestinal tract examinations is the second biggest cause [H33]. A United Kingdom report [N5] gives detailed recommendations for reducing patient doses (a second report [N11] deals specifically with computed tomography). It estimates that about half of the current collective effective dose to patients from x rays could be avoided. This conclusion is drawn in spite of the relatively low frequency of examinations (about twice as many examinations per caput are performed in France and the United States).

138. Recommendations to restrict doses raise a number of questions: more stringent referral criteria are a subject of some dispute [F1, K7, K8], the value of access to old radiographs may be limited [O1] and the benefits of rare earth filtration are challenged. However, since it has been suggested that in the United Kingdom the collective effective dose from diagnostic x rays could be halved [N5], there is probably a potential for similar dose reductions in many countries. If this potential is realized, as it probably will be in a number of countries, doses will go down.

1. Specific x-ray examinations and techniques

139. Fluoroscopy and photofluorography usually cause higher doses than screen/film radiography, particularly with older equipment, and are thus largely being replaced in industrialized countries. It is less clear if, or how quickly, this change will occur in developing countries. There, the higher cost of screen/film radiography is a more important consideration than in industrialized countries [T8]. In Tunisia, where over 50% of the equipment is fluoroscopic, the technique is thought to be excessively utilized [G16]. The authors judge that 60%-70% of the general practitioners equipped with fluoroscopy use the examination only to please patients, not for diagnostic advantage. Information campaigns are under way to reduce the demand for fluoroscopy.

140. In general, chest screening is becoming less frequent. For conventional posterior/anterior chest examinations with full-size images on film, doses are decreasing. In Manitoba, Canada, the average entrance surface dose decreased from 0.3 mGy in 1979 to

0.07-0.12 mGy in 1987 [H6, H24]. Some techniques may give a higher dose to patients, however. The difference in transmission between mediastinum and lungs is a complication that can be alleviated with shaped filters or with image processing in computed radiology. Alternatively, the problem can be circumvented by beam modulation, a technique that produces high image quality but with an increase in dose of up to 25% compared to air-gap screen/film systems [A10]. Beam modulation may, however, obviate the need for additional examinations, which could reduce patient dose for the entire diagnostic procedure. However, such specialized equipment is not expected to be in wide usage in the near future.

141. The growing use of computed tomography has been noted, with greater numbers of scanners and higher frequencies of examination in countries of health-care level I [C9, N5, S14]. In the United States, computed tomography is the most frequently performed x-ray examination in hospitals, accounting for 56% of the total examinations [G8]; including all other medical centres and practices, computed tomography constitutes some 9% of all examinations [B10]. Furthermore, the number of slices imaged on each patient has risen as the time required to perform scans and reconstruct images has decreased: However, since little change has occurred in the dose required per slice, the dose per examination is likely to have increased substantially [N5]. Indeed, the average effective dose equivalent due to a body scan at the Mayo Clinic in the United States was 15.6 mSv (range: 9-60 mSv) in 1988 [V8]; in 1980, the comparable figure for the United States was 1.1 mSv [N1].

142. About half of the computed tomographies in the Nordic countries in 1987 were head examinations [S14]. Computed tomography has largely replaced encephalography and cerebral angiography that was performed in cases of trauma, tumours or apoplectic strokes. In these applications, magnetic resonance tomographs may tend to replace computed tomography, although the latter is expected to remain an important tool, along with ultrasound, for abdominal examinations. Likewise, computed tomography will probably remain important in oncology, for therapy planning and for follow-up examinations after treatments [S14]. Judging from United Kingdom statistics, computed tomography now contributes more than any other single type of diagnostic procedure to the collective dose from x-ray examinations (about 20%), and the trend is still rising [S42, S43].

143. As indicated in the UNSCEAR 1988 Report [U1], the number of skull x-ray examinations increased significantly between 1964 and 1980. The more recent data in Tables 7 and 8 reflects mixed trends, but a report from the United States [M18] shows that several investigators suspected overutilization of skull radiography because of concerns of possible malpractice suits. The attention drawn to this may have altered this trend. Also, plain film skull examinations are increasingly being replaced by computed tomography examinations.

144. The number of countries with mammography screening programmes has been increasing [C6, M9, R6, T1, V6]. While doses per examination are reasonably low, with surface doses now in the range of 1 mGy [V1], the impact of mammography screening on the collective dose is not negligible. For instance, it is estimated that, when fully implemented, a nationwide screening programme in Sweden will increase the collective effective dose equivalent due to diagnostic x rays by about 5% [V4]. However, because doses per examination are decreasing, the collective dose does not increase as fast as the number of examinations. For instance, in Manitoba, Canada, the number of examinations in a population of about 1 million increased from 4,800 in 1978 to 24,000 in 1988, i.e. about fivefold. The collective breast dose has also increased, but at a much slower rate, from 40 man Gy in 1978 to 97 man Gy in 1988 [H31] (the average breast dose decreased by 50% during that period).

145. In dental radiology, the trend is very clearly towards reduced doses per examination [G3, K4, S1]. Thus, the absorbed dose to the parotid glands for common radiographic techniques decreased by one order of magnitude for every 20-year period between 1920 and 1980 [B15]. This trend is expected to continue. Goren et al. [G3] reported a dose reduction by half in the United States but noted that only 13% of surveyed dental practices used high-speed class E films. According to them, if such films were used at all dental practices, the dose would again be halved. However, it must be noted that the slower class D film is sometimes used owing to its higher average film contrast [W12]. Nevertheless, some dose reduction attributable to the use of class E film is expected. Other factors, such as reduced beam size, are also expected to lead to dose reductions. Digital computed dental radiology exists, but apparently the resolution and latitude are still inferior to that of standard dental film [W18]. The relatively bulky sensors may impede projections and the small image area hampers the evaluation of bone lesions and neutralizes dose reductions because more views are required [G20]. Thus, the technique is not expected to spread rapidly in the near future.

2. Alternatives to x-ray examination

146. Conventional radiology still dominates clinical radiology (over 80% of all examinations in the Nordic countries are done using conventional methods), and

no radical decrease in the need for conventional radiology is expected [S14]. Nevertheless, in many cases, the information needed clinically can be obtained in more than one way. Besides diagnostic x-ray examination, there may be methods in nuclear medicine, or endoscopy, ultrasonography, magnetic resonance tomography or other alternatives. Of these, ultrasonography is the most rapidly growing imaging modality, with sales of equipment growing 20% annually, an estimated 60,000-90,000 units in operation worldwide and some 60-90 million examinations annually [M8]. This corresponds to 4%-6% of the 1,600 million x-ray examinations performed annually worldwide. To some extent, x-ray examinations causing high individual doses are being replaced. For instance, magnetic resonance tomography, or sometimes transcranial-Doppler sonography, may be substituted for cranial angiography [R8].

147. An example of a diagnostic situation where nuclear medicine is an alternative to x rays is provided by non-cutaneous melanomas. A study in Italy indicated that radioimmunoscintigraphy, using monoclonal antibodies labelled with ^{111}In or ^{99m}Tc, had a significantly higher diagnostic sensitivity than conventional x-ray examinations [C9]. The investigators plan to compare radiation doses and to perform cost-benefit analyses.

148. The increasing use of alternative methods is not always accompanied by a corresponding decrease in conventional x-ray usage. The use of diagnostic ultrasound during pregnancy more than doubled in the United States between 1980 and 1987 [C5]. Prenatal x-ray examinations are rare, but considering that radiation exposure of the fetus can now be avoided, it might have been expected that they would be even rarer instead of having remained about the same during the period. A possible explanation is that the use of x rays is related to the number of Caesarean sections, since pelvic x-ray examinations are still used to assess the need for such delivery [C5]. Trends in obstetric radiography are discussed further in the following Section.

149. In contrast, urography does seem to indicate decreasing use of x rays as there is increasing access to ultrasound. The frequency of x-ray urography examinations was 16.8 per 1,000 inhabitants in Italy in 1978 and 10.5 per 1,000 in 1988 [C9]. Doses per examination in Italy were 7.1 mSv in 1983 and 4.8 mSv in 1988, corresponding to per caput doses of 0.09 and 0.05 mSv, respectively [C9]. It should be noted that not only ultrasound but also more sensitive screen/film combinations and fewer films per examination contribute to the decreasing doses per caput [C9]. Furthermore, computed tomography is also replacing urography, and an important reason for the decrease in the number of urographies is that indications, e.g. for calculus checking, have changed [S14]. Some contrast urography has been replaced by scintigraphy and other methods in nuclear medicine, which usually impart effective doses that are an order of magnitude or so lower [N10, W21].

150. According to the same report [S14], urethrocystography and hysterosalpingography have also decreased, at least in the Nordic countries in the 1980s. In Sweden, the number of cholecystographies decreased by about 70% after 1975, to some 2.4 per 1,000 inhabitants in 1987 (a 72% decrease from 1970-1974 to 5 per 1,000 in 1985-1989). This decrease was due to the replacement of cholecystography with ultrasonography. The other Nordic countries have even lower current frequencies of cholecystography: a frequency of 0.4 per 1,000 inhabitants was reported for Norway in 1988.

151. Some trends in x-ray diagnostics, ultrasonography and endoscopy have been investigated in the Federal Republic of Germany [K9]. For abdominal or total body (paediatric) examinations, there were marked decreases (30%-60%) during 1978-1984 in x-ray diagnostic examinations in hospitals and corresponding increases in sonographic examinations. Abdominal x-ray examinations also decreased by about 60%, while endoscopy increased (mainly gastroscopy, but also some coloscopy). During a similar period, 1981-1984, the frequency of abdominal x-ray examinations made by radiologists in private practice (who rarely use sonography) increased, but by the relatively small amount of about 20% [K9]. It was also found that orthopaedic practitioners in the Federal Republic of Germany were increasingly favouring sonography for screening and follow-up examinations of hip joint diseases in infants [K9]. Before the introduction of hip joint sonography, 1.45 x-ray exposures were taken per examined infant; in 1984; after the introduction of sonography, 0.95 x-ray exposures per infant were taken. In the United States, the number of ultra-sonographic examinations in radiology departments of hospitals increased from 3.5 million in 1980 to 12.1 million in 1990 [M2]. During the same period, the number of x-ray examinations also increased from 114 million in 1980 to 181 million in 1990.

152. Endoscopy not only complements but to a large extent replaces x-ray examination of the gastrointestinal tract, as was observed in the Netherlands [G15]. In Sweden the number of x-ray examinations of the stomach also decreased, from 187,000 in 1975 to 33,000 in 1987, and will presumably decrease further, as endoscopy is now available at almost all Swedish hospitals [S14]. In contrast, colon examinations remained relatively constant over the period,

partly because coloscopy is more painful for the patient and more difficult to manage. These trends may not be universal, even in countries of health-care level I (see Table 7).

153. The number of magnetic resonance tomographs has almost doubled each year in the United States [S5]. According to one estimate, which is almost certainly too low, the total number of units in operation worldwide was about 1,200 in 1989, with 800 of these in the United States, 150 in Japan, 60 in the Federal Republic of Germany, 30 in France, 30 in Italy, 24 in the United Kingdom and 40 in other countries [B11]. Another estimate, based on interviews with all suppliers of such tomographs, indicated that about 3,500 units were in operation worldwide in January 1990. Of these, about 1,800 were in the United States and 550 in Japan. About 375 units were mobile [S12]. With regard to the examination profile, 48% of the magnetic resonance tomographies in Sweden in 1989 involved the brain and 36% the back [S12]. Other applications included studies of the abdomen, joints and limbs. Recently, magnetic resonance mammography has also become available [K5].

154. In spite of this development, computed tomographs using x rays also continue to increase. Smathers [S6] believes that magnetic resonance tomography will largely supplant computed tomography. Equally, it can be postulated that, instead of decreasing, as Smathers believes, computed tomography will continue to increase and eventually reach a plateau. In fact, the use of computed tomography of the skull has been increasing at such a pace in several countries that the use of magnetic resonance tomography of the skull has been decreasing. This particular trend is not expected to continue for long, since if it did, measures would be presumably taken to limit the possible overuse of computed tomography.

3. Particular patient groups

155. Trends in obstetric radiography are a source of particular concern because of the risks to the irradiated fetus. It has been suggested that the abdominal irradiation of pregnant women has been virtually replaced by other diagnostic techniques [M6]. This notion is supported to some degree by a Swedish study, which shows that the number of x-ray examinations during pregnancy in 1987 was 38% of the number in 1975 [S14]. In the United Kingdom the number of x-ray examinations during pregnancy did not seem to be lower in 1970-1981 than in 1950-1959 or 1960-1969 [G6], but the number of films per examination did decrease, and the timing of x-ray examinations shifted towards late pregnancy with practically no first trimester exposures after 1972. Gilman et al. [G6] estimated that 12% of all pregnant women in the United Kingdom had been examined with x rays in 1976-1981. An independent study by the National Radiological Protection Board (NRPB) [K14] gave an estimate of 4.2% in 1977. The difference may be due in part to the NRPB estimate being low and in part to a statistical uncertainty of the Gilman estimate [K14]. According to Gilman et al. [G6], the withdrawal of the so-called "10-day rule" of ICRP [I9] may lead to an increase in the frequency of x-ray examinations of pregnant women.

156. From time to time concern is expressed about the undue medical exposure of children [D9]. It may be expected that various radiation protection recommendations will be introduced in response to such concern; as a result, the rate of increase of examinations of children may be restrained in the future. The pattern may be more complex in developing countries: as shown in Table 9, the fraction of examinations performed on children is larger in developing countries than in industrialized countries (an exception are hip/femur examinations, which are performed on a higher fraction of children in level I countries than in countries of levels II-IV).

157. In most cases, while a smaller fraction of the patients at health-care level I are children, the frequency of examination of children is still greater than at other health-care levels because the total x-ray examination frequency is high. However, because chest fluoroscopy is frequent at all health-care levels and because there is a higher fraction of children among patients at lower health-care levels, the frequency of examination for children under 16 is about 2, 12 and 4 per 1,000 population at levels I, II and III, respectively. It was mentioned in Section II.B that the higher fraction of children among patients in levels II and III countries is probably due partly to the demographic structure in developing countries, where a greater part of the population consists of children. Since the frequencies of examinations are generally increasing in developing countries, the frequency of examinations of children can also be expected to increase.

158. A somewhat different kind of exposure occurs if x-ray examinations are performed intentionally on persons who are not really patients. For instance, healthy persons may be subjected to examination in connection with employment or for insurance purposes. Thus, an estimated 1 million pre-employment lumbar spinal x-ray examinations were performed in the United States in 1978 [M17], corresponding to 4.4 examinations per 1,000 population. Due to their dubious predictive value [M17], these examinations are being eliminated in several countries, albeit at differing rates. There were 140,000 employment-

related x-ray examinations in the United Kingdom in 1983 [W9], representing as many as 2.5 per 1,000 population. These examinations (mostly of the chest) caused a collective effective dose equivalent of about 5 man Sv, corresponding to a per caput dose of about 0.1 μSv.

159. In connection with the increased incidence of osteoporotic fractures among elderly persons, bone densitometry has become an important tool for measuring bone mineral content, especially in industrialized countries. There are two types of bone absorptiometers besides computed tomography: single photon absorptiometry (SPA) and dual photon absorptiometry (DPA). SPA is mainly used for cortical bone, DPA mainly for cancellous bone. Formerly, ^{153}Gd was used as a photon source, but more recent equipment is based on x rays [W13] or ^{125}I. The entrance surface dose sustained by the patient in an examination of this type is about 0.02-0.05 mGy for x-ray equipment [K15, H41], corresponding to an effective dose equivalent of about 0.8 μSv, and 0.01-0.18 mGy for ^{153}Gd equipment, with the lower doses in more recent tests [S27]. Computed tomography can also be used, but the effective dose equivalents may be up to three orders of magnitude greater [K15].

160. The Committee is aware that small subsets of the population of patients are subjected to repeated examinations to an extent that allows substantially higher doses than average. It has, however, proved difficult to obtain data illustrating the full extent of this variation. A well-known study of breast cancer incidence in tuberculosis patients in Massachusetts involved 2,573 women who had been examined by x-ray fluoroscopy on average 88 times, with an average of the mean absorbed dose to the breast of 790 mGy [B30]. However, it is believed that this study is not representative of current conditions. It might be expected that many of the patients concerned were old, meaning that the potential for expression of late effects of radiation should be limited. However, scoliosis patients are routinely subjected to periodic examinations in childhood [D10]. Some premature babies may be subjected to repeated chest x-ray examinations. Preston-Martin et al. [P18] assert that patients with parotid gland tumours had experienced a greater amount of prior radiography (mostly dental) than controls.

161. In theory, it should be possible to compile further statistics on multiple examinations in countries such as Germany, where a document is available to patients on request for the recording of radiological procedures (*Röntgenpaß*). In reality, few patients seem to avail themselves of this opportunity [B31], so the information to be had may be limited. A study at major hospitals in Nürnberg and Munich indicated that of those patients undergoing x-ray examinations, which was two thirds of all admitted patients, about 52% had 4 or more films taken, including 12% with more than 20 films and 1% with more than 100 films [S16]. The county council of Stockholm, Sweden, keeps a computerized record of all patients, based on social security number [B37]. The record shows that no more than nine patients, i.e. 0.001% of the population concerned, had 14 or more examinations in 20 years. In the United Kingdom, about 1% of the population accumulated a lifetime effective dose equivalent due to diagnostic x rays of more than 100 mSv [H15]. The maximum dose encountered in the study was about 200 mSv. Most of the patients with the highest doses had no more than 10-15 examinations, albeit almost always they included several examinations of the lower gastro-intestinal tract and urographic examinations. In a Canadian case study [R5], a 60-year-old male had 29 different examinations between 1957 and 1983, apparently resulting in an effective dose equivalent of 283 mSv, 41% of which came from fluoroscopy.

4. Effects of quality assurance programmes

162. The technical and physical parameters involved in quality assurance are discussed at length in a British Institute of Radiology Report [M7]. Standardized methods, guides, training and involvement of manufacturers must be implemented in quality assurance. The standards adopted in several countries for diagnostic x-ray examinations describe indications and contraindications for procedures, patient preparation, contrast agent, positioning, technical parameters (e.g. voltage, grid, screens), number of views, other possible examinations and special regulations for radiation protection. A complementary report on the optimization of image quality and patient exposure [M19] puts quality assurance in diagnostic radiology in a wider perspective (see also [G19]). A report from the United States [N3] discusses quality assurance for all types of diagnostic imaging equipment. Numerous authors stress the importance of patient dose surveys in auditing the optimization process, so that not only theoretical output from technical parameters but also actual results are assessed [B9, F2, N5, N11, V9].

163. Quality assurance programmes for x-ray diagnostics were begun in the United States in the early 1970s and became firmly established in 1980, when federal recommendations were made [B33]. Their success is easily explained: they have led to both economic savings and dose reductions [B34, P5]. Nonetheless, such programmes are likely to gain still wider acceptance in the future, as evidenced by a survey of over 2,000 automatic film processors in the United States, which revealed underprocessing in 9%

of mammography facilities, 33% of hospitals and 42% of private practices [S53]. In dental radiology in the United States, quality assurance programmes became generally accepted more recently: about 80% of the dental hygiene programmes surveyed had some sort of programme in 1990, as opposed to about 50% in 1985 [F10]. Quality assurance programmes are likely to become established all over the world (see, e.g. [P4]). In fact, the cost reductions attainable should make quality assurance even more attractive in developing countries [B9].

164. The introduction of quality assurance is expected to decrease doses per examination worldwide, as it results in lower doses per projection, fewer retakes and fewer unnecessary examinations [G18, N5]. Mikušová et al. [M39] attributed 15-18-fold variation in entrance surface doses in gastro-intestinal tract examinations to the lack of a quality assurance programme and calculated that effective doses in such examinations can be reduced 70% or more. They stated that their results showed the need of a quality assurance programme in Czechoslovakia.

165. It is difficult to predict the pace at which quality assurance will be introduced in different countries. Data from the UNSCEAR Survey of Medical Radiation Usage and Exposures are summarized in Table 24. It appears that quality assurance is relatively well established for x-ray diagnostics, even in developing countries (although a few responses from countries of health-care level I mention a reluctance to accept quality assurance). Note that in Canada and in the United States, while there are only recommendations at the national level, there are provincial or state regulations that are legally binding.

166. Some observations on the effect of quality assurance can be quoted. In the United States, per caput doses in dental radiography are decreasing. In Spain, quality assurance programmes are being started in collaboration with the Commission of European Communities, which has adopted [M22, M38] the reference dose levels originally suggested by Shrimpton et al. [S38] and chosen as guidelines in the United Kingdom [N5]. Before quality assurance was implemented, entrance doses were up to five times higher than these maximum values, but with quality assurance at least some of the causes of higher doses could immediately be successfully corrected [C9, V18]. For lower gastro-intestinal tract examinations in the Madrid area, effective dose equivalents at one centre were 0.8 ± 0.1 mSv, while they ranged from 5.5 ± 1.0 to 14.1 ± 2.2 mSv at four others [C13]. The authors concluded that quality assurance programmes should yield significant dose reductions. In Sweden, mandatory quality assurance requirements were introduced in 1981 and are an important explanatory factor behind dose reductions [G19].

167. Several quality assurance programmes of varying scope are in effect in European countries and elsewhere [B35, D5, E4, G19, H21, L4, V15, W4]. For a discussion of patient exposure criteria in the European Community, see [H46, M38, W20]. The Commission of the European Communities has prepared two documents to provide guidance for optimization of image quality and patient dose in adult and paediatric radiology [C3, C17]. Organ doses under optimal exposure conditions are available for examinations of adults [P7]. As shown in Denmark [H12] with respect to fluoroscopic systems, such programmes need not depend on the availability of health physicists; provided a suitable test protocol is devised, radiographers on site can perform very useful quality assurance. A study by the European Federation of Medical Physicists [C4] tabulated the occurrence in 20 European countries of assessment protocols (17 countries had from 5 to 13 protocols for equipment, 16 countries had from 2 to 10 protocols for image quality), of routine quality assurance procedures (6 countries required quality assurance procedures at regular intervals, 12 others required such procedures occasionally or at least on installation); and of auxiliary equipment checks; and it recorded the implementation of various recommendations.

168. Reject and repeat rates, which reflect the quality of radiographs, have been reported by many groups but rarely from developing countries. Bassey et al. [B32] provide an analysis from Nigeria (health-care level III since 1980). At first, the repeat rate was 12.4%. As a result of increasing awareness and corrective actions in response to the project, the repeat rate dropped rapidly, to an average of 2.5% (average for the entire year analysed: 3.7%). The authors noted that a formal quality assurance programme would reduce repeat rates and exposures further. As such, these repeat rates were not particularly high, in fact, 3.7% is low compared to the United Kingdom [N5]. But, as the authors say, criteria for repeating may differ, and films of marginal quality may have been accepted in Nigeria for economic or practical reasons [B32].

169. Quality assurance can certainly be applied not only in hospitals but also in general medical practice, although general practitioners may be less aware of quality assurance methods. In New Zealand, a study using an anthropomorphic ankle phantom examined by 22 general practitioners resulted in 2 fully acceptable sets of radiographs, 8 deficient sets and 12 rejected sets, 4 of which were completely undiagnostic [L5]. Nevertheless, the authors were not overly concerned, since the range and number of radiographic procedures performed in general practice is small and presents very little radiation hazard to patients and staff.

G. SUMMARY

170. For countries of health-care level I, the population-weighted average annual frequency of diagnostic x-ray examinations in 1985-1990 was 890 per 1,000 population, rather similar to the estimate in the UNSCEAR 1988 Report [U1] of 800 per 1,000 population. Examination frequencies in individual countries of health-care level I ranged from 320 to 1,290 per 1,000 population, and both increasing and decreasing national trends are evident. For health-care levels II-IV, data are less comprehensive, but at a first approximation the average frequency is 120 examinations per 1,000 population at level II and 64 per 1,000 population for levels III and IV combined. While the total x-ray examination frequency seems to be relatively constant at health-care level I, indications are that the frequencies of examinations are increasing at levels II-IV. During the 1980s, some 60% of all examinations were of the chest, 15% of the extremities, 10% of other skeleton and 10% of the digestive system. The pattern of examinations varies with time and with health-care level.

171. Broadly speaking, the total examination frequencies are expected to continue to increase at all health care levels. There are two main reasons for this: the increasing proportion of older people in populations and increasing urbanization. The increasing availability of alternative modalities, in particular ultrasound, may, however, limit somewhat the rate of increase. Patients subjected to x-ray examination are, on average, older than randomly chosen members of the public. Nonetheless, many examinations are rather frequently performed on children under 16 years of age. With the exception of hip/femur examinations, a greater fraction of examined patients are children in countries of health-care level II and III, perhaps because those countries have younger populations. However, examination frequencies exceed those of health-care level I only in the case of chest fluoroscopy.

172. The doses to patients from diagnostic x-ray examinations vary widely. In certain cardiac procedures, entrance surface doses of several gray occur. High doses are delivered in fluoroscopy with conventional equipment. This does not mean that fluoroscopy is an unfavourable procedure, even from the restricted view of dose limitation, since with modern image intensifiers low doses can be achieved. Fluoroscopy during extracorporeal lithotripsy causes smaller doses than those encountered in conventional renal stone extraction. Computed tomography is being used more frequently, and effective doses (at present averaging about 5 mSv per examination) are increasing. Chest x-ray doses are decreasing, with effective doses per examination now often under 0.1 mSv, but the vast number performed still causes chest examination to contribute several tens of per cent of the collective effective dose. Mammography examinations now give low absorbed doses to breasts, often under 1 mGy, but extended screening programmes, commonly aimed at all women over age 40 years, could add several per cent to collective doses. Dental x rays often entail effective doses less than 0.1 mSv per examination but affect large groups, and thus add a per cent or so to the collective dose. Chiropractic x-ray examinations cause low doses per examination and affect few people. Children are a particularly sensitive group. Chest examination of neonates and scoliosis testing of teenage girls were mentioned as problem areas.

173. Per caput annual effective dose equivalents from the diagnostic use of x rays reported from a number of countries of health-care level I ranged from 0.3 to 2.2 mSv. For countries of health-care level I, the population-weighted average of values from 1982 to 1990 is 1.2 mSv. The estimate of per caput dose from analysis of population-weighted frequencies and doses of examinations is 0.9 mSv, which is little different from the estimate of 1.0 mSv given in the UNSCEAR 1988 Report. For countries of health-care level II, which have a population of 2.6 billion, information is still limited, yet more complete than for the UNSCEAR 1988 Report [U1]. The estimated per caput effective dose equivalent is 0.1 mSv (1988 estimate: 0.2-1.0 mSv). Doses at health-care levels III and IV (0.04 mSv) are more uncertain, but they do not much affect the worldwide average due to the low examination frequencies.

174. These overall trends are derived from non-homogeneous data. Both examination frequencies and patient doses vary rather widely, between neighbouring countries and even within countries. Also, similar total examination frequencies or total effective doses may be composed in different ways in different countries. Particular importance is attached to the trends for computed tomography, which is characterized by increasing examination frequency as well as increasing doses. Quality assurance programmes have amply demonstrated that dose variation can be decreased and unnecessary exposure reduced.

175. The estimates of average individual and collective doses to the world population from diagnostic medical x-ray examinations (0.3 mSv and 1.6 million man Sv) are at the lower end of the ranges suggested in the UNSCEAR 1988 Report [U1] (0.35-1.0 mSv and 1.8-5 million man Sv). There is, at present, somewhat less uncertainty about the frequencies and doses from fluoroscopy examination in countries of health-care levels II-IV. The doses from dental x-ray examinations are less than those from medical x-ray examinations by two orders of magnitude.

III. DIAGNOSTIC USE OF RADIOPHARMACEUTICALS

176. The rapid pace of change in nuclear medicine makes assessment difficult, but a few trends can be identified. Of the many different radionuclides used in nuclear medicine examinations, ^{99m}Tc and ^{131}I are the most important. As a rule, the dose per procedure is less for ^{99m}Tc, which has a shorter half-life, so it is preferred and used in the majority of cases. Even so, the usage of ^{131}I is great enough to make an important nominal contribution to the collective dose. In 1986, for example, only 13% of all nuclear medicine examinations in Sweden employed ^{131}I, but it contributed 51% of the collective dose of 420 man Sv [V4]. By comparison, 56% of the examinations in 1971 were made with ^{131}I, which contributed 92% of the collective dose of 520 man Sv. In the USSR, 77% of all examinations in 1981 utilized ^{131}I [N4]. The most commonly used radionuclide in developing countries is ^{131}I, and this is the main reason the average effective dose per examination is higher in these countries than in industrialized countries.

A. FREQUENCIES OF EXAMINATIONS

177. The frequencies of diagnostic nuclear medicine examinations performed in countries are listed in Table 25 (total frequency) and Table 26 (frequency of the main types of examinations). The results are mainly from the UNSCEAR Survey of Medical Radiation Usage and Exposures, supplemented with published data. As a first approximation, the total frequency of all nuclear medicine examinations is about 16 per 1,000 population in countries of health-care level I, 0.5 per 1,000 population in countries at level II, 0.3 per 1,000 population at level III, and 0.1 per 1,000 population at level IV. The number of countries at levels III and IV reporting information is much too small to be considered representative. The distributions of available data for 1985-1990 are illustrated in Figure V.

178. Generally higher examination frequencies (20-40 per 1,000 population) are reported for Belgium, Czechoslovakia, the Federal Republic of Germany, Luxembourg and the United States. The reasons for the higher frequency seem to differ: there are many liver/spleen and renal examinations in Czechoslovakia; many bone examinations, lung perfusions and thyroid scans in the Federal Republic of Germany; many cardiovascular examinations and lung perfusions in the United States; and all examinations are more frequent in Belgium and Luxembourg. Although the total nuclear medicine examination frequency in Canada (13 examinations per 1,000 population) is typical of health-care level I countries, there are about 10 times as many brain examinations (4 per 1,000 population) as the average for health-care level I (0.4 per 1,000 population). In some countries, all practitioners are permitted to use radiopharmaceuticals, while in many other countries, they are available only in hospitals or clinics.

179. In nuclear medicine, not only the total examination frequencies but also the patterns of examinations appear to differ more than the frequencies and patterns of x-ray examinations. Averages for the main kinds of examination at different health-care levels are given in Table 27 and illustrated in Figure VI, which shows that bone and cardiovascular examinations are the most frequent. However, these averages may conceal widely differing practices. Some such differences are discussed below. Three types of average measure are given in Table 27: the population-weighted average, the unweighted average with its standard deviation, and median values. Of these, the population-weighted averages are the most relevant for purposes of collective dose estimation, while unweighted averages and medians may be of interest when individual countries are compared to others.

180. Huda et al. [H17] point out differences between North American and European countries: ^{99m}Tc is used more frequently in Manitoba, in Canada, and in the United States. Examinations of the brain are less frequent in Europe than in North America, and cardiovascular examinations are somewhat less frequent. Within Europe there are no differences in examination frequencies between Sweden and the Federal Republic of Germany [H18, K10]. However, the use of ^{99m}Tc is as common in the Federal Republic of Germany as in North America but not as common in Sweden. There could, of course, be local deviations from this pattern within North America. The data for the United States are averaged over a large number of states; the data for Manitoba and Nova Scotia quoted in the text and Tables refer to only small parts of Canada, so that the extrapolations made from these must be regarded as tentative approximations.

181. Intra-regional differences in examination patterns may occur even where nuclear medicine has a similar total radiological impact. For instance, the Netherlands and Sweden are similar in many respects, and the impact of diagnostic nuclear medicine is similar in the two countries. Nevertheless, there are several important differences between the two countries [B3, V4]. Thus, while the use of ^{99m}Tc is similar (used in 65%

of examinations in the Netherlands and 63% in Sweden), much more ^{123}I and much less ^{131}I are used in the Netherlands than in Sweden (in 10.1% and 3.0% of examinations in the Netherlands compared with 0.6% and 14.1% of examinations in Sweden). The use of ^{201}Tl is more common in the Netherlands than in Sweden (6.8% and 2.5% of examinations, respectively).

182. The use of ^{51}Cr also differs in countries with similar nuclear medicine practice. Renal clearance with ^{51}Cr are important in Sweden (9.1% of examinations), but the radionuclide is hardly used at all in the Netherlands (0.2% of examinations). Canada [H17] and Germany [K10], with somewhat higher per caput doses from nuclear medicine, report little or no use of ^{51}Cr-EDTA, although other ^{51}Cr radiopharmaceuticals are used in Canada (sodium chromate and chromic chloride); ^{99m}Tc rather than ^{51}Cr is used for inulin and creatinine clearance measurements of the glomerular filtration rate.

183. Figure VI shows that nuclear medicine examinations in countries of health-care level I are more frequent by an order of magnitude or more than in countries of lower health-care levels. Only for thyroid uptake studies are the relative differences not quite so great. At health-care level I some 30% of examinations were of bone, some 20% were of the lung and some 15% were cardiovascular. These examinations are all being performed more frequently. The percentages of brain (5%), liver/spleen (5%-10%), renal (5%-10%) and thyroid (15%) examinations are decreasing. Trends in individual countries may deviate from this general pattern. Generally, the data indicate increased frequencies with time in the total number of nuclear medicine examinations. Myanmar reports a steadily decreasing examination frequency, from 0.54 per 1,000 population in 1976-1980 to 0.11 per 1,000 population in 1985-1990.

184. Nuclear medicine is continuing to develop in China, and more than 800 hospitals now practice nuclear medicine [W7]. The most frequent imaging procedures are liver scintigraphy, thyroid imaging, and lung, kidney, bone, brain and heart imaging, in that order [W7]. The most common function tests are thyroid uptake, renogram and cardiac function [W7]. In function tests, ^{99m}Tc is the most frequently used isotope [L14, W7]. Thus, the data cited in the UNSCEAR 1988 Report [U1], according to which ^{99m}Tc was not used in China, were not representative. Wang and Liu [W7] regard ^{113m}In as the primary alternative when ^{99m}Tc is unavailable and stress that the long half-life of the ^{113}Sn parent makes ^{113m}In generators suitable in developing countries, where low cost and long transport times are important considerations. Nonetheless, ^{131}I is still a big contributor to effective dose in China [Z6] and in India.

185. Information from other developing countries is very limited. In Tunisia, diagnostic nuclear medicine *in vivo* is practised at one clinic in Tunis, which is equipped with scintiscanners. Radionuclides are brought from France on a regular basis, which ensures supply but excludes short-lived isotopes [M13]. In Nigeria, with a population of about 100 million, one scanner is available in Lagos. About 79% of the 1,000 patients referred in 1982-1984 had thyroid-related pathology, and most of the other examinations concerned the liver, the brain or bone [F5]. In Zaire, with a population of 30 million, one nuclear medicine facility exists in Kinshasa, but apparently work there is hampered by many very difficult problems [I6].

186. Most of the examinations in nuclear medicine are performed on adult patients. For instance, 98% of all examinations in the United States are performed on patients who are at least 15 years old (and 90% were 30 years or older) [U1]. Examinations of children appear to be somewhat more frequent in eastern Europe [D1, U1]. There is no particular type of examination specifically aimed at children, apart perhaps from neonatal hypothyroidism screening, which is performed by radioimmunoassay *in vitro* and thus causes no patient dose [I6].

187. The age- and sex-distributions of patients subjected to diagnostic nuclear medicine examinations are given in Table 28. On average, the population examined is older than the general population and also older than those receiving x-ray examinations. Relatively high proportions of renal examinations are performed on children in countries of health-care level I. At health-care level II, bone and brain examinations of children are relatively frequent. The proportion of children examined is higher in countries at health-care levels II-IV, as was also the case for diagnostic x-ray examinations, but the difference between health-care levels is smaller than for x-ray examinations. As with x-ray examinations, the excess of children among examined patients may well depend on demographic factors (there are more children in these countries). Since total nuclear medicine examination frequencies are much lower at health-care levels II-IV, the frequency of examined children is consistently smaller at these health-care levels than at level I, in spite of the higher percentage of children among examined persons.

188. As expected, more women have thyroid examinations and more men have cardiovascular examinations (with the exception of China). Otherwise, the sex distributions appear to be fairly standard.

B. DOSES IN EXAMINATIONS

189. The average amounts of radioisotope compounds administered for some important procedures in diagnostic nuclear medicine are listed in Table 29. Only the major radiopharmaceuticals reported in use are included. The listing must necessarily compress the information received, which was of uneven detail to begin with, making it difficult to calculate effective doses. Some comments are, however, relevant.

190. The activity administered per examination seems to be more standardized than the factors that influence dose in diagnostic x-ray examinations. This is also true for different levels of health care. Thus, the vast differences in dose per examination between countries of different levels are due to the choice of radiopharmaceuticals not to different amounts of activity for any given procedure.

191. Thyroid examinations contribute as much as half of the collective dose from all diagnostic nuclear medicine procedures. Typical effective dose equivalents in the province of Manitoba, Canada, in 1981-1985 were 3.9 mSv for ^{131}I, 1.2 mSv for ^{123}I and 1.5 mSv for ^{99m}Tc. The substitution of other nuclides for ^{131}I in most cases reduced the estimated collective dose by a factor of 3.6 [H35]. Cardiovascular examinations caused comparatively high doses, from about 10 mSv (^{99m}Tc erythrocytes) to about 20 mSv (^{201}Tl chloride). Brain examinations with ^{99m}Tc gluconate caused 8-10 mSv, bone examinations with ^{99m}Tc phosphate up to about 7 mSv.

192. Tomographic investigations with single photon emission computed tomography (SPECT) require, on average, higher activities per examination than similar planar examinations. Consequently, SPECT tests could lead to higher patient doses [E1], at least for examinations such as myocardial scintigraphy, regional cerebral blood flow, bone scintigraphy, liver scintigraphy, radionuclide ventriculography and tests with tagged monoclonal antibodies. In principle, positron emission tomography (PET) should also require high activities per examination, but the doses do not seem to be extremely high, at least not with ^{18}F substances, which result in effective dose equivalents of up to 6 mSv per procedure [M43].

193. Examinations of children form an important part of the evaluation of patient doses, since the dose per unit activity can be much higher for children than for adults [I5, T6]. Two important differences between children and adults should be taken into account when considering the use of radiopharmaceuticals and evaluating doses. Physiological differences such as differing body weights can lead to a different (higher or lower) effective dose for children after administration of a given amount of activity [S15, T6]. Age-related dose coefficients [I5, I14] take these physiological differences into account. Another difference is the greater sensitivity of children, reflected in the higher risks per unit dose. As mentioned in Section I.B., this could in principle also be taken into account.

194. Absorbed doses, effective dose equivalents and effective doses per unit activity of various radiopharmaceuticals administered to patients have been derived and are listed in ICRP Publication 53 (for H_E) [I5] and in its Addendum (for E) [I14]. Supplementary information can be found in the MIRD (medical internal radiation dose) reports, most recently on ^{99m}Tc-labelled bone imaging agents [W6], red blood cells [A5], ^{111}In-labelled platelets [R21] and ^{99m}Tc-DTPA aerosol [A13]. Some MIRD estimates may be inexact, [K26, T15], particularly with respect to Auger emitters [H25, K27, S48].

195. There is not yet a wide basis for calculating effective doses from nuclear medicine examinations. For instance, individual differences in metabolism could contribute to variability. Furthermore, individual organ doses may vary with disease conditions, although effective dose may be a more robust quantity. Table 30 lists typical effective dose equivalents from examinations. The effective dose equivalents were calculated using the dose factors in ICRP Publication 53 [I5], but patient ages or sizes were not considered. There are three further sources of variation in estimated effective doses (effective dose equivalents):

(a) each examination category represents several types of procedure. Perhaps the most extreme example is kidney examinations: renograms are occasionally made with ^{125}I-hippurate with a typical effective dose of 0.01 mSv while renal scintigraphy with ^{99m}Tc gives at least 1 mSv per examination;

(b) a given procedure can be done with different radionuclides. A good example is thyroid scintigraphy: performed with ^{99m}Tc, the effective doses are under 1 mSv; performed with ^{131}I, they approach 100 mSv. The difference is important since ^{99m}Tc is typically less accessible in developing countries;

(c) the amount of activity administered for a procedure differs; this, however, is not a major source of variation in doses.

196. In principle, it is desirable for analytical purposes to specify the age distributions of patients; however, these are likely to be different for each type of examination. To illustrate the dependence of dose on age,

Table 31 provides the average and per caput effective dose equivalents from the average activities administered and the frequencies of examinations determined for Manitoba, Canada [H17]. The age-dependent doses per unit activity administered were taken from ICRP Publication 53 [I5].

197. The effective dose equivalents to children in Table 31 were computed with age-related dose conversion factors where possible, but when no data were available it was assumed that the activity administered to a child was the same as that to an adult. The effective dose to children per unit activity can be much higher than that to adults, and examinations of children are not all that rare. This is particularly true in the case of renal examinations, which constitute some 10% of all procedures.

198. Doses to unborn children after the administration of radiopharmaceuticals to pregnant patients may, according to Cox et al. [C18], be seriously underestimated by current methodology. Although their primary concern is with therapeutic administrations, they also discuss lung perfusion scintigrams using ^{99m}Tc albumin aggregates, which they believe is the most frequent examination in pregnant women. In their opinion, it results in a uterine dose of 10 mSv rather than the 0.3 mSv calculated by conventional methods.

C. WORLDWIDE EXPOSURES

199. Representative frequencies of nuclear medicine examinations for each health-care level and doses per examination cannot be well established from the available data. Nevertheless, the approximate values do give an indication of the collective dose from this practice. This analysis is shown in Table 32. The population-weighted frequencies of examinations were derived in Table 26 and listed in Table 27. The effective dose equivalents from typical examinations were given in Table 31, with the values for adults being used in Table 32. Higher doses were indicated in Table 30 for China for thyroid scans and liver/spleen examinations whenever the preferred isotope, ^{99m}Tc, was not available. It is not known how often this occurs, but in order not to underestimate the collective dose, the higher doses have been assumed for these examinations in health-care levels II-IV. The product of frequency and dose per examination gives the estimated collective effective dose from each examination.

200. The collective effective dose equivalent from nuclear medicine examinations worldwide is estimated to be 156,000 man Sv, with 127,000, 20,000 and 10,000 man Sv from health-care levels I, II and III-IV, respectively. Most of the collective dose (81%) is received at level I. The dose per examination averages 5.7 mSv at level I, but it is about four times higher at levels II-IV. The per caput dose is 0.09 mSv at level I but is, because of much lower frequencies, an order of magnitude less at levels II-IV.

201. The contributions of the various examinations to the collective doses are given in Table 33. At health-care level I, cardiovascular and bone scans account for 70% of the collective dose. Because of the high dose assumed for thyroid scans at level II-IV, this examination is by far the largest contributor to total collective dose from nuclear medicine in these countries.

202. This analysis of collective dose is very approximate since only a single typical examination has been assumed in each case, and the representativeness of the frequencies and doses applied cannot be established. It does, however, indicate that the collective dose from nuclear medicine examinations worldwide is about 10% of that from diagnostic medical x-ray examinations.

