SOURCES, EFFECTS AND RISKS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation
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NOTE

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ANNEX C

Exposures from medical uses of radiation

CONTENTS

Introduction

1. The Committee has previously reviewed data on exposures from medical uses of radiation in its Reports of 1958 [U1], 1962 [U2], 1972 [U3], 1977 [U4] and 1982 [U5]. Medical radiation may be incurred from (a) diagnostic and interventional x-ray examinations; (b) diagnostic nuclear medicine examinations; and (c) radiation therapy from either external or internal sources. In many countries, diagnostic medical examinations contribute the largest proportion of the collective effective dose equivalent from man-made sources received by the population.

2. The aim of this Annex is to assess the magnitude of radiation exposures delivered world-wide in the course of medical practice. Once this has been achieved, (a) sources of radiation exposure may be compared; (b) areas of concern can be identified; (c) possible detriment estimated; and (d) efforts channelled for an optimum global radiation dose reduction (if indicated). Thus far, the Committee has estimated that the

collective effective dose equivalent for the world from diagnostic medical radiation is about 400 man Sv per million population (i.e., about 0.4 per caput).

3. For diagnostic and interventional uses of radiation, there is a possibility of dose reduction, although one must be careful not to decrease at the same time the associated benefits. Medical radiation differs from other radiation sources in several ways. The first is that, with the exception of medical occupational radiation exposure, those receiving the doses delivered in the course of medical procedures are those who are expected to benefit directly from such procedures. The second difference is that the dose to patients during radiography is usually received over a short time and most often involves only a limited portion of the body. A third difference from other sources is that the exposed population is highly selected, insofar as many of the exposed individuals are suffering from some form of illness and insofar as their age distribution is quite different from the age distribution of the population at large.

4. One of the limitations of the previous Reports of the Committee, as well as of this Annex, is that good data on frequency of examinations and absorbed dose from medical examinations and occupational sources are available predominantly from developed countries, which account for less than 25% of the world's population. Fragmentary data on examination rates and numbers of machines and little or no data on absorbed doses are available for another 25% of the population, and no data are available at all for 50% of the world's population.

5. The present availability of radiodiagnosis is very uneven throughout the world: one x-ray machine is shared by fewer than 2,000 people in some countries and by 100,000-600,000 people in other countries. The frequency of procedures is also very uneven (15-20 procedures annually per 1,000 population in some countries and about 1,000 procedures annually per 1,000 population in others) [R1]. At present, there are approximately 5 10^9 people in the world and some authors indicate that more than three quarters of the world's population have no chance of receiving any radiological examination, regardless of what disease they may have. In many developing countries, between 30% and 70% of x-ray machines are out of order [M32, P2]. The lack of good data from areas that account for approximately three quarters of the world's population has led the Committee to adopt an extrapolation procedure for estimating world-wide medical use of radiation.

6. In the UNSCEAR 1958 Report [U1], the Committee was predominantly interested in exposures that might have hereditary effects, so it calculated a genetically significant dose (GSD). It became evident during the 1958 analysis that a major portion of dose was contributed by relatively few types of examinations. By 1977, and even more by 1982, the Committee became interested in estimating the mean doses to other tissues, particularly those tissues regarded as more susceptible to the induction of stochastic effects (e.g., the thyroid, active bone marrow, the lung and the female breast). For calculation of possible subsequent cancer induction, age at exposure was recognized to be important, but little data existed on this parameter.

7. Although it is of interest for the Committee's purposes to compare the risk from medical radiation with risks from other sources of man-made radiation or from natural background radiation, such comparison has always posed a difficult problem. The effects of radiation depend upon the energy of the radiation, instantaneous dose rate, the time over which the total dose is received, and the part of the body exposed. In this respect, diagnostic examinations are markedly different from radiotherapy procedures, in which substantially higher doses are given to a much smaller group of patients, in whom non-stochastic effects are present in the short term. The Committee has always felt that the potential stochastic risks to patients from diagnostic medical radiation and nuclear medicine should not be summed or compounded with the risks from radiotherapy. The reasons for this are that the risk coefficient for a given effect may vary with the magnitude of the absorbed dose and the dose rate. In addition, the radiation risk coefficient for cancer patients is unknown and their lifespan and age distribution are likely to be different from other populations. Radiation therapy is therefore assessed in this Annex only in terms of average absorbed doses in organs. It would be of interest to evaluate the absorbed doses to tissues outside the target volume in patients who have undergone radiation therapy for estimation of possible later stochastic effects. Unfortunately, the Committee has been unable to obtain data on the number and exact treatment regimes that have been utilized.

8. In 1977, the International Commission on Radiological Protection (ICRP) introduced a quantity called the "effective dose equivalent", defined as the sum of all the organ dose equivalents weighted for the relative radiation risk. The effective dose equivalent as defined for purposes of radiation protection [12] should not, in principle, be used to estimate the detriment in population groups with sex or age distributions that differ significantly from those of the working population, and it was not the original intention of the ICRP that the effective dose equivalent concept should be extended to patients. However, in the absence of good age distribution data on exposed patients, the Committee utilized the effective dose equivalent concept in the UNSCEAR 1982 Report [U5] as the best available estimate of medical exposure for the purpose of comparison with other sources of radiation exposure. This Annex examines the age distribution of populations undergoing different radiological examinations and points more specifically to the limitations to the use of collective effective dose equivalent for estimating detriment. A more detailed discussion of this problem is presented in section I.F.

9. In addition to examining the population structure itself, the Committee felt that it was important to examine trends in the utilization of various procedures used for a given diagnostic objective as well as trends in types of equipment. Over the past decade there have been many technological advances that may be

affecting medical exposure: old techniques are being replaced by new ones; additional examinations are being performed; and procedures are being carried out with different types of equipment, leading to increases or decreases in the mean absorbed doses in organs in the course of examinations. This Annex examines trends where sequential data are available. Although it is clear that trends vary markedly from country to country, it appears that, globally, the extent to which medical radiation is utilized is increasing. The World Health Organization published a report [W19] containing recommendations intended to alert the medical and governmental communities to the fact that, particularly in industrialized countries, many clinically unproductive radiological examinations are being performed. In contrast, there is probably substantial under-utilization in developing countries.

10. In an attempt to estimate the global use of medical radiation, the Committee has made use of the good correlations that exist between population per x-ray machine and population per physician (Figure I). A good correlation has been found between the number of x-ray examinations per unit of population and the number of physicians per population [M27]. Four levels of health care have been defined, based upon the number of population per physician in a given country in 1982. In countries with the highest level of health care (level I), more than one physician is available per 1,000 population. In countries of the next category (level II), one physician is available per 1,000-3,000 population. In countries with lower levels of health care, one physician serves 3,000-10,000 people (level III) and more than 10,000 people (level IV). By estimating the average number of medical radiation examinations in countries of the various health care levels and reported doses from representative countries, the doses to the world population can be determined. This approach is used in evaluating the doses from x-ray examinations, from diagnostic use of radiopharmaceuticals, as well as therapeutic uses of radiation.