203. Estimates of collective dose from nuclear medicine examinations in a number of countries have been published or supplied in direct response to the UNSCEAR Survey of Radiation Usage and Exposures. These estimates are summarized in Table 34. Because the conditions, assumptions and methods underlying these results vary widely, direct comparison may not always be valid.

204. The collective doses shown in Table 34 can be compared with total medical radiation doses to determine the relative contribution of doses from nuclear medicine examinations. The collective effective dose equivalent from nuclear medicine examinations in the United States in 1982, 32,100 man Sv, amounted to about 35% of the 92,000 man Sv from diagnostic x-ray usage [N1]. In contrast, the 1,000 man Sv from nuclear medicine in the United Kingdom in 1982 constituted only about 5% of the 20,000 man Sv from diagnostic x-ray usage.

205. Alternative estimates could be derived for the effective dose equivalent from nuclear medicine examinations in Canada by extrapolating the estimates for Manitoba and Quebec to the entire country. These results would be 3,200 and 9,900 man Sv, respectively, to be compared with the estimate given in Table 34, 4,200 man Sv. The difference in the three estimates stems mainly from different assumptions about the number of examinations [L7]. Of the 260 nuclear medicine clinics in Canada, over half are located in Ontario and only 10 in Manitoba [L12], so extrapolation from Manitoba may be uncertain. The

arithmetic average of the three estimates of dose per examination is 5.1 mSv, which is similar to the value derived in Table 32 for level I countries.

206. Maruyama et al. studied the usage of radiopharmaceuticals in Japan in 1982 [M10, M11, M12]. They provided detailed age- and sex-distributions of patients for each radiopharmaceutical used in several general procedures (e.g. renogram, scintigram, blood flow) [M10]. They also derived age- and sex-specific organ-dose conversion factors and a set of sex-specific effective dose equivalents for each radiopharmaceutical used [M11]. Most of the numeric values were fairly similar to the values in ICRP Publication 53 [I5]. This comprehensive material underlies the entry for Japan in Table 34. The distribution of the collective dose over age groups and for different radiopharmaceuticals is given by Maruyama et al. [M12].

207. The per caput effective dose equivalents in Table 34 vary by two orders of magnitude, partly owing to variation in examination frequencies. In contrast, most of the effective dose equivalents per examined patient fall within a fairly narrow range, 2-5 mSv, in countries of health-care level I. The exceptions, with effective dose equivalents in the 10-30 mSv range, are countries in which the use of long-lived radionuclides, such as ^{131}I and ^{198}Au, is proportionally higher. Doses in Poland are in the upper range, with an effective dose equivalent per examination which is three times that observed in India. The main reason is that half of all examinations are performed with ^{131}I, resulting in some 20 mSv per examination. The range of the average effective dose equivalent per examination in China (15-34 mSv) [Z6] encompasses the value derived in Table 32 (20 mSv).

208. For countries of health-care level I, a population-weighted annual per caput effective dose equivalent of 0.073 mSv can be derived from Table 34. This gives some corroboration to the value derived in Table 32. In the UNSCEAR 1988 Report [U1] the estimated value was 0.05 mSv, although weighting for population would, in fact, have given 0.07 mSv. The present estimate (0.09 mSv) is hardly different, but as it is based on data from more countries, it is more reliable.

209. For health-care level II, the previous estimate of the per caput dose from nuclear medicine examinations was 0.004 mSv [U1]. The present estimate, 0.008 mSv, is again more soundly based, especially because there are data from China and India. There are still inadequate data for levels III and IV. With the frequency of all examinations only slightly less than for level II and the important thyroid scans comparable in frequency, the similar per caput dose derived for level III should mean that the collective dose will not be underestimated.

210. Annual per caput and collective effective dose equivalents from nuclear medicine examinations worldwide are summarized in Table 35. The total collective dose from the practice (160,000 man Sv) is about twice as great as the estimate in the UNSCEAR 1988 Report [U1]. Even the present estimate is highly approximate, but the underlying database has been strengthened.

D. TRENDS

211. The number of diagnostic nuclear medicine examinations increased in industrialized countries in the 1970s, but remained relatively constant in the 1980s [H17, H18]. However, the frequency of nuclear medicine examinations in hospitals in the United States increased from 5.6 million in 1980 to 7.5 million in 1990 [M2]. The frequency of examinations is expected to increase in developing countries. The data from the UNSCEAR Survey of Medical Radiation Usage and Exposures are too incomplete to allow quantifying trends.

212. One of the important developments is that new ^{99m}Tc-labelled compounds are replacing established compounds containing other radionuclides in level I and to some extent level II countries [P13]. Usually, this leads to lower doses per examination. Other important trends are the introduction of complex biological agents (such as radiolabelled monoclonal antibodies) for novel imaging applications and the proliferation of new compounds for studies with positron emission tomography (PET). These developments can be expected to lead to more examinations per caput. The proliferation of single photon emission computed tomography (SPECT) and positron emission tomography are also expected to lead to the wider use of three-dimensional rendering [H23, P22, W17], as was already discussed for x rays in Section II.F. Computed x-ray tomography and magnetic resonance tomography both provide higher resolution, however, which means that purely anatomical imaging is not an important procedure in current nuclear medicine practice [E2]. Instead, measurements of flow and biochemical reactions are important.

1. Specific methods in nuclear medicine

213. While the total number of nuclear medicine examinations may have remained relatively constant in industrialized countries from 1980 to 1990, the choice or pattern certainly has changed. As an example, data from Sweden [H18, V4] reveal a very complex pattern. The two most important changes concern the relative use of ^{99m}Tc (19% of all tests in 1971, 65% in 1987) and ^{131}I (52% in 1971 and 12% in 1987).

Gold-198 was phased out in 1977. The use of ^{125}I is decreasing, while that of ^{51}Cr, ^{123}I and ^{201}Tl is increasing. All of these trends refer specifically to the one country studied. While the trend in relative use of ^{99m}Tc and ^{131}I is presumably widespread, there may be national differences for other radionuclides. For instance, the use of ^{201}Tl (and of ^{111}In) is probably decreasing in the Federal Republic of Germany. In particular, myocardial scintigraphy with ^{201}Tl is being replaced with antimyosine immune scintigraphy, radionuclide ventriculography and other methods that give lower patient doses [B7]. One reason for national differences is the varying availability of radionuclides with short half-life (this factor is particularly relevant in developing countries).

214. The field of paediatric nuclear medicine will possibly grow [P13]. Table 28 shows that renal imaging is the most frequent examination in children, at least in countries at health-care level I. For adults, distributions vary, but on average, bone scans appear to be the most common examination. MAG-3, a recently introduced ^{99m}Tc-labelled mimic of hippuran (which is labelled with iodine) is particularly suitable for paediatric renal imaging [H22, P13]. Since ^{99m}Tc gives smaller doses than iodine, doses are not expected to increase at the same rate as the number of examinations.

215. Radioactively labelled monoclonal antibodies are a valuable diagnostic tool for finding tumours and metastases through radioimmunoscintigraphy. Their use for therapeutic purposes is mentioned in Chapter V. In a diagnostic context, they are associated with relatively high effective dose equivalents: 34 mSv (for ^{111}In), 30 mSv (^{131}I) and 7 mSv (^{99m}Tc) [R15].

216. Single photon emission computed tomography has evolved rapidly since the early 1980s, when it was still rare [P22]. Not only it is now a standard method for tumour localization but it is also used in a variety of applications, such as functional brain studies [H23], cardiac studies, bone imaging and abdominal imaging [P22]. It can also be used in conjunction with labelled monoclonal antibodies. In contrast to the very expensive positron emission tomography technique, single photon emission computed tomography may be affordable in at least some developing countries [P23], in particular if personal computer algorithms for tomography gain wider acceptance, permitting significant reductions in equipment costs [S49].

217. Positron emission tomography provides quantitative, locational, functional and biochemical information that would be difficult to obtain by other means [B13]. While positron emission tomography began as a technique for brain studies [J2], it is now used also for myocardial examination and oncological work [R11, T16]. Whole-body imaging in oncology is an expected development [D14]. The use of labelled anticancer drugs will allow *in vivo* dosimetry, an application likely to become important in the treatment of diffuse disease [O4]. However, there are two problems: equipment is costly, and the short-lived isotopes used require cyclotron facilities nearby.

218. Ott [O4] has stressed that it is hardly necessary to have a cyclotron at each hospital; regional cyclotron facilities within one or two hours distance could serve many users in densely populated areas. While positron cameras are expected to become less expensive, Ott did not foresee a price reduction by more than half in the near future [O4]. Some university institutions have been able to fabricate cameras at low costs [O4, S8], but the cyclotron requirement is likely to continue to keep positron emission tomography generally inaccessible to developing countries. In industrialized countries, the number of positron emission tomography centres is likely to grow rapidly. There were 99 of them in 1991 and 122 in 1992 [G14]; 80% of these were in the United States (75) and Japan (21) in 1992, with 2 each in Australia, the Federal Republic of Germany and Sweden and 5 each in Belgium, Canada, Italy and the United Kingdom. Generator-produced positron emitters may contribute to further growth. They would allow limited positron emission tomography studies without having to invest in a cyclotron [T16]. Generators producing ^{82}Rb from ^{82}Sr are already available, and a ^{62}Cu (from ^{62}Zn) generator is being developed.

219. Hill [H40] expects a rapid increase in the use of positron emission tomography for general imaging purposes. He points out that gamma camera images are greatly inferior to other radiological images in terms of spatial resolution, contrast discrimination and acquisition speed, because the collimator of the gamma camera reduces photon efficiency by at least three orders of magnitude and introduces scatter. Hill stresses that while positron emission tomography lends itself to high-level studies of human metabolism, it should also be an appropriate tool for nuclear medicine in general [H40]. Since the extra information gained with the most advanced positron emission tomography techniques is not necessarily of clinical significance [W29], radiation protection considerations will presumably restrain some of the future growth of positron emission tomography.

220. Limited access to positron emission tomography is likely to restrict this nuclear medicine usage in developing countries in the near future. However, this does not mean that nuclear medicine will be non-existent. Some advanced methods, such as three-dimensional rendering, may be available with reasonable investment costs. However, the high cost of

radiopharmaceuticals, as well as infrastructure problems that limit the availability of short-lived radionuclides, will presumably lead to other examination patterns than in industrialized countries. Thus, radionuclide imaging will presumably not grow very fast, since there are alternatives [I6]. However, there are no obvious alternatives to functional studies which may spread somewhat faster [I6, I7]. Diagnostic *in vitro* analysis with ready-made radioimmunoassay kits is likely to increase, since the technique will work under various conditions and is useful in diagnosis of parasitic infections, which are important in developing countries [I6, I15].

221. It should not be assumed that the evolution of nuclear medicine practice will be similar in all developing countries. On the contrary, there are great differences between individual countries [I6, I7]. At this stage, however, the quantity of nuclear medicine performed seems to be small in most developing countries, even if the methods that do find use differ greatly from country to country. Of course, there are local interruptions in the practice of nuclear medicine, caused not so much by equipment failure as by the erratic supply of radionuclides [I6, I7]. The potential of diagnostic nuclear medicine to detect diseases at an earlier stage and, accordingly, to reduce the direct and indirect costs of illness will presumably encourage developing countries to increase the availability of nuclear medicine, in spite of the difficulties.

2. Alternatives to nuclear medicine

222. The main alternative to nuclear medicine examinations is ultrasonography. Liver scintigraphy with ^{99m}Tc and renal localization with ^{125}I are tending to be replaced by ultrasonography [V4]. The frequency of thyroid scintigraphies in the Federal Republic of Germany decreased by 40% from 1978 to 1984, and at the same time the frequency of thyroid ultrasonic examinations increased by 272% [K9]. Scintigraphy is still the basic procedure for thyroid examination, while ultrasound is used for screening. Ultrasonography is used not only for thyroid and abdominal studies but also increasingly for cardiovascular, renal, locomotive (including hip-joint in children), infant skull, gynaecological and ear, nose and throat examinations.

223. The trend is, however, not universal, In private radiology practices ultrasound equipment is less common. In this case the frequencies of nuclear medicine procedures (e.g. thyroid and bone scintigraphies) have been steadily increasing [K9].

224. Echocardiography is generally regarded as useful for the screening of patients with suspected early cardiomyopathy, while angiography with radiopharmaceuticals is expected to remain the normal procedure when the disease has progressed [C9]. Magnetic resonance tomography is expected to complement (and to some extent supplant) computed tomography with x rays, as was discussed in this context in Section II.F.2. But it can also be regarded as an alternative to some types of radionuclide imaging, including single photon emission computed tomography [S6].

3. Effects of quality assurance programmes

225. Quality assurance programmes, first introduced by the World Health Organization around 1980, are well established for nuclear medicine use in countries of health-care level I. Early efforts in the United States, in particular, helped to establish these programmes [S28]. Table 24 summarizes the regulations and recommendations in countries responding to the UNSCEAR Survey of Medical Radiation Usage and Exposures. It should be noted that responses to the survey are not always consistent, perhaps reflecting differences at the state and federal levels in countries. Bäuml [B40] has compiled references to quality assurance methods and their implementation and results. Further discussion of quality control procedures in nuclear medicine is given in an NCRP report from the United States [N3] and, for radiopharmaceuticals, in an Australian Radiation Laboratory Report [B38].

226. Results of quality assurance testing demonstrate the need for such programmes. This is illustrated by tests of 125 batches of 32 different types of radiopharmaceutical in Australia 1989 [B39]. No less than 23 batches (18%) failed to meet full specifications. A test in Sweden of 81 of the 91 gamma cameras in the country revealed inferior properties for general planar imaging in a third of the cameras, considerable variations in bone imaging and insufficient uniformity in a third of the single photon emission computed tomography systems [L13].

E. SUMMARY

227. In diagnostic nuclear medicine practice, the two most important isotopes are ^{99m}Tc, the use of which is increasing, and ^{131}I, the use of which is decreasing rapidly but which still contributes much to the collective dose. In industrialized countries, the per caput doses due to exposures of patients in nuclear medicine examinations range from 0.02 to 0.2 mSv (population-weighted per caput effective dose equivalent: 0.09 mSv). The dose per examination is a few millisievert in most industrialized countries and 10-40 mSv in developing countries. The difference is due to the more frequent use of long-lived radionuclides in developing countries.

228. Examination frequencies and, hence, per caput doses are higher in North America than in Europe and much higher in industrialized countries than in developing countries. In countries with similar per caput doses, there can still be important differences in choice of procedure. In industrialized countries, examination frequencies are probably no longer increasing as quickly as they did 10 years ago. One of the reasons for this is the competing use of computed tomography and ultrasonography. New techniques, such as positron emission tomography, are expected to become established in industrialized countries. In developing countries, *in vitro* kits as well as some functional study procedures are likely to find increasing use.

229. The estimated effective dose equivalents from diagnostic nuclear medicine examinations for different levels of health care and worldwide are summarized in Table 35. For health-care level I, the annual per caput dose has been adjusted from the previous estimate [U1] of 0.05 mSv, to 0.09 mSv. Access to important new data from China and India permit an improved estimate of the annual per caput effective dose equivalent for countries of health-care level II, now estimated to be 0.008 mSv (previous estimate: 0.004 mSv). For health-care levels III and IV, per caput doses are assumed to be comparable to those in level II. However, because of the low examination frequencies, this estimate has little influence on the collective dose. The estimated per caput effective dose equivalent worldwide is now 0.03 mSv annually, and the estimated collective dose from the practice is 160,000 man Sv. This is twice the 1988 estimate, but it is still only 10% of the estimated collective dose from diagnostic x-ray examinations.

IV. THERAPEUTIC USE OF RADIATION

230. In teletherapy, an external source of radiation allows a beam of photons to be directed towards the patient. For deep-seated tumours, high energy photons are obtained primarily from ^{60}Co sources or linear accelerators [P8]. Older ^{137}Cs sources are being replaced for various reasons. Other, less common types of teletherapy apparatus are mentioned in Section IV.D. For the teletherapy of superficial tumours, x rays are utilized. Very soft Bucky x rays are used for skin disorders. In brachytherapy [T18], sealed radioactive sources are inserted into a body cavity (intracavitary or intraluminal application), placed on the surface of a tumour or on the skin (superficial application), or implanted through a tumour (interstitial therapy). Commonly used sources are ^{198}Au or ^{125}I for permanent implants, ^{137}Cs or ^{192}Ir for low-dose-rate temporary applications, and ^{60}Co or ^{192}Ir for high-dose-rate temporary applications (in the case of ^{60}Co or ^{192}Ir, always using remote afterloading). Older ^{226}Ra sources for low-dose-rate temporary applications are now much less used.

231. In therapy, the objective is to deliver a radiation dose to the patient. Neither individual nor collective effective doses are directly relevant for comparisons with doses from other sources, not even with diagnostic procedures. Furthermore, although they are mentioned below, per caput doses of any kind are difficult to interpret, since they result from averaging very high doses to very few people over an entire population. In the present context, the radiological impact of therapy can perhaps best be described simply by the number of patients and the target doses. Such information was collected in the UNSCEAR Survey of Medical Radiation Usage and Exposures. Effective doses are also discussed below, but the limitations are stressed. Although the numbers of treatments are discussed in this Annex, the data are assumed to refer to the overall courses of treatment and, therefore, to the numbers of treated patients.

A. FREQUENCIES OF TREATMENTS

232. The frequencies of radiotherapeutic treatments reported in response to the UNSCEAR Survey of Medical Radiation Usage and Exposures are given in Table 36 (total frequency) and Table 37 (frequencies of major treatments). In a few cases, it is not clear whether the number of treatments (which may be several dozen per treated patient) or the number of patients was reported. Some totals may be underestimates because certain treatments were excluded. The population-weighted average frequencies of treatments are somewhat less than those given in the UNSCEAR 1988 Report [U1]. The data were dominated at level I by the United Kingdom and the United States, both of which reported 2.4 treatments per 1,000 population but which are missing from the 1985-1990 period. China and India, with lower frequencies, have been added to the listing for level II for 1985-1990. The distributions of the total frequencies of radiotherapy treatments in countries are illustrated in Figure VII. The average annual frequencies of the main types of treatments are shown in Figure VIII.

233. Results from individual countries seem at times to be inconsistent. In many cases, the sums of reported frequencies of specific treatments in Table 37 deviate considerably from the totals listed in Table 36, which may be smaller or larger. The varying number of countries in the periods reported and the different types of treatment included under the broad categories introduce uncertainty and make it difficult to compare results. For the Nordic countries, the total frequencies are believed to be based on better statistics, while the frequencies for specific therapies are extrapolations from small samples. Turkey reports very high frequencies of treatment for leukaemia, lymphoma, Wilms' tumour and neuroblastoma compared to breast, respiratory system or female genital organ therapies. These frequencies, from one hospital, may reflect a non-random selection of patients. In some countries, there are large differences between regions. As one example, which is probably typical of many countries, adequate facilities and advanced services are available at Lima, Peru, but access to radiotherapy is much less satisfactory in rural areas [Z11, Z12, Z13, Z14].

234. Although there are uncertainties in specific data, the general trend agrees with earlier data, which suggested increased teletherapy treatment frequencies in most countries. The number of teletherapy machines in developing countries is considered to be only one tenth the number that would be justified by cancer incidences [R7].

235. Marked variation has been noted between the Nordic countries, in spite of their homogeneity [L16]. This variation is not fully evident from Table 36. Thus, in 1987 according to Lote et al. [L16], 25%-26% of cancer patients in Denmark and Norway received megavoltage radiotherapy, as compared with 36%-38% in Finland, Iceland and Sweden. The number of radiation fields given per patient was 45 in Finland and 34-37 in the other Nordic countries.

236. The age- and sex-distributions of radiotherapy patients are given in Table 38. In general, the age distributions conform with expectations. Thus, Wilms' tumour patients and neuroblastoma patients are usually under age 15 years, leukaemia and lymphoma patients are of all ages, and patients with other cancers are usually over age 15 years, with a sizable fraction over 40. The sex distributions are also as expected. Overall, neither age- nor sex-distributions differ significantly between health-care levels. Some specific deviations may be mentioned, however: for leukaemia, the 0-15 years age group is very small in Myanmar, for no obvious reason. This may be a random fluctuation. The age distribution for lymphoma patients includes a significantly higher proportion of children in countries of health-care level II than in countries of health-care levels I and III, where the proportions are not significantly different. This may reflect the distributions of Burkitt's lymphoma and of Hodgkin's disease.

B. DOSES IN TREATMENTS

237. Information on target organ doses and entrance surface doses in teletherapy and brachytherapy treatments is given in Table 39. The doses used differ, but no particular difference distinguishes the levels of health care from one another.

238. Absorbed doses in tissues or organs other than the target of the treatment could be used in assessment of patient doses, although general comparisons would be difficult. Some such absorbed doses were listed in the UNSCEAR 1982 Report [U3], but effective dose equivalents were not evaluated for four reasons:

(a) the proportionality between dose and response assumed for effective dose or effective dose equivalent calculations does not hold if organ doses exceed a few gray;
(b) the short life expectancy of the patients invalidates assumptions underlying the choice of organ weighting factors for effective dose or effective dose equivalent calculations;
(c) little is known about the dose distribution outside the target volume;
(d) in therapeutic nuclear medicine, the metabolic data assumed in normal dose assessments may not be valid.

239. Since the UNSCEAR 1982 Report [U3], the situation has changed somewhat, at least with respect to the first three reasons: (a) a tentative first estimate of the risk of cancer induction in target organs exists [I4], which facilitates the approximative consideration of beam and target organ doses in effective dose or effective dose equivalent calculations [B19]; (b) cancer therapies are becoming more successful, and the average life-span of surviving cancer patients is increasing, with particularly dramatic improvements for childhood cancers; (c) extensive calculations by Williams et al. [W34] of organ doses outside the beam are available and summarized in ICRP Publication 44 [I4]. Thus, it is now at least feasible to compute effective doses.

240. However, the detriment associated with such effective doses cannot be calculated in the same manner as for healthy workers, nor even as for patients in diagnostic examinations, and it is in any case a by-product of indispensable, life-saving treatment. Furthermore, radiotherapy patients are unique in that deterministic harm constitutes a sizable part of the radiation-induced detriment. Such complications of treatment are discussed in ICRP Publication 44 [I4].

Effective doses are not well suited to describe such effects. Still, effective doses may be useful as supplementary information, to allow for comparisons between treatments and countries.

241. Even with the new data in ICRP Publication 44 [I4], effective dose computations in radiotherapy must be simplifications. For instance, as suggested by Beentjes [B19], it is assumed for the present purpose that all radiotherapy delivers dose distributions similar to those from ^{60}Co sources. Using data from Beentjes [B19], absorbed doses to non-target organs from scattered radiation from ^{60}Co treatments of four major target areas have been calculated (Table 40). It was assumed that these areas are representative of all radiotherapy except skin and female breast radiotherapy, and that the dose to target organs is always 60 Gy. Leakage radiation (a few per cent of the scattered radiation) is disregarded.

242. Cancer mortality following radium treatment for fibrosis with uterine bleeding may illustrate the relevance or otherwise of effective doses in non-target organs. In a study of 4,153 women treated between 1925 and 1965 [I16], average doses were provided for all organs, allowing the calculation of an average effective dose from scattered radiation of 1,070 mSv. To this a correction for target organ doses should be added. Based on the considerations of ICRP [I4] and the interpretation of Beentjes [B19], one may assume at most two fatal second cancers, i.e. less than 0.1% with a cure rate of 50% of 4,153, and a cancer fatality probability coefficient of 0.05 [I8], which corresponds to 40 man Sv, or 10 mSv per woman. The cumulated effective dose, 1,080 mSv, corresponds to a collective effective dose of 4,440 man Sv. With a fatality probability coefficient of 0.05 per man Sv, 222 extra cancer deaths would be expected in the cohort. Actually, after an average observation period of 26.5 years, an excess of 147 cancer deaths was recorded [I16]. Thus, the estimate from effective dose calculations agrees reasonably well with observations.

243. The so-called Bucky, or grenz ray, therapy, which uses 8-17 kV x rays to treat skin disorders, cannot be directly compared to other radiotherapy. Bucky therapy is relatively popular in, for instance, the United States and in Sweden, which has some 15 facilities offering this treatment. The short penetration (half-value layer in tissue: 0.5 mm) precludes any effects in other organs than skin from Bucky therapy. Nevertheless, skin doses of 5-50 Gy are received for a procedure (therapy course) consisting of 10 consecutive treatments; for foot verrucae up to 200 Gy per procedure of 10 treatments are delivered, i.e. 20 Gy per treatment with 4-6 weeks between treatments [L8]. In this particular application, skin surrounding the verrucae is shielded from radiation with vaseline. At least 22 cases of skin cancer following Bucky treatment are known, all with doses higher than 50-200 Gy. For cumulated doses under 100 Gy, no excess cancer risk has been proven [L8].

C. WORLDWIDE EXPOSURES

244. According to the UNSCEAR 1988 Report [U1], about 2.4 persons per 1,000 population were subjected to either teletherapy or brachytherapy annually. Results from the UNSCEAR Survey of Medical Radiation Usage and Exposures show a lower frequency (about 1.4 per 1,000), but this is only a sampling difference. It is expected that treatment frequencies will increase gradually, based on other considerations. The treatment frequency in countries of health-care level II is about 25% of that in level I countries, in conformity with the earlier observation [U1].

245. The UNSCEAR Survey of Medical Radiation Usage and Exposures responses are insufficient to permit analysis for health-care levels III and IV, but there is no particular reason to expect any significant change from the estimates in the UNSCEAR 1988 Report [U1]: 0.1 procedures per 1,000 population for health-care level III and 0.05 per 1,000 population for level IV, i.e. 4% and 2% of the treatment frequency in level I countries.

246. The age- and sex-distributions of tele- and brachytherapy patients appear to agree fairly well with expectations based on age and sex statistics for the corresponding diseases. The doses used for treatment vary, but no particular trend seems to distinguish the different levels of health care. Some new technologies may lead to fewer side effects and/or better results than conventional therapy.

247. The number of radiotherapy patients is suggested as a simple measure that is correlated with the radiological impact associated with therapy (including deterministic treatment complications). Since more reliable numbers are unavailable, the treatment frequencies reported in the UNSCEAR 1988 Report [U1] have been combined with data on populations in the health-care levels, leading to an estimated 4.9 million procedures annually (0.9 per 1,000 population).

248. It may also be of interest to assess the effective dose, using the approach of Beentjes [B19, B36] but modifying it to obtain effective dose rather than somatic effective dose as he did. The collective effective dose equivalent and collective effective dose due to radiotherapy in the Netherlands in 1978-1979 is computed in Table 41 using the normalized organ doses of Table 40 and various further assumptions stated in the Tables. The result is a collective effective

dose equivalent of 19,100 man Sv and a collective effective dose of 10,400 man Sv. The latter value will be used for extrapolation to worldwide exposures. For this purpose, it was assumed that the distribution of different types of cancer is similar in countries of different health-care level. In fact, both distribution and frequency of cancers vary considerably. However, it is believed that variations in distribution do not seriously affect the collective dose estimate, which can indicate only the order of magnitude of the worldwide collective dose. Variations in the frequency of different cancers are to some extent taken into account when therapy frequencies are used as multipliers in the dose calculation.

249. Table 42 lists collective effective doses, estimated on the assumption that they are proportional to the effective doses in the Netherlands [B19], correcting for size of population and for treatment frequency (but, to retain compatibility with effective dose for diagnostic practices as far as possible, not correcting for patient age [B36]). The result is rather imprecise. The estimated annual collective effective dose in Table 42, 1,500,000 man Sv worldwide, does however show that the secondary effects of radiotherapy are not negligible. Probably, they are of the same order of magnitude as those caused by diagnostic practices. It is important, however, to view the secondary effects from therapy in relation to the consequences of no treatment, in which case continuing debilities and early deaths would surely prevail.

D. TRENDS

250. Increasing life-span will make cancer therapy more relevant; increasing affluence will make more equipment available. Radiotherapy is thus likely to become more frequent in most countries [Z11]. Increased awareness of the early symptoms and signs of cancer will presumably also increase demand for radiotherapy. In Peru, 60% of cervical cancer patients now come for treatment in the later stages of the disease, while for instance only 17% of Swedish patients are at the late stages [Z3].

251. The cancer incidence in industrialized countries is roughly 3,500 cases per million population per year. About half of the cases are suitable for radiation therapy. On a global basis, some 10 million new cancer cases occur each year, 6 million of which would be aided by radiotherapy. Since the treatment capacity of one radiotherapy unit is about 500 patients annually [W10], an increase up to about four units per million population could be expected in the long run. In other words, some 3,000 units are probably needed to supplement the 6,000-7,000 units existing worldwide today. However, while more than half of all cases come from developing countries, access to radiotherapy is limited [D16]. In Africa, 45% of the 560 million inhabitants are under 15 years old, so it is almost certain that cancer will become a bigger problem as the population ages. Yet only a third of African countries have any radiotherapy facilities, and in many cases these are ill-equipped and understaffed.

252. Radiotherapy is being developed to achieve higher therapeutic effects and better tolerability, using e.g. hyperfractionation [H11, P8, P24, W27]. Some promising ideas are under consideration. Although their success has so far been limited [H40], some possible advances will be mentioned here. For instance, inverse dose planning means that instead of calculating the dose distribution for a proposed beam configuration, the optimal beam conditions for a desired dose distribution in the patient's body are calculated [A3, B16, K6]. As this technique becomes common, fewer patients will suffer radiation-induced complications after treatment. Another possibility is that target doses could be adjusted to take account of the patient's genetically determined radiation sensitivity [A7, S35]. Such adjustments may be quite important, since genes conferring radiosensitivity may be much more frequent than in the population at large, possibly occurring in as many as 15% of all cancer patients [B3, H3, N2, S20]. Attention to this factor would also reduce the number of complications and thus the radiological insult to the population. The use of whole-body treatment for leukaemia is increasing. The UNSCEAR 1988 Report [U1] considered briefly the doses to fetuses in the radiotherapy of pregnant women. Supplemental information is now available on the use of lead shielding in such cases [L15].

253. Treatment accelerators with higher energies and external beams of fast neutrons have been mentioned as likely new developments [S6], and there is some preliminary experience of fast neutron therapy, which has had, however, only limited success [B8, H13, K11, P16]. Another possible refinement would be photon activation using Mössbauer resonance absorption, in which (for example) an ^{57}Fe compound administered to the patient is induced to produce Auger cascades through photon irradiation. In principle, this technique should permit lethal doses to cancer cells at the expense of only very low doses to normal cell. There are, however, still doubts whether the technique will work in humans, at least for other than very superficial tumours, for which many alternative methods already exist [H20].

254. Proton therapy constitutes another advance [C27]. Thus far, some 7,000 patients have been treated. More than 2,000 were treated in the USSR alone, where clinical work started at three centres in the 1960s, and there were a fairly constant number of

patients (a few hundred each year) during the 1980s [G11]. The advantage of protons is that they cause steep dose gradients at the lateral and back sides of the target dose distributions, thus reducing the irradiation of other than target organs, albeit at great investment costs for the complicated facility.

255. External therapy has been used not only for treating cancer but also for treating benign conditions. For instance, 20,012 patients (99% of them younger than 2 years of age) were treated for haemangiomas at Radiumhemmet in Stockholm between 1909 and 1959. While some centres still advocate the radiation therapy of haemangiomas, it has declined rapidly since the early 1960s [F9]. It appears likely that such therapy will in the future be applied only in special cases, such as bony haemangiomas.

256. Alternative and supplementary treatment options will continue to appear, and in some cases they will be preferred in patient groups at high risk. For instance, children with brain tumours are conventionally treated with radiotherapy, but mental retardation is a frequent side effect, occurring in 38% of all long-term survivors in one study, with younger children being more seriously affected [L9]. Therefore, the tendency is to delay radiation therapy and use chemotherapy for children under 2-3 years of age, who are most sensitive to radiation [L9]. It is not known, however, whether delaying irradiation really improves the functional status of the patients [M14].

257. Quality assurance programmes, instigated in particular by the World Health Organization, are even more important (but also more difficult) in therapy use than in diagnostic use. A number of incidents might have been avoided by a more systematic approach to quality assurance. In one United Kingdom centre, more than 200 patients were treated with overdoses of 25% in 1988 [S36]. A listing of reports that contain technical details on quality assurance programmes in radiotherapy has been published [B40]. A particularly important collection of papers [H9] discusses radiotherapy quality assurance from European, North American and Latin American perspectives. Brahme [B17] discussed quality assurance for external beam therapy.

258. There is scope for other errors in a computer-controlled treatment than in a conventional treatment. Not only must all normal quality assurance be performed, but it is also necessary to check the computer control [M20]. Input of data into check-and-confirm systems may actually contribute to systematic errors, if used as an uncontrolled setup system [L3].

259. A joint study in Finland and the USSR [K20] found unacceptable variations in dose distribution between treatment planning systems and suggested that the quality assurance programmes be improved. Zaharia [Z3, Z10] discussed quality assurance in radiotherapy in developing countries, with special emphasis on Latin America, pointing out the limitations imposed by a lack of resources. For instance, accelerators and quality assurance programmes are unlikely to be available, and cobalt units must be used.

E. SUMMARY

260. Treatments by radiotherapy are intended to deliver high doses to target organs to eliminate malignant or benign conditions. All attempts to calculate effective doses from data on non-target organs will inevitably be open to serious criticism. The secondary effects associated with such doses are difficult to estimate and cannot be directly compared with effects of radiation in other situations. They must be assessed bearing in mind that they are a by-product of indispensable life-saving treatment. Thus, the frequency of treatments and the target doses are primary estimators of the impact of radiotherapy. Nevertheless, effective dose calculations may provide valuable supplementary information.

261. The frequency of radiotherapy treatments by teletherapy and brachytherapy is estimated to be 2.4 per 1,000 population in countries of health-care level I and 25%, 4% and 2% of this value in countries of health-care levels II, III and IV, respectively. The total number of procedures performed annually worldwide is estimated to be 4.9 million.

262. Estimates have been made of the collective effective dose from radiotherapy, determined by considering tissues and organs other than gonads outside the target area. The results, summarized in Table 42, indicate an annual collective somatically effective dose of 1,500,000 man Sv worldwide. Some 66% of this collective dose concerns health-care level I countries, which is directly proportional to treatment frequencies.

V. THERAPEUTIC USE OF RADIOPHARMACEUTICALS

263. Relatively few data are available or were submitted to the Committee for the assessment of therapeutic nuclear medicine. The problems of effective dose, discussed for teletherapy and brachytherapy in Chapter IV, are equally evident for therapy with radiopharmaceuticals. As in those other types of radiotherapy, simple information on the number of patients and doses may be the most suitable measure of the secondary effects of therapy with radiopharmaceuticals.

A. FREQUENCIES OF TREATMENTS

264. A number of different radio-pharmaceuticals are used in the treatments of various diseases, but the use of ^{131}I to treat thyroid conditions predominates. Much less frequent procedures include the treatment of polycythaemia vera with ^{32}P and of hepatic tumours as well as arthritis with ^{90}Y. Frequencies of therapeutic treatments using radiopharmaceuticals in countries responding to the UNSCEAR Survey of Medical Radiation Usage and Exposures are listed in Tables 43 and 44. The population-weighted average frequency of all treatments in 1985-1990 for countries of health-care level I is 0.1 per 1,000 population; the unweighted average of reported values is 0.2. Considering statistical fluctuation, these estimates are hardly different from the estimate of the UNSCEAR 1988 Report [U1], which was 0.4 per 1,000 population. In conformity with other observations from the UNSCEAR Survey of Medical Radiation Usage and Exposures, the treatment frequencies at health-care levels II and III are about an order of magnitude lower than at level I. The distributions of the total frequencies of treatments with radiopharmaceuticals and the average annual frequencies of the main types of treatment are illustrated in Figures IX and X.

265. The age- and sex-distributions of patients are given in Table 45. As expected, thyroid disorders occur more frequently in women. No differences in the age or sex ratio of these patients can be detected between health-care levels. As with tele- and brachytherapy, no trends with time in treatment frequencies are obvious.

266. Blaauboer and Vaas [B6] have estimated that the frequency of thyroid therapy courses using ^{131}I in the Netherlands is 0.35 per 1,000 population. This is somewhat higher than the value of 0.097 per 1,000 population given in Table 44. There are no doubt large uncertainties in estimates depending on the reliability of the underlying samples.

B. DOSES IN TREATMENTS

267. The average activities administered in the therapeutic use of radiopharmaceuticals are listed in Table 46. The amounts used for similar treatments are comparable in most cases, although a 20-fold difference between the extreme values of activity can be identified for thyroid tumour treatment using ^{131}I.

268. While this conventional treatment and its properties are well known, some attention is being given to potential problems with other therapeutic uses of radiopharmaceuticals. Thus, since around 1980, monoclonal antibodies labelled with ^{90}Y or ^{125}I, for example, have been used for radioimmunotherapy (albeit apparently in few cases). In the present context, the question has been raised whether better estimates of bremsstrahlung organ doses are needed when high-energy beta sources such as ^{90}Y are used for radiotherapy [W8]. In the case of ^{90}Y, measurements indicate that the bremsstrahlung doses are usually less than 1% of the beta doses, but Williams et al. [W8] conclude that bremsstrahlung doses are not negligible.

269. Table 47 gives the absorbed doses to non-target organs from ^{131}I thyroid therapy in Japan in 1982, using Maruyama's data on activity and patient number [M10] and the dose conversion factors for adults given in ICRP Publication 53 [I5]. Using these data and an approach similar to that of Beentjes [B19], it is possible to calculate the effective dose equivalent and effective dose. In this case, there is a marked difference between H_E (180 mSv) and E (23 mSv), since the higher absorbed doses appear in remainder organs. The H_E value corresponds to about 530 man Sv, or a per caput effective dose equivalent in Japan from thyroid radionuclide therapy of about 4.4 μSv. This demonstrates that radionuclide therapy contributes but a small part of the per caput dose to the population.

270. Cox et al. [C18] state that radionuclide therapy on pregnant women, particularly in unsuspected early pregnancy, may be associated with much higher fetal doses than would be expected from current methods for dose estimation.

C. WORLDWIDE EXPOSURES

271. The data in Table 43 indicate somewhat lower frequencies of treatments with radiopharmaceuticals than were estimated in the UNSCEAR 1988 Report. However, the data are broader-based than the earlier data. The population-weighted average for 1985-1990 is 0.10 per 1,000 population in countries of health-care

level I, 0.02 per 1,000 population for level II and 0.025 per 1,000 population for level III. The 1988 values [U1] were 0.4, 0.1 and 0.016 per 1,000 population, respectively, and for level IV, 0.008 per 1,000 population, mostly based on extrapolation from diagnostic nuclear medicine frequencies.

272. As in the evaluation of tele- and brachytherapy in Section IV.C, an extrapolated collective effective dose was estimated analogous to that used by Beentjes [B19] and based on the dose data for Japan given in Table 47. This amounts to about 9,300 man Sv worldwide, of which some 6,000 man Sv arise in countries of health-care level I (Table 48). Thus, the estimated secondary effects from therapy with radiopharmaceuticals are negligible in comparison with those from other medical radiation usage.

D. TRENDS

273. Indications are that ^{131}I continues to be used in 99% of therapies [U1]. In the early 1980s, radioimmunotherapy using monoclonal antibodies, which concentrate selectively in tumours, was regarded as "the magic bullet", but the technique still seems to be in development [G1]. A possible refinement is the increased potential for and use of boron neutron capture therapy [A4, F11]. In this technique a compound or monoclonal antibody is tagged with ^{10}B. Neutron-irradiation of this target produces ^{11}B, which fissions instantaneously, yielding alpha particles. The technique will presumably affect only a few patients in the near future, but it could lead to exposures of staff [S6].

E. SUMMARY

274. In therapy using radiopharmaceuticals, the treatment of thyroid conditions with ^{131}I is by far the most common procedure. Polycythaemia vera is treated with ^{32}P, and some benign diseases are sometimes treated with radiopharmaceuticals. Although new procedures may be introduced, they are unlikely to significantly alter current use patterns in the near future.

275. The estimated frequency of treatments with radiopharmaceuticals in countries of health-care level I is 0.1 per 1,000 population. The frequencies are 20% and 10% of this value in countries of health-care levels II-III and IV, respectively. The total number of procedures performed worldwide is estimated to be 210,000 (Table 48). The collective effective dose from such treatments (9,300 man Sv) corresponds to a per caput effective dose of 1.8 μSv; it is a minor component of the total effective dose from all uses of medical radiation.

VI. EXPOSURES OF THE GENERAL PUBLIC

276. Inevitably, medical radiation procedures, like other practices involving radiation, will cause some inadvertent exposure of members of the general public. There are difficulties in putting these exposures into perspective, expressing the exposures per unit practice, for example. There may be some merit in continuing to consider the levels of health care in countries. Most data are available only for countries of health-care level I. Hence, to the extent that information is at all available, the discussion below is limited to doses to exposed persons, numbers of exposed persons, and per caput doses obtained by averaging over populations.

A. DIAGNOSTIC X-RAY EXAMINATIONS

277. It appears very rare that unintentional irradiation of the general public from x-ray facilities occurs, with the possible exception of certain uses of mobile equipment. Use of portable equipment under field conditions could cause some inadvertent exposures, if proper shielding has not been provided. Because of these difficulties, the Basic Radiology System of the World Health Organization has been devised as non-mobile equipment [W3].

278. Some exposure is possible of parents who are requested to hold and/or calm children subjected to x-ray examinations. Few publications address this problem specifically, but it seems reasonable to assume that the doses per examination would be similar to those encountered occupationally. Parents would not be involved as frequently, nor for as long times, as medical staff, so in most cases the integral doses over longer periods of time should be lower than those sustained by exposed medical staff.

B. RADIOPHARMACEUTICALS

279. There are few data on exposures of the public from use of radiopharmaceuticals, but the problem could be larger than that corresponding to use of

x rays, since the sources can be brought outside of the clinic and beyond the radiation protection measures present there. There are, in principle, two routes of such exposure: family members (or some other individuals or visitors) could be exposed to radiation from radiopharmaceuticals in the patient's body, and radioactive wastes released into sewage systems or deposited at refuse dumps could increase background exposures. Excretion of radionuclides from patients, as well as radioactive waste from hospitals and exposures due to radioisotope production, are evaluated in Annex B, "Exposures from man-made sources of radiation". However, exposures of members of the public from radioisotopes present in the bodies of patients are considered in this Annex. The contamination of restroom facilities in hospitals, is reviewed by Ho and Shearer [H16].

280. The problem of radiation from radiopharmaceuticals present in patients is not trivial if the patient is a small child or a parent to a small child. In such cases, family members are likely to be moderately exposed. However, estimated doses to family members are low, usually below 1 mSv, in diagnostic practice, even if the persons involved are in close bodily contact more or less continuously [M3, M28]. Leucocyte scans with ^{111}In constitute a possible exception where special actions may be necessary, if doses exceeding about 1 mSv are to be avoided [M27]. Equivalent dose rates from patients undergoing some typical examinations are given in Table 49 [N6]. The dose rates are of course higher, and the problem can be much more difficult in therapy cases (see Section C below).

281. A study concerning diagnostic nuclear medicine referred to the situation in the United States [B12]. Patients were equipped with dosimeters in order to estimate the effective dose equivalents to critical groups (family members and co-workers) as well as to the entire population. For practical reasons, the dosimeters were put on the patients rather than on the members of the critical groups themselves, and then doses to critical groups were computed using suitable models. The average effective dose equivalents to members of critical groups were 7-20 μSv annually, and the per caput effective dose equivalent to a member of the general public was 0.4 μSv annually [B12]. Since the population of the United States is about 250 million, even this very low individual figure corresponds to a not negligible collective effective dose equivalent of some 100 man Sv (the estimate is, of course, not very precise).

282. Often, patients have to wait between injection and imaging. In some countries, such as the United States, separate waiting rooms are recommended for injected patients, but in other countries this is not the case. Harding et al. [H26] studied doses incurred by relatives, other staff and accompanying nurses in the waiting room at a hospital in the United Kingdom. Median doses were about 2 μSv or less, with a maximum (for a relative) of 33 μSv. Similar conclusions were drawn by Siewert [S4] for the Federal Republic of Germany.

283. One aspect of inadvertent exposures is that breast-fed infants may be exposed via excretion of radiopharmaceuticals in milk of examined mothers. Many studies have been made of this subject (e.g. [T4]). A number of references appear in reports of NCRP and UNSCEAR [N1, U1]. Table 50 shows that in some cases, the effective dose equivalent to a breast-feeding child could be two orders of magnitude higher than that to the mother [I5, J1]. On the other hand, the concentrations of a radiopharmaceuticals in milk usually decrease very rapidly to insignificant levels. Discarding the first, or the first few, milk fractions during the day of administration, thus, usually renders the dose to the infant negligible (a small fraction of a mSv) [J1]. Fibrinogen tagged with ^{125}I is a rare exception, where breast-feeding within three weeks can lead to effective dose equivalents to infants of 10-15 mSv, with a concurrent effective dose equivalent to the mother of about 0.5 mSv [J1]. Inadvertent exposure of the fetus is possible in cases of undeclared early pregnancy. Uterine doses, relevant in such circumstances, are available in ICRP Publication 53 [I5].

284. Little is known about the geographic variations of exposures of the general public from diagnostic nuclear medicine practice. The number of examinations are higher in developed countries, and it seems safe to assume that the doses incurred in the United States due to radiation from radiopharmaceuticals in patients (0.4 μSv per caput annually [B12]) represent the upper end of the possible dose range.

C. RADIATION THERAPY

285. If potential exposures due to accidents or incorrect shielding of facilities are disregarded, the main exposures to the general public may be due to radiation from patients undergoing brachytherapy. Approximate dose rates around the beds of such patients have been computed, for example 0.3 mSv h^{-1} at 1 m and 0.1 mSv h^{-1} at 2 m from a patient containing 3,700 MBq ^{137}Cs or 5,500 MBq ^{131}I [S14]. It is worth noting that afterloading is probably very uncommon in countries of health-care levels II to IV, which means that doses to the public (and to staff) may be higher per treatment than in countries of health-care level I. Dose rates of 0.01 mSv h^{-1} have been observed in rooms above or below a brachy-

therapy patient's room in a hospital in the United States [B14]. Proper shielding reduced this dose rate by some 20%-45%. Although the authors primarily deal with doses to staff, members of the public (other patients, visitors, staff not involved in radiation work) could also be exposed to these radiation fields.

286. Thus, given a suitable set of conditions, public exposure could be modelled. In the United States study just discussed [B14], the model chosen suggested that shielding reduced inadvertent exposure of staff and public by 0.0006 man Sv per average brachytherapy. Of this exposure reduction, 0.00025 man Sv was occupational, so the public exposure without extra shielding should be at most (total minus occupational)/(remaining fraction of dose rate) = (0.0006 - 0.00025)/(1 - 0.45) = 0.0006 man Sv. On the very approximate assumption that all brachytherapy causes doses similar to the doses in ^{137}Cs gynaecological treatments at the specific hospital in the United States, and that the average frequency of brachytherapy for treatment of malignancies in countries of health-care level I is 0.08 per 1,000 population (see Table 42, assuming one third of total treatments are brachytherapy), the per caput dose to the general public due to brachytherapy in countries of health-care level I would be some 0.05 μSv.

287. The problem of radiation from radiopharmaceuticals in the bodies of patients undergoing therapy is more complicated than in diagnostic nuclear medicine. Relatively few patients are involved, but the activities are high enough to cause doses that could exceed a few mSv to exposed members of the public. Hence, various precautions against inadvertent exposure of fellow patients or family members are common [C21]. As an example, Koshida et al. [K18] suggest that ^{131}I therapy patients should not be discharged from the hospital unless the maximum residual activity is less than 510 MBq, the patient's children are aged over 1 year and they keep at a distance of at least 50 cm. In a later paper, they reduced this value to less than 100 MBq [K28]. For the patient to return to the general ward, or for the patient to be discharged from the hospital when children are younger and/or will be closer than 50 cm, stricter recommendations apply.

288. Approximate dose rates around the beds of such patients are similar to those given above. Further illustrations showing how such dose rates change due to radioactive decay after ^{131}I administration can be found in Orito et al. [O5, O6]. Family members may wish to ignore radiation exposure in order to be able to spend as much time as possible with the patient [H18]. Other problems in the therapeutic use of radiopharmaceuticals are the same as those for diagnostic uses.

D. VOLUNTEERS IN MEDICAL RESEARCH

289. The Committee has not previously been able to evaluate the doses to healthy volunteers in medical research. Such volunteers might be considered a small subgroup of the general public. Data on these exposures are not readily available, but some statistics for the Federal Republic of Germany and for the United Kingdom are presented in Table 51. German regulations are somewhat different for three types of research (general medical research using labelled compounds, clinical trials of pharmaceuticals labelled for some specific purpose during the trial, and trials of radiopharmaceuticals), hence the separation of the corresponding volunteer groups in Table 51. This Table clearly shows that the number of volunteers is small enough not to dominate the collective dose to the general population, but it is theoretically possible that some individual doses could be relatively high (i.e. comparable to the dose limit for radiation workers of 50 mSv in a single year). It should be remembered that radioactive labelling in research projects may differ from that normally encountered in radiopharmaceuticals, and can include long-lived nuclides such as ^{14}C [L26]. One difficulty may be to identify the volunteers. In diagnostic use of x rays, extra exposures may be given to patients for research purposes, thus making it difficult to distinguish patients and volunteers.

290. Some factors act towards reducing doses to volunteers. Ethics committees that exist in many countries, albeit with varying regulatory status, usually attempt to prevent unnecessary exposure of volunteers. The 1990 recommendations of the ICRP [I8] suggest that appropriate national bodies might consider dose constraints for volunteers. Such constraints would truncate the upper end of the dose range, thus reducing the average dose to volunteers. Even formal limits have been discussed (Canada [C7]) or implemented (the Federal Republic of Germany [K9] and the United States [U16]), in spite of objections [P6] that dose limits are inappropriate in medical research. To the extent that such limits are used, they can be expected to reduce the average of doses to volunteers, by cutting off the upper tail of the dose distribution.

E. SUMMARY

291. While x-ray examinations are more frequent, examinations and therapy with radiopharmaceuticals constitute the more important route of exposure of the general public. The annual per caput effective dose equivalent caused to members of the public by patients with radionuclides in their bodies is estimated to be 0.4 μSv or less.

VII. EXPOSURES FROM ACCIDENTS IN MEDICAL RADIATION USAGE

292. Most of the available reports on accidents are case studies of particular events. So far, the material permits little in the way of estimating of the accident frequency per unit population or per unit of practice. It must be emphasized that all of the frequency estimates given below are highly imprecise and, owing to erratic reporting, are very likely to be underestimates.

293. Accidents in diagnostic x-ray examinations are not likely to have grave individual consequences. Of the 38 incidents of patient overexposure due to faulty radiation equipment that were reported to the United Kingdom Health and Safety Executive between 1986 and 1990, 30 involved diagnostic x-ray equipment. In these incidents, about 760 patients (about 0.003 per 1,000 population annually, corresponding to about 6 per million x-ray examinations in the United Kingdom) were overexposed, with effective dose equivalents from 0.5 to 13 mSv and a collective effective dose equivalent of some 5 man Sv [G10].

294. In nuclear medicine misadministrations occur, sometimes with fatal results [M29]. The extravasation of correctly measured but incorrectly injected radiopharmaceuticals can also lead to radiation injury [S50]. In the United States about 75 misadministrations in therapy and about 1,300 misadministrations in diagnostic nuclear medicine are reported annually (in all, about 0.006 per 1,000 population annually, or about 140 per million nuclear medicine examinations in the United States). Some 40 of these concern ^{131}I, which can easily be injected in therapeutic quantity [N13]. About 95% of all diagnostic misadministrations involve the correct prescribed activity but the wrong radiopharmaceutical or the wrong patient.

295. While various accidents in teletherapy have caused lethal damage, the serious underexposure of cancer patients may also well have led to fatal results [S51]. It is very difficult to assess the frequency of these accidents. Apart from the general problem of underreporting, these particular accidents are so rare that it is a problem to establish a baseline population or time period. Arias [A14] discusses three teletherapy accidents: Texas, United States, 1986, where two patients died of overexposures from a linear accelerator; Maryland, United States, 1987-1988, where 33 patients were overexposed by up to 75%; Zaragoza, Spain, 1990, where 27 patients 14 of whom died, were overexposed from a linear accelerator. Distributing these 62 patients over the combined population of Spain and the United States and, rather arbitrarily, over 10 years, there would be some 0.00002 victims annually per 1,000 population, or about 10 per million therapy procedures. A separate kind of accident can occur if a disused teletherapy source is removed from the hospital and the public is exposed. A well-known example, the Goiania accident, is discussed in Annex B, "Exposures from man-made sources of radiation".

296. The European Federation of Medical Physicists has initiated a scheme to share information about accidents to patients. So far, only radiotherapy accidents have been reported. Reports obtained to date from Czechoslovakia, the Federal Republic of Germany, Norway, Poland, Russia, Spain, Turkey and the United Kingdom indicate that 1,344 patients in these countries were exposed to higher than prescribed doses and 989 patients to lower than prescribed doses between 1982 and 1991 [H19]. These 134.4 patients annually would correspond to some 0.0003 victims per 1,000 population (the number is of course higher than that given in the preceding paragraph, which deals exclusively with grave accidents).

297. A total of 91 incidents concerning ionizing radiation were reported in the Federal Republic of Germany in 1990 [B7]. Of these, 21 had some connection to medical uses of radiation. Radiopharmaceuticals for diagnostic purposes were lost or stolen in eight cases. There were various failures of remote afterloading equipment for brachytherapy in nine cases, failure of linear accelerators in two cases, failure of one gamma teletherapy device and leakage of faeces contaminated with 131I from the drain of a therapy ward in one case. There were minor exposures of staff in five of the afterloading events. No exposure of patients took place in any of the 21 events.

CONCLUSIONS

298. The use of ionizing radiation in medical diagnostic and therapeutic examinations and treatments convey radiation doses to the individuals involved along with direct benefits in health care. Because of widespread usage of radiation and radioactive materials in medical procedures, the collective dose to the world population is significant. With additional information available on radiation exposures of patients, particularly that received in response to the UNSCEAR Survey of Medical Radiation Usage and

Exposures, improved estimates of worldwide exposures can be made.

299. The Committee has previously extrapolated available data on medical radiation usage to the entire world on the basis of the number of physicians per 1,000 population, a statistic that is available for all countries. This procedure has been maintained for the analysis of this Annex. Four levels of health care are defined to characterize medical radiation usage. Relatively complete data are available on examination and treatment frequencies for countries of health-care levels I and II. At health-care levels III and, in particular, IV, information is still insufficient in many respects, although the contribution to the worldwide collective dose from these countries is small.

300. There are indications that exposures of populations from the diagnostic and therapeutic uses of ionizing radiation are increasing worldwide. Much of this increase can be justified on clinical grounds, particularly in developing countries, where medical services are obviously not yet sufficiently available. The general trends observed with time and between levels of health care cannot be used to anticipate particular conditions in individual countries. Circumstances vary widely, and national trends may differ greatly from the average trends. Nevertheless, the averages for several countries of each level of health care and for five-year time periods should be reasonably representative, i.e. the conclusions drawn here about worldwide exposures should be generally valid.

301. For countries of health-care level I, the population-weighted estimate of the frequency of diagnostic medical x-ray examinations (890 per 1,000 population) is slightly higher than the estimate in the UNSCEAR 1988 Report (800 per 1,000 population), although it seems unlikely that the difference would be statistically significant. Thus, at health-care level I, the total frequency of all x-ray examination was relatively constant during the 1980s. Reduced rates of increase or, in a few countries, decreases are due to the introduction of alternative methods, such as ultrasound and endoscopy. For countries of health-care levels II-IV, examination frequencies appear to be increasing, as expected on the basis of needs for the services and on demographic trends.

302. The estimated per caput effective dose equivalent from x-ray examinations at health-care level I is 1.0 mSv, unchanged from the estimate in the UNSCEAR 1988 Report [U1]. Some examinations with higher doses, such as computed tomography, are becoming more frequent. At the same time, however, better equipment and techniques are allowing doses in other examinations to be reduced. From the wider database available, the per caput effective dose equivalents at levels II and III-IV are estimated to be 0.1 and 0.04 mSv (previously 0.2, 0.07 and 0.03 mSv at levels II-IV, respectively [U1]). The use of fluoroscopy for chest examinations has been clarified for China (level II), but the prevalence of this procedure, which gives higher doses, cannot be certain for other countries at health-care levels II-IV.

303. The estimated effective dose equivalent from diagnostic nuclear medicine examinations increased in countries of health-care level I (0.09 mSv compared with 0.05 mSv previously [U1]) and also in countries of health-care levels II-IV (0.008 mSv compared with less than 0.004 mSv previously [U1]). The estimate for developing countries is higher, since it has become clear that the main radionuclides being used there are long-lived ones. However, the radiological impact of diagnostic nuclear medicine remains small in comparison with that of diagnostic x-ray examinations.

304. For tele- and brachytherapy, the treatment frequencies reported in the UNSCEAR Survey of Medical Radiation Usage and Exposures are lower than those obtained in 1988. This is interpreted as sampling variation as the treatment frequencies are no doubt continuing to increase. The primary measure of the impact of therapy on the population used here is simply the number of patients treated. In addition, estimates of the effective dose and the collective effective dose are shown for illustrative purposes. Therapy with radiopharmaceuticals appears to be slightly less frequent than had previously been estimated [U1]. The frequencies of treatments worldwide are estimated and the effective doses calculated.

305. The estimated doses to the world population from all medical uses of radiation are summarized in Table 52. The per caput effective dose equivalent from diagnostic examinations ranges from 1.1 mSv at level I to 0.05 mSv at levels III-IV. The worldwide per caput effective dose equivalent is 0.3 mSv. From therapy treatments, the per caput effective dose equivalents computed from scattered radiation in non-target organs are estimated to be 0.7, 0.2, 0.03 and 0.02 at levels I-IV, respectively and 0.3 mSv worldwide. The collective effective dose equivalent from diagnostic examinations is estimated to be 1,800,000 man Sv, with nearly 90% from x-ray examinations and the remainder from nuclear medicine and dental examinations. The collective effective dose from therapeutic treatments is estimated to be 1,500,000 man Sv, but this is not strictly comparable to other doses.

306. Effective doses to patients from medical uses of radiation cannot, in general, be used directly in calculations to infer detriment. In Section I.B, various

problems with the estimation of detriment from doses to patients were mentioned. For therapeutic uses of radiation, an added difficulty is that much of the secondary effects are not cancer or hereditary disease but deterministic radiation harm.

307. Much, and optimally most, of the collective dose from medical uses of radiation is offset by direct benefits to the examined or treated patients. There are two basic ways to reduce the risks of radiation detriment to patients: (a) by reducing the collective dose by lowering the number of patients exposed to ionizing radiation or (b) by reducing the individual dose in particular procedures. The number of patients exposed can be lowered by using strict referral criteria. Guidelines on the selection of patients for various x-ray examinations have been given [R26, S2, U11, U12, U13, U14, U15]. Referral criteria that are particularly appropriate for radiology in developing countries are given by WHO [W23, W24, W25, W26]. The use of alternative methods, such as ultrasound and endoscopy, also reduces the number of exposed patients. The dose per procedure can be reduced if the procedure is optimized and if quality assurance programmes are set up to eliminate deviations from the optimum.

Table 1
Medical radiation facilities
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	Year	Population (thousands)	Number of radiologists	Diagnostic x-ray units		Teletherapy units			Nuclear medicine clinics
				Medical	Dental	X-ray	^{60}Co, ^{137}Cs	Accelerators	
Health-care level I									
Argentina	1985-1989	33000	2981	5705	18361	235	95	10	390
Australia	1970-1974	12550	420	2107					
	1985-1989	16260	1320	6000	7100	36	15	35	66
Austria	1977	7535							132
Belgium	1986-1990	9921	1021			21	39	20	107
Bulgaria	1980	8862							
Canada	1985-1989	25309	1900	23000	16500	130	31	58	265
Costa Rica	1989	2927					1		
Cuba	1988	10402	632	900			13	1	1
Czechoslovakia	1970-1974	10023	480	1800	2400				
	1981-1985	10320	892	2000	2600	88	46	7	39
	1986-1990	10350	932	2100	2700	78	52	11	43
Denmark	1986-1990	5100	250	1800	4500	10	2	22	30
Ecuador	1985-1989	10500	128	430	640	6	8	0	13
Finland	1970-1974	4610	220						36
	1980-1984	4820	380	2200	3200	31	7	11	51
	1985-1989	4930	400	2100	3900	24	3	21	52
France	1982	54219		13998					
	1987-1990	55632		19548	32438		316	147	548
German Dem. Rep.	1975-1978	16800	700						
	1985-1988	16600	1000	3300	3400	60	9	24	
Germany, Fed. Rep.	1980-1984	59200					196	111	
	1986-1990	62700	3100				185	129	
Greece	1980	9643							
Iceland	1987	245	24	65			1	1	
Ireland	1988	3538							
Italy	1985	57355		17400					
Japan	1970-1974	110044	8742	56607	31612	1113	359		548
	1980-1984	118693	11890	58962	34916		558	108	885
	1985-1989	122264	11754	61345	40005		440	441	1091
Kuwait	1970-1974	1310		172	40	3	2	0	
	1980-1984	1557	61	230	62	2	2	0	
	1985-1989	1856	105	288	95	2	2	1	
Libyan Arab Jamahiriya	1977	2598							
	1986-1990	4000		325			1		
Luxembourg	1988	371	22	144	155	3	1	0	3
Malta	1970-1974	320	4	10	1	2	0	0	
	1980-1984	325	6	16	2	1	2	0	
	1985-1989	344	8	25	3	1	1	0	
Netherlands	1980-1984	14300	650	3000	6000	150	6	35	70
	1985-1989	14600						38	

Table 1 (continued)

Country	Year	Population (thousands)	Number of radiologists	Diagnostic x-ray units		Teletherapy units			Nuclear medicine clinics
				Medical	Dental	X-ray	^{60}Co, ^{137}Cs	Accelerators	
New Zealand	1970-1974	2920	102	563	789	41	8	2	6
	1980-1984	3202	141	635	930	33	8	6	9
	1985-1989	3320	161	688	987	23	8	7	9
Norway	1970-1974	3900	200	2000	3000	180	1	3	15
	1980-1984	4100	320	2400	4200				36
	1985-1989	4200	350	2200	5000	50	2	13	39
Poland	1985-1989	37572	1500	6793	1289	92	30	21	
Portugal	1988	9778	323						
Romania	1980	22201	975	2746	1100	202	20	2	39
	1985-1989	23000	975	2746	1100	202	20	2	39
Singapore	1985-1989	2647	4	20	6				1
South Africa	1986	32500				13	25	10	
Spain	1985-1989	38558	1645	9000	18000				
Sweden	1970-1974	8129	542	2700	5500	31	23	12	
	1980-1984	8327	645	2400	12500	24	17	27	125
	1985-1989	8414	920	2000	12900	22	14	33	120
Switzerland	1972	6193	92	6000	4000		25	6	
	1982	6335	173	7500	5500	150	26	14	43
	1990	6509		8000	6000	120	19	20	43
USSR	1980	265542							
	1988	283682							
USSR, RSFSR	1976-1980	136528	15860	24760	2880				
	1981-1985	140228	16770	29550	3680				
	1986-1990	146237	17080	31550	4840				
United Kingdom	1981-1985	54600	1600	11000					288
United States	1970-1974	213669	12216	97788	110974	3441			
	1980-1984	234238	12595	129695	187772	3299			
	1985-1989	248630	12381	108903	142699	1324			
Uruguay	1978-1982	2908		33					
Venezuela	1978-1982	15024		150					
Yugoslavia	1970-1974	4776		318	99	7	2		5
	1980-1984	10788		568	239	6	6	1	22
	1985-1989	18681		1624	741	27	14	10	36
Health-care level II									
Algeria	1986-1989	22200				4	3	1	
Barbados	1980-1984	250				2	1	0	1
	1985-1989	250	5	20	1	2	1	0	1
Bolivia	1978-1982	4613		171					
Brazil	1982	127100		13400		230	50	38	68
	1990	150238	12432	10500		1399	99	133	147
Chile	1988	12748					8	2	
China	1970-1974	27056	734	315	315	4	1	0	4
	1981-1985	1010000	81500	68300				37	250
	1986-1990	1080000	120000	120000			600	80	264
China, Taiwan Prov.	1990	20300							
Colombia	1978-1982	25892		1811					
Dominican Republic	1981	5648		71					

Table 1 (continued)

Country	Year	Population (thousands)	Number of radiologists	Diagnostic x-ray units		Teletherapy units			Nuclear medicine clinics
				Medical	Dental	X-ray	^{60}Co, ^{137}Cs	Accelerators	
Ecuador	1970-1974 1980-1984	6522 8129	30 83	155 305	97 350	2 6	3 7	0 0	5 10
Guatemala	1990	8660				2	4		
Honduras	1990	5049	10	51					
India	1985-1989	776000	4000	45000			151	11	94
Iran (Islamic Rep. of)	1980	38345							
Iraq	1985-1989	17250	1	3			3	3	1
Jamaica	1970-1974 1985-1989	1900 2409							
Mauritius	1986-1989	1040					1		
Mexico	1986-1990	82734					78		102
Nicaragua	1981 1990	2844 3820	6	35					
Paraguay	1978-1982	3168		77					
Peru	1980-1984 1985-1989	18000 20000	150	1390 2400	1654 1836	20 20	8 11	1 1	20 30
Tunisia	1985-1989	7500	88	740	451	0	3	1	3
Turkey	1986-1990	57000	1077	3500	5000	24	30	10	42
Health-care level III									
Belize	1990	183							
Cape Verde	1985-1989	330	1	1	1	0	0	0	0
Congo	1986-1989	1700				1	1		
Djibouti	1985-1989	383							
Dominica	1990	71	1	4	5				
Egypt	1988	51897	320	72	60	2	22	9	3
Gabon	1986-1989	1000					1		
India	1970-1974	560000					62		34
Kenya	1988	23883				1	2		1
Liberia	1980-1984 1986-1989	1650 2200		24		1	1		
Morocco	1986-1989	24300				2	3		
Myanmar	1979-1980 1981-1985	35712 39215	35 43	328	15	3	6	1	1
Nigeria	1977-1983 1986-1989	80556 91200		900		3	2		
Philippines	1985-1989	54000	441	1538	25				
Saint Lucia	1990	150	1	9					
Sri Lanka	1979	14647							
Sudan	1984 1986-1990	21215 26000	38	141 210	30	1	2	1	1

Table 1 (continued)

Country	Year	Population (thousands)	Number of radiologists	Diagnostic x-ray units		Teletherapy units			Nuclear medicine clinics
				Medical	Dental	X-ray	^{60}Co, ^{137}Cs	Accelerators	
Thailand	1976-1980 1981-1985 1986-1990	45156 49723 54799	140 290 440	987 1419 1881	159 239 493	50 35 29	10 20 30	0 1 5	
Vanuatu	1985-1989	137	0	6	3	0	0	0	0
Zimbabwe	1986-1989	8600				3	3	1	1
Health-care level IV									
Cameroon	1986-1989	9700				1	3		
Côte d'Ivoire	1977	7088							
Ethiopia	1981-1985 1986-1990	46000 50000							1 1
Ghana	1977	10808		108					
Madagascar	1986-1989	10000					1		
Mozambique	1986-1989	14550					1		
Rwanda	1970-1974 1988-1990	4040 6950	0 2	26 30	2 3				
Senegal	1986-1989	6700				1	1		
Uganda	1986-1989	16600				1			
United Rep. of Tanzania	1986-1989	21700	7				2		
Zaire	1986-1989	32500					1		

The entries in this Table are qualified as follows:

Algeria: Data from IAEA (International Atomic Energy Agency) and from [U1, U17].

Argentina: The number of radiologists excludes 2,149 non-radiologist physicians licensed to use x rays.

Austria: The value given for nuclear medicine clinics is the estimated number of scanners/cameras.

Barbados: Data also from PAHO (Pan American Health Organization).

Brazil: Survey response published as [A11]. Data also from [C14, D4, U1]. Number of radiologists includes 200 radiotherapists and 232 nuclear medicine specialists. Number of nuclear medicine clinics for 1982 is estimated from number of scanners/cameras (207); number for 1990 includes 450 scanners/cameras; 401 further units do *in vitro* work only. Number of ^{60}Co, ^{137}Cs teletherapy units exclude 7 non-operative units; number for accelerators excludes 10 non-operative units.

Cameroon: Data from IAEA (International Atomic Energy Agency) and from [U1, U17].

Canada: The numbers given for ^{60}Co, ^{137}Cs teletherapy units represents licensees, some probably with more than one unit.

Chile: Data from PAHO and from [U17].

Congo: Data from IAEA and from [U1, U17].

Cuba: Data from PAHO and from [U17].

Dominica: Data from PAHO.

Egypt: Numbers of radiologists, diagnostic x-ray units and clinics estimated from Kasr-El Eini Centre, which serves ca. 25% of patients using radiation. Data on therapy units from IAEA.

France: Data from [M40, S17]. The numbers given for diagnostic x-ray units exclude 339 military medical and dental units.

Gabon: Data from IAEA (International Atomic Energy Agency) and from [U1, U17].

German Dem. Rep.: 40% of all x-ray examinations are performed by non-radiologist physicians. The 3300 x-ray units (generators) in 1985-1988 correspond to 5100 tubes.

Germany: 55% of all x-ray examinations are performed by non-radiologist physicians. 75% of diagnostic nuclear medicine is performed outside specialized clinics.

Honduras: Data from PAHO (Pan American Health Organization).

Iceland: Data also from [L16, S14].

India: The number of radiologists excluded 31,000 non-specialist physicians using x rays.

Iraq: Data also from [U1, U17]. Other entries than population size refer to the Institute of Radiology and Nuclear Medicine, Baghdad, which serves an unknown fraction of the population.

Kenya: Data from IAEA and from [U1, U17].

Liberia: Data from IAEA and from [U1, U17].

Libyan Arab Jamahiriya: Data from IAEA and from [U1, U17].

Madagascar: Data from IAEA and from [U1, U17].

Mauritius: Data from [D16, U1, U17].

Morocco: Data from IAEA and from [U1, U17].

Mozambique: Data from [D16, U1, U17].

Table 1 (continued)

New Zealand: Number of radiologists includes 9, 22 and 28 radiotherapists and 4, 7 and 7 nuclear medicine specialists in 1970-1974, 1980-1984 and 1985-1989, respectively. Number of medical x-ray units includes 9, 5 and 0 mass miniature chest units and 70, 80 and 85 chiropractice units in 1970-1974, 1980-1984 and 1985-1989, respectively.
Nicaragua: Data from PAHO.
Nigeria: Data from IAEA and from [U1, U17].
Philippines: Number given for diagnostic medical and dental x-ray units represent facilities.
Portugal: Data from [C15].
Saint Lucia: Data from PAHO.
Senegal: Data from IAEA and from [U1, U17].
Singapore: Population size from [U17]. Other entries refer to the National University Hospital, which serves an unknown fraction of the population.
South Africa: Data from IAEA and from [U1, U17].
Spain: The number given for diagnostic x-ray units for medical examinations excludes units in which fewer than 1,000 examinations per year are performed.
Sweden: Data also from [S21]. Number of radiologists includes 82, 120 and 155 radiotherapists in 1970-1974, 1980-1984 and 1985-1989, respectively. X-ray teletherapy units excludes Bucky units.
Switzerland: Besides radiologists, all generalists, surgeons, internists, paediatricians (sum 1982: 5,970) and dentists (number 1982: 2,728) are licensed to use x rays.
Tunisia: Data also from [G16]. Number of radiologists includes foreign doctors; of the 76 Tunisian doctors, 4 were radiotherapists, 3 nuclear medicine specialists. Accelerator not taken into use (1990).
Uganda: Data from [D16, U1, U17].
USSR: Data also from [U17].
USSR, RSFSR: Data for one republic, the Russian Soviet Federative Socialist Republic. Radiologists include diagnostic x-ray specialists only.
United Rep. of Tanzania: Data from IAEA and from [B18, U1, U17].
Yugoslavia: 1970-1974 data include Bosnia and Herzegovina and Slovenia; in 1980-1984, data include Bosnia and Herzegovina, Croatia and Slovenia; 1985-1989 data include all of Yugoslavia except for Montenegro, Kosovo and Vojvodina.
Zimbabwe: Data from IAEA and from [D16, U1, U17].

Table 2
Average number of medical radiation facilities per 1,000 population by health-care level
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

Medical radiation staff / facilities	*Year*	*Health-care level*			
		I	*II*	*III*	*IV*
Radiologists	1970-1974	0.062	0.023		
	1980-1984	0.076	0.064	0.004	
	1985-1990	0.072	0.041	0.006	0.0003
Medical x-ray units	1970-1974	0.45	0.014		0.0006
	1980-1984	0.38	0.071	0.016	0.010
	1985-1990	0.35	0.086	0.018	0.004
Dental x-ray units	1970-1974	0.44	0.012		0.00004
	1980-1984	0.46	0.077	0.005	
	1985-1990	0.38	0.086	0.003	0.0004
Therapy x-ray units	1970-1974	0.014	0.0002		
	1980-1984	0.013	0.0017	0.0007	
	1985-1990	0.0048	0.0050	0.0001	0.0001
Cobalt-60 therapy units	1970-1974	0.0031	0.0001	0.0001	
	1980-1984	0.0034	0.0004	0.0004	
	1985-1990	0.0026	0.0004	0.0002	0.00009
Accelerators	1970-1974	0.0010			
	1980-1984	0.0012	0.0001	0.00002	
	1985-1990	0.0020	0.0001	0.00009	
Nuclear medicine clinics	1970-1974	0.0048	0.0003	0.0001	
	1980-1984	0.0066	0.0003		
	1985-1990	0.0078	0.0003	0.00005	0.00002

Table 3
Annual medical radiation examinations and treatments
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	Year	Diagnostic examinations (thousands)			Therapeutic treatments (thousands)			
		Medical x rays	Dental x rays	Radio-isotopes	X-ray therapy	Tele-therapy	Brachy-therapy	Radio-isotopes
Health-care level I								
Argentina	1985-1989			415		29.0	6.0	5.3
Australia	1970-1974	4634	1000	52	49.9 [a]			
	1985-1989	9149		112	5.4	4.4	17.5	2.4
Belgium	1986-1990	12772	2855	365				3.0
Canada	1970-1974	18880 [b]			432 [a]			
	1985-1986	26563 [b]			519 [a]			
Cuba	1988-1990	6396		10	2.3 [a]		0.5	0.4
Czechoslovakia	1976-1980	11112	720	660	0.9	2.9	0.2	4.9
	1981-1985	10882	883	943	0.6	3.6	0.2	6.2
	1986-1990	9498	884	1183	0.3	3.7	0.3	9.4
Denmark	1985-1989	2600	2400	72	7.0	7.0	0.6	0.1
Ecuador	1985-1989	530	65.4	8.5	0.5	0.9	0.2	0.07
Finland [R16]	1977	5100	955	59				1.5
	1984	4600		85				1.8
	1986-1987	4300	1100	100	0.7 [a]			
France [L20, M40]	1982	45350						
	1988-1990	55060		387				
German Dem. Rep.	1974-1978	19000	2500	115				
	1981-1988	19000	2500	160				
Germany, Fed. Rep. of	1976-1980			1899				
	1981-1990	71600	16600	2450				
Italy	1974			400				
	1983-1985	42700		579				
	1989			551				
Japan	1970-1974	73064	91500	168	132	1656	15.5	4.4
	1980-1984	96300	99040	541	13	1762	13.6	3.0
	1985-1989	141500	95768	989				
Kuwait	1985-1989	1137	190	24.3	0.3	0.9	0.02	0.03
Luxembourg	1988	294	69.1	9.2	3.4	4.0	0.03	0.07
Malta	1970-1974	33.2	0.9		0.1	0.2	0.01	
	1980-1984	84.7	2.3		0.1	0.4	0.01	
	1985-1989	110	3.2		0.1	0.5	0.01	0.03
Netherlands	1980-1984	7900	5700	200	2.5	23	1.1	1.5
New Zealand	1970-1974	1790	~1000	18.9	3.9	3.2	0.3	0.5
	1980-1984	2263		25.9	1.5	6.0	0.3	0.6
	1985-1989	2114	913	24.5	1.1	8.6	0.2	0.5
Norway	1970-1974	1600	2500	16.0	1.0			0.06
	1980-1984	2200	3300	36.0				0.3
	1985-1989	2200	3500	39.0	0.04			0.6
Poland	1985-1989	24949	2300					
Portugal [C15, S52]	1988-1989	5900						
Romania	1980	13205	706	66.9	33.9	3.8	0.1	
	1985-1989				9.1	4.8	1.5	1.2
	1990	10688	704	55.8	111	46		
Spain	1986-1990	22290	9000					

Table 3 (continued)

Country	Year	Diagnostic examinations (thousands)			Therapeutic treatments (thousands)			
		Medical x rays	Dental x rays	Radio-isotopes	X-ray therapy	Tele-therapy	Brachy-therapy	Radio-isotopes
Sweden	1970-1974 1980-1984 1985-1989	4800 4700 4400	3600 7000 7000	77.0 128 122	6.8 2.2 1.6	9.2 11.4 13.3	2.0 1.6 1.5	2.7 3.3 3.6
Switzerland	1972-1976 1982	6446 6582	1834 2059	284				9.8
USSR	1981	254400						
USSR, RSFSR	1976-1985 1986-1990	136800 144250	8570 11740					
United Kingdom	1976-1980 1981-1989	22700 25230	6055 9000	369		150		11
United States	1985-1989	200000	100000	6783				
Yugoslavia	1985-1989	3350	83000	140	15.1	50.2	2.0	2.4
Health-care level II								
Barbados	1980-1984 1985-1989	54.2		0.2 0.3	0.1 0.1	0.3 0.3	0.04 0.05	0.02 0.04
Brazil [A11,C14,U1]	1982 1990	22750 15037		256				
Chile	1982	1911						
China [Z6]	1985	152087	2233	615		96		44
Ecuador	1970-1974 1980-1984	167 385	10.0 35.7	3.1 7.4	0.3 0.5	0.2 0.5	0.04 0.09	0.05 0.05
Honduras	1990	106						
India	1985-1989	81480		169		106	20.6	2.8
Iran (Islamic Rep.of) [U1]	1981	7221						
Nicaragua	1990	191						
Peru	1985-1989	300		4.8	0.3	2.7	0.9	0.3
Tunisia	1985-1989		100	7.0		6.5	3.0	0.3
Turkey	1981-1985 1986-1990	16663 29840		174		50 33		0.5
Health-care level III								
Belize	1990	15.1						
Cape Verde	1985-1989	22.7		0	0	0	0	0
Dominica	1990	12.9						
Egypt	1976-1980 1981-1985 1986-1990	11.0	<0.1	2.6 9.4 25	2.2 [c]		0.02	2.6 2.8 3.2
India	1970-1974	19600				40.9	11.4	
Myanmar	1986-1990	397	64					
Nigeria [U1]	1977	2014		<0.01				
Philippines	1985-1989	6148	0.6					
Saint Lucia	1990	19.0						
Sudan	1976-1980 1981-1985 1986-1990	1380		2.1 5.7 7.1	0.2	1.7	0.04	0.02 0.06 0.1

Table 3 (continued)

Country	Year	Diagnostic examinations (thousands)			Therapeutic treatments (thousands)			
		Medical x rays	Dental x rays	Radio-isotopes	X-ray therapy	Tele-therapy	Brachy-therapy	Radio-isotopes
Thailand	1976-1980	2276	64	11				0.008
	1981-1985	3749	115	9.1			0.04	0.011
	1986-1990	4318	115	14	0.09 [a]		0.04	0.013
Vanuatu	1985-1989	11.1		0	0	0	0	0
Health-care level IV								
Ethiopia	1981-1985			0.6				
	1986-1990			4.8				
Rwanda	1970-1974	28.0 [b]						
	1988-1989	61.1 [b]						

The entries in this Table are qualified as follows:

Barbados: The value given for medical x-ray examinations is estimated from the number examined in the public sector (35,200) and the number of pieces of equipment in the public sector (13 of 20 in Barbados).

Belize: Data from PAHO. Number of patients: 13,036.

Canada: Therapy numbers refer to treatments, not patients.

Chile: Data also from [U1].

Cuba: Data from PAHO (Pan American Health Organization). X-ray examinations refer to 5.7 million patients.

Czechoslovakia: The values given for x-ray therapy, teletherapy and brachytherapy for the years 1976-1980, 1981-1985 and 1986-1990 exclude treatment of benign conditions (39,000 patients annually 1976-1985, 24,000 patients annually 1986-1991).

Denmark: The value given for medical x-ray examinations includes 7,000 interventional radiology.

Dominica: Data from PAHO. Number of patients: 10,816.

Ecuador: The value given for medical x-ray examinations for the years 1980-1984 includes 19 interventional radiology; for the years 1985-1989 27,000 interventional radiology.

Finland: The value given for dental x rays includes 400,000 pantomographic examinations; the value of 0.7 given for x-ray therapy, tele- and brachytherapy represents primary stage radiotherapy only; the value of 2.2 represents total number of patients.

France: The value given for radioisotope examinations is estimated from Hôpital Henri Mondor, which serves about 2% of the population of France.

German Dem. Rep.: Total number of therapeutic treatments in 1985 = 40,000 of which 20,000 for cancer.

Germany, Fed.Rep.: The number of diagnostic examinations with radioisotopes is estimated from data covering 7% of the population for the years 1976-1980 and from data covering 21% of the population for the years 1981-1985 and 1986-1990. Total number of therapeutic treatments in East Germany 1985 = 40,000 of which 20,000 for cancer.

Honduras: Data from PAHO.

Italy: Data also from [U1].

Japan: Dental examinations include 1,650,000, 9,640,000 and 11,229,000 pantomographic examinations in the years 1970-1974, 1980-1984 and 1985-1989. Numbers for x-ray therapy and teletherapy refer to treatments, not patients.

Kuwait: The value for medical x-ray examinations includes 3,000 interventional radiology examinations.

Luxembourg: Numbers for x-ray therapy and teletherapy refer to treatments, not patients.

Malta: The value for medical x-ray examinations in the years 1985-1989 includes 150 interventional radiology examinations.

New Zealand: The value for medical x-ray examinations includes 359, 129 and 67 mass miniature chest examinations and 30, 41 and 47 chiropractic examinations in the years 1970-1974, 1980-1984 and 1985-1989, respectively.

Nicaragua: Data from PAHO.

Norway: The values given for x-ray therapy are from one hospital only, to indicate trend.

Romania: The values given for medical and dental x rays as well as for x-ray therapy and teletherapy are estimated from data comprising 60%-65% of the population. Numbers for 1990 x-ray therapy and teletherapy refer to treatments, not patients.

Spain: The value given for medical x-rays excludes military, legal and pre-employment examinations.

Saint Lucia: Data from PAHO. Number of patients: 16,300.

Sweden: The value for medical x-ray examinations includes 6,000 interventional radiology examinations.

Switzerland: The values given for radioisotope examinations and treatments are estimated from data covering 4% of the population.

Turkey: The values given for diagnostic examinations and therapeutic treatments with radioisotopes are estimated from data covering 1% of the population; the values for therapeutic treatments from data covering 2% of the population.

USSR: Data also from [U1].

Yugoslavia: Value for medical x-ray examinations includes 1,700 interventional radiology. Values given for therapeutic treatments are for Bosnia and Herzegovina, Croatia, Slovenia and Serbia, excluding Kosovo and Vojvodina (73% of the population of Yugoslavia).

[a] Value is for all therapeutic treatments.

[b] Value is for both medical and dental x rays.

Table 4
Medical radiation services worldwide, 1985-1990
Normalized quantities determined from UNSCEAR Survey of Medical Radiation Usage and Exposures

Quantity	*Level of health care*				*World*
	I	*II*	*III*	*IV*	
Normalized values					
Physicians per 1,000 population	2.6	0.55	0.18	0.053	0.98
Radiologists per physician	0.028	0.075	0.032	0.006	0.04
Radiologists per 1,000 population	0.072	0.041	0.006	0.0003	0.04
X-ray units per 1,000 population	0.35	0.086	0.018	0.0042	0.14
X-ray units per radiologist	4.9	2.1	3.1	14	3.4
X-ray examinations per x-ray unit [a]	2400	1600	3900	2000	2100
X-ray examinations per 1,000 population [a]	860	140	70	9	300
Nuclear medicine examinations per 1,000 population [b]	16	0.5	0.3	0.1	4.5
Tele- and brachytherapy patients per million population [c]	2.4	0.6	0.1	0.05	0.9
Radiopharmaceuticals therapy patients per million population [d]	0.4	0.02	0.02		<0.13
Absolute values [e]					
Population (millions)	1350	2630	850	460	5290
Physicians (thousands)	3600	1400	150	24	5200
Radiologists (thousands)	97	108	5.2	0.13	210
X-ray units (thousands)	470	230	15	1.9	720
X-ray examinations (millions) [a]	1160	360	60	4.0	1600
Nuclear medicine examinations (millions) [b]	22	1.4	0.3	0.05	24
Tele- and brachytherapy patients (thousands) [c]	3200	1600	85	23	4900
Radiopharmaceuticals therapy patients (thousands) [d]	600	65	21		~700

[a] Diagnostic medical x-ray examinations (does not include dental x-ray examinations); number of countries and population in sample: level I: 25 (935 million = 68% of entire level I population); level II: 8 (2,062 million = 78%); level III: 9 (175 million = 21%); level IV: 1 (7.1 million = 1.5%).

[b] Number of countries and population in sample: level I: 19 (634 million = 47% of entire population of level I countries); level II: 10 (2065 million = 79%); level III: 4 (171 million = 20%); level IV: 1 (50 million = 11%).

[c] Because of inconsistencies in data reported in Table 3 (i.e. number of separate treatments or of treated patients), the data of the UNSCEAR 1988 Report [U1] have been used.