11. This Annex also reviews doses to particular organs from various types of medical examinations. The individual and collective organ doses from various medical practices are computed to evaluate the contribution that medical practice makes to man's total radiation exposure. Since these data may also be used to determine whether special population groups are being highly exposed, they may be of epidemiological interest. There remain some difficulties, however, in comparison of absorbed doses, because the techniques presented in the radiologic physics literature sometimes measure exposure rather than absorbed doses. The determination of interest is the average absorbed dose in an organ. There is considerable variability from study to study in modelling, computational techniques and assumptions utilized. Because organ doses vary markedly from one procedure to another, it is useful to examine this variation within a given country as well as from country to country, in search of the underlying causes.

12. While absorbed dose data exist for many radiographic and nuclear medicine procedures, this Annex suggests that previous estimates of absorbed dose to the world's population may be somewhat low. The two most important reasons for this suspicion are the widespread use of fluoroscopy in developing countries and the large number of malfunctioning machines producing high absorbed doses (neither factor was widely appreciated in the past) [B16, D1]. For example, in the People's Republic of China, most radiographic examinations are performed with fluoroscopy machines that do not have image intensification systems [S32, Z4], resulting in higher dose equivalents per examination than in some other countries.

13. Finally, this Annex examines expected changes in the magnitude of medical exposure through the year 2000. The Committee recognizes that there is expected to be (a) a significant increase in total population of the world; (b) a marked aging of the population in many, mostly developed countries, with increased proportions of the population over the ages of 60 and 80; (c) an increase in the proportion of the world's population residing in cities; and, finally, (d) a shift in the spectrum of diseases [O4]. All of these factors are expected to play a significant role in the future use, availability and need for medical radiation.

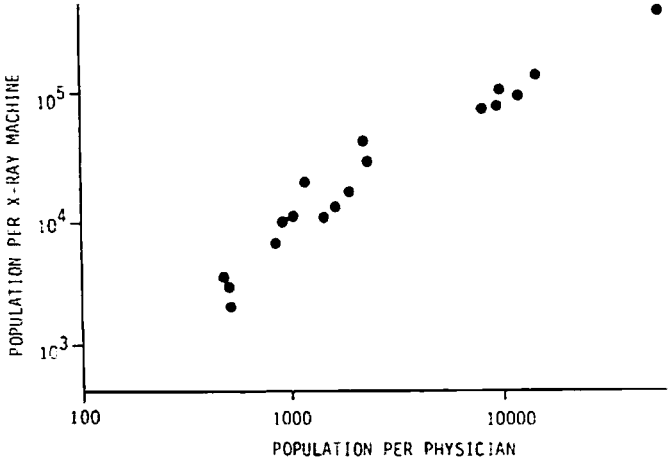

Figure I. Correlation between population per physician and population per x-ray machine in various countries. [M27, U6, U7, U8]

I. DIAGNOSTIC MEDICAL X-RAY EXAMINATIONS

A. FREQUENCY AND TRENDS

14. In the UNSCEAR 1977 Report [U4], data on the frequency of diagnostic x-ray examinations were available for only three countries: Japan, Sweden and the United States of America. The UNSCEAR 1982 Report [U5] reviewed the annual frequency of these examinations in several countries; however, it was difficult to discern world-wide trends since most countries had not conducted sequential surveys.

15. Information is now available from some other countries. The annual frequency of procedures per person varies significantly between countries [C7]. In many developing countries, radiology is used about

30 times less often per caput than in industrialized countries. The consumption of radiographic film per unit population is a poor parameter for assessing the global medical radiation exposure of the population because in many countries there is a preponderance of mass miniature radiography or fluoroscopy and these require higher values of dose. In its attempt to assess data, the Committee has therefore concentrated on numbers and types of machines as well as on the number of procedures.

16. Information on the annual frequency of diagnostic x-ray examinations in 13 countries of level I health care and one country of level II health care is collected in Table 1. The total frequencies in these countries range from 450 to 1,300 examinations per 1,000 population, with an average of 800 examinations annually per 1,000 population for level I countries. The number of diagnostic x-ray examinations is increasing, according to the results of sequential surveys in several countries.

17. From 1976 to 1980, the number of radiological examinations performed in hospitals in Canada increased by approximately 2.7 million. Most types of examinations increased in number. The examinations that decreased in frequency over that time period were those of the abdomen, breast and bronchus and those related to obstetrics and gynaecology [C1]. When the total examinations were considered for 1980-1981, there was an annual rate of approximately 1,000 medical x-ray examinations per 1,000 population (Table 1). Additional data have been reported from the province of Manitoba [M3], where the number of examinations reported per 1,000 population was 860 in 1974 and 840 in 1979.

18. In France in 1957, approximately 6.2 million radiographic examinations were performed. As of 1981, this number had risen to 45 million (835 examinations per 1,000 population). The number of various types of diagnostic radiologic examinations performed in France in 1982 is given in Table 1 [B9]. Le Gales et al. [L8] report that in France in 1980 approximately 9.8 million chest screening examinations were performed. About 60% of these were photofluorographic, 30% fluoroscopic, and the rest radiographic. In addition to screening for tuberculosis, there is also a well-defined radiologic screening programme in France for detection of congenital hip dysplasia. Bouvet et al. [B18] have reported that 3.4 million radiographies of the hip and pelvis were performed in 1982. Of these, 725,000 were carried out on children of less than one year of age. The annual birth rate in France is about 720,000.

19. In Italy in 1983, 744 medical x-ray examinations were carried out per 1,000 population [P1]. Indovina et al. [I9] indicate that mass screening in Italy resulted in 4.3 million chest photofluorographies in 1974 and 3.0 million in 1980.

20. The frequency of diagnostic x-ray examinations in Japan is made greater by the mass chest x-ray examination campaigns and by an emphasis on examinations of the abdomen and the gastro-intestinal tract (Table 1). Kumamoto [K22] reported that in 1980, 26.6 million (242 per 1,000 population) mass chest x-ray examinations were performed. This number is considerably lower than the 33 million photofluorographic examinations performed in 1975 [H4].

21. In the Netherlands in 1980, approximately 8.7 million examinations were performed [B6]. Approximately 40% of examinations were of the chest; half of these were mass miniature radiography. The total annual frequency was 648 per 1,000 population (Table 1).

22. A detailed report on the annual frequency and type of examinations performed in Norway in 1980 and 1983 has been published [S3, S4]. The total annual frequency for 1980 was 641 per 1,000 population (Table 1).

23. According to estimates by Kudritsky et al. [K19, K20], the number of x-ray procedures in the Russian Soviet Federative Socialist Republic (RSFSR) during 1970-1980 increased from 138.5 to 185.8 million and their annual frequency from 1,065 to 1,339 per 1,000 population. During that decade, the mean annual increase in the frequency of x-ray examinations remained constant at 2.3-2.4%. Somewhat lower annual frequency rates have been reported for the USSR by Vorobyev et al. [V7] and Nikitin [N9]. They indicated that between 1963 and 1981, the number of x-ray examinations increased by 21%. The ratio of photofluorographic to radiographic and fluoroscopic examinations increased substantially (Table 2). The annual frequency of various types of chest x-ray examinations was reported per 1,000 population as follows: photofluorography, 526; radiography, 118; and fluoroscopy, 149 [V7]. Similar figures have been reported by both Neamiro et al. [N6] and Nikitin [N9] (Table 1). About one half of all x-ray examinations in the USSR are chest photofluorography performed for prophylactic purposes.