[d] Number of countries and population in sample: level I: 16 (181 million = 13% of entire level population); level II: 6 (1,940 million = 74%); level III: 5 (133 million = 16%). It is assumed that the unknown frequency in level IV countries is lower than the frequency in level III countries.

[e] Absolute values refer to 1990.

Table 5
Comparison of effective dose and effective dose equivalent

Examination		*Ratio of effective dose to effective dose equivalent (EIH_E) as reported by*					
		[H36]	*[L22]*	*[S44]*	*[Z7]*	*[L2]*	*[W28]*
Diagnostic x-ray examinations							
Chest	AP	0.79-0.90			0.51		
	PA	0.85-0.92	0.99	0.83	0.75		0.80
	LAT	0.65-0.76	0.76	0.83			
Skull	AP	0.38-0.43	0.67				
	PA	0.28-0.31	0.59				0.62
	LAT	0.24-0.27	0.55				
Ribs				1.27			
Thoracic spine	AP			0.86-1.15			1.11
	LAT			0.85			
Lumbar spine	AP			1.36-1.40			1.01
	LAT			0.77			
Pelvis		1.00-1.20	0.80				0.86
Abdomen	AP	1.80-2.10	1.00	1.43			
	PA	0.88-1.10					1.00
	LAT			0.94			
G.I. tract	Upper						1.20
	Lower						1.14
Urography (I.V.)							1.05
Mammography						0.33	
CT	Head						0.52
	Chest						0.91
	Abdomen						0.81
	Pelvis						0.77

Examination	*Radiopharmaceutical*	*Ratio of effective dose to effective dose equivalent (EIH_E) as reported by*			
		[H36]	*[G21]*	*[G22]*	*[J8]*
Nuclear medicine examinations					
Brain	Tc-99m gluconate	0.62			0.61
Cerebral blood flow	Tc-99m HMPAO		0.91		0.73
	Tc-99m ECD		0.78		
	Tc-99m MRP 20		1.01		
Bone	Tc-99m pyrophosphate	0.74			0.74
Liver/spleen	Tc-99m sulphur colloid	0.56			0.65
Biliary	Tc-99m HIDA	0.63			0.76
Blood pool, multigated	Tc-99m erythrocytes	0.72			0.94
Myocardial	Tc-99m pyrophosphate	0.74			0.74
	Tc-99m MIBI			0.73	
	Tc-99m teboroxime			0.83	
	Tl-201 chloride	0.83			0.81
Lung	Tc-99m MAA	1.0			0.92
Kidney	Tc-99m gluconate	0.62			0.61
Inflammation	Ga-67 citrate	0.83			0.86
Thyroid scan	Tc-99m pertechnetate	1.1			1.1
Thyroid uptake/25%	I-131 sodium iodide	1.6			1.7
	I-123 sodium iodide	1.6			1.6

Table 6
Total annual number of diagnostic x-ray examinations per 1,000 population [a]
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

Country	*1970-1979*	*1980-1984*	*1985-1990*	*Country*	*1970-1979*	*1980-1984*	*1985-1990*
Health-care level I							
Australia	490		560	Malta	100		320
Belgium			1290	Netherlands	570	550	530
Canada	860	1020	1050	New Zealand	610	710	640
Cuba		140	620	Norway		640	620
Czechoslovakia	1110	1050	920	Poland			660
Denmark			510	Portugal			700
Finland	1080		870	Romania	790	600	470
France		840	990	Spain			570
German Dem. Rep.	1100	1100	1100	Sweden	590		520
Germany, Fed. Rep. of	860		1030	Switzerland	1040	1040	
Italy		740		USSR, RSFSR	950	1020	990
Japan	830		1160	United Kingdom	420	460	
Kuwait			720	United States		790	800
Luxembourg			810				
				Average	820	810	890
Health-care level II							
Barbados			160	Ecuador	26		53
Brazil		180	93	India			110
Chile		170		Iran (Islamic Rep. of)		180	
China		110	150	Mexico		70	
Colombia		210		Nicaragua		57	13
Costa Rica		270		Peru			15
Dominican Republic		20		Turkey			524
				Average	26	140	120
Health-care level III							
Belize			83	Philippines			110
Cape Verde			69	Saint Lucia			130
Dominica			180	Sri Lanka [U1]	21		
Ghana [U1]	22			Sudan			53
India [U1]	23			Thailand	50	75	79
Liberia [U1]	80			Vanuatu			100
Myanmar			10				
				Average	23	75	67
Health-care level IV							
Cote d'Ivoire [U1]	40			Nigeria	25		
Kenya [U1]	36			Rwanda	8.0		8.8
				Average	27		8.8

[a] Dental x-ray examinations not included.

Table 7
Average annual number of diagnostic x-ray examinations per 1,000 population [a]
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	Year	Chest examinations			Extremities	Spine	Pelvis	Skull	Abdomen	GI tract		Cholecystography	Urography	Angiography	Mammography	CT	Other (except dental)
		Radiography	Mass miniature	Fluoroscopy						Upper	Lower						
Health-care level I																	
Australia	1970-1974		150	120	79	24	16	41	14	19	6.8	9.4	12	1.6	0.30		
	1985-1990	120		0.14	130	39	30	32	18	23	13	4.7	18	10	12	30	78
Belgium	1985-1990	240			250	84	84	91	44	21	12	3.8	13	8.5	32	50	360
Canada	1980-1984	330			260	75	38			88	44		32		2.7		150
	1985-1990	310			240	91	47	60		72	36		26		6.0	22	130
Czechoslovakia	1975-1979	250	420		79	24	15	51	11	37	9.0	17	13	3.2			174
	1980-1984	200	310		86	20	22	40	10	35	8	14	11	3.5		2.8	293
	1985-1990	200	110		92	17	26	29	10	24	5.8	7.1	9.1	3.6	2.8	4.3	375
Finland	1975-1979	260	330		190	19	32	35	18	22	17	9.0	9.0	6.4	2.6	0.7	132
	1985-1990	320			220	24		18		8.4	11	1.4	6.6	5.2	27	14	215
France	1980-1984	290			190	87	62	74	29	21	15	12	36	9.6	4.8		13
	1985-1990	340			210	92	59	75	37	10	13	3.0	16	8.6	34		99
German Dem. Rep.	1975-1985	180	270	<4	710	27	21	-	-	30	4.2	22	21	1.8	2.4	0.7	50
Germany, Fed. Rep.	1975-1979	330			170	58	49	108	4.1	45	23		42		28		
	1985-1990	210			270	130	88	73	35	29	14	13	32	18	54	35	24
Italy	1980-1984	240	81		140	76	40	42	22	31	15	13	13		6.7	10.4	14
Japan	1970-1974	280	300		53	1.1	23	27	22	100	6.2		6.1				
	1975-1979	340	130		70	51	20	34	34	124	8.1		14	0.49	1.2	13	
	1985-1990	440	95		99	66	33	56	82	156	15		13	2.7	1.1	97	
Kuwait	1985-1990	220	51	62	150	60	13	65	58	6.9	2.1	1.5	12	1.7	1.0	9.9	3.4
Luxembourg	1985-1990	99		23	160	160	110	143	8.6	17	15	1.3	20	11	32	25	
Malta	1970-1974	47			27	4.6	2.3	6.0	2.5	6.2	1.1	1.5	2.9				2.9
	1985-1990	110			71	18	8.9	11	20	7.6	3.1	1.0	7.6	1.0	0.9	6.4	58
Netherlands	1970-1974	100	190	8	88	23	18	34	8.7	29	11	15	15	0.5	3.0		27
	1980-1984	160	14	13	160	29	27	41	12	19	10	4.8	14	4.8	12.4	9.7	31
	1985-1990	160	0	1.1	170	30	29	36	18	14	8.0	2.6	11	3.3	13	14	26

Table 7 (continued)

Country	Year	Chest examinations			Extremities	Spine	Pelvis	Skull	Abdomen	GI tract		Cholecystography	Urography	Angiography	Mammography	CT	Other (except dental)
		Radiography	Mass miniature	Fluoroscopy						Upper	Lower						
New Zealand	1980-1984	130	40	0	120	40	30	25	15			5.0	35				270
Norway	1980-1984	120	84	5.2	150	38	46	6.3	8.0	22	111	3.0	20	0.0	2.5	10.0	16
	1985-1990	140	44	26	150	35	55	4.0	7.5	13	9.2	0.40	12	5.8	18	24	80
Poland	1985-1990	130	160	5.8	79	67	12	43	33	35	19	11	9.2	0	0.37	1.0	61
Romania	1970-1974		410	242	36	27	9.3	24	2.0	11	4.8	12	5.3				
	1980-1984	20	210	191	36	8.1	9.2	12	4.9	57	16	5.0	3.1				20
	1985-1990	24	140	115	44	10	13	21	6.6	51	12	4	8.2	1.7	1.7	0.46	16
Spain	1985-1990	150			88	120	18	18	52	29	15		14		21	13	41
Sweden	1970-1974	120		111	65	22	35	44	12	30	16	18	23	1.2	3.1		94
	1985-1990	120			55	21	43	15	7.7	12	13	5	14	0.24	46	11	158
Switzerland	1970-1974	180	160	226	210	42	36	69	12	46	13	28	30				
	1980-1984	340	150	64	210	41	57	77	21	25	13	19	25				
USSR, RSFSR	1975-1979	51	510	165	84	8.1	9.1	24	2.3	40	4.9	5.5	4.4		1.0		46
	1980-1984	60	590	110	87	8.8	11	27	3.6	44	5.4	8.6	7.5		1.8		57
	1985-1990	69	570	45	96	9.2	11	26	5.5	40	5.5	16	13		1.3		79
United Kingdom	1975-1979	130	26		110	18	32	31	17	10	5.9	6.1	6.9	3.6	0.9	1.3	27
	1980-1984	150	12		110	20	36	35	19	12	6.8	5.9	10	2.5	4.0	4.7	38
United States	1980-1984	280			200	93	21	36	35	33	22	15	18		5.7	14.5	19
Health-care level II																	
Barbados	1985-1990	30			47	18	9.5	11	23	4.4	2.0	0.31	7.7	0.12	1.2	1.4	
Brazil	1985-1990	25			29	9.3		8.9		4.2	2.0		3.7				
China	1980-1984	5.9	0	74	7.7	1.7	0.4	1.5	14	2.217	0.453	0.292	0.057		0.08		6.2
	1985-1990	12	26	64	11	1.9	1.3	0	11	4.6	1.4	0.40	0.30	0.30			10
Ecuador	1970-1974	5.9	3.2	1.5	3.3	1.7	2.7	2.3	4.1	0.58	0.34	0.14	0.21		0.07		
	1985-1990	15	0	3.6	5.6	2.9	4.6	3.9	7.1	2.2	1.2	0.8	1.3	2.5	0.55		
India	1985-1990	54	0	0	17	6	4.3	5.3	3.0	2.3	1.1		5.0				7
Health-care level III																	
Belize	1985-1990	24	0	0	26	10	5.3	6.2	7.4	0.4	0.2	1.4	1.3	0	0	0	0.39

Table 7 (continued)

Country	Year	Chest examinations			Extremities	Spine	Pelvis	Skull	Abdomen	GI tract		Cholecystography	Urography	Angiography	Mammography	CT	Other (except dental)
		Radiography	Mass miniature	Fluoroscopy						Upper	Lower						
Myanmar	1985-1990	4.4	2.4		0.55	0.32	0.29	0.42	0.50	0.38	0.10	0.10	0.56			0.12	
Philippines	1985-1990	67	1.2	10	11	3.0	3.6	6.3	5.5	1.5	1.4	1.6	1.9	0.16	0.08		
Thailand	1975-1979	29			4.7	3.2	0.9	3.0	4.7	1.4	0.51	0.81	1.2				
	1980-1984	45			7.4	5.0	1.5	3.4	6.5	1.9	0.74	0.93	1.7	0.30	0.20	1.3	
	1985-1990	48			6.6	4.9	1.5	3.1	7.0	1.6	0.73	0.52	1.9	0.37	0.37	2.4	
Vanuatu	1985-1990			44	40	2.5	2.8	4.2	4.7	0.44	0.22		0.62				
Health-care level IV																	
Rwanda	1970-1974	5.2			1.4	0.15	0.15	0.20		0.70		0.03	0.20				
	1985-1990	4.2			2.4	0.30	0.30	1.5	0.70	0.001	0.01	0.003	0.03	0.00010			

The entries in this Table are qualified as follows:

Australia: The value of 30 given for CT includes 14.6 for CT of the skull.

Barbados: Independent estimate for 1990 for total number of examinations (last column): 60.

Belize: Data from PAHO.

Brazil: Values given under lumbosacral are for all spine examinations.

Canada: Data also from [U1]. Value for mass miniature may include a few fluoroscopies. Values given under 1985-1986 for mammography and computed tomography are for the years 1987-1988; for CT, estimated from sample covering 90% of the population.

China: Data also from [U1]. Values given under lumbosacral are for all spine examinations. Value for abdomen is estimated from sample covering 1% of the population.

Cuba: Data from PAHO and also from [U1].

France: Values given under lumbosacral are for all spine examinations.

German Dem. Rep.: Value for extremities includes skull and spine films. Value for other examinations includes abdomen.

India: Data also from [U1].

Italy: Data are for the north-east of Italy. Values given under lumbosacral are for all spine examinations.

Myanmar: Values estimated from a sample covering 33% of the population.

Netherlands: Value for mammography for the period 1984-1985 includes 3.1 screening.

New Zealand: Values exclude all fluoroscopy.

Norway: Data also from [U1]. Values given under lumbosacral are for all spine examinations.

Poland: Value for pelvis/hip excludes pelvis; for abdomen includes fluoroscopy only; and for mammography is for screening.

Rwanda: Data also from [U1]. Values estimated from figures from Kigali Hospital, serving assumedly one third of the population.

Spain: Data also from [U1]. Values given under lumbosacral are for all spine examinations.

Sweden: Value for lumbosacral examinations include the lumbar spine; value for angiography is for cerebral angiography; frequency of all angiography combined is 7 per 1,000 population for the entire period, 2 of which are peripheral venography, which is usually not performed with special angiography equipment.

Turkey: Value given for total (last column) is estimated from a sample covering 1% of the population.

USSR: Values for 1980 are for RSFSR only. Total value for 1987: the range for different republics is 498-1,127. Values given under lumbosacral are for all spine examinations.

United States: Data also from [U1]. Values given under lumbosacral are for all spine examinations. Value for chest radiography is for PA projection.

Vanuatu: Value given for abdomen includes cholecystography.

Yugoslavia: Value for mammography includes 0.1 screening.

[a] Dental x-ray examinations not included.

Table 8
Average annual number of diagnostic x-ray examinations per 1,000 population by health-care level
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

Examination	Year	Average [a]			Mean ± SD [b]			Median [c]		
		Level I	Level II	Levels III-IV	Level I	Level II	Levels III-IV	Level I	Level II	Levels III-IV
Chest	1970-1979	588	11	18	413 ± 234	11 [c]	17 ± 17	429	11	17
	1980-1984	588	80	45	348 ± 183	80 [d]	45 [e]	305	80	45
	1985-1990	527	118	51	261 ± 149	46 ± 34	21 ± 27	240	30	5.4
Extremities	1970-1979	87	3.3	3.2	99 ± 59	3.3 [c]	3.0 ± 2.3	82	3.3	3
	1980-1984	151	7.8	7.4	143 ± 61	7.7 [d]	7.4 [e]	142	7.7	7.4
	1985-1990	137	15	6.2	143 ± 71	22 ± 17	8.7 ± 14	138	17	1.5
Spine	1970-1979	25	1.7	1.9	25 ± 14	1.7 [c]	1.7 ± 2.2	23	1.7	1.7
	1980-1984	58	1.7	5	45 ± 30	1.7 [d]	5.0 [e]	39	1.7	5
	1985-1990	61	3.9	2	59 ± 45	7.6 ± 6.5	2.1 ± 3.3	50	5.7	0.3
Pelvis/hip	1970-1979	22	2.7	0.57	23 ± 14	2.7 [c]	0.5 ± 0.5	20	2.7	0.5
	1980-1984	31	0.44	1.5	41 ± 28	0.4 [d]	1.5 [e]	38	0.4	1.5
	1985-1990	38	3.4	2	40 ± 30	3.9 ± 3.7	1.4 ± 1.9	30	4.3	0.3
Skull	1970-1979	13	2.3	1.8	42 ± 26	2.3 [c]	1.6 ± 2.0	35	2.3	1.6
	1980-1984	37	1.5	3.4	38 ± 22	1.46 [d]	3.4 [e]	36	1.46	3.4
	1985-1990	46	5.8	3.7	45 ± 35	5.9 ± 4.4	2.2 ± 2.6	34	5.3	1
Abdomen	1970-1979	15	4.1	4.7	11 ± 7.8	4.1 [c]	2.3 ± 3.3	12	4.1	2.3
	1980-1984	22	14	6.5	16 ± 9.9	14 [d]	6.5 [e]	15	14	6.5
	1985-1990	36	7.9	3.4	28 ± 22	8.9 ± 9.1	2.6 ± 3.2	19	7.1	0.6
G.I. tract	1970-1979	73	0.92	1.6	44 ± 30	0.9 [c]	1.3 ± 0.9	42	0.9	1.3
	1980-1984	51	2.7	2.6	59 ± 39	2.7 [d]	2.6 [e]	46	2.7	2.6
	1985-1990	72	5	1.8	44 ± 39	5.1 ± 1.5	0.7 ± 1.1	33	6	0.3
Urography, cholecysto-graphy	1970-1979	19	0.48	1.2	25 ± 16	0.5 [c]	1.1 ± 1.3	20	0.4	1.1
	1980-1984	28	0.35	2.6	28 ± 12	0.3 [d]	2.6 [e]	26	0.3	2.6
	1985-1990	26	2.7	2.2	18 ± 9	3.9 ± 2.8	1.0 ± 1.4	16	3.7	0.3
Angiography	1970-1979	1.6	0	0.3	2.1 ± 2.2	0 [c]	0.2 ± 0.2	1.4	0	0.2
	1980-1984	5.7	0	0.3	5.1 ± 3.1	0 [d]	0.3 [e]	4.2	0	0.3
	1985-1990	7.1	0.27	0.11	5.8 ± 4.9	0.7 ± 1.0	0.06 ± 0.12	4.4	0.3	0
Mammography	1970-1979	5.2	0.07	0.12	4.4 ± 8.9	0.07 [c]	0.06 ± 0.09	1	0.07	0.06
	1980-1984	4.6	0.09	0.2	5.1 ± 3.4	0.08 [d]	0.2 [e]	4.4	0.08	0.2
	1985-1990	14	0.57	0.07	17 ± 17	0.3 ± 0.5	0.04 ± 0.12	12	0	0
Computed tomography	1970-1979	6.1	0	0.14	2.8 ± 3.1	0 [c]	0.07 ± 0.10	1.3	0	0.07
	1980-1984	11	0	1.3	8.7 ± 4.2	0 [d]	1.3 [e]	9.9	0	1.3
	1985-1990	44	0.42	0.42	22 ± 23	0.9 ± 0.9	0.3 ± 0.8	14	0.4	0
Total	1970-1980	814	26	29	737 ± 286	26 [d]	36 ± 22	806	26	32
	1980-1985	804	141	75	738 ± 267	151 ± 80	75 [e]	744	173	75
	1985-1990	887	124	64	755 ± 247	136 ± 167	82 ± 52	696	99	81

[a] Overall average: total number of examinations divided by the total population of countries (thousands).
[b] Mean or median of individual values of countries.
[c] Data from Ecuador only.
[d] Data from China only (except total).
[e] Data from Thailand only.

Table 9
Age- and sex-distribution of patients undergoing x-ray examinations, 1985-1990
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*
Chest radiography						
I	Australia	10	22	68	51	49
	Czechoslovakia	11	31	58	55	45
	Germany, Fed. Rep. of	5	21	74	53	47
	Japan	6	22	72	52	48
	Kuwait	6.9	37	57	52	48
	Netherlands	5.6	16	78	54	46
	New Zealand	13	24	63	56	44
	Poland				55	45
	Romania	34	31	35	57	43
	Spain	8.5	21	69	57	43
	Sweden	4.6	16	80	49	51
	Switzerland	8	31	61	57	43
	USSR, RSFSR	13	24	63		
	United Kingdom	6	24	70	52	48
	Average	8%	23%	69%	53%	47%
II	China	13	45	43	63	37
	Ecuador	8.2	57	35	59	41
	India	28	38	34	63	37
	Jamaica	7.6	50	43	49	51
	Turkey	30	30	40	60	40
	Average	20%	42%	39%	63%	37%
III	Djibouti	32	35	33	52	48
	Myanmar	10	40	50	60	40
	Philippines	12	50	37	57	44
	Average	11%	46%	42%	58%	42%
Chest photofluorography						
I	Australia	9.5	14	76	53	47
	Japan	7.7	47	45	51	49
	Kuwait	19	46	35	55	45
	Poland				56	44
	Romania	5.6	71	23	55	45
	USSR (RSFSR)	6	50	44		
	Yugoslavia	0	35	65	55	45
	Average	7%	48%	46%	53%	47%
III	Myanmar	3	37	60	54	46
	Philippines	4	58	38	45	55
	Average	4%	49%	47%	49%	51%
Chest fluoroscopy						
I	Netherlands	3.9	14	82	57	43
	Poland				59	41
	Romania	15	38	47	53	47
	Switzerland	10	34	56	52	48
	USSR, RSFSR	2	34	64		
	Yugoslavia	17	33	50	50	50
	Average	5%	33%	62%	55%	45%
II	China	20	53	27	57	43
	Turkey	5	65	30	50	50
	Average	19%	54%	27%	57%	43%
III	Philippines	35	23	46	56	44
	Vanuatu	27	45	28	59	41
	Average	35%	23%	46%	56%	44%

Table 9 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
		Extremities				
I	Australia	22	37	41	50	50
	Czechoslovakia	17	46	37	59	41
	Germany, Fed. Rep. of	11	33	56	50	50
	Japan	22	19	69	50	50
	Kuwait	23	45	32	51	49
	Netherlands	20	43	37	52	48
	New Zealand	26	47	27	56	44
	Poland				53	47
	Romania	25	37	38	58	42
	Sweden	15	27	57	46	54
	Switzerlnd	22	39	38	58	42
	USSR, RSFSR	15	33	52		
	United Kingdom	21	50	29	53	47
	Yugoslavia	17	33	50	50	50
	Average	18%	32%	52%	52%	48%
II	China	19	50	32	64	36
	Ecuador	6.5	50	43	76	24
	India	25	48	28	71	29
	Jamaica				52	48
	Turkey	25	55	20	65	45
	Average	22%	49%	30%	67%	33%
III	Myanmar	22	40	38	68	32
	Philippines	27	47	25	69	32
	Vanuatu	26	60	13	70	30
	Average	25%	44%	30%	69%	32%
		Skull				
I	Australia	22	41	37	49	51
	Czechoslovakia	17	50	33	53	47
	Germany, Fed. Rep. of	18	33	49	52	48
	Japan	24	30	46	49	51
	Kuwait	22	44	34	52	48
	Netherlands	22	41	38	48	52
	New Zealand	24	41	35	56	44
	Norway	16	44	40	58	42
	Poland				51	49
	Romania	16	42	42	54	46
	Spain	19	35	46	52	48
	Sweden	8.4	38	53	45	55
	Switzerland	19	43	38	54	46
	USSR, RSFSR	15	44	41		
	United Kingdom	21	40	39	52	48
	Yugoslavia	6.3	25	69	60	40
	Average	19%	37%	44%	51%	49%
II	Ecuador	2.9	56	41	56	44
	India	22	59	19	68	32
	Turkey	20	40	40	60	40
	Average	22%	58%	21%	67%	33%
III	Djibouti	19	44	37	52	48
	Myanmar	39	42	19	70	30
	Philippines	24	50	27	63	37
	Vanuatu	16	54	30	62	38
	Average	30%	47%	24%	66%	34%
		Lumbosacral spine				
I	Australia	3.3	36	61	44	56
	Czechoslovakia	3.9	31	65	50	50
	Germany, Fed. Rep. of	4	32	64	46	54
	Japan	1.2	35	64	56	44

Table 9 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
I (continued)	Kuwait	8.4	44	47	44	56
	Netherlands	5.9	40	54	49	51
	New Zealand	5.4	40	55	51	49
	Norway	1.5	39	59	47	53
	Poland				50	50
	Romania	4.2	41	55	50	50
	Sweden	3.2	30	67	43	57
	Switzerland	4	47	49	50	50
	USSR, RSFSR	9	39	62		
	United Kingdom	8	38	54	46	54
	Yugoslavia	13	25	63	40	60
	Average	6%	36%	61%	50%	50%
II	China	7.2	46	47	58	42
	Ecuador	4	56	40	64	36
	India	5.3	48	47	62	38
	Turkey	15	50	35	60	40
	Average	7%	47%	47%	60%	40%
III	Djibouti	12	38	50	44	56
	Myanmar	7.2	39	53	55	45
	Philippines	15	42	43	62	38
	Vanuatu	7.4	52	41	59	41
	Average	12%	41%	47%	59%	41%
Pelvis						
I	Australia	14	26	61	38	62
	Czechoslovakia	11	29	60	52	48
	Germany, Fed. Rep. of	5	15	80	49	51
	Japan	3.5	17	79	46	54
	Kuwait	15	31	54	40	60
	Netherlands	17	17	66	38	62
	New Zealand	19	25	55	42	58
	Romania	33	34	34	43	57
	Spain	15	25	61	47	53
	Sweden	3.6	11	85	35	65
	Switzerland	20	25	55	50	50
	USSR, RSFSR	7	41	52		
	United Kingdom	14	30	56	40	60
	Yugoslavia	2.5	38	60	20	80
	Average	9%	27%	64%	44%	56%
II	China				58	42
	Ecuador	10	65	25	40	60
	India	16	50	34	68	32
	Turkey	15	50	35	50	50
	Average	16%	50%	34%	62%	38%
III	Myanmar	9.4	30	61	52	48
	Philippines	17	46	37	52	48
	Vanuatu	20	60	20	48	52
	Average	14%	39%	47%	52%	48%
Hip/femur						
I	Australia	11	14	75	38	62
	Czechoslovakia	87	4	9	43	57
	Germany, Fed. Rep. of	4	9	87	52	48
	Japan	24	25	51	43	57
	Kuwait	14	23	63	41	59
	Netherlands	17	17	66	38	62
	New Zealand	19	23	58	54	46
	Romania	21	37	42	57	43
	Sweden	12	7.7	81	35	65
	Switzerland	8	33	58	53	47

Table 9 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
I (continued)	USSR, RSFSR	28	23	49		
	United Kingdom	15	32	53	42	58
	Yugoslavia	17	33	50	50	50
	Average	21%	23%	56%	45%	55%
II	Ecuador	16	58	26	42	58
	India	16	50	34	68	32
	Turkey	15	40	45	55	45
	Average	16%	49%	35%	67%	33%
III	Djibouti	30	45	25	51	49
	Myanmar	16	30	54	53	47
	Philippines	19	45	37	61	39
	Vanuatu	29	47	24	66	34
	Average	18%	39%	44%	58%	42%
Abdomen						
I	Australia	10	24	66	53	47
	Czechoslovakia	8.6	27	64	53	47
	Germany, Fed. Rep. of	8	24	68	41	59
	Japan	8.2	24	68	54	46
	Kuwait	11	38	51	43	57
	Netherlands	6.1	23	71	53	47
	New Zealand	13	28	59	49	51
	Norway	17	31	53	47	53
	Poland				54	46
	Romania	15	36	48	54	46
	Spain	11	39	51	52	48
	Sweden	11	17	72	47	53
	Switzerland	4	31	65	54	46
	USSR, RSFSR	17	20	63		
	United Kingdom	10	27	63	44	56
	Yugoslavia	5.9	35	59	50	50
	Average	11%	25%	63%	50%	50%
II	Ecuador	4.9	39	56	55	45
	India	16	45	39	64	36
	Jamaica				48	52
	Turkey	30	30	40	50	50
	Average	17%	44%	39%	63%	37%
III	Djibouti	25	40	35	42	58
	Myanmar	17	39	44	51	49
	Philippines	19	45	36	50	50
	Vanuatu	10	66	23	35	65
	Average	18%	43%	39%	50%	50%
Upper GI tract						
I	Australia	1.4	20	79	40	60
	Czechoslovakia	1.2	35	64	52	48
	Germany, Fed. Rep. of	4	21	75	41	59
	Japan	0.7	24	76	53	47
	Kuwait	1.6	43	56	49	51
	Netherlands	3	29	69	51	49
	New Zealand	5.1	30	66	50	50
	Norway	0.5	33	66	45	55
	Poland				47	53
	Romania	8.9	39	52	52	48
	Spain	5	28	67	51	49
	Sweden	1.8	17	81	45	55
	Switzerland	2	40	58	58	42
	USSR, RSFSR	4	28	68		
	United Kingdom	2	30	68	49	51
	Yugoslavia	0	33	67	50	50
	Average	3%	27%	70%	49%	51%

Table 9 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
II	China	5.4	46	49	57	43
	Ecuador	10	60	30	33	67
	India	11	45	45	69	31
	Jamaica				45	55
	Turkey	15	50	35	60	40
	Average	8%	46%	47%	62%	38%
III	Myanmar	5.5	41	54	54	46
	Philippines	10	46	44	60	40
	Vanuatu	9.1	36	55	52	48
	Average	8%	44%	48%	57%	43%
Lower GI tract						
I	Australia	4	30	66		
	Czechoslovakia	2.5	16	81	42	58
	Germany, Fed. Rep. of	0.5	6	94	44	56
	Japan	1.9	13	85	52	48
	Kuwait	7.2	28	65	46	54
	Netherlands	2.2	24	74	40	60
	New Zealand	0.6	22	78	41	59
	Norway	0.2	24	76	38	62
	Poland				46	54
	Romania	16	33	51	48	52
	Spain	4	25	71	42	58
	Sweden	3.4	15	82	40	60
	Switzerland	1	23	76	50	50
	USSR, RSFSR	1	25	74		
	United Kingdom	1	14	85	39	61
	Yugoslavia	0	22	78	50	50
	Average	2%	19%	79%	46%	54%
II	China	5.4	46	49	57	43
	Ecuador	9.9	60	30	43	57
	India	7.2	28	65	76	24
	Jamaica				36	64
	Turkey	10	40	50	50	50
	Average	6%	39%	55%	64%	36%
III	Myanmar	3	48	49	58	42
	Philippines	13	29	59	55	45
	Vanuatu	17	50	33	60	40
	Average	9%	37%	55%	56%	44%
Cholecystography						
I	Australia	0.5	33	67		
	Czechoslovakia	0.7	29	70	24	76
	Germany, Fed. Rep.	1	12	87	34	66
	Japan	0	21	79	59	41
	Kuwait	0.4	44	55	30	70
	Netherlands	0	20	80	37	63
	New Zealand	1.7	38	61	33	67
	Norway	0	22	78	35	65
	Poland				29	71
	Romania	0.8	40	59	38	62
	Sweden	0.3	24	76	37	63
	Switzerland	1	36	63	38	62
	USSR, RSFSR	3	30	67		
	United Kingdom	0.5	19	81	30	70
	Yugoslavia	0	20	80	90	10
	Average	1%	24%	75%	44%	56%
II	Ecuador	1	80	19	66	34
	India	14	18	68	60	40
	Turkey	2	28	70	30	70
	Average	13%	19%	68%	58%	42%

Table 9 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
III	Myanmar	0.9	55	44	50	50
	Philippines	7.6	61	32	53	47
	Average	5%	58%	37%	52%	48%
Urography						
I	Australia	9	29	62	51	49
	Czechoslovakia	4.3	30	66	51	49
	Germany, Fed. Rep. of	5	19	76	54	46
	Japan	8.3	24	67	55	45
	Kuwait	15	41	44	55	45
	Netherlands	11	27	63	50	50
	New Zealand	17	31	52	49	51
	Norway	3.5	31	65	51	49
	Poland				46	54
	Romania	5.2	37	58	47	53
	Spain	3.1	35	62	56	44
	Sweden	9.7	20	70	57	43
	Switzerland	27	38	35	79	21
	USSR, RSFSR	7	35	58		
	United Kingdom	9	21	70	68	32
	Yugoslavia	0	13	87	100	0
	Average	7%	28%	65%	57%	43%
II	Ecuador	18	45	36	45	55
	India	19	48	33	84	16
	Jamaica				47	53
	Turkey	10	50	40	55	45
	Average	18%	48%	34%	81%	19%
III	Myanmar	2	46	52	52	48
	Philippines	13	39	48	64	36
	Vanuatu	5.9	59	35	65	35
	Average	8%	42%	50%	59%	41%
Angiography						
I	Australia	1.7	8.9	89	58	42
	Czechoslovakia	1.6	18	81	58	42
	Germany, Fed. Rep. of	4	9	87	59	41
	Japan	0.2	27	73	47	53
	Kuwait	1.9	36	62	53	47
	Netherlands	0	5.9	94	63	37
	New Zealand	0	21	79	54	46
	Poland				48	52
	Romania	2.9	46	51	67	33
	Sweden	2.9	20	77	49	51
	USSR, RSFSR	4	22	74		
	Average	2%	21%	77%	53%	47%
II	Ecuador	15	50	35	72	28
	India	17	33	50	90	10
	Turkey	5	35	60	55	45
	Average	16%	33%	50%	87%	13%
III	Myanmar	11	45	44	60	40
	Philippines	21	34	45	68	32
	Average	17%	39%	45%	65%	35%
Mammography						
I	Australia	0.1	30	70		
	Czechoslovakia	0	35	65	0	100
	Germany, Fed. Rep. of	0	27	75	1.7	98.3
	Japan	0	51	49	0	100
	Kuwait	0	44	56	0	100

Table 9 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
I (continued)	Netherlands	0	28	72	1	99
	New Zealand	0	25	75	0	100
	Norway	0	25	75	0.3	99.7
	Romania	0.3	58	42	0	100
	Spain	1.2	37	62	0.6	99.4
	Sweden	0	8.9	91	0.2	99.8
	USSR, RSFSR	0	25	75		
	United Kingdom	0	0	100	0	100
	Yugoslavia	0	44	56	0	100
	Average	0.10%	32%	68%	0.41%	99.59%
III	Myanmar	0	40	60	0	100
	Philippines	0	11	89	0.5	99.5
	Average	0%	23%	77%	0.29%	99.71%
Computed tomography						
I	Australia	4.5	30	66	46	54
	Czechoslovakia	8.9	33	58	52	48
	Germany, Fed. Rep. of	7	14	79	48	52
	Japan	5	15	80	55	45
	Kuwait	5.4	45	49	51	49
	Netherlands	5.8	25	69	53	47
	New Zealand	12	26	62	53	47
	Norway	6.1	27	67	53	47
	Poland				56	44
	Romania	7.4	39	54	67	33
	Sweden	6.8	21	73	53	47
	United Kingdom					
	Head	6	27	67	50	50
	Body	1	23	76	52	48
	Yugoslavia	10	30	60	40	60
	Average	6%	22%	73%	52%	48%
II	Turkey	30	30	40	50	50
III	Myanmar	4	40	56	52	48

The entries in this Table are qualified as follows:

China: Data are for Beijing area only (about 3% of the population).
Djibouti: Data from Institute P. Pascal only.
Germany, Fed. Rep. of: Data are from hospitals only.
Jamaica: Data are from Kingston Hospital only.
Myanmar: Data are from Gyangon General Hospital only.
Romania: Data are for 1990.
Sweden: Data are for Stockholm county only (about 20% of the population); age distribution: 0-14 years, 15-39 years, >40 years.
Switzerland: Data are for 1982.
Turkey: Values are estimated from sample of 1% of the population.
United Kingdom: Data are for 1981-1985, except for mammography and computed tomography.
Yugoslavia: Data are for Serbia only (about 40% of the population).

Table 10
Entrance surface doses and effective dose equivalents to patients undergoing diagnostic x-ray examinations [a]
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	Dose quantity	Year	Chest examinations			Extremities	Skull	Lumbo-sacral spine	Pelvis / hips	Abdomen	GI tract		Cholecystography	Urography	Angiography	Mammography Screening / clinical	CT (slice doses) [b]
			Radiography	Photofluorography	Fluoroscopy						Upper	Lower					
Health-care level I																	
Argentina	ESD	1985-1989		0.65 (0.3-1.5)	6.5 (4-12)	3 (1-5)	2 (1-3)	30 (20-45)	1.3 / 8 (0.8-15)	4 (3-7)	8 (1.5-20)	8 (1.5-20)	5.5 (4-10)	6.5 (4-10)	5 (3-8)	-/22 (7-35)	30 (15-55)
Australia	ESD	1970-1974		2.6	1.4 (0.1-16)	3 (0.2-41)	17 (0.1-92)	63 (0.7-348)	9.8 / 11 (0.1-99)	11 (0.2-88)	25 (5.3-60)	9.4 (8.7-101)	28 (8.3-109)	57 (4-671)			
		1985-1989	0.4 (0.1-1.5)			2.3 (0.6-4.2)	3.6 (2-5)	28 (10-90)	4.0 / 4.4 (0.7-14)	7.0 (1.2-25)	24		18	40 (8-126)		-/14 (0.4-58)	60 (20-560)
Canada	ESD	1985-1989	0.13 (± 0.10)			0.14 (± 0.07)	0.84 (± 0.40)	12 (± 5.5)	3.6 / 1.6	3.1 (± 2.1)	2.2	3.0 (± 2.1)	15	2.3 (± 1.0)			
Czechoslovakia	ESD	1970-1974	0.5 (0.5-29)	6.1 (0.7-39)		2.5 (0.2-40)	9 (3-46)	31 (5-150)	13 / 12 (2.8-76)	9 (4-30)	14 (3-280)	20 (3-100)	11 (2-30)	14 (3-100)	300 (100-800)		
		1986-1990	0.45 (0.05-28)	6 (0.6-38)		1.5 (0.2-35)	8 (3-45)	26 (4-130)	10/10 (3-59)	8 (4-29)	12 (3-260)	18 (3-98)	10 (2-30)	12 (3-97)	400 (120-800)	60/37 (-/1-45)	
	H_E	1976-1980	0.07	0.7			0.4	2.9	1.9	2.9	4.5	12.7	1.9	3		9.5/	
		1986-1990	0.07	0.7			0.5	3.1	1.9	2.8	2.5	7.7	1.9	3		9.5/-	
Finland	ESD	1978	1.2 [c] (0.3-5.7)	1.7 (0.9-3.6)				60 [c] (8-90)			290 (55-1400)			42 (8-80)		20 (1-200)	
		1988	0.27 (0.04-0.8)				3.1 [d] (1.0-8.0)	8 (3-30)		5 [d] (1-20)						6.3/- (2-14)	
	H_E	1978	0.21					7.6									
		1988	0.05				0.01	1.0		0.91						1.0/-	
France [U1]	H_E	1982	0.3				1.4	4.7	1.6	2.6	6.7	10	7.2	10			
Germany, Fed. Rep. of	ESD	1989-1991	0.18 (0.09-20)			0.12 (0.06-1.8)	3.7 (1.9-18)	18 (9.0-130)	3.7 (2.0-36)	4.0 (2.0-61)	2.4 (1.3-35)	2.0 (0.8-33)	5.0 (3.0-82)	2.4 (2.0-73)			
Italy (north-east) [P19, U1]	ESD [c]	1983	0.5 (± 0.7)	2.6 (± 0.9)			4.6 (± 2.9)			6.6 (± 3.1)				5.5-5.8 (± 2.6-1.7)			
	ESD [d]	1983	1.3 (± 1.7)				4.1 (± 2.9)	9.5 (± 8.3)	10.6/3.7 (± 12.4/2.7)	8.1 (± 4.7)				6.9-9.2 (± 4.6-6.6)			
	ESD [e]	1983	2.7 (± 2.8)				2.6 (± 1.9)	28.3 (± 24.9)	-/4.3 (± -/3.7)								

Table 10 (continued)

Country	Dose quantity	Year	Chest examinations			Extremities	Skull	Lumbo-sacral spine	Pelvis / hips	Abdomen	GI tract		Cholecystography	Urography	Angiography	Mammography Screening /clinical	CT (slice doses) [b]
			Radiography	Photofluorography	Fluoroscopy						Upper	Lower					
Italy (continued)	H_E	1983	0.18	0.25			0.22	2.5	2.3/0.9	1.9	9.3	9.0		7.1			
Japan	ESD	1970-1974		2.3 [f] (± 0.38)													
		1985-1989		1.7 [f]			3.5	5.3		3.6	3.5	4.3		3.0	1.6		
		1989	0.52				10				46	72					23-32
	H_E	1976-1980	0.10	0.30	0.12		0.3-0.9	1.5-1.6			13-14	1.0-1.2		0.6			
		1986	0.05				0.09	0.60	0.25	0.29	1.2	2.0	0.55	0.70			
		1989	0.06				0.05				2.7	3.0					0.5-6.9
Kuwait	ESD	1985-1989	0.43 (0.07-1.0)	0.033 (0.03-0.04)	2.4 (1.8-2.5)	0.15 (0.01-0.25)	2.2 (0.7-4.7)	4.2 (2.1-5.7)	3.0 / 2.8 (1.4-3.9)	3.8 (2.0-4.3)	2.3 (0.8-3.0)	2.3 (0.8-3.0)	2.8 (1.6-3.8)	2.9 (1.4-3.8)	2.1 (1.0-4.3)	3 (1.5-19)	70 (32-128)
New Zealand	ESD	1983-1984	0.83 (0.02-47)	0.6 (0.2-1.8)		0.62 (0.01-23)	5.6 (0.13-39)	33 (0.01-391)	9.5 / 5.9 (0.01-242)	9.0 (0.07-158)	36	41	9.6 (0.01-39)	10 (0.51-71)	291	9 (0.4-26)	32-78 (28-48)
	H_E	1981-1985	0.11	0.10		<0.001	0.3	1.4	1.1/0.8	0.7	7.2	13	0.4	1.8	0.5	0.5	2, 12
Norway	H_E	1988	0.15		0.23			1.6	0.7 / 0.4	0.9	2.5/5	6.4/ 10		2.6			
Poland	ESD	1985-1989	1.5	6.0	10	1.0	15	22	/ 5.9	42	8.0		28	11			
Portugal [C25, S52]	ESD [f]	1989-1990	0.41 (0.08-4.2)			0.82 (0.98-14)	9.6 (0.65-28)	7.9 (1.8-31)		6.1 (0.80-14)				7.0 (0.76-31)			70 (12-231)
Romania	ESD	1980	6.3	8.3	9.7	-	24	62	30/26	18	46		35	71	-	-	12
		1990	2.4 (1.1-5.8)	5.9 (3.9-15)	13 (6.6-27)	-	20 (6.4-35)	53 (21-82)	25/19 (4.3-60)	19 (11-36)	55 (18-162)	77 (26-92)	40 (20-58)	48 (28-91)	21 (13-33)	-	18 (11-27)
	H_E	1980	0.50	0.72	0.74	-	0.11	2.4	3.1/1.6	1.1	3.0		1.3	4.3			1.3
		1990	0.23	0.66	1.0	-	0.12	1.9	2.7/1.3	1.4	3.4	5.2	1.4	3.5	0.15		1.9
Spain	ESD	1986-1990	1.0 (0.2-3.0)			0.9 (0.1-1.8)	6.7 (2-15)	39 (15-50)	19 (7-40)	12 (6-20)							
	H_E		0.29			0.10	0.14	2.1	2.0	1.2	5.5	9.7		6.7		/1.2	3.8
Sweden	H_E [g]	1970-1974	0.30 (0.19-0.40)		1.0 (0.51-3.1)	0.29	0.97	5.9	1.2/1.7 (0.57-2.0)	2.9	4.4	8.6	1.3 (0.57-1.4)	7.3	9.7		
		1985-1989	0.14 (0.01-1.0)		-	0.08 (0.03-0.20)	- 0.19 (0.17-0.20)	(3.0-11) 2.4 (0.39-6.4)	0.64/0.86 (0.20-4.3)	- 1.8 (0.47-3.9)	(1.3-6.6) 4.6 (0.86-17)	(5.3-13) 6.1 (1.0-27)	0.86 (0.26-2.1)	(5.1-7.3) 3.6 (0.21-14)	- -		5

Table 10 (continued)

Country	Dose quantity	Year	Chest examinations			Extremities	Skull	Lumbosacral spine	Pelvis / hips	Abdomen	GI tract		Cholecystography	Urography	Angiography	Mammography Screening /clinical	CT (slice doses) [b]
			Radiography	Photofluorography	Fluoroscopy						Upper	Lower					
Switzerland	ESD	1982	0.5 (0.1-1.3)	5.0 (3.9-9)	-		5.2 (1-14)	14 (0.8-30)	7.1/6.5 (0.6-15)	5.9 (1-11)	3.6 (0.5-8)	3.1 (0.5-9)	6.9 (1-13)	6.7 (5-10)			
	H_E	1982	0.06	0.6			0.6	0.8	0.85/0.2	1.4	0.4	0.4	0.4	2.1			
USSR [U1]	H_E	1982	0.36		1.2	0.01	0.17	4.4	1.5	1.5	1.5, 9.5	3.6, 14	2.0	2.5			
USSR, RSFSR	H_E	1976-1980 1981-1985 1986-1990	0.35 0.30 0.30	0.65 0.60 0.60	1.2 1.15 1.0	0.002 0.002 0.002	0.2 0.2 0.2	2.3 2.4 2.5	2.0 / 1.4 2.0 / 1.5 2.0 / 1.5	1.9 1.8 1.8	8.0 7.7 7.3	16.0 15.5 15.0	2.0 2.0 2.0	4.5 4.5 4.5	1.2 / - 0.5 / 0.4 /		
United Kingdom	ESD [k]	1983	0.23 (0.03-1.4)	1.2 -			4.4 (1.8-13)	20 (3.8-107)	6.6/ (0.9-32)	8.4 (0.7-62)							
	H_E	1981-1985 1986-1990	0.05			0.05	0.15	2.2	1.2/1.4	1.4	3.8	7.7	0.95	4.4	9.0	0.15-1.0	3.5, 8.0
United States	ESD	1984-1989	0.18 (0.01-0.94)					4.9 (0.70-25)		4.2 (0.58-19)						1.8 (0.4-12)	(33-63)
	H_E	1980	0.07			0.1	0.13	1.3	0.6	0.56	2.4	4.6	1.9	1.6			
Health-care level II																	
Brazil [D4]	ESD	1987	0.39 [c] (0.05-1.5)	6.5 [d] (1.5-24)			5.9 [c] (1.5-17)			8.7 [k] (1.5-25)							
China	ESD	1986-1990	1.1 (0.10-15)		10 (1-143)	2.3	13	33 (2-286)	11	8.5 (0.8-135)	52 (0.5-800)	58	27 (0.2-238)		26	/ 2.5	
	H_E	1986-1990	0.06		0.29	0.06		2.7	1.6	0.13	7.5		1.6				
Ecuador	ESD	1985-1989	0.81 (0.77-0.89)			0.77 (0.66-0.88)	2.5 (2.4-2.6)	9.8 (9.5-10)	2.1 / 1.0 (0.9-26)	4.6 (2.5-6.7)	3.3 (0.82-5.7)	2.6 (1.2-3.9)	2.6 (1.7-3.6)	3.7 (3.2-4.2)	1.2 (0.4-8.2)	7.9 (7.0-8.7)	14 (13.5-14.4)
India	ESD	1985-1989	0.2			0.19	9.5	50	50	5.5	34	25		29			
	H_E	1985-1989	0.016			0.0001	0.13	2.5	2.5	0.35	1.4	1.6		1.7			
Jamaica	ESD	1985-1989		0.25 (0.2-0.3)		1.2 (1.2-1.3)				1.2 (1.2-1.3)			1.2	1.7 (1.6-1.8)			

Table 10 (continued)

Country	Dose quantity	Year	Chest examinations			Extremities	Skull	Lumbosacral spine	Pelvis / hips	Abdomen	GI tract		Cholecystography	Urography	Angiography	Mammography Screening /clinical	CT (slice doses) [b]
			Radiography	Photofluorography	Fluoroscopy						Upper	Lower					
Health-care level III																	
Myanmar	ESD	1970-1980	0.7	3.6		0.26	3.7	4.7	3.8 / 3.8	4.7	3.4	4.0	3.4	4.2	4.2	/ 0.65	
		1981-1985	0.80	3.5		0.24	3.5	4.0	3.3 / 3.5	3.7	3.3	3.4	3.3	3.7	3.9	/ 0.60	
		1986-1990	0.32	2.9		0.23	2.9	3.9	2.9 / 3.0	3.3	2.8	3.0	3.0	3.3	3.8	/ 0.55	
	H_E	1976-1980	0.039	0.18		0.003	0.035	0.045	0.036	0.23	0.41	0.43	0.17	0.22	0.21	/ 0.03	
		1981-1985	0.040	0.18		0.002	0.035	0.040	0.035	0.19	0.40	0.41	0.17	0.19	0.20	/ 0.03	
		1986-1990	0.016	0.14		0.002	0.029	0.039	0.029/0.030	0.16	0.34	0.35	0.15	0.17	0.19	/ 0.03	
Thailand	ESD	1976-1980	0.29 (0.26-0.33)				4.1 (3.5-3.7)			4.2 (3.9-4.5)				4.9 (4.7-5.1)			
		1986-1990	0.21 (0.17-0.25)	0.09 (0.08-0.09)	6.5 (3.4-9.5)	0.07 (0.04-0.1)	2.4 (2.2-2.5)	2.8 (2.4-3.1)	3.2 / 2.5 (2.3-3.5)	2.6 (2.5-2.6)	3.4 (3.1-3.6)		3.1 (2.7-3.5)	2.9 (2.8-3.0)	2.6 (2.2-2.9)		

The entries in this Table are qualified as follows:

Australia: Value under CT is for skull CT only.
Canada: Data are for one Ottawa hospital only.
China: Data for Beijing area represent 3% of the population; data for entire nation are for 1986-1990.
Denmark: Data are also from [J11].
Ecuador: Value for chest radiography includes fluoroscopy (20% of examinations.)
Finland: Data are also from [H32, R25].
Japan: Data are also from [M4, U1].
New Zealand: Value under lumbosacral is for lumbar spine. Gastrointestinal tract ESDs refer to fluoroscopy only. When serial and follow-up films are added, total ESD is 75 mGy for upper GI and 99 mGy for lower GI tract. Value under angiography is for coronary catheterization. H_E for mammography 1976-1980: 1.6 mSv, 1986-1990: 0.6 mSv. ESD value under CT is multiple average dose to head for average years 1983-1984, to body for range. H_E value for CT is 2 for head, 12 for abdomen.
Norway: Values under GI tract are for barium/double contrast.
Peru: Data are from Instituto Peruano de Energia Nuclear only (bout 60% of all examinations).
Poland: Value under abdomen is for fluoroscopy.
Romania: Values under CT are, with the exception of the last entry (E, 1990), for chest.
Spain: Values under lumbosacral are for all spine examinations.
Sweden: Value under lumbosacral includes lumbar spine; value under angiography is for cerebral examination.
Thailand: Data are from National Cancer Institute and from the Rajavithi Hospital only.
USSR (RSFSR): Values under GI tract are for fluoroscopy examinations.
United Kingdom: Data also from [W22]. Entry under angiography is for lymphangiography only. Values under CT: first value refers to head; second value to body.
United States: Data also from [U1]. Value under mammography is for mostly screening; range under CT is multiple-scan absorbed doses in a sample and is not considered statistically representative.
Yugoslavia: Data are for Serbia only (about 40% of the population).

[a] The entrance surface dose (ESD) is given in mGy and the effective dose equivalent (H_E) is given in mSv. Average for years as indicated and range in parentheses.
[b] Doses are computed tomography dose index (CTDI) or multiple-scan average dose (MSAD).
[c] PA projection.
[d] LAT projection.
[e] AP projection.
[f] Converted from entrance surface exposure assuming that 1 mR = 0.0087/0.75 mGy ESD. Applies also for ranges where given.
[g] All but CT: Converted from energy imparted assuming that 1 mJ corresponds to 0.0143 mSv. CT data from [S58].
[h] For most frequent projections.

Table 11
Average effective dose equivalent from diagnostic medical x-ray examinations
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

Examination/site	*Average effective dose equivalent (mSv)*		
	Level I		*Level II*
	1970-1979	*1980-1990*	*1980-1990*
Chest radiography	0.25	0.14	0.04
Chest miniature	0.52	0.52	
Chest fluoroscopy	0.72	0.98	0.29
Extremities	0.02	0.06	0.03
Lumbosacral spine	2.2	1.7	2.6
Pelvis	2.1	1.2	2.0
Hip/femur	1.5	0.92	2.0
Skull	0.50	0.16	0.13
Abdomen	1.9	1.1	0.22
Lower GI tract	9.8	4.1	5.0
Upper GI tract	8.9	7.2	1.6
Cholecystography	1.9	1.5	1.6
Urography	3.0	3.1	1.7
Angiography	9.2	6.8	
Mammography	1.8	1.0	
Computed tomography	1.3	4.3	

Table 12
Factors of technique affecting doses to patients from x-ray examinations
[C26, D8, J12, L10, M21, N5, R4, R18, S13, S31, S53, S56, S57, W14]

Factor	*Effect*
Procedure-related	
Referral criteria	Stricter criteria reduce per caput doses by removing clinically unhelpful examinations
Availability of previously taken films	May eliminate some retakes and thus reduce per caput doses
Number of radiographs per examination	Positively correlated with dose
Fluoroscopy time and current	Positively correlated with dose
Quality assurance programmes, including repeat/reject rate assessments and patient dose surveys	May reduce per caput doses
X-ray beam collimation	Area positively correlated with dose
Shielding of sensitive organs	May reduce doses
Choice of projection	Dose depends on 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	Long time, low current combinations may increase dose due to reciprocity law failure
Kilovoltage	Higher kilovoltage may reduce dose and contrast
X-ray tube voltage wave-form	Three-phase and constant potential x-ray beams reduce dose and contrast
X-ray tube target metal	Molybdenum may increase dose and contrast compared to tungsten
Filter type	Rare-earth K-edge filters or other filters producing a beam of higher half-value layer reduce dose and contrast
Anti-scatter grids	Increase dose and image quality
Distance (air gap)	Adjustment for increased magnification nominally increases dose but may also obviate need for a grid
Attenuation between patient and image receptor	Low attenuation (e.g. carbon fibre couch top) reduces dose
Screen/film combination	Faster rare earth screens reduce dose, sometimes also image quality
Film processing	Long processing time or chemicals and temperature that increase speed of development reduce dose
Image intensifier	Sensitive (e.g. CsI) photocathodes and digital image processing may reduce dose
Recording method	Video recorder reduces fluoroscopy dose compared to cine camera
Pulsed fluoroscopy with image storage device	Reduces fluoroscopy dose
Spot film fluorography	With modern equipment, may reduce dose compared to radiography
Computed radiography	Potential for reduction of dose and of image quality

Table 13
Doses to patients from angiography examinations
[S37, V14]

Examination		*Entrance surface dose (mGy)*	*Organ absorbed dose (mGy)*							
			Eye lens	*Red bone marrow*	*Lung*	*Thyroid*	*Breast*	*Bladder*	*Testis*	*Ovary*
Cerebral	Conventional	282-482	-	7-52	0.2-14	10-73	0.1-7	-	0.02-0.2	0.2-1
	Conventional, PA	-	-	-	-	-	-	-	0.1	0.01
	Digital, PA	-	-	-	-	-	-	-	0.01	0.03
Neck	Conventional	142-230	32-107	5-12	-	5-87	-	-	0.03	0.04
	Subtraction, analog	502	2	12	-	4	1	-	0.02	<0.01
	Subtraction, digital	37	0.2	0.6	-	7	-	-	-	-
Thorax	Conventional	24-502	0.2	0.5-54	2-32	0.1-73	0.8-73	-	0.02-11	0.07-12
	Conventional, AP	-	-	0.9	6	20	20	0.05	-	0.05
	Conventional, PA	-	-	-	-	-	-	-	0.2	0.07
	Subtraction, analog	21-232	0.03	0.4	1	0.8-4	0.9	-	<0.01-0.3	<0.01-0.1
	Subtaction, digital, PA	-	-	0.4	1	4	0.9	<0.01	0.2	<0.01
Angiocardiography	Conventional	482	-	79	27	6	80	-	2	5
	Subtraction, analog	86-111	0.2-0.3	3-10	20-23	0.3-3	2-4	-	<0.01-2	<0.01-5
Abdomen	Conventional	482-523	-	33-41	27-32	0.9-1	60-89	-	0.2-0.3	3-9
	Conventional, PA	-	-	-	-	-	-	-	1.9	2
	Subtraction, digital, PA	-	-	-	-	-	-	-	1.5	1.6
Renovasography	Conventional	101-533	<0.01	0.5-36	0.2-19	0.04-0.9	0.2-29	-	0.08-1	0.2-29
	Conventional, AP	-	-	1	0.2	0.07	0.3	0.1	-	0.2
	Subtraction, digital, AP	-	-	2	0.2	1	2	1	-	2
	Subtraction, digital, PA	-	-	29	0.04	0.9	0.2	0.08	-	2
Pelvis	Conventional	78-402	<0.01	0.6-10	0.2-1	<0.01-0.08	0.2-0.5	-	3-29	1-29
	Conventional, PA	-	-	-	-	-	-	-	13	33
	Subtraction, analog	577	<0.01	9	-	0.07	-	-	227	19
	Subtraction, digital, PA	-	-	-	-	-	-	-	26	57

Table 14
Doses to patients from computed tomography examinations in the United Kingdom, 1989
[S42, S43]

Examination		*Effective dose equivalent* [a] *(mSv)*	*Effective dose* [b] *(mSv)*	*Collective effective dose equivalent* [a] *(man Sv)*	*Collective effective dose* [b] *(man Sv)*
Type	*Number*				
Head, routine	296650 (35%)	3.49	1.80	1035 (23%)	534 (16%)
Posterior fossa	68850 (8.1%)	1.22	0.71	84.0 (1.9%)	48.9 (1.5%)
Pituitary	17850 (2.1%)	1.10	0.59	19.6 (0.4%)	10.5 (0.3%)
Internal auditory meatus	18700 (2.2%)	0.43	0.34	8.0 (0.2%)	6.4 (0.2%)
Orbits	16150 (1.9%)	1.13	0.60	18.2 (0.4%)	9.7 (0.3%)
Facial bones	8500 (1.0%)	0.69	0.61	5.9 (0.1%)	5.2 (0.2%)
Cervical spine	15300 (1.8%)	1.94	2.89	29.7 (0.7%)	44.2 (1.3%)
Thoracic spine	5950 (0.7%)	7.76	5.82	46.2 (1.0%)	34.6 (1.1%)
Chest, routine	67150 (7.9%)	9.13	8.33	613 (14%)	559 (17%)
Mediastinum	34000 (4.0%)	7.39	7.09	251 (5.5%)	241 (7.3%)
Abdomen, routine	98600 (11.6%)	8.82	7.16	870 (19%)	706 (21%)
Liver	29750 (3.5%)	10.20	7.18	303 (6.7%)	214 (6.5%)
Pancreas	22950 (2.7%)	6.71	4.57	154 (3.4%)	105 (3.2%)
Kidneys	14450 (1.7%)	8.62	5.81	125 (2.8%)	84.0 (2.6%)
Adrenals	8500 (1.0%)	3.74	3.04	31.8 (0.7%)	25.8 (0.8%)
Lumbar spine	59500 (7.0%)	5.98	3.60	356 (7.9%)	214 (6.5%)
Pelvis, routine	47600 (5.6%)	9.38	7.26	446 (9.9%)	345 (10%)
Other	19550 (2.3%)			108 (2.4%)	100 (3.0%)
Total	850000 (100%)	5.3	3.9	4500 (100%)	3300 (100%)

[a] Using ICRP 1977 weighting factors.
[b] Using ICRP 1990 weighting factors.

Table 15
Doses to patients from computed tomography examinations in Japan
[N8]

Examination	*Dose quantity*	*Dose to*	*Dose*		
			Minimum	*Maximum*	*Average*
Head	Absorbed dose (mGy)	Bone marrow	0.7	2.1	1.5
		Thyroid	0.2	0.8	0.5
		Eye	8.7	47.2	22.4
	Effective dose equivalent (mSv)		0.2	0.7	0.5
Chest	Absorbed dose (mGy)	Breast	8.7	39.6	15.9
		Lungs	12.6	35.0	19.6
		Bone marrow	3.9	11.5	5.7
		Thyroid	1.2	3.0	1.9
	Effective dose equivalent (mSv)		4.3	14.1	6.9
Upper abdomen	Absorbed dose (mGy)	Large intestine	0.7	1.7	1.0
		Ovary/testis	0.4 / 0.04	1.0 / 0.2	0.6 / 0.1
		Bone marrow	1.4	3.7	2.2
	Effective dose equivalent (mSv)	Female	2.6	7.4	3.8
		Male	2.5	7.2	3.7
Lower abdomen	Absorbed dose (mGy)	Large intestine	11.3	34.5	19.2
		Ovary/testis	8.7 / 0.5	27.1 / 1.6	15.1 / 1.0
		Bone marrow	3.5	9.5	5.6
	Effective dose equivalent (mSv)	Female	4.1	12.5	7.1
		Male	2.0	6.2	3.6

Table 16
Doses from mammography examinations

Country and year	*Technique*	*Absorbed dose in breast (mGy)* [a]		*Effective dose equivalent (mSv)*	
		Per film	*Per patient*	*Per patient*	*Per caput*
Australia, 1989 [I137]	Patients All with grid, screen/film	1.3 ± 0.4 (0.5-2.3)			
Australia 1989-1990 [T19]	48 mm phantom Xeroradiograph [b] Screen/film: With grid [c] No grid Overall	2.3 1.8 ± 0.8 0.8 ± 0.5 1.7 ± 0.8 (0.1-6.8)	 3.6 1.6 3.4		
Canada, Manitoba 1988 [H31]	47 mm phantom Xeroradiograph Screen/film Overall	3.3 1.4 (0.8-1.9)	 4.0	0.82 0.30 0.60	 0.014
Italy, 1987-1990 [R19]	50 mm phantom 39% with grid		1.5 (63%) 1.0 (39%)		
Ireland, 1989 [H43]	60 mm phantom Screen/film	1.5 (0.9-2.3)			
New Zealand 1988-1989 [W11] and UNSCEAR Survey	All screen/film: 30 mm phantom No grid Overall Magnification 45 mm phantom No grid With grid Overall	 0.6 ± 0.3 1.0 ± 0.6 2.5 (0.7-7.2) 1.1 ± 0.4 2.3 ± 1.0 2.0 ± 1.1 (0.5-4.8)		 0.30 0.60	
Poland, 1988 [D7]	30 mm phantom Xeroradiograph	4.8	6.4		
Portugal 1988-1989 [C15]	All screen/film: 40 mm phantom No grid Stationary grid Moving grid Overall	 0.8 1.0 2.0 1.4			
Sweden 1989-1990 [L10]	All screen/film: 45 mm phantom No grid Moving grid	 0.7 (0.5-1.1) 1.5 (1.2-1.9)			

[a] ± SD; range in parentheses.
[b] 2% of all centres.
[c] 80% of all centres.

Table 17
Average annual number of dental x-ray examinations per 1,000 population
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	*1970-1979*	*1980-1984*	*1985-1990*	*Country*	*1970-1979*	*1980-1984*	*1985-1990*
Health-care level I							
Australia	80			Netherlands	150	399	411
Belgium			288	New Zealand	321		275
Cuba				Norway	641	805	833
Czechoslovakia	72	86	85	Poland			61
Denmark			471	Portugal			86
Finland			223	Romania	20	32	42
France		540		Spain			232
Germany, Fed. Rep. of			264	Sweden	443	841	832
Italy		119		Switzerland	296	325	
Japan	831	834	783	USSR, RSFSR	50	74	80
Kuwait			219	United Kingdom	112	165	
Luxembourg			186	United States	350	456	402
Malta	3	6.2	8.2				
				Average	320	390	350
Health-care level II							
Brazil			4.7	Ecuador	1.5	4.4	6.2
Chile		3.9		Tunisia			1.3
China		0.8	2.1				
				Average		0.8	2.5
Health-care level III							
Egypt	0.7			Sri Lanka	0.8		
Myanmar			1.6	Thailand	1.4	2.3	2.1
				Average		0.8	1.7

The entries in this Table are qualified as follows:

France: Value represents number of films.
Germany, Fed. Rep. of: Pantomograms not included.
Italy: Value is for north-east of Italy.
Japan: Data also from [U1].
Netherlands: Data also from [V2, V10].
New Zealand: Data also from [W12].
Sweden: Data also from [S1, S3].

Table 18
Estimates of effective dose equivalent from dental x-ray examinations
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures, unless otherwise indicated

Country	Year	Entrance surface dose (mGy)	Effective dose equivalent (mSv)	Country	Year	Entrance surface dose (mGy)	Effective dose equivalent (mSv)
Health-care level I							
Argentina	1985-1989	4 (1.5-40)		New Zealand	1975-1979	5.2 (1.2-19)	
Australia	1970-1974	7.4			1985-1989	4.9 (1.2-22)	0.11
Czechoslovakia	1970-1979	25 (0.1-30)	0.15	Poland	1985-1989	3	
	1986-1990	18 (0.1-25)	0.15	Romania	1980-1984	10.7	0.004
France [B5]	1984	(3.9-13.5)	0.07		1985-1990	28 (3.3-46)	0.01
Japan	1970-1974	5.8 (3.5-8.7)		Spain	1986-1990	6.0 (0.9-12)	
	1980-1984	3.1	0.03, 0.04	Sweden	1980-1984	5	0.03
Kuwait	1985-1989	3.2 (0.76-9.7)		USSR, RSFSR	1985-1990		0.02
Netherlands	1974-1985	(0.9-31)	0.02-0.28	United Kingdom	1981-1985		0.02, 0.03
Health-care level II				**Health-care level III**			
Brazil	1987		0.2	Myanmar	1985-1990	6.4	0.32
Ecuador	1985-1989	1.9 (1.3-2.7)					

The entries in this Table are qualified as follows:

Australia: ESD given is per film.

France: The range of the ESD is the average for different projections. The value given for the effective dose equivalent is per film, the effective dose equivalent per caput is 0.037 mSv.

Japan: Data also from [U1]. The ESD has been estimated from exposure (mR) multiplied by 0.0087/0.75. The first value for effective dose equivalent for 1985-1989 is for intraoral, the second value for extraoral examinations. The per caput effective dose equivalent for Japan is 0.027 mSv [I12]. For 1989, H_g: 0.024 mSv; E: 0.052 mSv [M44].

Netherlands: Data also from [V2, V10]. Range of ESD: on average, 2.4 films are used per examination. Effective dose equivalent is for complete mouth survey; for pantomogram it is 0.13 mSv.

New Zealand: Data also from [W12]. The ESD values are per film. The ESD value for the period 1985-1989 is qualified by the fact that on average 1.6 films were used per examination.

Romania: Effective dose equivalent is per caput.

Spain: The values for ESD (and range) are for intraoral examinations.

Sweden: Data also from [S1, S3]. On average, 1.25 films were used per examination; 1985-1989: on average, 2.4 films were used per examination. The effective dose equivalent per caput is 0.01 mSv, for the complete mouth survey it is 0.14-0.23 mSv.

USSR: The value for effective dose equivalent is given for intraoral examinations.

United Kingdom: The first value of the effective dose equivalent is for intraoral, the second one for extraoral examinations. On average 2.4 films were used per examination (1981-1985).

Table 19
Mean absorbed doses from dental x-ray examinations in France [a]
[B5]

Organ	Mean absorbed dose (mGy)							
	Periapical incisor		Periapical molar		Panoramic projections			
						Circular		Elliptical
	Upper	Lower	Upper	Lower	Maxillary occlusal	2 centers of rotation	3 centers of rotation	
Lens	0.10	0.07	0.05	0.02	3.60	0.03	0.03	0.08
Thyroid	0.14	0.08	0.04	0.06	0.07	0.01	0.05	0.06
Parotids	0.01	0.02	0.40	0.41	0.04	0.90	1.40	0.08
Tongue	0.12	0.27	0.05	0.06	0.12	0.40	3.10	0.59
Sublinguals	0.03	0.03	0.10	0.13	0.04	-	-	-
Pharynx	<0.01	0.01	0.06	0.04	0.01	0.19	0.80	0.40
Sinuses	0.08	0.06	0.28	0.04	4.35	-	-	-
Back of neck	0.04	0.02	0.04	0.03	0.04	-	-	-
Brain	<0.01	<0.01	0.01	<0.01	0.01	-	-	-
Bone surface	0.07	0.09	0.65	0.74	0.10	0.10	0.15	0.15

[a] Underlined values are doses >0.2 mGy.

Table 20
Collective dose from diagnostic x-ray examinations worldwide, 1985-1990

Examination/site	*Number of examinations per 1,000 population*				*Effective dose equivalent per examination (mSv)*				*Annual collective effective dose equivalent (man Sv)*			
	Level I	*Level II*	*Levels III-IV*	*World*	*Level I*	*Level II*	*Levels III-IV*	*World*	*Level I*	*Level II*	*Levels III-IV*	*World*
Chest radiography	171	22	34	63	0.14	0.14	0.14	0.14	31500	8130	6240	45900
Chest miniature	260	20	1.5	77	0.52	0.52	0.52	0.52	182000	27100	1040	210000
Chest fluoroscopy	33	48	9.0	34	0.98	0.98	0.98	0.98	43100	124000	11500	178000
Extremities	121	11	5.6	38	0.06	0.06	0.06	0.06	10600	1800	440	12800
Lumbosacral spine	54	3.0	1.8	16	1.7	2.6	2.6	1.8	122000	20400	6130	148000
Pelvis	21	1.5	0.89	6	1.2	2.0	2.0	1.3	32800	7710	2320	42900
Hip/femur	12	1.1	0.89	4	0.92	2.0	2.0	1.1	15300	5740	2320	23300
Skull	40	4.4	3.3	13	0.16	0.16	0.16	0.16	8560	1860	690	11100
Abdomen	32	6.0	3.0	12	1.1	1.1	1.1	1.1	44700	16600	4160	65500
Upper GI tract	52	2.8	0.89	15	4.1	5.0	5.0	4.2	285000	36700	5800	328000
Lower GI tract	11	0.99	0.69	4	7.2	7.2	7.2	7.2	112000	16800	6520	137000
Cholecystography	9	0.21	0.78	3	1.5	1.6	1.6	1.5	18100	900	1630	20600
Urography	14	1.8	1.2	5	3.1	3.1	3.1	3.1	58200	14700	4660	77500
Angiography	6	0.21	0.10	2	6.8	6.8	6.8	6.8	57300	3670	880	61900
Mammography	12	0.43	0.06	3	1.0	1.0	1.0	1.0	17000	1170	84	18300
CT	39	0.32	0.38	10	4.3	4.3	4.3	4.3	224000	3610	2110	230000
Total	887	124	64	304					1262000	292000	56500	1610000
Average per examination (mSv)					1.05	0.90	0.67	1.0				
Average dose per caput (mSv)					0.93	0.11	0.043	0.30				

Table 21
Contribution of different types of diagnostic examinations to the collective dose

Examination/site	*Contribution to total collective dose (%)*			
	Level I	*Level II*	*Levels III-IV*	*World*
Upper GI tract	23	13	10	20
Computed tomography	18	1	4	14
Chest mass miniature	14	9	2	13
Chest fluoroscopy	3	42	20	11
Lumbosacral spine	10	7	11	9
Lower GI tract	9	6	12	9
Urography	5	5	8	5
Angiography	5	1	2	4
Abdomen	4	6	7	4
Pelvis	3	3	4	3
Chest radiography	2	3	11	3
Hip/femur	1	2	4	1
Cholecystography	1	0.3	3	1
Mammography	1	0.4	0.1	1
Extremities	0.8	0.6	0.8	0.8
Skull	0.7	0.6	1	0.7

Table 22
Annual individual and collective effective dose from diagnostic x-ray examinations
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	Year	Effective dose equivalent (mSv)		Collective effective dose equivalent (man Sv)	Reference
		Per individual patient	Per caput		
Health-care level I					
Canada	1980	0.8 [a]	1.0 [a]	24000 [a]	[U1]
Czechoslovakia	1980	0.9	0.6	8600	[K17]
Denmark	1986-1990	1.4	0.7	3600	
Finland	1978 1987	0.6 0.8	0.7 0.7	3300 3500	[U1] [R9]
France	1982	2.0	1.6	89000	[U1]
Germany, Fed. Rep. of	1979 1983 1988	2.0 [a] 1.0	1.7 [a] 1.5 1.0	102000 90000 61000	[U1] [B7] [S17]
Italy	1983	1.1	0.8	48000	[P19, U1]
Japan	1979 1989	 1.9	1.3 2.2	151000 266000	[U1] [M32]
New Zealand	1981-1985	0.67	0.4	1400	
Netherlands	1980 1987	0.57 0.56	0.34 0.31	4800 4500	[B6] [B6]
Norway	1988	0.9	0.6	2500	[S22]
Poland	1976 1988	 1.2	1.7 0.8	58700 30000	[U1] [L21]
Portugal	1988-1989	0.76	0.53	5400	[S52]
Romania	1980 1990	1.1 1.1	0.6 0.5	14100 12300	
Spain	1985-1986	1.4	0.8	31100	[V5]
Sweden	1985	1.1	0.6	4600	[V4]
Switzerland	1985-1990	0.4	0.4	2700	
USSR	1980 1986-1987	1.1 1.15	1.1 1.15	292000 326000	[N4] [N4, S18]
USSR, RSFSR	1976-1980 1981-1985 1986-1990	1.18 1.14 1.14	1.13 1.16 1.10	153700 163300 161000	
United Kingdom	1983 1989	0.7	0.3 0.35	16000 20000	[H10] [S43]
United States	1980	0.5	0.4	92000	[N1, U1]
Health-care level II					
China Beijing area Entire nation	 1983 1985	 0.6 0.6	 0.4 0.09	 3600 94000	 [Z1, Z4] [Z6]
India [b]	1989	0.2	0.02	16800	[S40]
Iran (Islamic Rep. of) [b]	1980	0.5	0.09	3500	[U1]
Iraq [b]	1972	0.7 [a]	0.2 [a]	1700 [a]	[U1]
Turkey [b]	1977		0.2 [a]	7000 [a]	[U1]
Health-care level III					
Myanmar	1986-1990	5	0.05	2000	
Thailand [b]	1970		0.2 [a]		[U1]

Table 22 (continued)

The entries in this Table are qualified as follows:

Italy: Data for the north-east of country have been extrapolated to the entire country.
Japan: Collective effective dose equivalent includes 16,100 man Sv from stomach mass screening; 69,000 man Sv from chest mass screening; 5,600 man Sv from computed tomography; 2,900 man Sv from dental radiography.
Spain: Excluding military and pre-employment screening.

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[a] Estimated from genetically significant dose, GSD [0.3 mSv and average ratio GSD/H_E for health-care level *I* (*0.3/1*; range of level *I* ratios: *0.14/1-0.5/1*)].
[b] Apparently excludes fluoroscopy. For approximate adjustment, it could be assumed that 50% of all examinations are fluoroscopic and that these cause, on average, 15 times higher absorbed doses per examination [U1].

Table 23
Estimated doses to the world population from diagnostic medical and dental x-ray examinations

Health-care level	*Population (millions)*	*Annual per caput effective dose equivalent (mSv)*		*Annual collective effective dose equivalent (10^3 man Sv)*	
		Medical	*Dental*	*Medical*	*Dental*
I	1350	1	0.01	1300	14
II	2630	0.1	0.001	290	3
III	850	0.04	0.0003	40	0.3
IV	460	0.04	0.0003	20	0.1
Total	5290	-	-	1600	17
Average	-	0.3	0.003	-	-

Table 24
Regulations or recommendations on quality assurance
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures, unless otherwise indicated

Country	X-ray diagnostics			Radiation therapy			Nuclear medicine		
	Legal regulations	Recommendations	No QA rules	Legal regulations	Recommendations	No QA rules	Legal regulations	Recommendations	No QA rules
Health-care level I									
Argentina		*			*			*	
Australia	*			*			*		
Belgium			*			*			*
Canada [a]	*	*			*	*		*	
Czechoslovakia		*				*		*	
Denmark	*			*			*		
Ecuador	*				*			*	
Finland		*		*				*	
France	*			*			*		
Germany, Fed. Rep. of	*			*			*		
Japan [b]			*			*			*
Kuwait	*			*			*		
Luxembourg	*			*			*		
Malta		*				*			*
New Zealand			*	*				*	
Norway			*			*			*
Poland		*			*			*	
Romania		*			*			*	
Singapore		*						*	
Spain	*			*			*		
Sweden	*			*			*		
Switzerland		*		*				*	
USSR, RSFSR		*			*		*		
United Kingdom		*			*			*	
United States [c]	*	*			*			*	
Yugoslavia	*			*			*		
Total	12	12	4	12	8	6	10	12	4

Table 24 (continued)

Country	X-ray diagnostics			Radiation therapy			Nuclear medicine		
	Legal regulations	Recommendations	No QA rules	Legal regulations	Recommendations	No QA rules	Legal regulations	Recommendations	No QA rules
Health-care level II									
Barbados	*				*			*	
China	*			*			*		*
Honduras [d]		*							
India		*		*				*	
Iraq	*			*			*		
Jamaica			*			*			*
Nicaragua [d]			*						
Peru [c]			*			*			*
Turkey		*			*			*	
Total	3	3	3	3	2	2	2	3	3
Health-care level III									
Cape Verde		*							
Djibouti			*			*			*
Dominica [d]			*						
Egypt	*			*			*		
Myanmar		*							
Philippines		*							
Saint Lucia [d]			*						
Sudan		*			*			*	
Thailand		*			*			*	
Total	1	5	3	1	2	1	1	2	1
Health-care level IV									
Ethiopia					*			*	
Rwanda		*				*			*
Total		1			1	1		1	1

[a] For x-ray diagnostics, legal provincial regulations prevail and federal recommendations have been made. For radiation therapy, recommendations exist in some provinces. In practice, recommendations on nuclear medicine are enforced as legal regulations.

[b] The Japanese Industrial Standards are used as technical guides for x-ray diagnostics and radiation therapy.

[c] For x-ray diagnostics, a few states have legal regulations and federal recommendations have been made.

[d] Data from PAHO.

[e] Regulations in preparation.

Table 25
Total annual number of nuclear medicine examinations per 1,000 population
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	*1970-1979*	*1980-1984*	*1985-1990*	*Country*	*1970-1979*	*1980-1984*	*1985-1990*
Health-care level I							
Argentina			11.5	Kuwait			13.1
Australia	3.8	8.9	8.3	Luxembourg			23.5
Austria [U1]	18.0			Netherlands			11.6
Belgium			36.8	New Zealand	5.6	7.3	7.5
Bulgaria [U1]		13.0		Norway	3.9		9.3
Canada			12.6	Romania		3.0	3.5
Czechoslovakia	13.6	18.3	22.9	Sweden	9.8		12.6
Denmark	14.0	14.2	13.4	Switzerland	44.9		
Finland [A12, L18]	12.6	17.7		USSR [N4]		3.9	
France [L20, U1]		9.0	6.9	United Kingdom		6.8	
Germany, Fed.Rep.	31.1	39.7	39.8	United States			25.7
Italy	6.0		7.3	Yugoslavia			6.1
Japan			8.3				
				Average	11	6.9	16
Health-care level II							
Barbados			1.0	Iraq			1.2
Brazil [C14]			1.7	Jamaica	2.8		2.0
China			0.6	Peru			0.2
Cuba [U1]	0.8			Tunisia			1.0
Ecuador	0.5		0.8	Turkey			2.5
India		0.1	0.2				
				Average	0.9	0.1	0.5
Health-care level III							
Egypt	0.07	0.21	0.48	Sudan	0.12	0.28	0.28
Myanmar	0.54	0.36	0.11	Thailand	0.25	0.18	0.26
				Average	0.25	0.25	0.30
Health-care level IV							
Ethiopia		0.014	0.10				

Table 26
Average annual number of diagnostic nuclear medicine examinations per 1,000 population
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures, unless otherwise indicated

Country	Year	Bone	Brain	Cardiovascular	Liver/spleen	Lung		Kidney	Thyroid		Other
						Ventilation	Perfusion		Scan	Uptake	
Health-care level I											
Argentina	1985-1989	2.8	0.4	1.6	1.1	0.24		0.8	4.5		
Australia	1970	0.05	1.0		0.6	0.001	0.5	0.1	1.5 [b]		
	1980	2.0	1.5	0.2	1.7	0.3	0.9	0.1	0.8	0.05	0.3
	1984	2.6	0.3	1.0	1.2	0.6	0.9	0.5	0.8	0.07	0.9
	1991	3.4	-	1.5	0.2	1.5 [a]		0.8	0.6	0.01	0.3
Canada	1985-1989	16.8	4.0	0.8	1.0	0.2	0.4	0.3	0.9	0.8	0.5
Czechoslovakia	1970-1974	0.09	1.3	0.02	3.6	0.05	0.1	6.1	1.7	1.0	
	1976-1980	2.1	0.4	0.2	2.6	0.2	0.4	4.3	1.8	0.5	0.6 [c]
	1981-1985	3.4	0.5	0.5	1.9	0.4	1.1	6.7	1.9	0.2	1.6 [c]
	1986-1990	4.6	0.6	1.2	2.2	0.6	1.8	8.4	1.8	0.2	1.6 [c]
Denmark	1977-1980	2.2	2.4	0.6	1.2	0.1	0.5	3.9	1.3	0.7	1.1
	1981-1989	2.7	1.4	1.0	0.7	0.4	0.7	4.5	1.0	0.5	1.3
	1986-1990	2.5	0.8	1.1	0.1	0.4	0.7	4.8	1.6	0.3	1.1
Finland [A12]	1975	0.6	3.4	0.3	1.9	0.06	0.6	3.3	1.3	0.6	0.5
	1982	3.1	4.9	0.6	2.2	0.05	1.1	3.0	1.8	0.2	0.7
France [L20, U1]	1990	2.6		0.7		1.4			1.9		0.4
Germany, Fed. Rep. of	1976-1980	4.4	4.0	0.2	4.0	0.05	2.2	3.9	9.3	1.8	1.2
	1981-1985	9.6	1.4	2.4	1.3	0.2	2.9	2.7	18.2	0.2	0.9
	1986-1990	10.3	1.1	2.8	0.9	0.2	3.1	2.5	17.7	0.2	0.9
Italy	1974	0.06	0.6	0.09	1.2 [d]	0.06	0.04	0.7	0.2	3.0	0.2
	1985	2.0	0.2	0.3	1.5	0.02	0.2	0.3	2.0	0.7	0.1
Japan	1985-1989	2.1	0.3	0.9	0.9	0.3		1.8	0.4	0.4	1.4
Kuwait	1985-1989	1.7	0.2	1.8	1.1	0.4	0.8	3.9	3.2	0.03	
Netherlands	1985-1989	3.6	1.2	1.5	1.5	0.4	0.7	0.8	1.1	0.3	0.4
New Zealand	1970-1974	0.3	1.2	0.3	0.7		0.3	0.06	0.4	1.2	0.2
	1975-1979	1.5	2.4	0.1	1.3	0.1	0.6	0.2	0.7	0.7 [e]	
	1980-1984	2.2	1.3	0.4	1.2	0.4	0.5	0.5	0.7	0.3 [f]	
	1985-1989	2.8	1.0	0.4	0.6		0.6	0.8	0.7	0.3	

Table 26 (continued)

Country	Year	Bone	Brain	Cardiovascular	Liver/spleen	Lung		Kidney	Thyroid		Other
						Ventilation	Perfusion		Scan	Uptake	
Norway	1970-1974 1985-1989	0.2 3.4	0.7 0.2	 1.5	0.8 0.5	0.01 0.2	0.1 0.6	0.5 1.0	0.7 1.1	0.8 0.6	0.2 0.3
Romania	1980 1985-1989	0.06 0.05	0.2 0.2	0.04 0.03	1.0 1.1	0.06 0.06		0.3 0.3	1.4 [g] 0.7	 0.7	0.02 0.4
Sweden	1974 1985-1987	0.5 4.2	1.5 0.4	0.004 0.7	1.4 0.7	0.3 0.2	0.3 1.2	2.7 3.0	1.7 1.6	1.5 0.5	
Switzerland	1976	5.8	5.1	7.0	4.3	1.1	1.4	0.4	4.5	5.0	10.3
United Kingdom	1981-1985	1.7	0.9	0.2	0.9	0.3	0.5	0.5	0.4	0.1	1.2
United States	1985-1989	8.3	0.4	5.4	1.9	2.3	3.0	1.2	1.6	0.7	0.8
Yugoslavia	1985-1989	0.7	0.3	0.2	0.7	0.005	0.1	2.5	1.3	0.2	0.1
Health-care level II											
Barbados	1985-1988	0	0.4	0	0.09	0	0.1	0.08	0.4	0	
China	1985	0.002	0.003	0.0003	0.02			0.15	0.06	0.25	0.11
Ecuador	1970-1974 1985-1989	0 0.1	0.0003 0.01	0 0.05	0.01 0.1	0 0	0 0.03	0.01 0.01	0.21 0.2	0.25 0.3	
India	1985-1989	0.03	0.006	0.02	0.03	0.001	0.001	0.03	0.04	0.06	0.006
Iraq	1985-1989	0.1	0.08	0	0.08	0	0	0.02	0.9	0	0.006
Jamaica	1970-1974 1985-1989	0 0.2	1.0 0.7	0 0.001	0.3 0.1	0 0	0.1 0.2	0.1 0.04	1.0 0.7	 0	0.1 <0.01
Peru	1985-1989	0.09	0.02	0.001	0.05	0	0.002	0.01	0.03	0.009	
Tunisia	1985-1989	0.2	0.004	0.02	0.05		0.04	0.008	0.3	0.3	0.01
Turkey	1991	0.35	0.008	0.35	0.17		0.04	0.18	1.4		0.05
Health-care level III											
Myanmar	1975-1979 1978-1984 1985-1990	0.0009 0.002 0.0002	0.03 0.02 0.00003	0.001 0.001 0.00005	0.15 0.08 0.0002		0.0001 0.0008 0.00003	0.008 0.001 0.00005	0.12 0.07 0.0003	0.12 0.07 0.0003	0.23 0.19 0.11

Table 26 (continued)

Country	Year	Bone	Brain	Cardiovascular	Liver/spleen	Lung		Kidney	Thyroid		Other
						Ventilation	Perfusion		Scan	Uptake	
Egypt	1975-1979		0.01	0.001				0.1	0.02	0.02	
	1980-1984	0.1	0.03	0.005	0.01		0.004	0.03	0.03	0.0009	
	1985-1990	0.2	0.003	0.03	0.02	0.02	0.02	0.09	0.06	0.0008	0.008
Sudan	1985-1990	0.01	0.02		0.0007		0.0001	0.01	0.25	0.02	
Thailand	1976-1980	0.001	0.03	0.0007	0.04	0.00006	0.0002	0.002	0.07	0.10	0.0009
	1981-1985	0.01	0.01	0.002	0.005	0.0001	0.0005	0.005	0.05	0.001	0.0001
	1986-1990	0.04	0.003	0.007	0.024	0.002	0.002	0.006	0.08	0.09	0.001
Health-care level IV											
Ethiopia	1981-1985	-	0.001	-	0.004	-	-	0.0003	0.004	0.004	-
	1985-1989	-	0.02	-	0.03	-	-	0.0009	0.03	0.03	-

The entries in this Table are qualified as follows:

Australia: Administration of Tl-201 in cardiovascular examinations: 1980, –70%; 1984, –30%, 1991, –70%. Administration of Tc-99m in cardiovascular examinations: 1980, –30%; 1984, –70%; 1991, –30%.
Canada: Data are for Nova Scotia Province only (about 3.5% of the population). Data for 1985-1989 are weighted annual averages for Nova Scotia and Prince Edward Island, together comprising 4% of the population of Canada.
Egypt: Estimated from Kaar-El-Eini Centre Hospital, serving 25% of patients examined with radiation.
France: Values for 1990 are estimated from one hospital serving about 2% of the population.
India: Data also from [U1].
Iraq: Value given under "Other": Tc-99m.
Italy: Values given under "Other" are for oncology (Ga-67.)
Jamaica: Values given under "Other": placenta, Meckel's, Tc-99m.
Japan: Value given under "Other" is for Ga-67 examinations.
New Zealand: Value given under "Other" is for placental blood pool, In-113m.
Norway: Values given under "Other" are for full range of textbook procedures.
Romania: Values given under "Other" are for 1980 and 1990 for pancreas.
Sweden: Lung ventilation value for 1974: all Xe-133 gas; for 1985-1987: –70% Tc-99m aerosol, 20% Xe-133 gas, 10% In-133m. Renal value for 1984: –50% I-131 hipp, 40% I-125 hipp, 10% Cr-51 EDTA, <1% Tc-99m DTPA/DMSA; for 1985-1987: –45% Cr-51 EDTA, 30% I-131 hipp, 20% Tc-99m DTPA/DMSA, 5% I-125 hipp. Thyroid scan value for 1974: –75% I-131 NaI, 25% Tc-99m pertechnetate; for 1985-1987: –70% Tc-99m pertechnetate, 30% I-131 NaI.
Tunisia: Value given under "Other": gastrointestinal studies, colloids.
Thailand: Data are from the National Cancer Institute and the Rajavithi Hospital only.
Yugoslavia: Data are for Serbia only (about 40% of the population).