24. An estimation of the annual frequency and type of examinations performed in Spain in 1986 has been made by Vano et al [V4]. The total annual frequency was 490 per 1,000 population (Table 1). The increment between 1985 and 1986 was 2.5%.

25. Wall et al. [W6] have indicated that the frequency of diagnostic examinations in the United Kingdom in 1983 was 488 per 1,000 population (Table 1). This is not significantly different from the value of 440 reported in the UNSCEAR 1977 Report [U5]. The annual increase in frequency for most types of examinations was 2-3%.

26. Growth of diagnostic radiological procedures in the United States appears to have been fairly rapid. There has been a general increase in almost all types of general radiographic examinations since 1964. The rate of hospital-based examinations per 1,000 population was 370 in 1964, 400 in 1970 and 570 in 1980, which is similar to the hospital x-ray examination rate of 650 per 1,000 estimated for Canada. The total frequency of medical x-ray examinations in the United States is 790 per 1,000 population [M28]. The increase

in frequency of examinations in Canada and the United States is probably due to a number of factors, including, among others, a change in the age distribution of the population. The number of medical diagnostic machines per 1,000 population increased from 0.53 in 1969 to 0.61 in 1981.

27. Zhang et al. [Z4] and Zhang [Z5] conducted a survey of radiological services in Shangdong Province, China, for the years 1976-1980, and this information has also been included in Table 1. The authors reported that during this time the annual frequency of examinations in rural areas increased by 77% (from 146 to 259 examinations per 1,000 population), while in urban areas the frequency was significantly higher but had increased much less as a percentage of the total (from 577 examinations per 1,000 population in 1976 to 710 in 1980, corresponding to a 23% increase). Chest fluoroscopy accounted for more than 70% of all examinations performed, chest radiography for only 2%, skeletal radiography for 6%, and special examinations for 4%. The authors also indicated that the majority of chest fluoroscopy was for screening purposes. Similar urban rates have been reported by Sun et al. [S32], who indicated that the total annual frequency of radiographic procedures in Beijing was 761 per 1,000 population, with chest fluoroscopy accounting for 65% of all procedures. Approximately 90% of all x-ray equipment in China in 1980 was fluoroscopic (i.e. about 70,000 fluoroscopic units). Somewhat lower utilization rates (about 120 per 1,000 population) have been reported by Zhang [Z7] for the Zhoukou region of Hunan Province, although the distribution of types of examinations is similar to that reported by other authors.

28. A discussion of diagnostic radiologic procedures in the Islamic Republic of Iran in 1980 [S19] indicates that the estimated overall rate of diagnostic x-ray procedures was 180 per 1,000 population. The authors also suggested that the frequency of x-ray examinations in urban areas was higher than in rural areas and small towns, with the urban population receiving approximately twice the national average.

29. Data regarding the number and frequency of x-ray examinations available from Turkey for 1977 [Y1] indicate that the annual frequency was about 80 examinations per 1,000 population.

30. The number of diagnostic radiological examinations performed in various Central and South American countries is difficult to ascertain, but some trends can be indicated by the growth in the number of machines (Table 3). There has been an increase in the number of radiodiagnostic machines in Argentina and Chile, while in Costa Rica, Ecuador and Mexico, the number of units per 1,000 population has not increased.

31. By applying the extrapolation procedure described in paragraph 10, the number of diagnostic x-ray examinations and machines on a world-wide basis may be estimated. The basic data used to make these estimates for various levels of health care are shown in Table 4. From these values, the average annual examination rate per 1,000 population and the population per x-ray machine for each level of health care are derived from the data in Table 4 and are shown in Table 5. To the extent that populations, numbers of x-ray machines and examinations have increased in direct proportion to one another since the surveys took place, it will be approximately valid to estimate current levels of practice from present world population. The number of annual x-ray examinations world-wide is thus estimated to be approximately 1,400 million, and the number of diagnostic medical x-ray units, approximately 440,000. The number of medical x-ray examinations for the four levels of health care are listed in Table 6. As might be expected, the one quarter of the world's population in countries of health care level I receives three quarters of the examinations. The average number of examinations performed per year and per x-ray machine ranges from 3,000 to 5,500 for all levels of health care.

32. Table 7 indicates that, of the diagnostic x-ray examinations performed in some Latin American countries, chest examinations account for 22-50% and examinations of the extremities for 22-36% of the total. This is fairly consistent with the data in Table 1, which showed that in level I countries 32% of all examinations were of the chest and 19% examinations of the extremities. The Committee has reviewed available data over the past decade on the percentage of the total of diagnostic x-ray examinations accounted for by each type of examination. This is shown in Table 8 for three levels of health care. The main difference appears to be that examinations of the abdomen and digestive tract represent 18% of the total in level I countries but decrease to 13% in level II countries and to 6% in level III countries. At the same time, there is an increase in the percentage of chest examinations from level I countries to level III countries. It is of interest that examinations of the head and neck and urogenital examinations account for a fairly uniform percentage regardless of the level of health care.

33. As might be expected, the urban population receives more x-ray examinations than the rural population (Table 9). Similar findings have also been reported by Cockshott [C7], who terms this the "capital city syndrome" even though the data are for urban areas in general and not just capital cities. In effect, a segment of the population often receives a disproportionately high number of examinations. This disproportion is also evidenced by the data available from China [S32, Z4] and the Islamic Republic of Iran [S19]. Urban populations may receive two to 10 times as many examinations per caput as rural populations.

34. Information on the historical trend in the annual frequency of diagnostic examinations in various countries is summarized in Table 10. With the exception of China and Turkey, the countries are level of health care I. For these level I countries the annual growth rate for examinations from 1955 through 1983 ranged from 0% to 10%, with an average of 3% over the decade 1970-1980.

35. Dental radiography is the most common type of diagnostic x-ray examination. In the UNSCEAR 1977

and 1982 Reports, the Committee reported data on the annual frequency of these examinations in several countries, but no data were available on trends. At present, data indicating trends are available from three countries.

36. The use of dental radiology in the United Kingdom has been reported by Wall and Kendall [W3]. It is apparent from these data that there was a marked increase in the use of dental radiology from 1963 to the end of 1981 (Figure II). The frequency of dental x rays more than doubled between 1970 and 1983. In 1983, there were 9 million dental x-ray examinations (165 per 1,000 population). In 1981 most were intra-oral (6.7 million), but 150,000 were extra-oral and 910,000 were pantomographic. The average number of films per examination in 1981 was 1.8.