[a] Value is for ventilation and perfusion.
[b] Value is for both thyroid scan and thyroid uptake.
[c] Blood cells, Tc-99m, HMPAO.
[d] About 40% Au-198, 50% Tc-99m.
[e] Iodine-131 intake only.
[f] Iodine-131 uptake: 0.02.
[g] About 60% infection localization (Ga-67; 40% WBC (In-111 oxine).

Table 27
Average annual number of diagnostic nuclear medicine examinations per 1,000 population by health-care level
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

Examination	Year	Average [a]			Mean ± SD [b]			Median [b]		
		Level I	Level II	Level III-IV	Level I	Level II	Levels III-IV	Level I	Level II	Levels III-IV
Bone	1970-1980	0.84	0	0.001	1.4 ± 2.0	0	0.0005 ± 0.0006	0.60	0	0.0004
	1980-1985	2.6		0.041	2.4 ± 2.7		0.024 ± 0.045	2.1		0.002
	1985-1990	4.8	0.016	0.084	3.3 ± 2.6	0.11 ± 0.11	0.056 ± 0.099	2.8	0.10	0.011
Brain	1970-1980	1.3	0.23	0.022	1.9 ± 1.6	0.34 ± 0.59	0.017 ± 0.014	1.5	0	0.018
	1980-1985	1.1		0.013	1.1 ± 1.3		0.011 ± 0.011	1.0		0.011
	1985-1990	0.42	0.006	0.007	0.63 ± 0.92	0.12 ± 0.24	0.007 ± 0.008	0.36	0.010	0.003
Cardiovascular	1970-1980	0.53	0	0.0007	0.77 ± 2.1	0	0.0005 ± 0.0005	0.11	0	0.0004
	1980-1985	0.58		0.003	0.57 ± 0.74		0.002 ± 0.002	0.28		0.001
	1985-1990	2.6	0.008	0.014	1.3 ± 1.7	0.044 ± 0.11	0.008 ± 0.013	0.99	0.001	0
Liver/spleen	1970-1980	1.7	0.087	0.086	1.8 ± 1.4	0.12 ± 0.19	0.047 ± 0.069	1.2	0.013	0.021
	1980-1985	1.2		0.034	1.0 ± 0.75		0.029 ± 0.035	1.1		0.012
	1985-1990	1.4	0.023	0.016	0.89 ± 0.62	0.076 ± 0.06	0.014 ± 0.012	0.88	0.066	
Lung ventilation	1970-1980	0.13	0	0.0001	0.16 ± 0.32	0	0.00002±0.00003	0.06	0	0
	1980-1985	0.26		0.0001	0.19 ± 0.17		0.00003±0.00006	0.15		0
	1985-1990	1.2	0.001	0.008	0.49 ± 0.62	0.0001±0.0003	0.003 ± 0.007	0.25	0	0
Lung perfusion	1970-1980	0.34	0.024	0.0003	0.58 ± 0.65	0.036 ± 0.062	0.0001±0.0002	0.46	0	0.0001
	1980-1985	0.94		0.002	0.71 ± 0.81		0.001 ± 0.002	0.67		0.001
	1985-1990	2.2	0.002	0.008	0.78 ± 0.98	0.046 ± 0.071	0.005 ± 0.010	0.58	0.018	0
Kidney	1970-1980	1.8	0.041	0.006	1.9 ± 1.9	0.051 ± 0.079	0.0049 ± 0.0047	0.71	0.012	0.005
	1980-1985	1.3		0.009	1.6 ± 2.2		0.007 ± 0.012	0.48		0.001
	1985-1990	1.4	0.096	0.023	1.9 ± 2.1	0.053 ± 0.062	0.020 ± 0.036	0.88	0.27	0.006
Thyroid scan	1970-1980	1.3	0.40	0.066	2.1 ± 2.7	0.42 ± 0.55	0.067 ± 0.042	1.3	0.21	0.063
	1980-1985	2.5		0.048	2.3 ± 5.1		0.059 ± 0.049	0.90		0.056
	1985-1990	1.8	0.062	0.066	2.4 ± 4.0	0.39 ± 0.46	0.079 ± 0.087	1.4	0.25	0.063
Thyroid uptake	1970-1980	2.2	0.25	0.10	1.4 ± 1.5	0.083 ± 0.143	0.104 ± 0.092	0.77	0	0.060
	1980-1985	0.17		0.063	0.15 ± 0.16		0.078 ± 0.085	0.15		0.051
	1985-1990	0.55	0.17	0.052	0.38 ± 0.30	0.091 ± 0.13	0.051 ± 0.049	0.32	0.52	0.028
Total	1970-1980	10.9	0.86	0.25	15 ± 13	1.35 ± 1.23	0.24 ± 0.21	12.6	0.80	0.18
	1980-1985	6.9	0.10	0.19	12.7 ± 9.8	0.10 [c]	0.21 ± 0.13	10.3	0.10	0.21
	1985-1990	16.2	0.54	0.25	15 ± 10	1.1 ± 0.76	0.25 ± 0.15	12.0	1.0	0.26

[a] Overall average: total number of examinations divided by the total population of countries (thousands).
[b] Mean or median of individual values of countries.
[c] Data from India only.

Table 28
Age- and sex-distribution of patients undergoing diagnostic nuclear medicine examinations, 1985-1990
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*
		Bone				
I	Australia	6	25	69	47	53
	Canada	3.4	10	87	36	64
	Czechoslovakia	1.9	49	49	48	52
	Germany, Fed.Rep.	2	4	94	48	52
	Italy	0.8	8.2	91	34	66
	Kuwait	45	30	25	60	40
	Netherlands	3.9	24	72	53	47
	New Zealand	5.8	13	81	44	56
	Norway	2.6	11	86	52	48
	Romania	3.5	19	78	65	35
	Sweden	2.7	13	85	46	54
	Yugoslavia	3.4	30	67	41	59
	Average	3%	14%	83%	45%	55%
II	China	21	35	44	63	37
	Ecuador	5.1	25	70	63	37
	Iraq				30	70
	Peru	20	41	40	40	60
	Average	18%	35%	47%	51%	49%
III	Egypt	4.4	40	56	31	69
	Myanmar	0	40	60	60	40
	Sudan	0	2	98	49	51
	Thailand	0.3	33	67	17	83
	Average	1%	32%	67%	36%	64%
		Brain				
I	Australia [a]	20	22	58	52	48
	Canada	2.6	25	72	49	51
	Czechoslovakia	0	18	82	54	46
	Germany, Fed. Rep. of	0	25	75	25	75
	Italy	0	10	90	53	47
	Kuwait	4.7	76	20	90	10
	Netherlands	3.6	17	80	58	42
	New Zealand	4.5	30	66	53	47
	Norway	1.6	19	80	46	54
	Romania	8.6	48	43	57	43
	Sweden	0.1	26	74	50	50
	Yugoslavia	0	30	70	45	55
	Average	3%	23%	74%	46%	54%
II	China	17	24	59	60	40
	Ecuador	0	14	86	10	90
	Iraq				48	52
	Peru	48	26	26	40	60
	Average	24%	23%	53%	46%	54%
III	Myanmar	0	0	100	50	50
	Sudan	21	18	61	42	58
	Thailand	1.4	26	73	45	55
	Average	5%	16%	79%	46%	54%
IV	Ethiopia	12	64	24	58	42
		Cardiovascular				
I	Australia (thallium)	0.1	9	91	62	38
	Australia (technitium)	2	11	87	62	38
	Canada	6	9.5	85	62	38

Table 28 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
I (continued)	Czechoslovakia	3.8	52	45	64	36
	Germany, Fed. Rep. of	0	17	83	75	25
	Italy	0	11	89	76	24
	Kuwait	0.8	29	70	55	45
	Netherlands	0.6	9.1	90	66	34
	New Zealand	0.7	13	86	66	34
	Norway	0.1	23	77	58	42
	Romania	0	14	86	50	50
	Sweden (blood pool)	0	46	54	66	34
	Sweden (myocardical)	0	1.4	99	64	36
	Yugoslavia	2	25	73	75	25
	Average	1%	16%	83%	68%	32%
II	China				33	67
	Ecuador	0	10	90	75	25
	Average	0%	10%	90%	43%	57%
III	Egypt	0	0	100	70	30
	Myanmar	0	0	100	75	25
	Sudan	0	2	98	49	51
	Thailand	0.3	33	67	17	83
	Average	0%	11%	89%	51%	49%
Liver/spleen						
I	Australia	10	22	68	45	55
	Canada	5.7	16	79	44	54
	Czechoslovakia	4.7	55	40	58	42
	Italy	37	62	48	52	66
	Kuwait	1.6	25	73	45	55
	Netherlands	1.2	13	86	56	44
	New Zealand	1.2	14	85	50	50
	Norway	0.7	22	77	51	49
	Romania	2.9	34	63	50	50
	Romania	6.6	41	52	79	21
	Sweden	1.7	11	87	44	56
	Yugoslavia	8	30	62	66	34
	Average	5%	27%	67%	56%	44%
II	China	2.4	32	66	71	29
	Ecuador	5.8	32	62	50	50
	Iraq				34	66
	Peru	5.6	47	48	40	60
	Average	3%	34%	63%	62%	38%
III	Egypt	10	33	57	66	34
	Myanmar	0	50	50	50	50
	Sudan	4	45	51	50	49
	Thailand	0.3	27	73	50	50
	Average	4%	37%	60%	55%	45%
Lung ventilation						
I	Australia [b]	1	17	82	42	58
	Canada	1.7	10	88	66	34
	Czechoslovakia	0	63	37	53	47
	Germany, Fed. Rep. of	0	0	100	38	62
	Italy	0	5.6	94	54	46
	Kuwait	0	35	65	50	50
	Netherlands	0.6	14	85	61	39
	New Zealand	0.8	28	72	54	46
	Norway	1.4	15	83	40	60
	Romania [b]	0	37	63	67	33
	Sweden	0	21	79	49	51
	Average	0%	13%	86%	51%	49%
III	Egypt	0	58	42	48	52

Table 28 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
		Lung perfusion				
I	Canada	0.6	16	84	44	56
	Czechoslovakia	0.5	64	36	50	50
	Kuwait	0	35	65	50	50
	Netherlands	0.4	18	82	56	44
	New Zealand	0.6	24	75	54	46
	Norway	0.5	16	83	44	56
	Sweden	0.1	15	84	42	58
	Yugoslavia	0	33	67	65	35
	Average	0%	26%	73%	52%	48%
II	Ecuador	0	25	75	38	62
	Peru	8.3	33	58	50	50
	Average	5%	30%	64%	46%	54%
III	Myanmar	0	0	100	50	50
	Sudan	0	0	100	100	0
	Average	0%	0%	100%	69%	31%
		Kidney				
I	Australia	31	23	46	54	46
	Canada	25	31	44	30	70
	Czechoslovakia	21	39	40	50	50
	Germany, Fed. Rep. of	10	30	60	60	40
	Italy	14	21	65	54	46
	Kuwait	15	72	13	70	30
	Netherlands	14	38	48	45	55
	New Zealand	15	32	53	55	45
	Norway	3.8	26	70	49	51
	Romania	0.9	36	63	45	55
	Sweden	21	26	53	52	48
	Yugoslavia	5.7	32	62	29	71
	Average	14%	29%	57%	50%	50%
II	China	5.2	49	46	59	41
	Ecuador	0	89	11	10	90
	Iraq				58	42
	Peru	9.9	50	41	50	50
	Average	5%	52%	43%	54%	46%
III	Egypt	18	56	27	62	38
	Myanmar	0	100	0	75	25
	Sudan	15	36	49	52	48
	Thailand	1.7	22	76	14	86
	Average	8%	52%	40%	48%	52%
IV	Ethiopia	7.7	74	18	33	67
		Thyroid scan				
I	Canada	0.8	48	51	14	86
	Czechoslovakia	3.3	64	33	18	82
	Kuwait	5	75	20	20	80
	Netherlands	0.7	31	69	31	69
	New Zealand	1.7	29	69	16	84
	Norway	2.4	29	69	16	84
	Sweden	0.9	24	75	19	81
	Yugoslavia	0.5	30	70	28	72
	Average	1%	40%	59%	21%	79%
II	China	4.5	53	43	22	78
	Ecuador	9	22	69	14	86
	Peru	9.8	39	51	20	80
	Average	6%	49%	46%	21%	79%

Table 28 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
III	Egypt	9.5	62	33	24	76
	Myanmar	0	18	82	25	75
	Sudan	4	71	25	14	86
	Thailand	1.9	52	46	11	89
	Average	4%	50%	47%	19%	81%
IV	Ethiopia	0.7	80	20	40	60
	Thyroid uptake					
I	Australia	2	36	62	15	85
	Canada	0	42	58	14	86
	Czechoslovakia	0	56	44	24	76
	Germany, Fed. Rep. of	0	16	84	26	74
	Italy	1	37	62	16	84
	Kuwait	0	90	10	30	70
	Netherlands	0.4	37	63	40	60
	New Zealand	0	20	80	20	80
	Norway	1.5	22	77	17	83
	Romania	4.5	37	58	33	67
	Yugoslavia	0	45	55	18	82
	Average	1%	33%	66%	22%	78%
II	China	6.5	60	34	23	77
	Ecuador	9.1	22	69	14	86
	Iraq				24	76
	Peru	12	47	41	20	80
	Average	7%	55%	38%	22%	78%
III	Myanmar	0	35	65	30	70
	Sudan	4	71	25	14	86
	Thailand	1.8	52	46	12	88
	Average	2%	50%	48%	18%	82%
	Other					
I	Canada (Ga-67)	2.1	33	65	50	50
	Canada (In-111)	0	12	88	57	43
	Czechoslovakia, blood cells	6	59	35	52	48
	Italy (Ga-67)	0	26	74	50	50
	Netherlands	4.4	31	64	49	51
	Romania	0	63	37	100	0
	Yugoslavia	0	50	50	50	50
	Average	1%	35%	64%	58%	42%
II	China	2	27	71	64	36
	All organs					
I	Japan	3	7.7	89	54	46

The entries in this Table are as follows:

Canada: Data are for Nova Scotia Province only (about 3.5% of the population).
Peru: Data are from Instituto Peruano de Energia Nuclear only, where about 60% of all examinations are carried out.
Romania: Data are for 1990.
Sweden: Data are for Stockholm county only (about 20% of the population). Age distribution: 0-14 years, 15-39 years, >40 years.
Thailand: Data are from the National Cancer Institute and Rajavithi Hospital only.
Yugoslavia: Data are for Serbia only (about 40% of the population).

[a] Values are meaningful for early part of the period only, since CT and magnetic resonance imaging (MRI) have replaced Tc-99m.
[b] Includes lung perfusion.

Table 29
Average activity administered in diagnostic nuclear medicine examinations
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

PART I: BONE, BRAIN, CARDIOVASCULAR

Country	Year	Average activity administered (MBq) (Range in parentheses)							
		Bone		Brain			Cardiovascular		
		^{99m}Tc phosphate	Other/unknown	^{99m}Tc pertechnetate	^{99m}Tc gluconate	Other/unknown	^{99m}Tc erythrocytes	^{201}Tl chloride	Other/unknown
Health-care level 1									
Argentina	1985-1989		555			740			740
Australia	1970 1980 1984 1991	 730 783 827		456 754 801 -	 492 773 -		 643 874 878	 64 76 82	
Canada	1970-1974 1985-1989	 740 (74-925)	3.7 [a]		 740	18.5 [b]	 740 (555-925)		
Czechoslovakia	1970-1974 1976-1985 1986-1990	450 (400-600) 500 500 (400-600)	 180	45 (25-240) 180 240 (25-320)		700 [c]	450 (400-500) 500 500 (400-550)	 70 70	 700 [d]
Denmark	1989-1990	628		695	615	380 [c], 665 [c]	765	98	880 [d], 370 [f]
Finland [A12]	1975 1982	350 (185-555) 520 (370-800)		460 (370-555) 520 (370-740)			590 (370-740) 600 (370-740)		
Germany, Fed.Rep.	1986-1990	621		614	537	525 [c], 130 [g]	730	74.9	
Italy	1985-1989	614 (370-740)				583 [h] (492-740)	709 (55-925)		
Japan	1985-1989	720				135 [g]		100	
Kuwait	1985-1989	805 (716-894)		740 (626-854)			647 (555-739)		
Netherlands	1985-1989	500		350 (400-750)			750 (400-750)	100 (75-120)	
New Zealand	1970-1974 1985-1989	360 (100-677) 720 (74-1110)		468 (155-900) 730 (74-925)			 85 (63-167)		390 (344-574) [i] 731(111-1295)[i]
Norway	1970-1974 1985-1989	507 (± 121 SD) 574 (± 91 SD)		523 (± 130 SD) 615 (± 139 SD)			764 (± 145 SD)	96 (± 56 SD)	

Table 29 (continued)

Country	Year	Average activity administered (MBq) (Range in parentheses)							
		Bone		Brain			Cardiovascular		
		^{99m}Tc phosphate	Other/unknown	^{99m}Tc pertechnetate	^{99m}Tc gluconate	Other/unknown	^{99m}Tc erythrocytes	^{201}Tl chloride	Other/unknown
Poland [U1]	1981				592				
Romania	1980-1989 1990	370 455	185 [i] 5.3 [j]	370 555		740 [k]			0.4 [l] / 1.9 [m] 460 [k] / 585 [l]
Sweden	1974 1985-1989	330 420 (160-600)		400 530 (350-700)			370 650 (50-900)	55 72 (50-120)	
Switzerland	1976	555				111	555		
United Kingdom	1981-1985	518 (333-740)		491 (333-740)	572 (370-750)	536 [c] (370-740)	658 (296-800)	68 (40-100)	464 [k] / 566 [l] (185-800)
Yugoslavia	1985-1989	555 (350-740)				555 [c] (370-740)	555 (100-740)		
Health-care level II									
China Beijing area Entire nation	 1985-1989 1986-1989	 740 (55-925)	 4.8 [e]	 370 (296-555)		 138 [k]			 370 (222-518) 1.5 [e]
Ecuador	1970-1974 1985-1989	 740 (-925)				7.4 (-9.3) 555 [c] (-740)	 555 (-740)		
India	1985-1989	670 (370-925)		516 (370-925)			659 (407-1110)	74 (56-111)	
Iraq	1985-1989	(650-750)				(650-750) [k]			
Jamaica	1970-1974 1985-1989	 182 (-740)				370 [c] (-740) 182 [c] (-740)	 370 (-740)		
Peru	1985-1989	740 (555-925)				740 [c] (555-925)			
Tunisia	1970-1974 1985-1989	555 370				296 [c] 185 [c]	 259		
Health-care level III									
Egypt	1986-1990	540		270		500 [c]	500	81	270 [d]
Myanmar	1976-1985 1986-1990	370 370		370 370					185 [e] 185 [e]

Table 29 (continued)

Country	Year	Average activity administered (MBq) (Range in parentheses)							
		Bone		Brain			Cardiovascular		
		^{99m}Tc phosphate	Other/unknown	^{99m}Tc pertechnetate	^{99m}Tc gluconate	Other/unknown	^{99m}Tc erythrocytes	^{201}Tl chloride	Other/unknown
Sudan	1986-1990	555			444				
Thailand	1976-1980 1981-1985 1986-1990	275 269 197				312 [c] 350 [c] 359 [c]	740 584 475		
Health-care level IV									
Ethiopia	1970-1989			500 [c] (370-555)		500 (370-555)			

PART II: LIVER/SPLEEN, LUNG, KIDNEY

Country	Year	Average activity administered (MBq) (Range in parentheses)							
		Liver / spleen			Lung			Kidney	
		^{99m}Tc colloid	^{99m}Tc HIDA	Other/unknown	^{99m}Tc MAA	^{99m}Tc microspheres	Other/unknown	^{131}I hippurate	^{123}I hippurate
Health-care level I									
Argentina	1985-1989		111				74		
Australia	1970 1980 1984 1991	61 115 121 128			120 110 174	60 97 102 -	111 [o] 434 [o] 371/222 [p] 252 [o]		
Canada	1970-1974 1985-1989	111 (37-148)		111 [q]	111 (37-148)	185 (148-222)	18.5		
Czechoslovakia	1970-1974 1976-1985 1986-1990	60 (40-120) 240 240 (80-300)	160 160		160 (100-400) 240 280 (200-400)	160 (100-400) 240 (200-400)	 80 [p] 80 [p]		
Denmark	1989-1990	65-129	183			102	260 [o] / 10.5 [p]	1-29	108
Finland [A12]	1975 1982	74 (19-300) 120 (40-220)		130 (74-220) 120 (74-200)				0.9 (0.4-3.7) 1.0 (0.4-1.6)	
Germany, Fed. Rep.	1986-1990	135-143	168	141-160 [r]/3.7 [s]	129	148		1.4 [r]/11 [s]	40.4

Table 29 (continued)

Country	Year	Average activity administered (MBq) (Range in parentheses)							
		Liver / spleen			Lung			Kidney	
		^{99m}Tc colloid	^{99m}Tc HIDA	Other/unknown	^{99m}Tc MAA	^{99m}Tc microspheres	Other/unknown	^{131}I hippurate	^{123}I hippurate
Italy	1985-1989			140 [h] (55-448)			116/191 [h] (55-925)		
Japan	1985-1989	196			230				
Kuwait	1985-1989	92 (55-129)	92 (55-129)		155 (118-192)	1042 (908-1176)			
Netherlands	1985-1989	75 (75-110)	100		75 (75-150)			2	20 (2-20)
New Zealand	1970-1974 1985-1989	101 (26-259) 162 (37-370)			146 (33-370) 151 (30-750)				
Norway	1970-1974 1985-1989	118 (± 47 SD) 125 (± 40 SD)			95 (± 39 SD) 98 (± 29 SD)			4.2 (± 3 SD) 4.9 (± 1.1 SD)	
Poland [U1]	1981	148						1.2	
Romania	1980 1990	55.5		9.3 [v]/11.1 [n]/111 [q] 84 [h]/8.8 [v]	74 148		9.3 [v]/74 [w] 11.1 [v]	9.3 3.5	
Sweden	1974 1985-1989	70 125 (70-400)			66 87 (35-120)	440 (30-1900)	5.1 [o] 420 [o] (10-800)	0.9 0.9 (0.1-4.5)	
Switzerland	1976			74	37		185 [o]		
United Kingdom	1981-1985	91/57 (37-200)	144 (40-370)	56 [h] (8-150)	88 (37-222)	88 (37-222)	243 [o] / 1724 [w] (74-3700)	2.5 (0.4-3.7)	28 (10-185)
Yugoslavia	1970-1974 1985-1989			10 (8-12) 74 (60-150)			3.7 (3-5) 74 (60-150)	6 (5-8) 6 (5-8)	
Health-care level II									
China Beijing area Entire nation	 1970-1974 1985-1989 1986-1990	 222 (185-370)		 74 (37-100) 97 [h] / 22 [v]				 0.37 (0.26-0.56) 0.37	
Ecuador	1970-1974 1985-1989	 296 (-444)		9.3 (-13)	 296 (-444)			1.1 (-1.9)	
India	1985-1989	140 (74-189)				128 (74-277)		1.5 (0.3-2.6)	
Iraq	1985-1989	(80-120)							

Table 29 (continued)

Country	Year	Average activity administered (MBq) (Range in parentheses)							
		Liver / spleen			Lung			Kidney	
		^{99m}Tc colloid	^{99m}Tc HIDA	Other/unknown	^{99m}Tc MAA	^{99m}Tc microspheres	Other/unknown	^{131}I hippurate	^{123}I hippurate
Jamaica	1970-1989	37 (-111)			12 (-111)				
Peru	1985-1989	185 (111-259)			110 (74-148)				
Tunisia	1970-1974 1985-1989	74		19 [v]		111 74			
Health-care level III									
Egypt	1986-1990	135	135		135		270 [c]	9	
Myanmar	1976-1990	74			74				
Sudan	1986-1990	148	148		148				
Thailand	1986-1980 1981-1985 1986-1990	101 104 137			260 269 118		1152 [h]		
Health-care level IV									
Ethiopia	1970-1974 1986-1990	37 (37-74) 111		74 (37-74)					

PART III: KIDNEY, THYROID

Country	Year	Average activity administered (MBq) (Range in parentheses)							
		Kidney			Thyroid				
		^{99m}Tc gluconate	^{99m}Tc other	Other/unknown	^{99m}Tc pertechnetate	^{131}I uptake	^{131}I scan	^{123}I uptake	^{123}I scan
Health-care level I									
Argentina	1985-1989		555 [c]						
Australia	1970 1980 1984 1991	109 279 513 234	 490 [c] 427 [c] 415 [c]		61 145 156 178	1.4 0.5 0.7 1.0			

Table 29 (continued)

Country	Year	Average activity administered (MBq) (Range in parentheses)							
		Kidney			Thyroid				
		^{99m}Tc gluconate	^{99m}Tc other	Other/unknown	^{99m}Tc pertechnetate	^{131}I uptake	^{131}I scan	^{123}I uptake	^{123}I scan
Canada	1970-1974 1985-1989		 296 [c] (74-370)	11.1 [r]	 260 (185-370)	0.6 0.6 (0.4-0.6)	0.9		
Czechoslovakia	1970-1974 1976-1985 1986-1990		80 [c,y] (60-120) 180 [c] / 150 [y] 180 [c] / 150 [y]		60 (40-160) 240 240 (60-300)	1.5 (1-2) 1 1 (1-2)			
Denmark	1989-1990		150 [c] / 98 [z]		140		6.9		72
Finland [A12]	1975 1982				90 (37-185) 140 (48-370)	1.0 (0.4-2.0) 1.3 (0.4-1.9)	2.2 (0.7-3.7) 2.1 (1.1-3.7)		
Germany, Fed.Rep.	1986-1990		282 [c] / 160 [y]	315 [aa]/502 [ii]/ 10.2 [bb]	42.1		9.46	4.44	
Italy	1985-1989			1.4 [n]	78	1			
Japan	1985-1989		320 [c,z]		360 (males) 450 (females)		6		
Kuwait	1985-1989		259 (148-370)		185 (148-222)	0.3 (-0.7)			
Netherlands	1985-1989				50	0.2 (0.2-7)		2 (2-20)	30
New Zealand	1970-1974 1985-1989	210 (81-592)	116 [y] (74-1110) 340 [c] (20-623)		140 (22-460) 144 (9-370)	0.7 (0.11-3.9) 9.5 (0.7-33)			
Norway	1970-1974 1985-1989		150 113 (± 91 SD)		71 (± 39 SD) 69 (± 40 SD)	1.1 (± 0.5 SD) 1.2 (± 0.7 SD)	1.2 (± 0.3 SD) 1.5 (± 0.4 SD)		
Poland [U1]	1981	136	192 [y]		37	2.7			
Romania	1980 1985-1989 1990		148 [c] / 222 [i] 222 295 [c]	74 [w]	37 37 43.5	1.1	3.0 3.0 2.2		
Sweden	1974 1985-1989		140 115 (1-270)		70 90 (10-200)	0.4 0.9 (0.1-14)	1.8 2.5 (0.3-30)		
Switzerland	1976			185	13			37	
United Kingdom	1981-1985		246[c]/102[y] (37-555)		11-76 (0.6-200)		1.8/108[r] (0.18-500)	45 (0.2-10)	13 (2-100)
Yugoslavia	1970-1974 1985-1989				 74 (60-120)	0.4 (0.3-0.4) 0.4 (0.3-0.5)	3.7 (3-5)		

Table 29 (continued)

Country	Year	Average activity administered (MBq) (Range in parentheses)							
		Kidney			Thyroid				
		^{99m}Tc gluconate	^{99m}Tc other	Other/unknown	^{99m}Tc pertechnetate	^{131}I uptake	^{131}I scan	^{123}I uptake	^{123}I scan
Health-care level II									
China									
Beijing area	1970-1974					0.11 (0.07-0.15)	3.7 (1.5-9.3)		
	1985-1989					0.11 (0.07-0.15)	11.1 (7.4-18.5)		
Entire nation	1986-1990		260 [y] (222-296)		23	0.10	5.9		
Ecuador	1970-1974					3.0 (-5.6)	3.0 (-5.6)		
	1985-1989		296 [c] (-444)			3.0 (4.4)	3.0 (4.4)		
India	1985-1989		194 (74-555)		94 (15-148)	0.74 (0.2-1.9)	1.7 (0.9-3.7)		
Iraq	1985-1989		(200-400) [c, z]						
Jamaica	1970-1974					10 (-25)	10 (-26)		
	1985-1989		74 (-182)		74 (-148)				
Peru	1985-1989		740 (555-925)		185 (111-259)	0.4 (0.2-0.4)			
Tunisia	1970-1974		185 [c]		111	3.7			
	1985-1989		111 [c]		111	1.1			
Health-care level III									
Egypt	1986-1990		81 [c], 135 [y]		81	0.28	2.7		
Myanmar	1976-1980		74 [y]			0.37	1		
	1981-1985		74 [y]			0.37	1		
	1986-1990		74 [y]			0.37	1		
Sudan	1976-1980					1.1	1.1		
	1981-1985					1.1	1.1		
	1986-1990		148 [c], 74 [y]		37	1.3	1.3		
Thailand	1976-1980		12 [c]			0.5	0.45		
	1981-1985		20 [c]			0.35	0.47		
	1986-1990		21 [c]			0.12	0.23		
Health-care level IV									
Ethiopia	1970-1989		74 [y] (37-74)			1.7 (1.7-2.2)	1.7		

Table 29 (continued)

The entries in this Table are qualified as follows:

Australia: Owing to the substitution of CT and MRI for Tc-99m, the number for brain examinations with Tc-99m pertechnetate and Tc-99mTc-gluconate for 1991 is too small to state average. Information pertaining to Part III of Table: ^{67}Ga citrate tumour/infection, 1980: 166 MBq; 1984: 210 MBq; 1991: 212 MBq.

Czechoslovakia: Information pertaining to Part III of Table: Tc-99m HMPAO blood cells, 1976-1990: 160 MBq.

Canada: Data are for Nova Scotia Province only (about 3.5% of the population).

New Zealand: Almost all ^{131}I uptakes are done on patients receiving large therapeutic ^{131}I doses. In effective dose estimations uptake should be assumed = 0. About one third of ^{99m}Tc thyroid scans are also used to assess uptake.

Yugoslavia: Data are for Serbia and Macedonia only (about 50% of the population). Data for 1970-1974 are for Serbia only.

[a] Radioisotope used is Sr-85.
[b] Radioisotope compound used is I-131 RHSA.
[c] Radioisotope compound used is Tc-99m HMPAO.
[d] Radioisotope compound used is Tc-99m MIBI.
[e] Radioisotope compound used is Tc-99m DTPA.
[f] Radioisotope compound uses is Tc-99m PP.
[g] Radioisotope compound used is I-123 amphetamine.
[h] Radioisotope used is Tc-99m.
[i] Radioisotope used is Tc-99m pertechnetate.
[j] Radioisotope used is Se-75 methionine.
[k] Radioisotope compounds used are Tc-99m phosphate/phosphonate.
[l] Radioisotope compound used is Fe-59 citrate.
[m] Radioisotope compound used is Cr-51 citrate.
[n] Radioisotope used is I-131.
[o] Radioisotope used is Xe-133.
[p] Radioisotope form used is Tc-99m aerosol.
[q] Radioisotope compound used is In-111m colloid.
[r] Radioisotope compounds of Tc-99m are millimicrospheres, denatured erythrocytes and phytate.
[s] Radioisotope form used are Cr-51 denatured erythrocytes.
[t] ING.
[u] Sequence.
[v] Radioisotope used is Au-198.
[w] Radioisotope used is In-113.
[x] Radioisotope used is Hg-197.
[y] Radioisotope compound used is Tc-99m DMSA.
[z] Radioisotope compound used is Tc-99m MAG3.
[aa] Radioisotope compound used is Tc-99m gluconate.
[bb] Radioisotope compound used is Cr-51 EDTA.

Table 30
Effective dose equivalents to patients from diagnostic nuclear medicine examinations (mSv)

Examination	*Health-care level I*			*Health-care level II*
	Czechoslovakia, 1987 [H30]	*Denmark, 1990 [E3]*	*Italy, 1989 [D11]*	*China, 1985 [Z6]*
Bone	4.5	1.1-6.8	0.5	
Brain	3.5-6	0.6-11.3	3.7	1.8
Cardiovascular	4.3-17.2	3.0-22.5	13	
Liver/spleen	1.4-3.5	0.9-2.6	1.9	22, 1.2 [a]
Lung ventilation		0.07-0.25		
Lung perfusion	1.2	1.1	1.4	
Kidney	0.04-2.1	0.01-1.3	1.7	<0.1
Thyroid scan	1-36.3	2.1-13.7	2.1	94, 0.3 [b]
Thyroid uptake	3.1	3		1.5
Average	2-4	3	4.5	15-30

[a] When Tc-99m is available. Standard procedure: Au-198.
[b] When Tc-99m is available. Standard procedure: I-131.

Table 31
Age-dependent analysis of effective dose equivalents to patients from diagnostic nuclear medicine examinations

Organ	*Radiopharmaceutical*	*Dose factor (mSv/MBq)*	*Average activity [a] (MBq)*	*Effective dose equivalent per examination (mSv)*	*Examinations per 1,000 population [a]*	*Effective dose equivalent per caput (μSv)*
Age group: 0-9 years						
Bone	Tc-99m phosphate	0.025	380	9.5	0.17	1.6
Brain	Tc-99m gluconate	0.024	460	11.1	0.05	0.6
Cardiovascular	Tl-201 chloride	2.0	37	73	0.004	0.3
	Tc-99m erythrocytes	0.025	555	13.9	0.006	0.08
Age group: 10-19 years						
Bone	Tc-99m phosphate	0.010	570	5.7	0.20	1.1
Brain	Tc-99m gluconate	0.011	690	7.6	0.19	1.5
Cardiovascular	Tl-201 chloride	0.36	55	19.7	0.004	0.08
	Tc-99m erythrocytes	0.011	830	9.1	0.006	0.05
Age group: adults						
Bone	Tc-99m phosphate	0.008	790	6.3	6.39	40.3
Brain	Tc-99m gluconate	0.009	962	8.7	4.47	38.7
Cardiovascular	Tl-201 chloride	0.23	76	17.5	0.79	13.8
	Tc-99m erythrocytes	0.0085	1156	9.8	1.19	11.7
Liver/spleen	Tc-99m colloid	0.014	117	1.6	4.81	7.9
	Tc-99m HIDA	0.024	226	5.4	0.16	0.9
Lung	Tc-99m MMA	0.012	114	1.4	1.83	2.5
Kidney	Tc-99m gluconate	0.009	523	4.7	0.75	3.5
Thyroid	Tc-99m pertechnetate	0.015	250	3.8	1.12	4.5
	I-131 ionic	6.6 [b]	0.38	2.5	1.36	3.4
Total					23.6	127.2

[a] Activity administered and examination frequency for Manitoba, Canada [H17]. For children, it was assumed here that activities administered were reduced according to Beentjes [B20].

[b] Assumed thyroid uptake: 15%.

Table 32
Collective doses from nuclear medicine examinations, 1985-1990

Examination	*Number of examinations per 1,000 population*				*Effective dose per examination (mSv)*				*Annual collective effective dose (man Sv)*			
	Level I	*Level II*	*Levels III-IV*	*World*	*Level I*	*Level II*	*Levels III-IV*	*World*	*Level I*	*Level II*	*Levels III-IV*	*World*
Bone	4.8	0.016	0.084	1.3	6.3	6.3	6.3	6.3	40700	270	690	41700
Brain	0.42	0.006	0.007	0.11	8.7	8.7	8.7	8.7	4930	140	80	5150
Cardiovascular	2.6	0.008	0.014	0.68	14	14	14	14	49900	300	260	50400
Liver/spleen	1.4	0.023	0.016	0.38	3.5	22	22	4.3	6660	1330	460	8450
Lung ventilation	1.2	0.001	0.008	0.30	0.3	0.3	0.3	0.3	470	1	3	480
Lung perfusion	2.2	0.002	0.008	0.56	1.4	1.4	1.4	1.4	4160	7	15	4180
Kidney	1.4	0.096	0.023	0.41	4.7	4.7	4.7	4.7	8880	1190	140	10200
Thyroid scan	1.8	0.062	0.066	0.51	3.8	94	94	12	9290	15300	8130	32700
Thyroid uptake	0.55	0.167	0.052	0.24	2.5	2.5	2.5	2.5	1860	1100	170	3130
Total	16.4	0.38	0.28	4.4					127000	19600	9900	156000
Average dose per examination (mSv)					5.7	20	27	6.7				
Average dose per caput (mSv)					0.094	0.0075	0.0076	0.030				

Table 33
Contribution of various types of nuclear medicine examinations to the collective dose, 1985-1990
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

Examination	*Contribution to total collective dose (%)*			
	Level I	*Level II*	*Levels III-IV*	*World*
Cardiovascular	39	1	3	32
Bone	32	1	7	27
Thyroid scan	7	78	82	21
Kidney	7	6	1	7
Liver/spleen	5	7	5	5
Brain	4	1	1	3
Lung perfusion	3	0.4	0.2	3
Thyroid uptake	1	6	2	2
Lung ventilation	0.4	0.004	0.03	0.3

Table 34
Annual individual and collective effective dose from nuclear medicine examinations
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	Year	Effective dose equivalent H_E (mSv)		Collective effective dose (man Sv)	Reference
		Per individual patient	Per caput		
Health-care level I					
Australia	1980	2.5	0.02	290	[U1]
Bulgaria	1980	8.4	0.11	970	[U1]
Canada	1980	3.8	0.17	4200	[L7]
Manitoba	1985	5.2	0.13	127	[H17]
Quebec	1989	6.4	0.42	2800	[R10]
Czechoslovakia	1983	2.2	0.04	430	[H30]
	1987	2.4	0.06	610	
Denmark	1985	3	0.05	250	[E3]
	1990	3	0.05	250	
Finland	1982			430 [c]	[A12]
German Democratic Republic	1978	3.4	0.03	480	[E5]
	1981	2.2	0.02	340	
Germany, Fed. Rep. of					
(Bavaria and West Berlin)	1985-1986	2.7-3.2 [a]	0.11-0.12 [a]	7000	[K10]
Greece (northern part)	1984-1988	2.5 [b]			[P20]
Italy	1982	2.9	0.03	1510	[D11]
	1983	3.3	0.03	1890	
	1989	4.5	0.04	2450	
Japan	1982	4.1	0.035	4240 [f]	[M11, M12]
Netherlands	1984	2.9	0.034	480 [g]	[B20]
		2.7 [c]	0.031	450 [c]	[B20]
Poland	1981	25.7 [d]	0.06	2000	[S41, U1]
Sweden	1986	3.5	0.05	420	[V4]
USSR	1981	8.2	0.032	8600	[N4]
United Kingdom	1982	2.5	0.02	1000	[H10]
United States	1982	5.0	0.14	32100	[M41, N1]
Health-care level II					
China	1981-1985	8 [h] 15-34 [i]	0.005 0.02	4980 21000	[U1, Z6]
India	1985-1989	7.9 [i]	0.002	1340	

[a] Value for Bavaria and West Berlin extrapolated to the entire country (except new Bundesländer).
[b] Corresponds to 2.0 mSv/examination (some patients had more than one examination).
[c] Estimate accounting for age distribution of population.
[d] High value caused by ubiquitous use of I-131, 47% of all examinations with an average collective dose per patient of 51.5 mSv.
[e] Of this value 51% is due to Tc-99m, 47% to I-131 and 2.1% to all other nuclides.
[f] Collective dose component to women is 1,910 man Sv.
[g] The collective dose due to the somatic part of the effective dose equivalent is reported to be 575 man Sv [B20].
[h] Probably underestimate due to low precision in computation.
[i] Using two different methods to estimate collective dose per examination from [Z6]. High value depends on I-131 thyroid scintigraphy with collective dose per examination being 94 mSv.
[j] Mainly due to use of I-131.

Table 35
Estimated doses to the world population from nuclear medicine examinations

Health-care level	Population (millions)	Annual per caput effective dose equivalent (mSv)	Annual collective effective dose equivalent (10^3 man Sv)
I	1350	0.09	130
II	2630	0.008	20
III	850	0.008	6
IV	460	0.008	4
Total	5290	-	160
Average	-	0.03	-

Table 36
Total annual number of radiotherapy treatments per 1,000 population
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	Teletherapy			Brachytherapy		
	1970-1979	1980-1984	1985-1990	1970-1979	1980-1984	1985-1990
Health-care level I						
Argentina						0.2
Australia	2.0		1.5	0.8		0.2
Canada		1.6	2.9			
Cuba			0.2			0.05
Czechoslovakia	2.9	4.2	2.7	0.2	0.1	0.1
Denmark			1.2			0.1
Finland			1.2			
Iceland [L16]			1.2			
Japan	0.7		0.7	0.2	0.2	
Kuwait			0.2			0.06
Luxembourg						0.07
Malta						0.03
Netherlands			1.8			0.1
New Zealand	0.4	0.4	0.6	0.1	0.08	0.07
Norway	0.5 [a]		3.9	0.2		0.1
Romania		1.7	6.8		0.06	
Sweden	0.6		0.8	0.3	0.2	0.1
Switzerland			1.8			0.1
United Kingdom		2.4 [b]				
United States		2.4 [b]				
Yugoslavia			0.6			0.9
Average	1.0	2.4 [b]	1.2	0.26	0.17	0.24
Health-care level II						
Barbados			0.6			0.2
China			0.2			0.08
Ecuador	0.03		0.08	0.006		0.02
India			0.1			0.03
Iraq			0.1			0.009
Jamaica			0.1			0.07
Peru	0.09		0.1	0.03		0.04
Turkey	0.7	0.9	0.7			
Average	0.1		0.2	0.02		0.06
Health-care level III						
Egypt			0.04			0.0005
India	0.07			0.02		
Myanmar		0.2	0.2	0.01	0.01	0.02
Sudan			0.08			0.0003
Thailand			0.09		0.04	0.04
Average			0.1	0.02	0.03	0.02

[a] Malignant disease only.
[b] Value includes brachytherapy.

Table 37
Average annual number of teletherapy and brachytherapy treatments per 1,000 population
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures, unless otherwise indicated

PART I: TELETHERAPY

Country	Year	Leukaemia	Lymphoma	Breast tumour	Respiratory system	Female genital organs	Wilms' tumour	Neuro-blastoma	Benign diseases
Health-care level I									
Australia	1970-1974 1985-1989	0.010 0.021	0.12 0.017	0.27 0.19	0.16 0.29	0.042 0.11	0.003 0.0006	0.041 0.001	1.3 0.9
Czechoslovakia	1970-1974 1976-1980 1981-1985 1986-1990	0.004 0.006 0.006 0.004	0.058 0.028 0.024 0.017	0.19 0.15 0.16 0.16	0.19 0.15 0.17 0.16	0.19 0.071 0.076 0.075	 0.001 0.001 0.0004	 0.0001	1.2 3.4 3.8 2.3
Denmark	1985-1989	0.009	0.058	0.18	0.11	0.14	0.11		
Finland	1987	0.016	0.032	0.29	0.20	0.081	0.004	0.002	
Japan	1970-1974 1975-1979 1985-1990		0.75 [a] 0.025 0.046	3.33 [a] 0.075 0.059	2.34 [a] 0.093 0.17	 0.12 0.081			0.35 [a] 0.013 0.002
Kuwait	1985-1989	0.016	0.021	0.059	0.029	0.022	0.002	0.002	0.012
Netherlands	1987 1988-1989	0.028 0.045	0.076 0.15	0.49 0.98	0.44 0.85	0.11 0.22			
New Zealand	1970-1974 1975-1979 1980-1984 1985-1989	0.003 0.009 0.016	0.033 0.027 0.027 0.053	0.14 0.086 0.077 0.21	0.13 0.014 0.16 0.20	0.086 0.09 0.082 0.078	 0.001	 0.002	 0.007
Norway	1970-1974 1985-1989	0.001 0.002	0.044 0.074	0.18 0.18	0.047 0.16	0.27 0.17	 0.0001	0.0003 0.001	 3.3
Romania	1980 1990	0.043 [b] 0.025	 0.028	0.12 0.53	0.12 0.49	0.13 1.1			1.2 3.8
Sweden	1970-1974 1985-1989	0.029 0.024	0.075 0.093	0.36 0.41	0.054 0.077	0.089 0.14	0.002 0.002	0.007 0.001	0.009 0.023
Yugoslavia	1985-1989	0.017	0.031	0.12	0.13	0.26	0.010	0.061	0.007
Average	1970-1979 1980-1984 1985-1990	0.010 0.029 0.018	0.038 0.025 0.045	0.12 0.13 0.16	0.11 0.14 0.20	0.11 0.11 0.16	0.001 0.001 0.008	 0.020	0.40 2.0 0.48
Health-care level II									
Barbados	1985-1989			0.24	0.064	0.24	0.016		
China Beijing area Entire nation	 1970-1974 1985-1986 1986-1990	 0 <0.0001	 0.016 0.014	 0.019 0.021 0.036	 0.023 0.034 0.037	 0.009 0.010 0.045	 0 0.0001	 0.003 0.009	 0.001 0.004
Ecuador	1970-1974 1985-1989	0.0005 0.002	0.002 0.007	0.008 0.021	0.002 0.005	0.015 0.042	0 0.0001	0 0.001	0.002 0.005
India	1985-1989	0.0032	0.0047	0.011	0.0087	0.036	0.0007	0.0004	0.0036
Iraq	1985-1989	0.009	0.005	0.041	0.037	0.015	0.001	0.0009	0
Jamaica	1985-1989		0.004	0.055	0.005	0.002	0.0006		0.064
Peru	1970-1974 1985-1989	0.014 0.012		0.013 0.016	0.005 0.009	0.053 0.068	0.0006 0.001	0.0003 0.0004	 0.013
Turkey	1976-1979 1980-1984 1985-1990	0.19 0.22 0.17	0.16 0.28 0.18	0.10 0.10 0.10	0.13 0.12 0.046	0.04 0.06 0.040	0.04 0.07 0.042	0.03 0.02 0.006	
Average	1970-1980 1985-1990	0.016 0.004	0.015 0.005	0.016 0.026	0.011 0.025	0.042 0.041	0.003 0.001	0.002 	 0.004

Table 37 (continued)

Country	*Year*	*Leukaemia*	*Lymphoma*	*Breast tumour*	*Respiratory system*	*Female genital organs*	*Wilms' tumour*	*Neuro-blastoma*	*Benign diseases*
Health-care level III									
Egypt	1985-1990	0.002	0.006	0.026	0.003	0.0005	0.001	0.0005	0.004
India	1970-1974	0.0007	0.0017	0.0047	0.0022	0.020	0.0003	0.0001	0.0035
Myanmar	1980-1984 1985-1990	0.002 0.001	0.004 0.004	0.012 0.013	0.023 0.024	0.019 0.018	0.0002 0.0001	0.0001 0.0002	
Sudan	1985-1990	0.005	0.008	0.009	0.003	0.008	0.002	0.002	
Thailand	1986-1990	0.010	0.010	0.019	0.008	0.037	0.001		0.0002
Average	1970-1980 1980-1984 1985-1990	0.0007 0.002 0.005	0.002 0.004 0.007	0.005 0.012 0.018	0.002 0.023 0.009	 0.019 0.017	0.0003 0.0002 0.0008	0.0001 0.0001 0.0006	0.004 0.004

PART II: BRACHYTHERAPY

Country	*Year*	*Breast tumour*	*Prostate tumour*	*Female genital organs*		*Brain tumour*	*Other tumours*	*Benign diseases*
				Radium	*Afterloading*			
Health-care level I								
Australia	1970-1974 1985-1989	 0.016	0.001	0.068 [c] 0.019 [c]	 0.034		0.18 0.076	0.51
Czechoslovakia	1970-1974 1976-1980 1981-1985 1986-1990			0.064 0.16 0.091 0.034	0.16 0.031 0.046 0.10		0.003 0.002	0.006 0.002 0.0003
Denmark	1985-1989	0.020	0.0009	0.073	0.012		0.003	
Japan	1970-1974 1975-1979 1980-1984	0.001		0.082 0.19 0.025	 0.035		0.024 0.0007	
Kuwait	1985-1989				0.006			0.054
Malta	1985-1989				0.028			
Netherlands	1988-1989	0.017	0.001	0.049				
New Zealand	1985-1989				0.066			
Norway	1970-1974 1985-1989	0.001	 0.0005	0.13 0.043	 0.049	 0.0002	0.010 0.005	
Romania	1980				0.054		0.005	
Sweden	1970-1974 1985-1989		0.0004 0.002	0.037 0.029 [d]	0.006 0.14			0.001 0.004
Yugoslavia	1985-1989	0.029	0.015	0.15	0.63	0.022	0.004	
Average	1970-1979 1980-1984 1985-1990	0.0001 0.019	0.0005 0.005	0.16 0.034 0.062	0.068 0.035 0.22	 0.010	0.016 0.004 0.024	0.16 0.002 0.021
Health-care level II								
Barbados	1985-1989			0.24 [c]				
China	1986-1990	0.02		0.0004	0.007	0.008	0.047	
Ecuador	1970-1974 1985-1989			0.006 0.015	 0.002			
India	1970-1974 1985-1989	 0.0003	 0.00001	0.008 0.002	0.012 0.022		0.0006 0.002	0.0002 0.0007

Table 37 (continued)

Country	Year	Breast tumour	Prostate tumour	Female genital organs		Brain tumour	Other tumours	Benign diseases
				Radium	Afterloading			
Iraq	1985-1989			0.009 [e]				
Jamaica	1985-1989			0.061				0.012
Peru	1970-1974 1985-1989			0.031 0.044			0.001 0.0004	
Average	1970-1979 1980-1984 1985-1990	0.012	0.00001	0.024 0.002	 0.013	 0.008	0.0007 0.028	 0.001
Health-care level III								
Egypt	1985-1990			0.005				
Myanmar	1975-1979 1980-1984 1985-1990			0.011 0.012 0.016				
Sudan	1985-1990				0.0003			
Thailand	1981-1985 1986-1990			0.041 0.016	 0.023			
Average	1970-1979 1980-1984 1985-1990			0.008 0.029 0.010	0.012 0.016		0.0006	0.0002

Qualifications of entries in this Table have been given as follows:

Canada: Data for 1985-1989 from Nova Scotia and Prince Edward Island, about 4% of the population of the country. Data for earlier periods from Nova Scotia only, about 3.5% of the population of the country.
Cuba: Data from PAHO.
Denmark: Data also from [L16].
Finland: Data also from [L16].
Iraq: Data from Institute of Radiology and Nuclear Medicine, Baghdad.
Jamaica: Data from Kingston Hospital only.
Netherlands: Data also from [B6]. Values for 1988-1989 are number of treatments, not patients.
Norway: Data also from [L16]. Values include palliative treatments; doses for curative treatments only are about 10% higher. Value given for benign disease is for 1990.
Sweden: Data also from [L16]. Data for teletherapy are scaled up from non-random sample of 33% of patients (neither afterloading nor head/neck are evenly distributed in the country.) Data for brachytherapy are scaled up from non-random sample of 28% of patients: there were more children than average.
Turkey: Data from Hacettepe University (2% of the population).
Yugoslavia: Data for teletherapy exclude Montenegro, Vojvodina and Kosovo. Data for brachytherapy are for Croatia only (about 20% of the population of the former Yugoslavia).

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[a] Number of treatments, not patients.
[b] Value is for both leukaemia and lymphoma.
[c] Iridium, not radium.
[d] Radium and caesium.
[e] Manual administration of caesium-137.

Table 38
Age- and sex-distribution of patients undergoing teletherapy and brachytherapy treatments, 1985-1990
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

PART I: TELETHERAPY

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
		Leukaemia				
I	Australia	21	45	34	63	37
	Czechoslovakia	38	9.6	52	60	40
	Kuwait	73	20	6.7	53	47
	New Zealand	47	30	23	60	40
	Norway	25	35	40	70	30
	Romania	22	0	78	71	29
	Sweden	41	30	29	57	43
	Yugoslavia	95	5	0	50	50
	Average	43	17	39	61	39
II	Ecuador	56	33	11	50	50
	India	34	39	27	63	37
	Iraq	60	21	18		zz
	Turkey	87	10	2.9	56	44
	Average	35	38	27	63	37
III	Egypt	19	34	47	66	34
	Myanmar	4.2	46	50	50	50
	Thailand	83	13	4	51	49
	Average	39	29	32	56	44
		Lymphoma				
I	Australia	4	26	70	53	47
	Czechoslovakia	0	39	61	53	47
	Japan	13	23	64	56	44
	Kuwait	24	41	35	69	31
	New Zealand	2.3	28	69	64	36
	Norway	1	31	68	57	43
	Sweden	3.8	18	79	55	45
	Yugoslavia	17	33	50	50	50
	Average	11	25	64	55	45
II	Ecuador	2.8	40	57	78	22
	India	23	38	39	75	25
	Iraq	20	53	27	zz	zz
	Turkey	63	23	13	13	87
	Average	23	38	39	75	25
III	Egypt	18	37	46	62	38
	Myanmar	5.4	21	73	63	37
	Thailand	9.3	26	64	60	40
	Average	11	29	60	62	38
		Breast tumour				
I	Australia	0	11	89	1	99
	Czechoslovakia	0	14	86	1	99
	Kuwait	0.9	39	60	0	100
	New Zealand	0	7.6	92	1	99
	Norway	0.1	11	89	0	100
	Romania	0	7.3	93	0	100
	Sweden	0	5	95	2	98
	Yugoslavia	0	8.3	92	0	100
	Average	0.02	9.7	90.4	0.5	99.5
II	China	3.1	30	67	5	95
	Ecuador	0	29	71	0	100
	India	0	28	72	1	99
	Iraq	0	40	60	0	100
	Turkey	0.1	29	71	0	100
	Average	0.1	28.3	71.5	1.1	98.9

Table 38 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
III	Egypt	0.7	36	63	1	99
	Myanmar	0	17	83	1	99
	Thailand	0	41	59	0	100
	Average	0.2	32.8	66.9	0.6	99.4
	Lung/thorax					
I	Australia	0	1.3	99	75	25
	Czechoslovakia	0	3.2	97	89	11
	Japan	0.2	5	95	81	19
	Kuwait	1.8	3.6	95	85	15
	New Zealand	0	1.5	98	67	33
	Norway	0	1.4	99	75	25
	Romania	0	5.1	95	34	66
	Sweden	0.2	3.4	96	69	31
	Yugoslavia	0	13	87	90	10
	Average	0.1	5.1	94.9	76	24
II	China	1.6	32	67	71	29
	Ecuador	0	12	88	88	12
	India	0	13	87	80	20
	Iraq	1	8.4	91	83	17
	Turkey	0.7	11	88	94	6
	Average	0.2	15.1	84.7	79	21
III	Egypt	0	18	82	81	19
	Myanmar	0	3.3	97	71	29
	Thailand	0	23	77	23	77
	Average	0	16	84	57	43
	Gynaecological					
I	Australia	0	12	88	0	100
	Czechoslovakia	0	11	89	0	100
	Japan	0.3	12	87	0	100
	Kuwait	2.5	30	68	0	100
	New Zealand	0	22	78	0	100
	Norway	0.8	7.9	91	0	100
	Romania	0	42	58	0	100
	Sweden	0	5.9	94	0	100
	Yugoslavia	0	14	86	0	100
	Average	0.2	15.4	84.0	0	100
II	China	0.6	10	89	zz	zz
	Ecuador	1.4	14	84	0	100
	India	0	25	75	0	100
	Iraq	1.6	41	58	0	100
	Turkey	11	21	68	0	100
	Average	0.1	23.4	76.4	0	100
III	Egypt	0	33	67	0	100
	Myanmar	0.6	6.4	93	0	100
	Thailand	0.1	30	70	0	100
	Average	0.2	24.7	75.1	0	100
	Wilms' tumour					
I	Australia	100	0	0	56	44
	Czechoslovakia	95	5.5	0	55	45
	Kuwait [a]	100	0	0	67	33
	New Zealand [b]	100	0	0	50	50
	Norway [c]	100	0	0	100	0
	Sweden [b]	100	0	0	80	20
	Yugoslavia	100	0	0	50	50
	Average	99	1	0	60	40

Table 38 (continued)

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
II	Ecuador [c]	100	0	0	100	0
	India	65	11	24	68	32
	Iraq	100	0	0	50	50
	Turkey	100	0	0	68	32
	Average	66	11	23	68	32
III	Egypt	96	0	4	40	60
	Myanmar [a]	100	0	0	33	67
	Thailand	100	0	0	44	56
	Average	99	0	1	40	60
Neuroblastoma						
I	Australia	50	44	6	56	44
	Czechoslovakia	33	67	0	100	0
	Kuwait [d]	75	25	0	50	50
	New Zealand [c]	100	0	0	50	50
	Norway [c]	16	33	50	71	29
	Sweden [b]	100	0	0	80	20
	Yugoslavia	30	40	30	50	50
	Average	49	37	14	65	35
II	Ecuador	50	50	0	50	50
	India	73	17	10	64	36
	Iraq	100	0	0	67	33
	Turkey	89	11	0	67	33
	Average	73	17	10	64	36
III	Egypt	90	10	0	47	53
	Myanmar [c]	100	0	0	0	100
	Thailand	100	0	0	63	36
	Average	96	4	0	40	59
Benign diseases						
I	Australia	1	9	90	65	35
	Czechoslovakia	0	1.4	99	36	64
	Japan	4.2	38	58	58	42
	Kuwait	4		zz	50	50
	New Zealand	1.6	44	52	55	45
	Sweden		60	39	42	58
	Average	3	34	63	56	44
II	Ecuador	0	8.3	92	98	2.5
	India	3	43	54	51	49
	Average	3	43	55	52	48
All malignant tumours						
I	Japan	2.4	13	85	49	51
	Netherlands	0.2	6.4	93		zz
	Romania	1.3	14	85	37	63
	Average	2	13	86	47	53
II	China	4.3	24	72	44	56
	India	3	25	72	19	81
	Average	3	25	72	22	78

Table 38 (continued)

PART II: BRACHYTHERAPY

Health-care level	*Country*	*Age-distribution ()*			*Sex-distribution ()*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
Breast tumour						
I	Australia	0	23	77	0	100
II	China	3.1	30	67	5	95
	India	0	0	100	0	100
	Average	2	17	81	3	97
III	Thailand	0	63	37	0	100
Prostate tumour						
I	Australia	0	0	100	100	0
	Czechoslovakia	0	0	100	100	0
	Norway	0	0	100	100	0
	Average	0	0	100	100	0
II	Turkey	0	0	100	100	0
Gynaecological (radium)						
I	Australia	0	19	81	0	100
	Czechoslovakia	0	0	100	0	100
	Norway	0	10	90	0	100
	Average	0	12	88	0	100
II	China	0.6	10	89	0	100
	Ecuador	0	22	78	0	100
	India	0	40	60	0	100
	Iraq	0	0	100	0	100
	Jamaica	0	16	84	0	100
	Peru	0	12	88	0	100
	Average	0.3	22.2	77.2	0	100
III	Thailand	0	58	41	0	100
Gynaecological (afterloading)						
I	Australia	0	8.9	91	0	100
	Czechoslovakia	0	17	83	0	100
	New Zealand	0	25	74	0	100
	Norway	0	12	88	0	100
	Sweden	0	4.7	95	0	100
	Average	0	12	88	0	100
II	China	0.6	10	90	0	100
	Ecuador	0	42	58	0	100
	India	0	27	73	0	100
	Turkey	0	45	55	0	100
	Average	0.3	17.3	82.7	0	100
III	Egypt	0	33	67	0	100
	Thailand	0	34	66	0	100
	Average	0	34	66	0	100
Brain tumour						
I	Australia	0	100	0	100	0
	Norway [c]	0	0	100	0	100
	Average	0	81	19	81	19
II	China	7.3	37	55	64	3

Table 38 (continued)

Health-care level	*Country*	*Age-distribution 0*			*Sex-distribution 0*	
		0-15 years	*16-40 years*	*>40 years*	*Male*	*Female*
Other tumours						
I	Australia	0	100	0	100	0
	Czechoslovakia	4-5	95-96	0	11-66	34-89
	Norway	0	0	100	58	42
	Sweden [f]	0	0	100	50	50
	Average	1	68	31	60	15
II	India	0	12	88	68	32
III	Thailand	0	46	54	30	70
Benign diseases						
I	Czechoslovakia	0	0	100	0	100
	Kuwait				80	20
	Average	0	0	100	12	88
II	India	7	71	22	48	52
	Jamaica				30	70
	Average	7	71	22	48	52
All malignant tumours						
I	Romania	1.3	14	85	37	63
II	China	4.3	24	72	44	56

The entries in this Table are qualified as follows:

Myanmar: Data from Yangon General Hospital only.
Romania: Data are from a sample of 4 of the population in 1990. For leukaemia, values include lymphoma. For "All malignant tumours", data are for Co-60 only, namely 34 of all patients; most other patients were treated with x rays.
Thailand: Data from Department of Radiology, National Cancer Institute, Bangkok, only.
Turkey: Data are for 1986-1990.
Yugoslavia: Data are for Serbia only (about 40% of the population).

[a] Three patients.
[b] Five patients.
[c] One patient.
[d] Four patients.
[e] Six patients.
[f] Two patients.

Table 39
Doses to patients undergoing radiation teletherapy and brachytherapy, 1985-1989
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

PART I: TELETHERAPY

Country	Dose region	Absorbed dose (Gy) (Range in parentheses)							
		Leukaemia	*Lymphoma*	*Breast tumour*	*Lung/ thorax tumour*	*Gynaeco-logical tumour*	*Wilms' tumour*	*Neuro-blastoma*	*Benign disease*
Health-care level I									
Australia	Target	20 (8-25)	40 (35-45)	50 (30-60)	60 (20-60)	50 (30-55)	(10-25)	(10-40)	
Czechoslovakia	Target	15.5 (2-36)	35 (9.6-46.8)	49 (8-56)	51 (20-60)	53.4 (8-70)	(10-40)	(10-40)	(0.5-10)
	Surface	13.4 (1-43)	40.2 (10.5-50)	55.4 (7.2-60)	35 (25-40)	40 (14-60)	(10-40)	(10-40)	6 (1.5-6)
Finland	Target	24, 12 [a]	45	45-60	40-60	44-55	20-30	30	
Germany, F.R.	Target	(18-20)	40	(45-60)	50	(40-50)	40	40	
Kuwait	Target	18 (15-24)	36 (30-40)	45 (45-50)	40 (40-50)	40 (40-50)	45 (30-45)	45	(30-45)
	Surface	12	24	37 (26-30)	24 (24-30)	24 (24-30)			(4-25)
Malta	Target		35 (30-40)	50 (45-60)	45 (30-50)	45 (35-50)	25 (20-35)	30 (12-45)	
Netherlands	Target		40 (33.6-50)	59 (44.3-70)	46 [b], 69 [c] (32-70)	52.5 (40-75)			
New Zealand	Target	19 (18-24)	38 (35-40)	30-55	30-55	42 (33-45)	24 (15-25)	30 (6-35)	12-48 (-50)
Norway	Target	35 (20-40)	35 (30-45)	32 (20-60)	33 (20-50)	35 (30-50)	- 11	54 (30-61)	
	Surface	21	50 (43-60)	46 (29-85)	47 (29-71)	50 (43-71)			
Sweden	Target	(20-30)	(20-50)	(47-70)	(20-60)	(30-60)			(7-40)
	Surface		(20-35)	(30-45)		(28-45)			
Yugoslavia	Target	20 (20-30)	30 (20-50)	50 (50-70)	45 (43-60)	20 (20-60)	20 (20-40)	20 (20-40)	10 (10-20)
Health-care level II									
Barbados	Target			45 (30-50)	35 (20-45)	35 (20-45)			
China	Surface	50 (46-55)	40 (36-55)	40 (36-45)	40 (36-70)	50 (46-80)	40 (36-41)	40 (36-42)	30-60 (12-65)
	Target	60 (56-65)	50 (46-60)	50, 46 (46-56)	50, 48 (46-87)	60, 51 (56-100)	50 (46-51)	50 (46-52)	17-70 (14-75)
Ecuador	Target	1.5 (2.5)	1.5 (2.0)	2.0 (2.3)	2.0 (4.0)	2.0 (2.5)	1.0 (1.25)		2.0 (3.0)
	Surface	1.8 (3.0)	1.8 (3.0)	2.4 (2.9)	2.4 (4.8)	2.4 (3.0)	1.2 (1.5)		2.4 (8.6)
India	Target	22 (10-35)	40 (30-60)	47 (35-70)	51 (25-70)	55 (30-75)	30 (15-60)	30 (15-60)	(3-30)
	Surface	17 (6-40)	36 (7.5-85)	44 (9.9-71)	41 (11-70)	42 (9-86)	19 (15-35)	20 (5.6-45)	(0.9-65)
Iraq	Target	20 (18-24)	35 (35-40)	45 (40-45)	30 (30-40)	50 (45-55)	35 (30-40)	40	
Jamaica	Target		35	40	40	50	40	40	15
	Surface		40	47	46	56	47	47	18
Peru	Target	18 (18-24)	44 (25-50)	60 (50-70)	50 (60)	50 (40-60)	30 (20-40)	30 (25-35)	
	Surface	12.6 (12.6-17)	32 (15-30)	66 (41-58)	45 (-54)	21 (20-30)	21 (14-28)	20 (17-24)	17 [d] (12-23)
Health-care level III									
Egypt	Target			50	(50-60)	50	24-35	40	
Myanmar	Target	40 (20-40)	40 (20-40)	50 (40-60)	40 (20-40)	40 (40-60)	30 (20-40)		
	Surface	40 (20-40)	42 (21-42)	52 (41.5-62.3	42 (21-42)	41.9 (41.9-62.8)	30.1 (20.1-40.2)		
Sudan	Target	15	45	40	30	60	40	30	
	Surface	20		(36-40)	24	26	32	25	
Thailand	Target	24 (21-24)	44 (40-46)	50 (45-50)	65 (60-65)	45 (40-50)	30 (27-30)	40 (40-50)	(9-15) [e]
	Surface	14.4 (12.6-14.4)	26.4 (24-27.6)	30 (27-30)	39 (36-39)	27 (24-30)	18 (16.2-18)	24 (24-30)	

Table 39 (continued)

PART II: BRACHYTHERAPY

Country	Target absorbed dose (Gy) (Range in parentheses)						
	Breast tumour	Prostate tumour	Gynaecological		Brain tumour	Other tumours	Benign disease
			Radium	Afterloading			
Health-care level I							
Australia	20 (10-30)		25 (20-50)			25-40 (20-)	
Czechoslovakia			25 (20-60)	25 (20-60)		(40-60)	(20-25) [f]
Kuwait	20 (20-40)		40 (30-40)	40 (30-40)			20
Malta				70 (65-75)			
Netherlands			29 (14-40				
New Zealand				35 (15-75)			
Norway		160 (160-)	40 (40-)	25 (25-)	54 (54-)	20-30 (20-)	
Sweden		20 (15-20)	60	(20-45)		(30-60)	
Health-care level II							
Barbados			60 (40-80)				
China	26		38	33	20		
Ecuador			30 (40)	30 (32)			
India	15 (10-20)	(30-35)	49 (15-82)	29 (15-75)		(8-75)	20 (10-30)
Iraq			20 [g]				
Jamaica			26 (39)				36
Peru			44 (30-45)			38-60 (30-80)	
Health-care level III							
Egypt				30		24	
Myanmar			40 (30-50)				
Sudan				48			
Thailand	25 (20-30)		30 (25-30)	30 (25-30)			

The entries in this Table are qualified as follows:

China: Under teletherapy, the second values for the surface dose region under breast tumour, lung/thorax tumour and gynaecological tumour are from a nationwide study.
Myanmar: Data from Yangon Hospital only.
Thailand: Data from Department of Radiology, National Cancer Institute, Bangkok, only.
Yugoslavia: Excluding Montenegro, Vojvodina and Kosovo.

[a] Whole-body treatments.
[b] Lung proper only.
[c] Other respiratory tract.
[d] The entrance surface dose (Gy) has been estimated from exposure (R) multiplied by 0.0087/0.75. This applies also to range.
[e] Keloid.
[f] Endometrial hyperplasia.
[g] Combined with external beam.

Table 40
Doses from scattered radiation from therapy using cobalt-60
[B19, 14]

Organ	*Normalized dose to tissue (mSv per Gy to target organ)*							
	Target in neck		*Target in bronchus*		*Target in pancreas*		*Target in central pelvis*	
	Female	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*
Gonads	0.1	0.1	0.1	0.1	4.0	0.5	[b]	47
Breast	0.3	-	19	-	11	-	0.5	-
Red bone marrow [a]	6.7	6.1	66	62	67	58	65	60
Lung	0.9	0.9	127	95	21	18	0.5	0.5
Thyroid	[a]	[a]	82	78	0.8	0.7	0	0
Bone surface	5.0	4.8	30	31	24	23	13	13
Remainder								
Brain	1.7	1.9	3.3	3.4	0.2	0.1	0.1	0.1
Kidney	0.1	0.1	1.9	1.4	[a]	[a]	4.5	4.0
Pancreas	0.1	0.1	3.6	3.5	[a]	[a]	2.7	1.9
Spleen	0.1	0.1	3.8	3.0	212	183	2.6	1.8
Uterus	0.1	-	0.2	-	8.2	-	[b]	-
Effective dose equivalent (H_E)	1.8	1.5	37	26	55	32	11	22
Effective dose (E)	1.1	0.95	30	23	16	11	8.3	17

[a] Assuming bone marrow in beam gets 60% of dose to target organ.
[b] Organ in beam.

Table 41
Collective effective dose from radiotherapy in the Netherlands, 1978-1979 [a]
[B19]

Target region [b]	*Number of patients*		*Effective dose equivalent* [c] *(mSv)*		*Effective dose* [c] *(mSv)*	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Neck	414	628	108	92	64	57
Thorax	317	331	2210	1540	1790	1370
Pancreas and gall bladder	1635	1856	3320	1910	963	680
Pelvis	4533	4078	671	1300	496	1020
Collective dose (man Sv)			18630		10330	
Addition for target region			420 [d]		105 [e]	
Total			19050		10435	

[a] Breast cancer and skin cancer disregarded because there are no data on scattered radiation; lung cancer disregarded because treatment is in most cases only palliative.
[b] A target dose of 60 Gy is assumed.
[c] Per patient.
[d] 21,000 radiotherapy patients, cure rate 50%, at most 0.1% second cancers in target organs [14], yield 5.25 deaths from second cancers. With a probability coefficient of 0.0125 per man Sv [11], 5.25 deaths correspond to 5.25/0.0125 = 420 man Sv.
[e] Cancer fatality probability coefficient is 0.05 per man Sv [18].

Table 42
Estimated doses to the world population from teletherapy and brachytherapy

Health-care level	*Population (millions)*	*Annual number of procedures per 1,000 population [U1]*	*Number of procedures (millions)*	*Annual collective effective dose (10^3 man Sv)* [a]
I	1350	2.4	3.2	980
II	2630	0.6	1.6	480
III	850	0.1	0.085	26
IV	460	0.05	0.023	7
Total	5290	-	4.9	1500
Average	-	0.9	-	-

[a] Values are based on effective dose, E, assuming 10,400 man Sv per 14.3 million population (figures from the Netherlands [B19]) = 730 man Sv per million population at health-care level I and a treatment frequency of 0.0024, i.e. 730/2.4 = 300 man Sv per 1,000 procedures.

Table 43
Total annual number of treatments with radiopharmaceuticals per 1,000 population
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

Country	*1970-1979*	*1980-1984*	*1985-1990*	*Country*	*1970-1979*	*1980-1984*	*1985-1990*
Health-care level I							
Argentina			0.16	Malta			0.075
Australia	0.15	0.15	0.14	Netherlands			
Belgium	4		0.31	New Zealand	0.16	0.097	0.17
Canada			0.88	Norway	0.059		0.12
Czechoslovakia	0.073	0.12	0.18	Romania		0.051	0.052
Denmark	0.13	0.18	0.21	Sweden	0.34		0.43
Finland	0.32	0.36		Switzerland	1.55		
Japan	0.049	0.025	0.030	United Kingdom		0.20	
Kuwait			0.018	Yugoslavia			0.11
Luxembourg			0.19				
				Average	0.086	0.093	0.10
Health-care level II							
Barbados			0.15	Iraq			0.013
China			0.035	Jamaica	0.17		0.005
Ecuador	0.007		0.0065	Peru			0.011
India			0.0036	Turkey			0.008
				Average	0.044		0.021
Health-care level III							
Egypt	0.064	0.061	0.062	Thailand	0.008	0.011	0.013
Myanmar	0.014	0.011	0.005	Tunisia	0.035		0.042
Sudan	0.001	0.003	0.006				
				Average	0.025	0.025	0.025

Table 44
Average annual number of therapeutic treatments with radiopharmaceuticals per 1,000 population
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures unless otherwise indicated

Country	*Year*	*Thyroid tumours*	*Hyperthyroidism*	*Polycythaemia vera*	*Other tumours*	*Benign diseases*
Health-care level I						
Argentina	1985-1989	0.16				
Australia	1970	0.001	0.13	0.013		
	1980	0.024	0.12	0.012		
	1984	0.022	0.083	0.024		0.022
	1991	0.11 [a]		0.010		0.011
Belgium	1986-1990					
Canada	1985-1989	0.009	0.57	0.28		0.023
Czechoslovakia	1970-1974	0.016	0.013	0.011	0.007	0
	1976-1980	0.031	0.022	0.007	0.012	0.024
	1981-1985	0.035	0.022	0.008	0.018	0.038
	1986-1990	0.050	0.046	0.009	0.022	0.055
Denmark	1977-1980	0.023	0.097		0.006	
	1981-1985	0.029	0.15		0.005	
	1989-1990	0.023	0.19		0.001	
Finland [A12]	1975	0.005	0.29	0.012		0.008
	1982	0.038	0.28	0.040		0.005
Japan	1985-1989	0.025	0.005			
Kuwait	1985-1989	0.018				
Malta	1985-1989	0.003	0.064	0.008		
Netherlands	1984	0.097				
New Zealand	1970-1974	0.011	0.14	0.014		
	1985-1989	0.018	0.11	0.036		
Norway	1970-1974	0.004	0.033	0.0008	0.022	
	1985-1989	0.019	0.084	0.001	0.012	0.006
Romania	1980	0.041	0.010			
	1985-1989	0.043	0.009			<0.001
	1990	0.038	0.004			0.52
Sweden	1970-1974	0.31		0.032	0.001	0.003
	1985-1989	0.39		0.034	0.003	0.001
Switzerland	1976	1.0		0.022		0.52
United Kingdom	1981-1985	0.015	0.14	0.025	0.013	
Yugoslavia	1985-1989	0.009	0.029	0.005	0.053	0.014
Average	1970-1979	0.059	0.068	0.014	0.009	0.013
	1980-1984	0.033	0.10	0.024	0.013	0.025
	1985-1990	0.063	0.022	0.016	0.028	0.018
Health-care level II						
Barbados	1985-1989	0.15				
China						
Beijing area	1985-1989		0.005			
Entire nation	1986-1990	0.00006	0.0056		0.011	0.018
Ecuador	1970-1974	0.002	0.005			
	1985-1989	0.003	0.004			
India	1985-1989	0.0006	0.0029	0.0001		
Iraq	1985-1989	0.012		0.001		

Table 44 (continued)

Country	*Year*	*Thyroid tumours*	*Hyperthyroidism*	*Polycythaemia vera*	*Other tumours*	*Benign diseases*
Jamaica	1970-1974 1985-1989	0.093	0.077 0.005			
Peru	1985-1989	0.002	0.008			
Turkey	1991		0.008			
Average	1970-1979 1980-1984 1985-1990	0.023 0.0004	 0.0004	 0.0001	 0.011	 0.018
Health-care level III						
Egypt	1975-1979 1980-1984 1985-1989	0.024 0.017 0.023	0.040 0.044 0.039			
Myanmar	1975-1979 1980-1984 1985-1989	0.0006 0.001 0.0002	0.013 0.010 0.0038			
Sudan	1975-1979 1980-1984 1985-1989	0.001 0.0001 0.0003	0.0005 0.002 0.0038	 0.0006 0.0015		
Thailand	1976-1980 1981-1985 1986-1990	0.008 0.011 0.013			<0.0001 <0.0001 0	
Tunisia	1970-1974 1985-1989	0.011 0.013	0.023 0.027	0.0009 0.002		
Average	1970-1979 1980-1984 1985-1990	0.010 0.009 0.011	0.023 0.024 0.020	 0.001 0.002	0.00004 0.00003	

The entries in this Table are qualified as follows:

Canada: Nova Scotia Province only (about 3.5% of the population).
Turkey: Data are from Gazi University (1% of the population).
Yugoslavia: Data exclude Montenegro, Vojvodina and Kosovo; "other" tumours and benign diseases based on Croatia data only (about 20% of the population).

[a] Value is for both thyroid tumours and hyperthyroidism.

Table 45
Age- and sex-distribution of patients undergoing treatment with radiopharmaceuticals, 1985-1990
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 tumours					
I	Canada	0	25	75	10	90
	Czechoslovakia	0	74	26	31	69
	Kuwait				37	63
	Netherlands	2	20	78	33	67
	New Zealand	0	40	60	7	93
	Norway	0	32	68	20	80
	Romania				25	75
	Yugoslavia	0	0	100	50	50
II	Ecuador	0	32	68	10	90
	Iraq				40	60
	Peru				20	80
III	Thailand	0.7	15	84	23	77
	Hyperthyroidism					
I	Canada	o	26	74	25	75
	Czechoslovakia	0	49	51	26	74
	Netherlands	0	32	68	19	81
	New Zealand	0	28	72	25	75
	Norway	0	14	86	22	78
	Romania	0			25	75
	Yugoslavia	0	0	100	10	90
II	China					
	Beijing area	0	67	33	29	71
	Entire nation	1.5	55	43	26	74
	Ecuador	0	33	67	15	85
	Iraq				21	79
	Jamaica	0	58	42	33	67
	Peru				30	70
III	Thailand	0	31	69	17	83
	Polycythaemia vera					
I	Czechoslovakia	0	57	43	51	49
	New Zealand	0	0	100	53	47
	Yugoslavia	0	17	83	90	10
	Other tumours					
I	Czechoslovakia	0	9.8	90	61	39
	Norway	0	23	77	0	100
	Benign diseases					
I	Canada	0	0	100	50	50
	Czechoslovakia	0	0	100	19	81
	Romania				36	64

The entries in this Table are qualified as follows:

Canada: Nova Scotia Province only (about 3.5% of the population).
Romania: Data are for 1990 only.
Thailand: Data are from Department of Radiology, National Cancer Institute, Bangkok, and Rajavithi Hospital only.
Yugoslavia: Data are for Serbia only (about 40% of the population).

Table 46
Average activity administered in therapy treatments with radiopharmaceuticals
Data from UNSCEAR Survey of Medical Radiation Usage and Exposures

Country	Year	Average activity administered (MBq) (Range in parentheses)						
		Thyroid tumours	Hyper-thyroidism	Polycythaemia vera	Other tumours		Benign diseases	
		^{131}I iodide	^{131}I iodide	^{32}P phosphate	^{90}Y colloid	Other	^{198}Au colloid	Other
Health-care level I								
Australia	1970	5550	351	157				
	1980	4225	310	160				
	1984	4950	430	182				183 [b]
	1991	983 [a]		169				265 [b]
Canada	1970-1974	3700	185					111 [c]
		(-5550)	(-1100)					(-185)
	1985-1989	3700	185					111 [c]
		(-5550)	(-1110)					(-185)
Czechoslovakia	1970-1974	6500	200	185		600-3000 [d]		
		(5000-12000)	(150-300)	(100-250)		(400-5500)		
	1985	6500	200	185		600-3000 [d]	185	185 [b]
		(5500-22000)	(150-300)	(100-250)		(400-5500)	(150-450)	(150-450)
Japan	1976-1980		180					
	1981-1985		400					
Kuwait	1985-1989	3630	535	176				
		(1700-7770)	(399-671)	(152-180)				
Malta	1985-1989	3700	259 (-370)					
Netherlands	1988-1990	5500	500					
		(3700-5800)	(150-1800)					
New Zealand	1973	3145	400	154				
		(2220-3700)	(74-1480)	(111-204)				
	1985-1989	1632	425	172				
		(370-4200)	(150-2700)	(100-259)				
Norway	1970-1974	3000	195			3700 [e]		
		(1000-5000)	(131-259)					
	1985-1989	3600	310			300 [f]	110	750 [g]
		(2100-5100)	(152-468)					
Romania	1980	3700	222					
	1985-1989	3700	222					
Sweden	1974	1700	344	230	185		160	150 [b]
	1985-1989			224		2874 [h]	150	187 [b]
				(140-335)		(2000-3700)	(110-185)	(150-200)
Switzerland	1976	925		185				74
United Kingdom	1981-1985	3304	335	207	191			
		(110-5000)	(120-1550)	(111-444)	(55-280)			
Yugoslavia	1970-1974	3700	185 (100-200)					
	1985-1989	3700	185 (100-200)					
Health-care level II								
Barbados	1985-1989		296 (222-296)	294 (222-370)				
China								
Beijing area	1970-1974		296 (148-740)					
	1985-1989		259 (111-740)					
Entire nation	1986-1990		162			8.7 [g]		

Table 46 (continued)

Country	Year	Average activity administered (MBq) (Range in parentheses)						
		Thyroid tumours	Hyper-thyroidism	Polycythaemia vera	Other tumours		Benign diseases	
		^{131}I iodide	^{131}I iodide	^{32}P phosphate	^{90}Y colloid	Other	^{198}Au colloid	Other
Ecuador	1970-1974	3700 (-9250)	296 (-444)					
	1985-1989	3700 (-9250)	296 (-444)					
India	1985-1989	5330 (3700-7400)	190 (74-226)	127 (74-296)				
Iraq	1985-1989	1850 (-5550)	200 (-1000)	200 (-400)				
Jamaica	1970-1974	370	182					
	1985-1989		370					
Peru	1985-1989	3700 (2960-4440)	259 (185-370)					
Health-care level III								
Egypt	1976-1980	2700	600					
	1981-1985	2500	800					
	1986-1990	4000	1000					
Myanmar	1976-1980	1850	185					
	1981-1985	1850	185					
	1986-1990	1850	185					
Sudan	1976-1980		185					
	1981-1985	3700	185	185				
	1986-1990	3700	222	259				
Thailand	1985-1989	270						

The entries in this Table are qualified as follows:

Canada: Nova Scotia Province only (about 3.5% of the population).
Jamaica: Value for thyroid tumours treated with ^{131}I iodide to be checked.
Yugoslavia: Excluding Montenegro, Vojvodina and Kosovo.