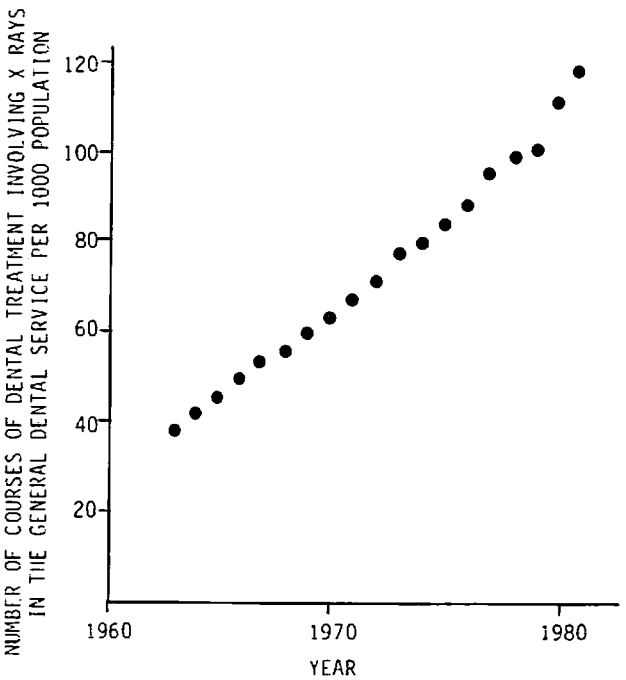

Figure II. Growth in the use of dental radiography in the United Kingdom since 1963.
[W3]

37. In France in 1984, 27.5 million intra-oral films and 1.76 million pantomographic films were taken [B11]. Between 600 and 1,200 examinations annually were performed per machine.

38. In Japan, a survey carried out in 1976 [K9] indicated that the annual number of oral radiographic films per caput in Hiroshima and Nagasaki ranged from 0.8 to 1.0. Exposure frequencies were approximately 1.5 times greater among the non-exposed individuals than among the atomic bomb survivors. According to Maruyama et al. [M11], who estimated the use of dental radiography in Japan in 1980, the annual number of exposures for intra-oral radiography was 90 million (769 exposures per 1,000 population), with an average of 1.7 exposures per examination (435 examinations per 1,000 population). Pantomographic examinations were estimated to be 9.6 million (82 per 1,000 population). This represents a total annual dental examination rate of 517 per 1,000 population. No increase in intra-oral examinations had occurred by 1985; however, there was a small increase in pantomographic examinations, to 11 million examinations.

39. According to the UNSCEAR 1977 Report [U5], the number of single dental exposures per 1,000 population in Sweden in 1974 was 1,500. Preliminary data from Sweden obtained for 1984-1985 [V2] indicate that about 1,800 dental films were obtained per 1,000 population. In the United States, there has also been a substantial increase in the frequency of dental x-ray examinations per 1,000 population [M10], although the increase was not as rapid as in the United Kingdom [W3]. The number of dental x-ray examinations in the United States increased from 67 million in 1970 to 105 million in 1982. Exposures increased from 280 million to 380 million during the same period. Between 1970 and 1982 in the United States the average annual compounded growth rate for examinations was 4.2%. The number of exposures (films) increased at an average annual compounded growth rate of 3.4%. The number of exposures per patient declined somewhat as pantomographic procedures gradually replaced full-mouth series. In 1970, approximately 6% of all dental x-ray examinations were pantomographic, and this number had risen to 18% by 1982. In 1982, the annual dental radiographic examination rate was 456 per 1,000 population. Dental x-ray machines increased from 98,000 in 1966 to 201,000 in 1981 [M10].

40. It appears that there has been relatively rapid growth in the number of dental x-ray examinations in countries of health care level I, ranging between 50 and 100% in the years 1970-1980. While there has been some increase in intra-oral dental x-ray examinations, the largest increase has occurred in pantomographic examinations. There has been growth not only in the number of examinations, but also in the number of dental x-ray machines.

41. By applying the extrapolation procedure described in paragraph 10, the total number of dental examinations performed world-wide for the various levels of health care can be estimated. The basic data required were taken from published information and have been collected in Table 11. Very limited data are available for level III countries and no data are available for level IV countries. The estimated total number of procedures for each level of health care is shown in Table 12. According to this estimate, 340 million dental radiographic procedures are conducted annually.

B. AGE AND SEX DISTRIBUTION OF PATIENTS

42. Knowledge of the age and sex distribution of those receiving examinations is important for evaluating the applicability of the collective effective dose equivalent as a measure of detriment for medical radiation, as well as for assessing the genetically significant dose.

43. Table 13 shows the percentage of the population of various countries, grouped by age and sex, receiving various examinations. Comparison for various examinations reveals some interesting differences between countries.

44. While only 31% of the population of the United States is 45 years or older, these individuals receive 51% of all the examinations; also, the 11% of the population older than 65 receive 25% of all the examinations. In the Islamic Republic of Iran, where only 16% of the population is over the age of 45, almost 50% of all examinations are performed on individuals under the age of 30 [S19]. In China, 44% of chest examinations are performed on persons under the age of 30, whereas in Norway, the United Kingdom and the United States the comparable figure is 20%. In general, the less developed a country, the younger the mean age of the population and the younger the population exposed in diagnostic radiology.

45. In the course of three surveys carried out in the USSR, Kudritsky et al. [K19, K20] analysed the distribution of x-ray examinations and identified some general regularities for various age groups in the population. The lowest frequency, observed in children under 15, was 20-50% of the mean value for the entire population. The frequency of x-ray examinations increased gradually with age, reaching a maximum for persons between 40 and 59 years, for whom it was 1.5 to two times higher than the average frequency. In the group aged 60 and above, the frequency of x-ray examinations was again somewhat lower, reaching levels 30% below the average.

46. In most of the countries of health care level I, the x-ray examinations are almost equally divided between males and females, the main exceptions being mammograms, cholecystograms and barium enemas. For these examinations there is in most countries a clear female predominance. In the Islamic Republic of Iran, 63% of all examinations are performed on males.

47. Although age and sex differences of populations receiving x-ray examinations are presented in this Annex, there has been no attempt to introduce any age-dependent correction factor in calculation of the effective dose equivalent commitment. A preponderance of old and ill persons in a population should theoretically reduce its risk of long-term effects compared to a population of workers. On the other hand, screening x-ray examinations involving children would, by a similar comparison, substantially increase the longer term risk to a population. At present there is very little information available on the impact of neoplastic and non-neoplastic diseases on radiation risk coefficients or upon reduction in lifespan.

C. IMPACT OF SPECIALIZED TYPES OF EXAMINATIONS

48. In the UNSCEAR 1977 and 1982 Reports, the Committee suggested that the increasing use of newer techniques might decrease the radiological exposure of the population. It was uncertain whether imaging modalities that do not utilize ionizing radiation (such as ultrasound) would replace existing radiologic procedures or simply add to the total number of procedures. Since 1982, magnetic resonance imaging has also become available; in this technique, images are generated by the induction of radiowaves in a magnetic field, and no ionizing radiation is utilized. At present, the main use of magnetic resonance appears to be for brain and spinal cord imaging, but no numerical data exist on the frequency or availability of this technique.

49. Hinz et al. [H14] and Schwarz et al. [S5, S6, S7] have examined the replacement of specific radiographic examinations by sonography. Their reports cover the years 1977-1982. The authors specifically considered procedures related to the stomach, abdomen, gallbladder, pancreas and urinary system. In those areas, there was a decrease of about 50% in radiographic examinations (Figure III) and an increase of about 150% in sonographic examinations (Figure IV). Decreases of 10%, 2% and 46% were found in contrast examinations of the small bowel, colon and gallbladder, respectively.

50. Pelvic imaging procedures were specifically considered, with the expectation that radiological examinations of the pelvis might have decreased as pelvic ultrasound examinations increased. The data are of limited value, however, because most surveys include x-ray examinations of the hip and pelvis in the same category. While ultrasound might be expected to have substantially reduced the number of oral cholangiograms, in the United States, at least, the marked increase in frequency of biliary ultrasound certainly had not decreased their number, although it may have reached a plateau as from 1980. There has been a substantial increase in radionuclide hepatobiliary imaging, while percutaneous cholangiography and intravenous cholangiography have markedly declined [E6].

51. Although there was a marked increase in echocardiography and nuclear medicine cardiac studies in the United States between 1972 and 1980 (Table 14), the number of invasive cardiac contrast procedures has substantially increased rather than decreased. It may be concluded that in developed countries ultrasound has replaced some radiographic procedures in imaging of the gallbladder, the kidneys and the foetus.

52. Data are available concerning the use of computerized tomography in several countries. In Japan, 14.4 million procedures (123 per 1,000 population) were performed in 1979 [N10, N11]. Of the total, about 75% were computerized tomographic scans of the head and the remainder were computerized tomographic body scans. Over 60% were performed on patients 45 years or older. Some related data are also available from the United States [E6]. Prior to 1970 computerized tomography and ultrasound procedures were hardly used at all. Table 15 shows that the increase in computerized tomography of the head coincides with a substantial reduction in the number of radionuclide brain scans being performed and

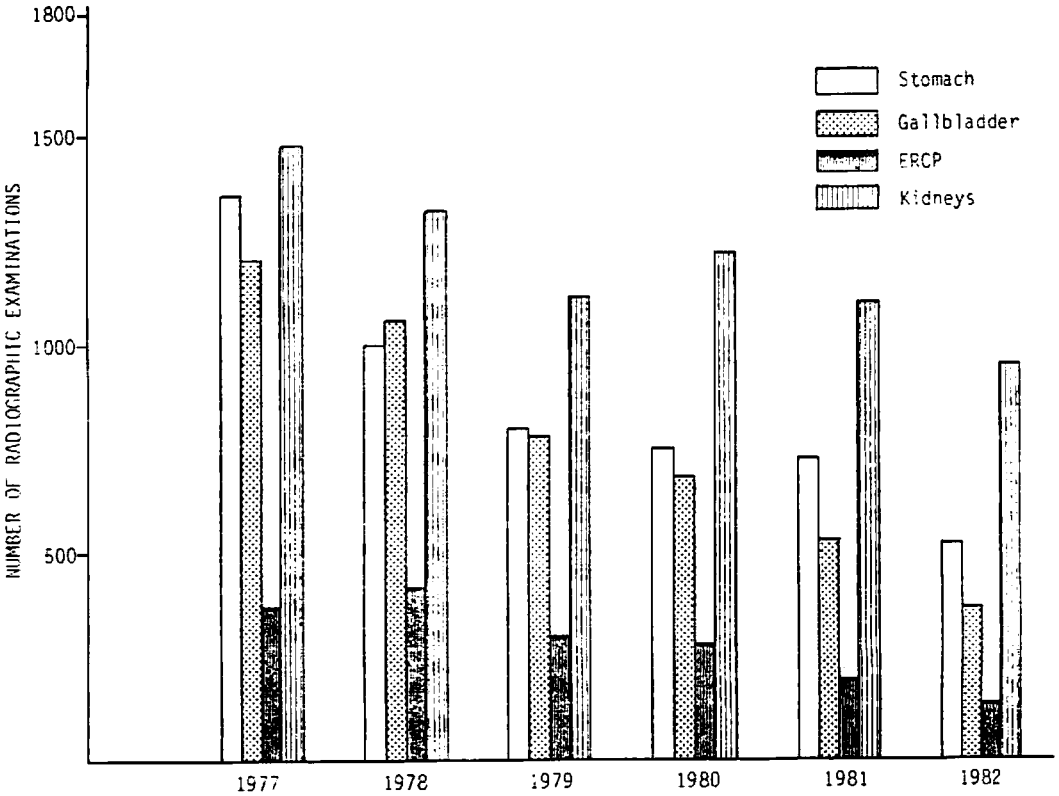

Figure III. Changes as a function of time (1977-1982) in the number of x-ray examinations of various organs in a University clinic in the Federal Republic of Germany. (ERCP = encoscopic retrograde cholangio pancreatography).
[H14]

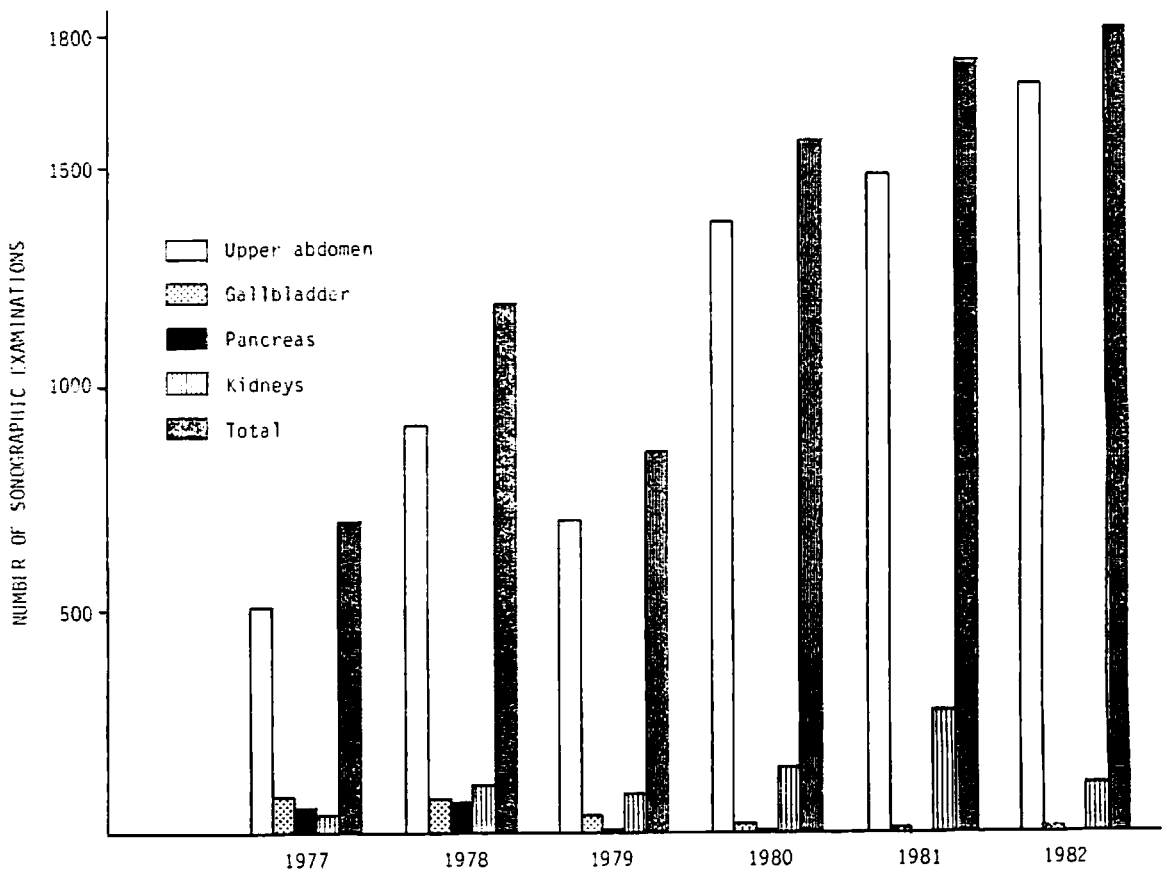

Figure IV. Changes as a function of time (1977-1982) in the number of sonographic examinations of various organs in a University clinic in the Federal Republic of Germany.
[H14]

that, during the same period, pneumo-encephalograms became extremely rare.