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[a] Value is for both thyroid tumours and hyperthyroidism.
[b] Yttrium-90 colloid.
[c] Chromic phosphorus-32.
[d] P-32 $Na_2H\ PO_4$ (600 MBq), Au-198, P-32 colloid (3,000 MBq).
[e] Gold-198.
[f] Phosphorus-32.
[g] Iodine-131.
[h] Iodine-131 MIGB.

Table 47
Absorbed dose to non-target organs from therapy treatments of adult thyroid with iodine-131 iodide in Japan, 1982 [a]

Organ	*Dose factor [I5] (mGy/MBq)*	*Absorbed dose (mGy)*	*Number of therapies [M10]*
Bladder wall	0.52	209	2956
Bone surface	0.047	18.9	2956
Breast	0.043	17.3	2956
Stomach wall	0.46	185	2956
Small intestine	0.28	113	2956
Upper large intestine	0.059	23.7	2956
Kidney	0.06	24.1	2956
Lung	0.053	21.3	2956
Red bone marrow	0.054	21.7	2956
Ovary	0.043	17.3	2328
Testis	0.028	11.3	628

[a] 402 MBq administered [M10]; assumed thyroid uptake: 15%.

Table 48
Estimated doses to the world population from therapeutic treatments by nuclear medicine procedures [a]

Health-care level	*Population (millions)*	*Annual number of procedures per 1,000 population*	*Number of procedures (thousands)*	*Annual collective effective dose (10^3 man Sv) [b]*
I	1350	0.1	135	6.0
II	2630	0.02	53	2.4
III	850	0.02	17	0.8
IV	460	0.01	5	0.2
Total	5290	-	210	9.3
Average		0.04	-	-

[a] Based on extrapolation of data from the Netherlands [B19].
[b] Assuming an effective dose per treated patient of 40 mSv/0.9 (40 mSv calculated for thyroid therapy in Japan; thyroid therapy assumed to be 0.9 of all treatments), as calculated for Japan with the methodology of Beentjes [B19].

Table 49
Equivalent dose rates from adult patients undergoing nuclear medicine examinations [N6]

Examination	*Radiopharmaceutical*	*Amount administered (MBq)*	*Time after administration*	*Distance (cm)*	*Equivalent dose rate ($\mu Sv\ h^{-1}$)*
Bone	Tc-99m MDP	740	0	100	9
			1 h	100	6.3
			2 h	100	4.7
			3 h	100	3.5
Liver	Tc-99m S colloid	150	0	100	2
Blood pool	Tc-99m RBC	740	0	100	14
Tumour	Ga-67 citrate	110	0	100	3.5
CSF	In-111 DTPA	19	0	100	0.8
Heart	Tl-201 chloride	740	0	[a]	20
Heart	Tc-99m HSA	190	0	[a]	15
Bone	Tc-99m MDP	740	0	[a]	25
Heart	Tc-99m RBC	1000	20 min	100	18

[a] Side of stretcher.

Table 50
Effective dose equivalent to mother and breast-feeding child for common nuclear medicine examinations [J1]

Examination	*Radiopharmaceutical*	*Activity administered (MBq)*	*Effective dose equivalent (mSv)*	
			Mother	*Child*
Thyroid scintigraphy	Tc-99m pertechnetate	120	1.3	3.6
Renography	I-131 iodohippurate	0.4	0.02	2.8
Clearance	Cr-51 EDTA	4	0.01	0.006
Thrombosis test	I-125 fibrogen	4	0.44	13

Table 51
Exposures of volunteers in medical research and clinical trials

Country	*Year*	*Radionuclide administered*	*Number of studies*	*Number of volunteers* [a]	*Activity administered per volunteer (MBq)* [b]	*Committed effective dose (mSv)* [c]	*Ref.*
Clinical trials of labelled pharmaceuticals							
Germany, Fed. Rep. of	1978-1988	H-3 C-14 S-35	15 62 2	85 (3-8) 452 (3-30) 14 (7)	3.7 (1.9-16.7) 3.7 (0.37-11) 3.7	0.03-0.3 0.2-6 0.4	[B7]
Total	11 years		79	551			
Use of radioactive substances in medical research							
Germany, Fed. Rep. of	1988	Cr-51 Fe-59 Tc-99m In-111 I-123 Xe-133	2 1 5 1 3 1	18 (6-12) 12 107 (10-32) 80 105 (15-70) 26	3.79 1 350-740 20 150-185 900		[B7]
Clinical trials of radiopharmaceuticals							
Germany, Fed. Rep. of	1988	Tc-99m MAB In-111 MAB I-125 I-131 MAB	32 6 3 2	1286 (15-120) 175 (10-80) 500 (100-200) 35 (15-20)	220-1300 74-75 3.7 185		[B7]
Clinical trials of labelled pharmaceuticals							
United Kingdom	1978-1986	H-3 C-14 S-35	4 55 1	40 (3-15) 201 (2-10) 3	~10.5 ~1-3 2.8	0.03-0.3 0.01-5.5 0.3	[N7]

[a] Number of volunteers per study in parentheses.
[b] Activity administered per study in parentheses.
[c] Estimated to give upper limit values.

Table 52
Estimated doses to the world population from medical uses of radiation

Medical radiation use	*Effective dose equivalent per caput (mSv)*					*Collective effective dose equivalent (10^3 man Sv)*				
	Level I	*Level II*	*Level III*	*Level IV*	*World*	*Level I*	*Level II*	*Level III*	*Level IV*	*World*
Diagnosis										
Medical x-ray examinations	1.0	0.1	0.04	0.04	0.3	1300	290	40	20	1600
Dental x-ray examinations	0.01	0.001	0.0003	0.0003	0.003	14	3	0.3	0.1	17
Nuclear medicine	0.09	0.008	0.008	0.008	0.03	130	20	6	4	160
Total	1.1	0.1	0.05	0.05	0.3	1400	310	46	24	1800
Therapy [a]										
Radiotherapy	0.7	0.2	0.03	0.02	0.3	980	480	26	7	1500
Nuclear medicine	0.004	0.0009	0.0009	0.0004	0.002	6	2	0.8	0.2	9
Total	0.7	0.2	0.03	0.02	0.3	990	480	27	7	1500

[a] Evaluated for effective doses.

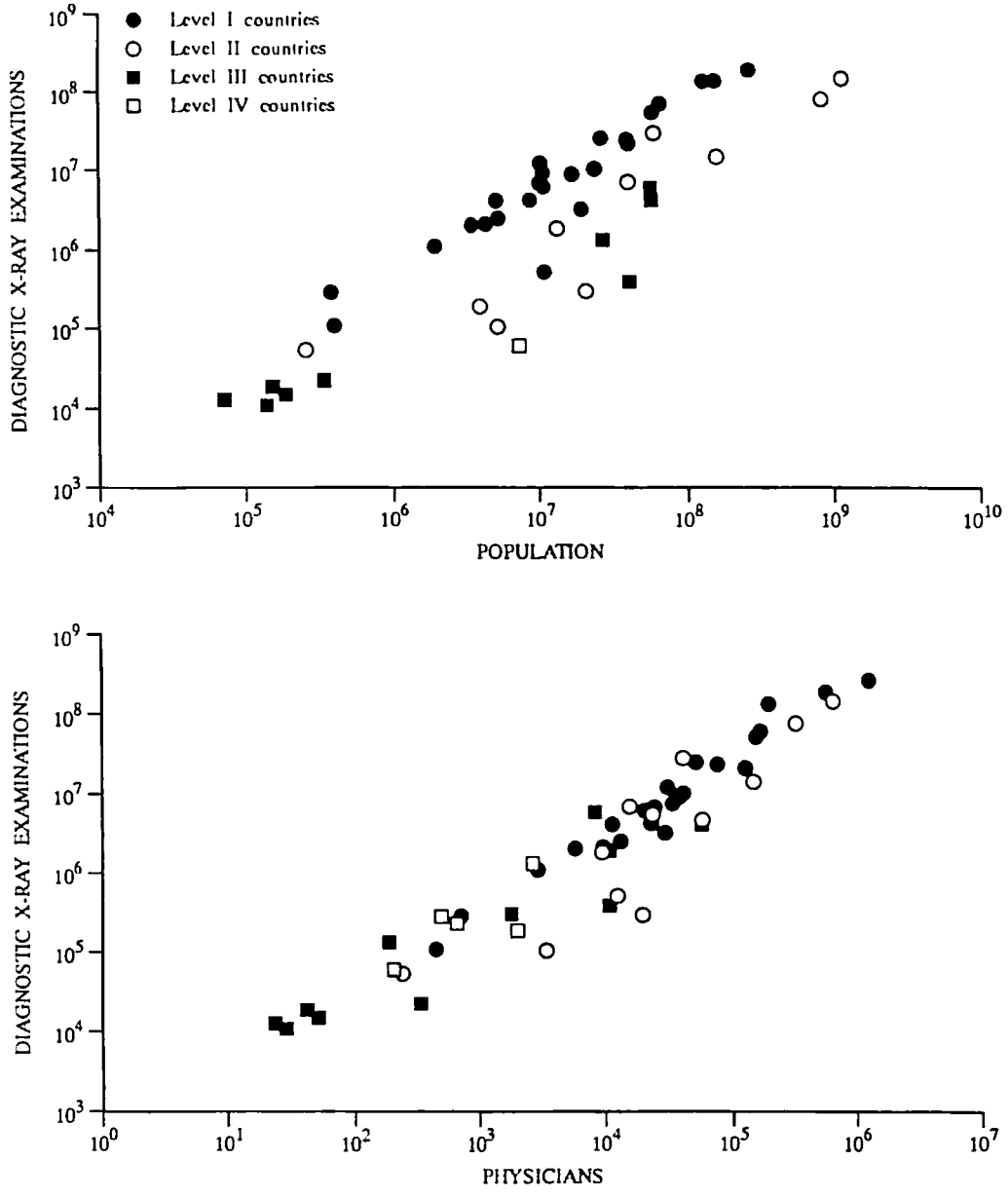

Figure I.
Diagnostic medical x-ray examinations in relation to population and number of physicians.

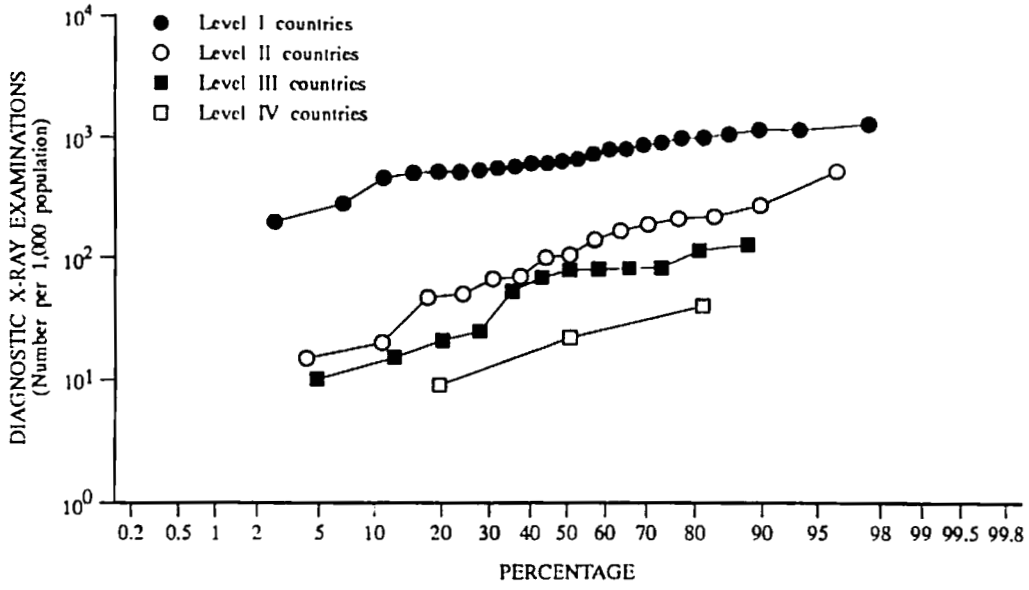

Figure II.
Distribution of total annual frequency of diagnostic medical x-ray examinations.

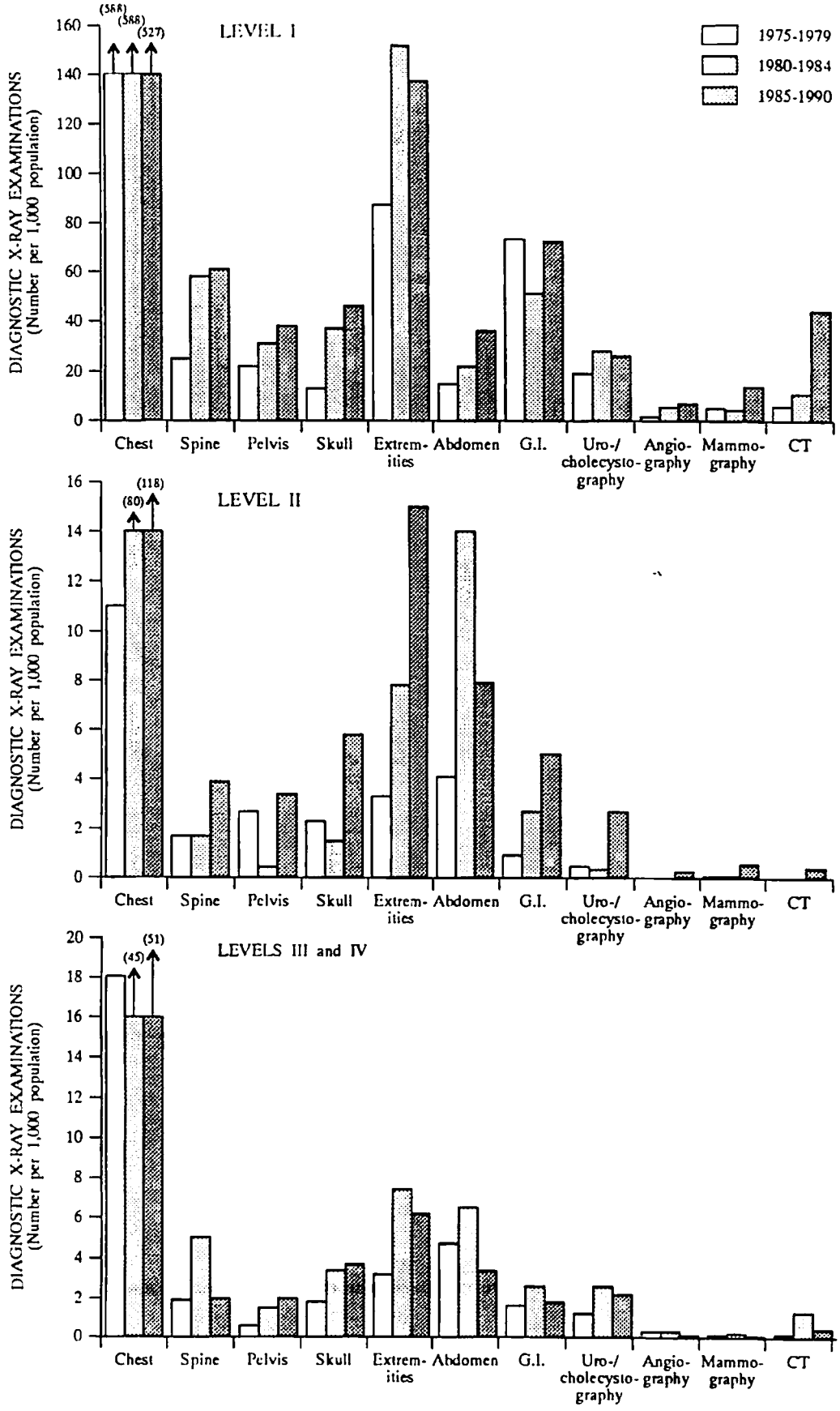

Figure III.
Average annual frequency of diagnostic medical x-ray examinations.

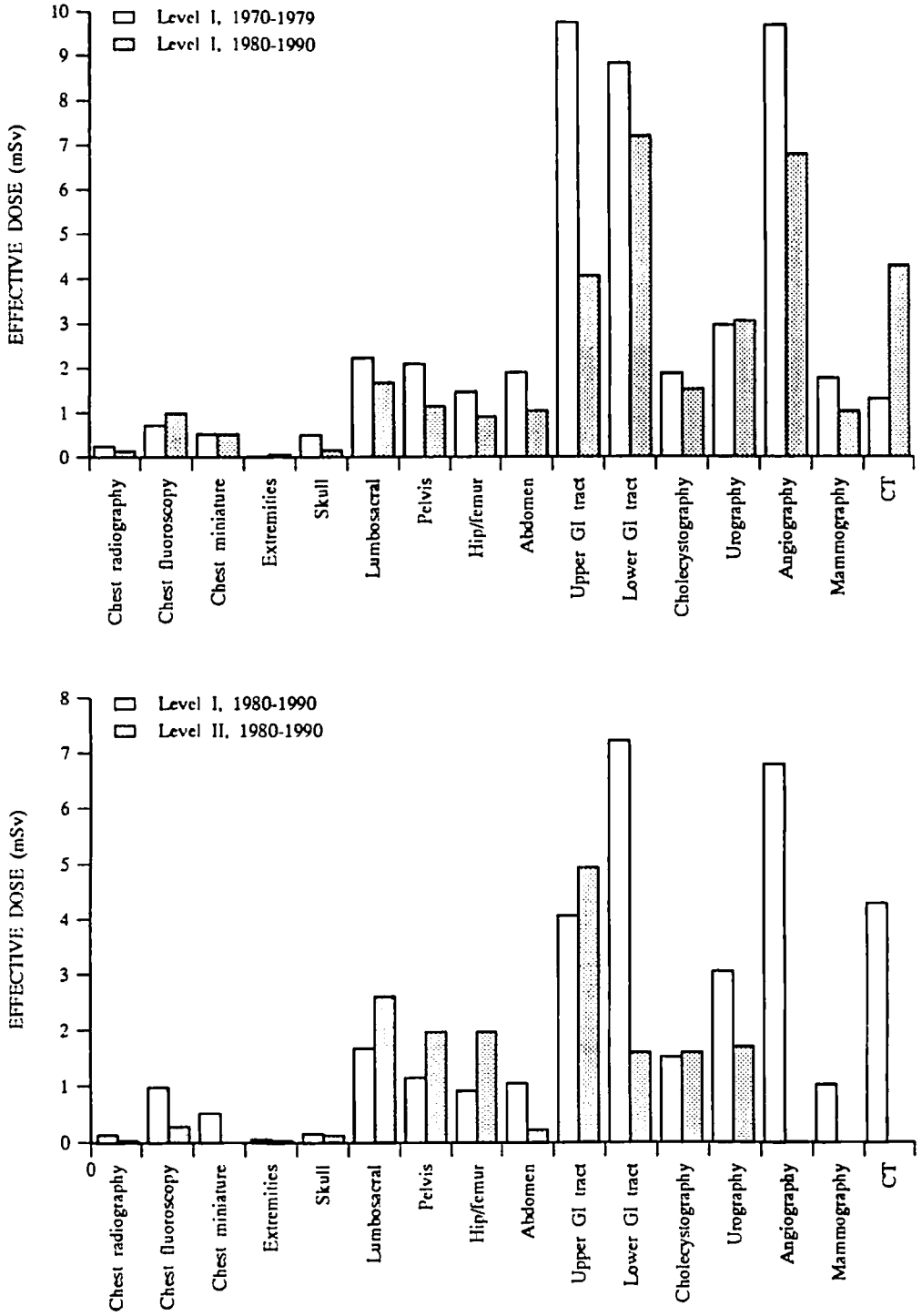

Figure IV.
Population-weighted average effective dose in diagnostic medical x-ray examinations.

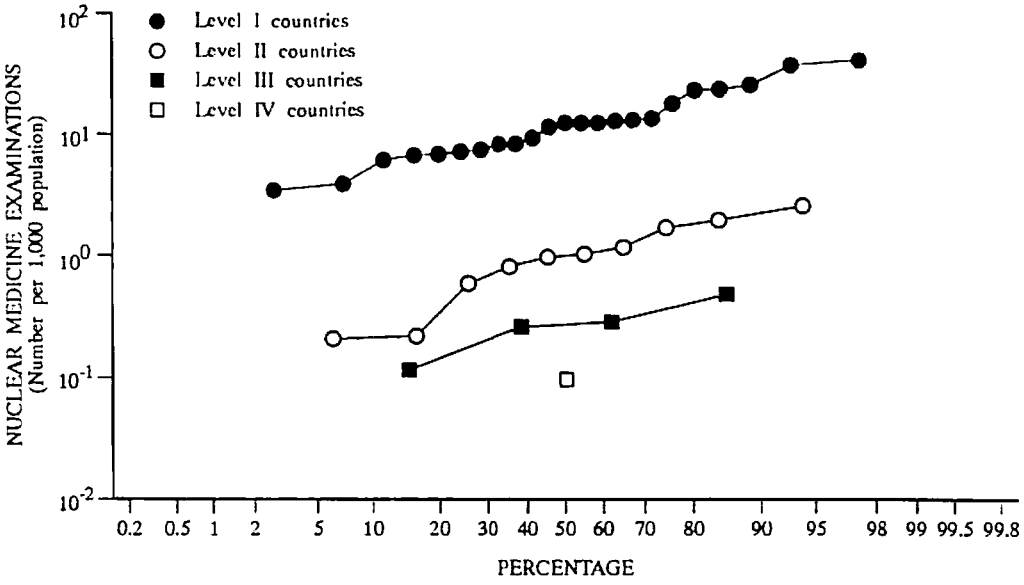

Figure V.
Distribution of total annual frequency of diagnostic nuclear medicine examinations in 1985-1990.

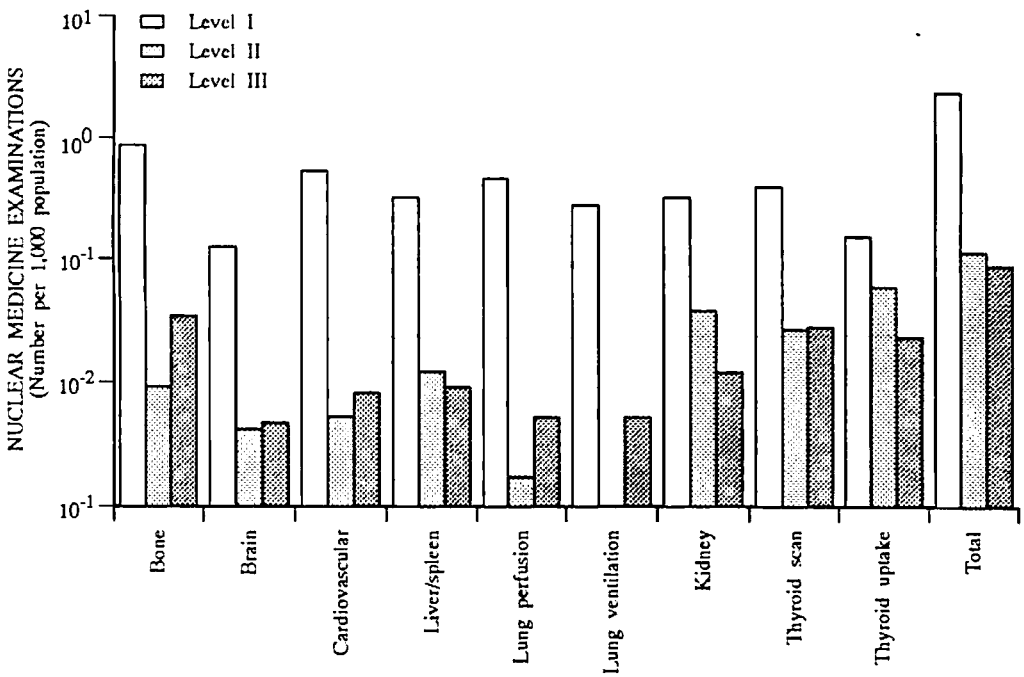

Figure VI.
Average annual frequency of diagnostic nuclear medicine examinations in 1985-1990.

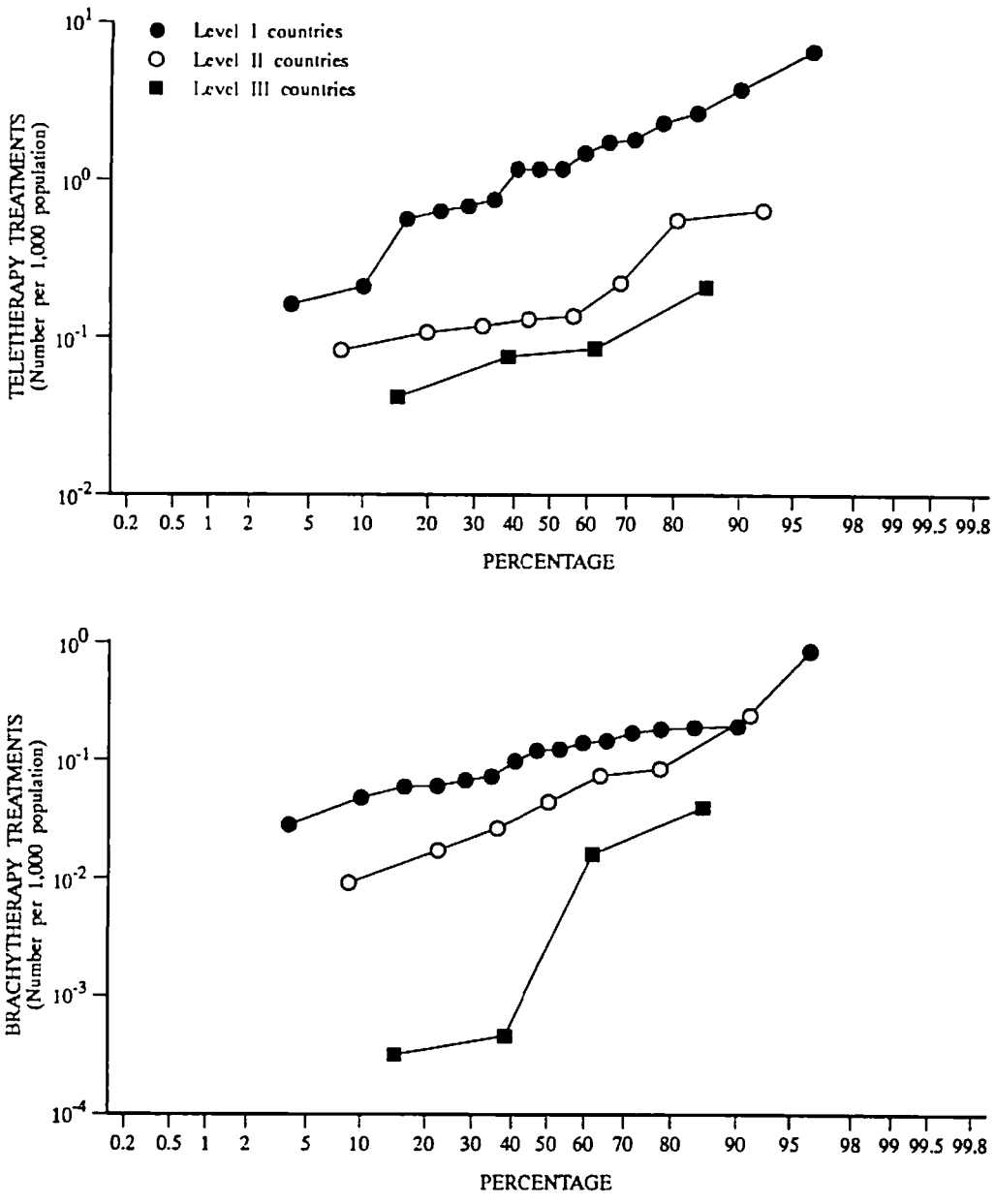

Figure VII.
Distribution of total annual frequency of radiotherapy treatments.

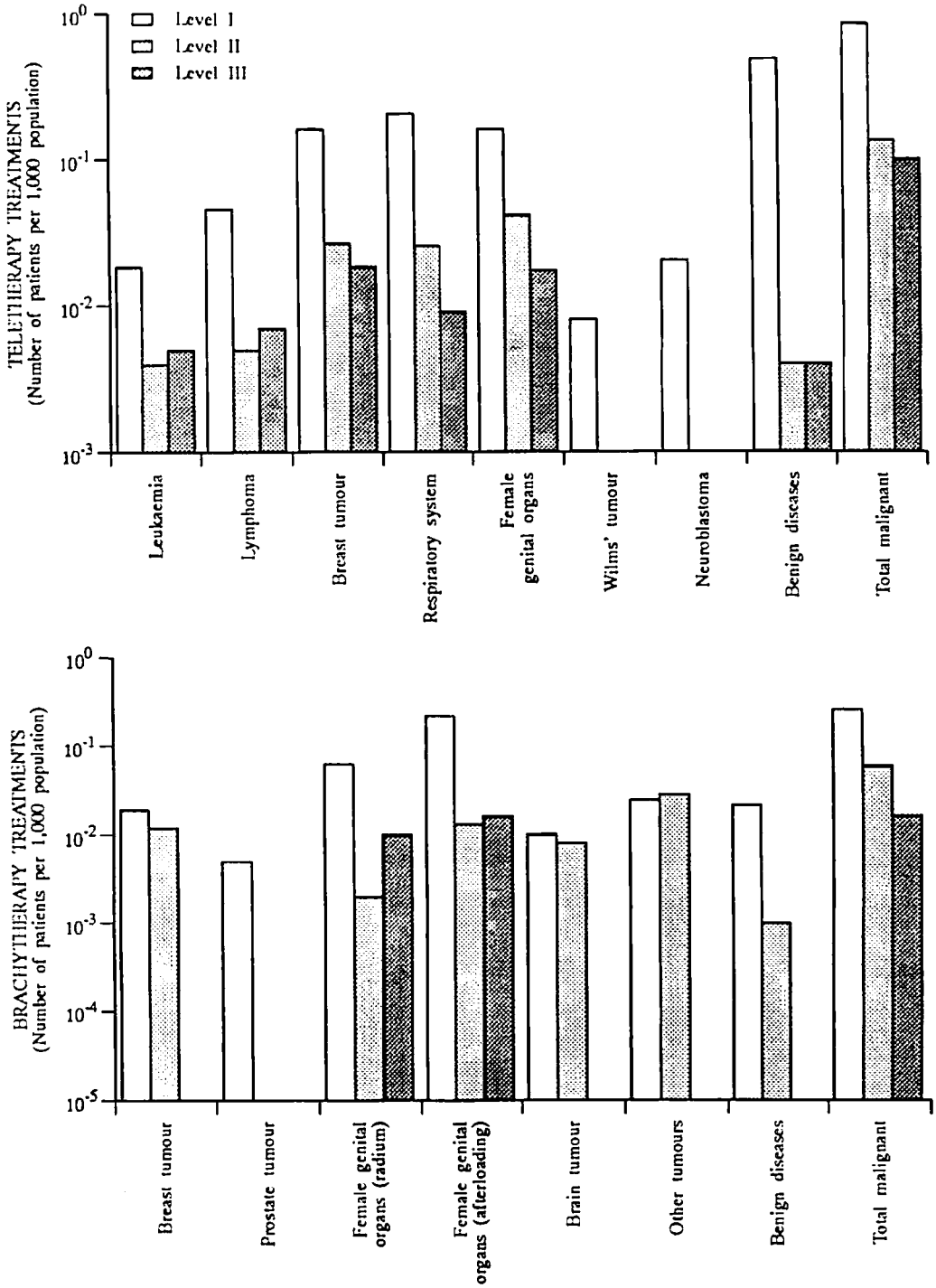

Figure VIII.
Average annual frequency of radiotherapy treatments in 1985-1990.

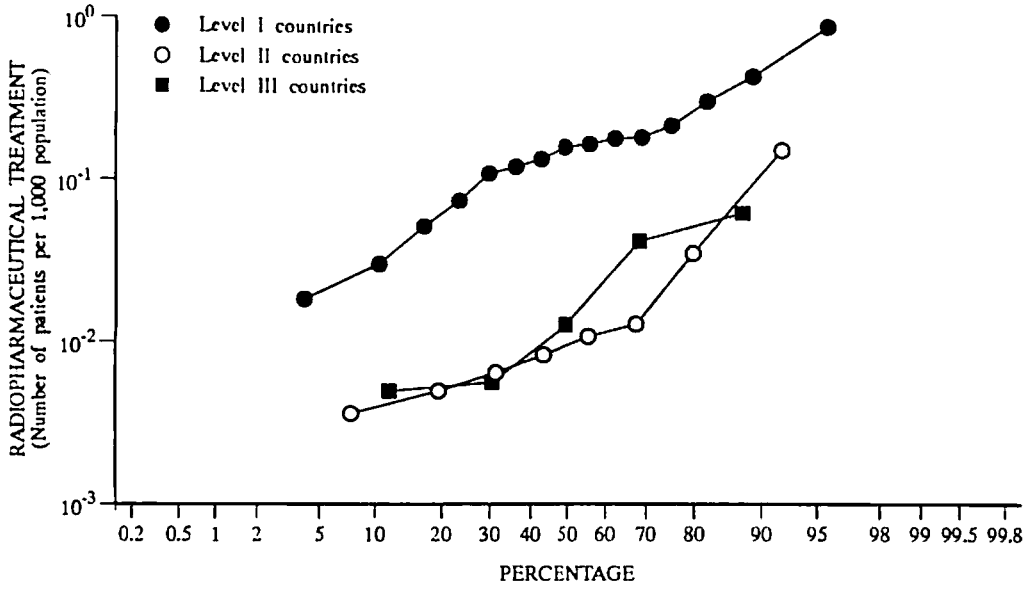

Figure IX.
Distribution of total annual frequency of therapy treatment with radiopharmaceuticals.

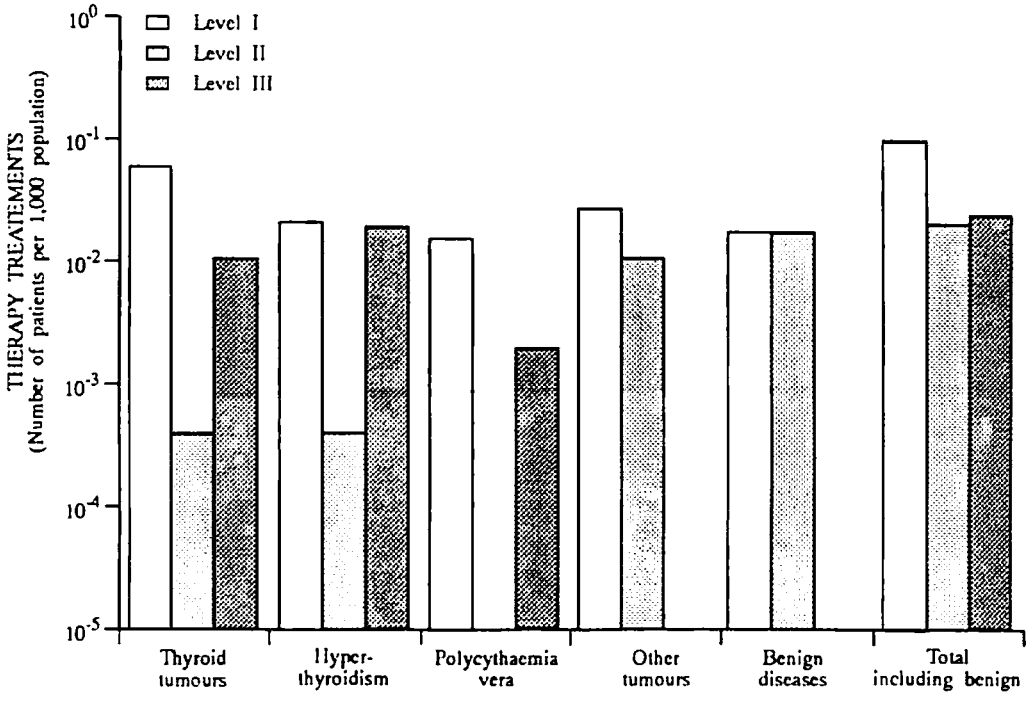

Figure X.
Average annual frequency of therapy treatments with radiopharmaceuticals in 1985-1990.

References

PART A

Responses to UNSCEAR Survey of Medical Radiation Usage and Exposures

Country	*Response from*
Argentina	J. Skvarca. Ministerio de Salud y Acción Social, Departamento de Radiofísica, Buenos Aires, Argentina. (September 1990 and December 1991).
Australia	D. Webb. Medical Radiation Section, Australian Radiation Laboratory, Victoria, Australia. (May 1990, December and April 1991).
Barbados	J. Rajendran. Queen Elizabeth Hospital, St. Michael, Barbados. (February 1990).
Belgium	SPRI-DBIS, Ministère Volksgezondheid & Leefmilieu, Bruxelles, Belgium. (November 1991).
Belize	C. Borrás. Pan-American Health Organization, Washington. (December 1991).
Burma	S. Tun Aung and U. Maung Gyi. Radiotherapy and Radiology Department, Mandalay General Hospital, Myanmar, Burma. (1990). T. Than OO and S. Than Tun Aung. Radiotherapy Department, Yangon General Hospital, Myanmar, Burma. (April 1990).
Canada	P. Dvorak. Bureau of Radiation and Medical Devices, Health and Welfare, Ottawa, Canada. (April, March 1990 and October 1991).
Cape Verde	D. Dantas Dos Reis. Dr. Agostinho Neto Hospital, Ministry of Health, Praia, Cape Verde. (April 1990 and October 1991).
Chile	C. Borrás. Pan-American Health Organization, Washington. (December 1991).
China	Z. Liangan. Institute of Radiation Medicine, Chinese Academy of Medical Sciences, China. (November 1991 and January 1992). Wu Shengcai, Yue Baoreng and Cui Jianguo. Laboratory of Industrial Hygiene, Ministry of Public Health, China. (June 1990).
Costa Rica	C. Borrás. Pan-American Health Organization, Washington. (December 1991).
Cuba	C. Borrás. Pan-American Health Organization, Washington. (December 1991).
Czechoslovakia	E. Kunz. National Institute of Public Health, Centre of Radiation Hygiene, Praha, Czechoslovakia. (April 1990). V. Klener. National Institute of Public Health, Centre of Radiation Hygiene, Praha, Czechoslovakia. (November 1991).
Denmark	K. Ennow and O. Hjardemaal. National Institute of Radiation Hygiene, Brønshøj, Denmark. (June 1990 and January 1992).
Djibouti	Ministry of Public Health and Social Affairs, Djibouti. (April 1990).
Ecuador	M.F. Campaña. Dirección de Ciencias Biofísicas, Comision Ecuatoriana de Energia Atomica, Quito, Ecuador. (February 1990).
Ethiopia	S. Demena. Department of Internal Medicine, Nuclear Medicine Unit, Addis Ababa, Ethiopia. (April 1990 and October 1991).
Finland	S. Rannikko. Finnish Centre for Radiation and Nuclear Safety, Department of Inspection and Metrology, Helsinki, Finland. (April and October 1991).
France	P. Pellerin. Service Central de Protection contre les Rayonnements Ionisants, Le Vésinet, France. (April 1990).

Country	*Response from*
Germany, Fed.Rep.	W. Burkart. Bundesamt für Strahlenschutz, Institut für Strahlenhygiene, Neuherberg, Germany. (October 1991).
Guatemala	C. Borrás. Pan-American Health Organization, Washington. (December 1991).
India	U. Madhvanath. Division of Radiological Protection, Bhabha Atomic Research Centre, Bombay, India. (December 1991).
Iraq	A. Al-Douri. Physics Department, Institute of Radiology and Nuclear Medicine, Baghdad, Iraq. (1991).
Italy	Ministero della Sanità, D.G.S.I.P., Div. VIIa, Rome, Italy. (June 1990). F. Dobici. ENEA, Divisione Radioisotopi e Macchine Radiogene, Rome, Italy. (October 1991).
Jamaica	A. Beach. Radiotherapy Department, Kingston Public Hospital, Kingston, Jamaica. (July 1990).
Japan	T. Maruyama. Division of Physics, National Institute of Radiological Sciences, Chiba-shi, Japan. (1991).
Kuwait	F. Sulaiman. X-ray Office, Ministry of Public Health, Safat, Kuwait. (April 1990 and November 1991).
Luxembourg	P. Kayser. Direction de la Santé, Division de la Radioprotection, Luxembourg. (February 1990).
Malta	M. Gauci. Occupational Health Unit, Department of Health, Valletta, Malta. (April 1990).
Mexico	R. Ortiz Magaña. Comisión Nacional de Seguridad Nuclear y Salvaguardias, Mexico. (October 1991).
Netherlands	L.B. Beentjes. Health Physics Department, University of Nijmegen, Netherlands. (July 1990 and October 1991).
New Zealand	B.D.P. Williamson and V.G. Smyth. National Radiation Laboratory, Christchurch, New Zealand. (July 1990).
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Peru	R. Ramírez Quijada. Instituto Peruano de Energía Nuclear, Lima, Peru. (1990). L. Pinillos Ashton. Ministry of Health, Lima, Peru. (1990).
Philippines	M. Elesango. Radiation Health Service, Department of Health, Manila, Philippines. (April 1990).
Poland	M.A. Staniszewska and J. Jankowski. Institute of Occupational Medicine, Department of Radiation Dosimetry, Łódź, Poland. (April 1990).
Romania	C. Milu. Radiation Hygiene Laboratory, Institute of Hygiene and Public Health, Bucharest, Romania. (April 1990). C. Diaconescu. Radiation Hygiene Laboratory, Institute of Public Health and Medical Researches, Iassy, Romania. (November 1991).
Rwanda	Division Surveillance Epidemiologique, Ministere de la Sante, Kigali, Rwanda. (June 1990).
Singapore	T. Goh. Diagnostic Imaging Services, National University Hospital, Singapore. (1990).
Spain	E. Vañó Carruana. Catedra de Fisica Medica, Facultad de Medicina, Universidad Complutense, Madrid, Spain. (April 1990 and October 1991).
Sweden	W. Leitz, J. Karlberg and P. Hofvander. National Institute of Radiation Protection, Stockholm, Sweden. (May 1990 and October 1991).

Country	*Response from*
Switzerland	J. Marti. Radiation Protection Division, Federal Office of Public Health, Bern, Switzerland. (November 1991).
Thailand	Ministry of Public Health, Bangkok, Thailand. (February 1990).
Tunisia	S. M'Timet. Centre National de Radioprotection, Ministere de la Sante Publique, Tunis Jebbari, Tunisie. (August 1990).
Turkey	A. Gönül Buyan, F. Gözbebek and B. Ceyhan. Turkish Atomic Energy Authority, Ankara, Turkey. (October 1991).
United Kingdom	B.F. Wall. National Radiological Protection Board, Chilton, Great Britain. (March 1990 and October 1991).
United States	R.L. Burkhart. Centre for Devices and Radiological Health, Food and Drug Administration, Maryland, United States. (April 1990).
Vanuatu	R.E. Fey. Ministry and Department of Health, Port Vila, Vanuatu. (April 1990).
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