53. Evens et al. [E3, E4, E5, E6] and Hughes [H21] examined trends in the use of computerized tomography in the United States during 1981-1983. Total scans increased from 2,337,000 in 1981 to 4,303,000 in 1983. Cranial scans accounted for 75% of such procedures in 1981 but decreased to 63% in 1983. During the same period, computerized tomography scans of the spine increased from 3% to 10% and other body scans increased from 22% to 27%. However, the rate of increase in the use of computerized tomography slowed markedly with the percentage increase over the previous year being 53% from 1981 to 1982 and 21% from 1982 to 1983.

54. Imaging procedures of the abdomen are difficult to evaluate since many computerized tomographic examinations of the abdomen and ultrasound examinations are done for retroperitoneal pathology. The increasing use of abdominal ultrasound and computerized tomography may have decreased the number of ordinary x-ray examinations of the abdomen being performed in the United States between 1980 and 1982 [E6]. Whether this is a real finding or simply due to different reporting of the two surveys is unknown. Computerized tomography has decreased the need for some arteriograms [B2, K7, W12], but in general there has been a net increase in examinations utilizing relatively large amounts of ionizing radiation. Another interesting question is whether computerized tomography of the lumbar spine has partially replaced myelography. In the United States the frequency of myelography examinations has continued to increase in spite of increasing computerized tomographic examinations of the spine.

55. Another particularly important trend is that of mammography. Table 16 indicates the significant increase of mammography examinations per 1,000 female population. At present, the rate in the United States is slightly greater than 10 per 1,000 females annually.

56. In the past decade there has been a rapid expansion of both digital and interventional technologies. Digital technology in this context refers to the recording of transmitted photons on an image intensifier or other such receptor rather than on film. This process allows computer manipulation of the images. This technology has found widespread use in vascular radiology, but it can also be used in other examinations. Interventional technology refers to a number of techniques in which radiology is used to guide the radiologist or other physician in a semi-surgical diagnostic or therapeutic procedure. Examples of such procedures are placement of drainage catheters, needle biopsy of various lesions, catheter placement for infusion of pharmaceuticals, and balloon catheter placement for occlusion or dilatation of blood vessels. Most of these procedures require lengthy periods of fluoroscopy and may result in high absorbed doses to the patient as well as to the operator. Data on the frequency of such procedures are not available at this time.

D. EXPOSURE AND ABSORBED DOSE

57. The distribution of exposure or absorbed dose in a patient as a result of a diagnostic x-ray examination depends upon (a) the amount of incident radiation; (b) the location and direction of the incident beam; and (c) the quality and attenuation of the radiation in the body. The amount of incident radiation depends upon exposure at skin entrance and the size of the radiation field. Exposure for an examination is sometimes reported free-in-air (i.e., without the body present) and sometimes as skin surface exposure (i.e., with the body there). Alternatively, the absorbed dose in soft tissue at the surface may be reported. The ratio of the exposure on the body to exposure free-in-air for examinations that contribute significantly to the radiation dose is approximately 1.2 to 1.4. Some authors have reported results in terms of energy deposited in the total body or in a given organ rather than in terms of average energy absorbed per unit mass. It would be worthwhile to unify methods of expression of patient exposure and dosimetry.

58. While the average absorbed dose in a given organ of the body depends on all the factors listed above, some consolidations are possible when considering relative distribution of absorbed dose in the body. If the physical characteristics of the beam (tube potential, tube current, radiation field size, location and filtration) are the same for a series of exposures, the relative absorbed dose distribution is independent of the amount of incident radiation. Approximate but adequate constancy is also obtained for a small range of patient sizes for a particular type of examination. While the exposure at the body surface of adults for a given type of examination may range over a factor of up to 40 (Figure V) [U9], the relative absorbed dose is usually considered to be adequately constant so that the effective dose equivalent for a given type and projection of an examination is proportional to the exposure or absorbed dose of the incident radiation. It should be noted, however, that relative absorbed dose distributions change so that a different numerical proportionality is obtained for children and infants than for adults.

59. In the UNSCEAR 1977 Report [U4], typical skin doses in the primary beam for various examinations were given. More recently, data on trends and variability of exposures in the United States have become available from the Nationwide Evaluation of X-ray Trends (NEXT) programme [U9]. In this programme, exposure is measured for five projections using specified geometry and measured free-in-air. Histograms for composite data for the years 1973-1980, shown in Figure V, indicate a rather wide distribution of such exposures. Very similar data for 1975-1985 are available from the NEXT programme in Canada [C2] Italy [I1]. With the advent of rare-earth screens and faster film-screen combinations, one might expect that the mean exposure at skin entrance would be decreasing. However, data from the United States suggest that as of 1983, in spite of technological advances, there has been little reduction in average exposure [U9]. Therefore, one is led to conclude that world wide, skin doses have not

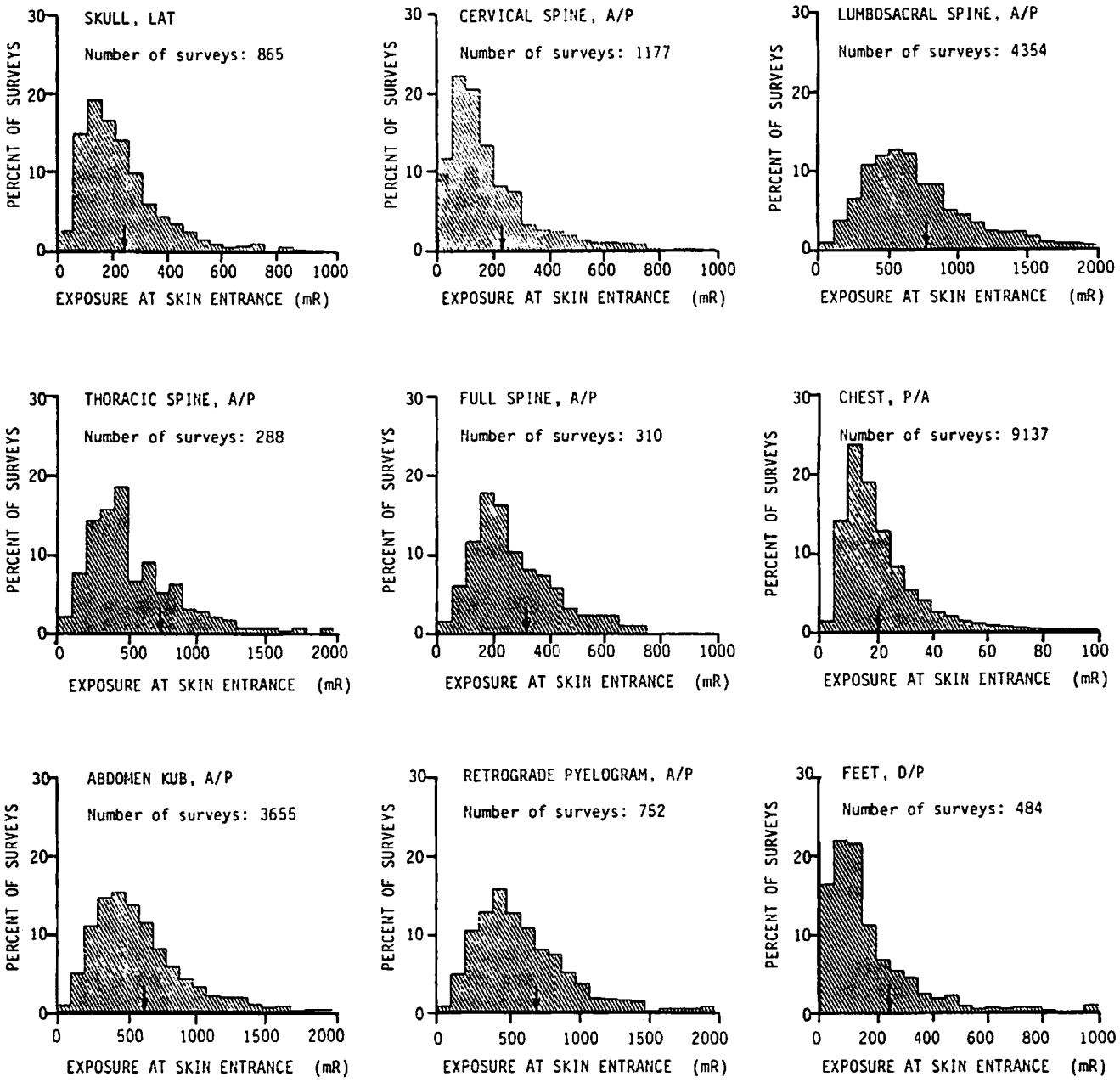

Figure V. Exposure at skin entrance (ESE) for various examinations (mR). (Exposure determined as "free-in-air"); (arrow refers to mean exposure value).
[U9]

changed significantly from those identified in the UNSCEAR 1977 Report.

60. For purposes of this Annex, in order to be able to compare results from different studies, exposures measured free-in-air have been converted to skin exposure using a backscatter correction factor of 1.3. The skin exposures were then converted to skin dose equivalent utilizing an absorbed dose to exposure conversion factor of 1 rad per roentgen or 1 centigray per roentgen. Mean skin doses in the primary beam for various diagnostic x-ray examinations have been measured in Canada, Italy, Poland, United Kingdom and the United States (Table 17). Skin doses were measured by placing thermoluminescent dosimeters (TLDs) on the skin surface of 1,340 patients during 22 types of diagnostic radiographic examinations in Beijing, China [J4]. These results are not significantly different from results in other countries. Mean skin doses for five common diagnostic examinations in the United Kingdom have been reported by Harrison [H2]. These data indicate an approximately tenfold range in dose within one country, with almost all of the distributions showing a long tail that extends into the upper range of doses. Absorbed doses reported for a given examination also differ significantly between countries.

61. In addition to actual measurements and surveys made of doses received from radiological examinations, simpler methods have been described involving the use of nomograms to estimate exposure or absorbed dose from machine parameters. Veitch et al. [V6] investigated the use of nomograms for estimating

the exposure to the skin of a patient from three-phase equipment. Substantial work had been done years ago on single-phase equipment [S22, M24]. More recently, Edmonds [E1] described a simple and rapid method for calculating patient skin doses based on peak voltage, current, source skin distance and filtration. In fact, the method provides a quick estimate of exposure, although it may overestimate the dose for three-phase x-ray equipment by a factor of nearly 4 [S12]. A nomogram for estimating skin doses in x-ray diagnostic examinations has also been published [W1].

62. Absorbed doses in various organs are needed in order to calculate the effective dose equivalent. The organs of interest include the thyroid, bone marrow, the lungs, the female breast and the gonads. A Monte Carlo computer technique and a mathematically describable anthropomorphic phantom have been developed and can be utilized to calculate tissue-air ratios for selected organs [K4, R8]. Drexler et al. [D5], Jones [J10] and Kramer [K16] calculated organ doses for x-ray diagnosis utilizing Monte Carlo methods for both male and female phantoms designed according to ICRP reference persons. By utilizing these techniques, one can derive mean absorbed doses in a number of organs, normalized to unit exposure measured free-in-air under different conditions of beam quality and field size. These provide information for thyroid, bone marrow, lung, female breast and gonads. Williams et al. [W15] constructed three-dimensional phantoms using computer tomographic data from patients, which allows very accurate calculations of absorbed dose in organs.

63. Monte Carlo calculations of organ doses take into account only the primary radiation and radiation scattered within the patient. The scattered radiation and leakage radiation from the diagnostic source assembly, as well as other stray radiation, is usually not included. When the organ of interest is within the useful beam, stray radiation is not likely to account for more than 1% of the organ dose. However, when the organ of interest is at least several centimetres outside the useful beam, neglecting the contribution from the stray radiation may result in underestimating organ dose by as much as 25-50% [B5]. To account for this, international [I3] and national [D4] standards required for equipment restrict the dose rate outside the beam to 1 per hour and require efficient collimation.

64. It is much more difficult to calculate organ doses when fluoroscopy is utilized. The reason for this is that automatic brightness controls are often used for fluoroscopic examinations, and the exposure rate and beam quality change as the beam is moved. Thus, even when exposure parameters are known and exposure times recorded, the confidence limits on the absorbed doses from fluoroscopy are larger than those from radiography. To overcome this difficulty (at least partially), area exposure product meters can be used [I4].

65. Fluoroscopic examinations also present other unique problems due to the continuous changes in beam direction, length of examination time, field size and positioning in the course of examination. During standard radiographic procedures, matters such as the incident exposure side of the patient are quite straightforward, but during fluoroscopic examinations the incident and exit sides of the patient are often changing. The length of time that a fluoroscopic procedure takes, and thus the resulting absorbed dose, varies widely depending on the complexity of the examination, the co-operation of the patient and the skill of the operator of the equipment. Harrison [H2] has reported total fluoroscopic screening times used in the United Kingdom for a barium meal examination. The average time was 146 seconds, but the range was 1-620 seconds. Rowley et al. [R9] have also reported the median exposure times for various fluoroscopic examinations in local areas of England. They report the following: barium swallow, 180 seconds; barium meal, 180 seconds; and barium enema, 150 seconds. Little difference in time was noted in relation to the sex of the patient, however, males consistently received higher absorbed doses due to larger body size. Longer screening times of 337 seconds for a barium enema and 240 seconds for a barium meal are reported by Pandovani [P1] in Italy. Maccia et al. [M1, M2] have reported on the use of fluoroscopy in France; their mean fluoroscopic times for various examinations are shown in Table 18. It is of interest that fluoroscopy is used to position or centre patients in 25-50% of examinations that are usually considered radiographic examinations.

66. In general, fluoroscopic procedures result in much higher doses to the individual patient than most other types of standard radiographic examinations. For this reason, the achievable dose reductions could in principle be larger. Several authors investigated the effect of variation in equipment design on patient dose. Tole [T4] reported that fluoroscopic machines with the tube placed over the table often give substantially higher organ doses (particularly to the male gonads) than machines with the tube under the table. This occurs because for most fluoroscopic examinations the patient is in the supine position or facing forward and the male gonads are relatively anterior in location and closer to the x-ray tube as well as being unshielded. Zeck and Young [Z3] pointed out the very high radiation levels that can be associated with C-arm fluoroscopes. In general, the minimum source-skin distance for a C-arm device is 30 cm. Spacers are usually used to maintain this distance but are sometimes removed and not replaced. If the patient is then positioned close to the tube, the entrance skin exposure rates will be much higher than usually calculated.

67. Fluoroscopy times accompanying coronary angiograms are usually about 10-20 minutes [A3]. Cascade et al. [C5] have recently reported exposures and fluoroscopy times for the relatively new technique of percutaneous transluminal coronary angioplasty. In this technique, fluoroscopy is utilized to monitor the progress of a balloon catheter introduced in order to dilate one or more stenotic coronary arteries. When only one stenosis was dilated, the fluoroscopy time was 36 minutes and skin dose was 0.5 Sv. When two

stenoses were dilated, the fluoroscopy time was 51 minutes and patient skin dose was 1.0 Sv. Similar data have been reported by Faulkner [F2].

68. While technical parameters affecting absorbed dose are relatively well known in some countries, the technical factors used for specific examinations are often unknown. Large portions of the population receive uncertain but possibly large doses. For example, Hussain [H22] surveyed x-ray installations in Bangladesh and reported that the current and voltage indicators on many machines did not work at all and that over 40% of machines either had no collimator or that it was not functional. Thus the exposure at skin surface, field size and location of the centre of the field are generally not known. Under these conditions, calculations of absorbed doses to various organs or determination of effective dose equivalent are virtually impossible.

69. Similar conditions were described for India by Bhargava [B16]. In a survey of diagnostic x-ray installations, 20% of the machines produced excessive exposure during fluoroscopy and showed excessive leakage from the tube housing. In 20% of the machines neither cones nor collimators were used to control the beam size. Das et al. [D1], reporting on exposure to the patient's skin for various examinations in India, indicated that a fluoroscopic examination of the chest results in a skin dose of approximately 120 mSv.

70. In Beijing, China, Sun [S32] has measured skin exposure during 2,395 fluoroscopic chest examinations at 44 hospitals, and he reports mean skin doses of about 10 mSv. Wu et al. [W23] have reported on skin exposures in 370 patients who had various upper gastro-intestinal examinations in China. For most examinations, the skin doses were 50-180 mSv. Weng and Wu [W11] measured skin exposures for 30 patients in China having cardiac catheterization. The skin dose in the field was 100 mSv for the fluoroscopy alone and an additional 260 mSv for the radiographic portion. All these measurements were made on the skin surface utilizing thermoluminescent dosimeters. Because the use of fluoroscopy is still widespread in developing countries where data are scanty, the absorbed dose to the population may be estimated only very roughly.

71. Absorbed dose from mass screening examinations continues to be of interest to the Committee. The average skin dose equivalent in the field for a mass chest x-ray examination in Japan in 1980 was 1.5 mSv for adults and about 0.8 mSv for children [K22]. In many countries mass chest screening is often performed with photofluorography. Bengtsson et al. [B13] have indicated that the average dose to the breast from such examinations is about 2.0 mSv, almost as high as the absorbed dose from a mammogram. The effective dose equivalent for chest x-ray mass screening in France has been reported to be 0.07 mSv for radiography, 0.32 mSv for photofluorography and 0.98 mSv for fluoroscopy [L8]. The collective effective dose equivalent for this practice in France in 1980 was about 4,500 man Sv. In Japan, mass screening of the stomach is often performed utilizing photofluorography. Maruyama et al. [M13] have indicated that 4.1 million such examinations were performed in Japan in 1980; this represents about one examination per 30 people. The collective effective dose equivalent from this practice was estimated to be about 16,000 man Sv.

72. Knowledge of absorbed doses to the uterus, embryo and foetus is useful in situations where a pregnant woman has been exposed to diagnostic x rays. Glaze [G4] and Drexler [D5] described a computer-assisted procedure for estimating both patient exposure and foetal dose from radiographic examinations. The dose incurred in paediatric x-ray examinations is also of interest since a large portion of the child's body is often included in the primary beam [N2]. Morris [M36] calculated doses in Australia for patients in the age group 2-4 years and for those under the age of two. Similar Monte Carlo calculations are also available to assess the doses from paediatric x-ray examinations to the total body, bone marrow, thyroid, lungs, ovaries and testes [G5]. For typical examinations in paediatric x-ray diagnosis, Williams et al. [W16] and Zankl et al. [Z2] used a Monte Carlo code to calculate the doses to a baby and child phantom constructed from tomographic data.

73. Radiation doses to neonates requiring intensive care were examined in the United Kingdom by Robinson et al. [R5]. These babies are of particular concern since they may receive larger numbers of radiographs than adults, and the treatments often include barium examinations and computerized tomography scans. The marrow dose from all examinations was found to vary approximately inversely with birth weight. In addition, children with lower birth weight received more examinations (Table 19). Gustafsson et al. [G8, G9] have examined the relationship between body weight and energy imparted for children of various ages and body sizes. The energy imparted was less per kilogram for the older and larger children. There was, however, substantial variation in energy absorbed for children of the same weight. This variation was ascribed to technical factors, such as beam collimation. Gustafsson also discussed the relationship of beam direction to dose. Performing a chest radiograph in the posterior/anterior projection causes relatively larger dose to the bone marrow than when it is done in the anterior/posterior projection. The latter projection, however, delivers a larger dose to the breast and thyroid. Leibovic et al. [L4] reported on paediatric angiocardiography procedures, which provide the highest exposure per examination of any diagnostic paediatric procedure. The authors noted that as much as 25% of the exposure from such examinations was contributed by manual test exposures to adjust the technique. The average dose rate to the skin in the posterior/anterior projection for cine filming was 0.7 mSv per second and in the lateral projection 2.1 mSv per second. Fluoroscopy exposure rates were approximately 5% of this.

74. Of special interest is the dose received by the breast in mammography. Bates [B3] has reported on skin exposures in 27 screening centres in the United States. The results showed that a substantial reduction

in exposures and tissue dose was achieved during the course of this project. Rimondi [R3] has reported doses from mammography in Italy. He indicated that, even with the same type of x-ray apparatus and film-screen combination, very different exposure values were obtained, ranging over two orders of magnitude. Skin doses in this survey ranged from 2 to 220 mSv. The mid-plane doses were from 0.18 to 11.1 mSv.

75. Hammerstein [H1] and Stanton et al. [S26] reported doses measured in a breast phantom designed to simulate a breast with a uniform mixture of equal amounts of adipose and glandular tissue. Similar results have been reported by Panzer [P5] from a study of 170 facilities in the Federal Republic of Germany. Average glandular doses for non-screen films ranged from 5 to 35 mSv with a median value of 16 mSv, and for screen-film systems from 0.8 to 19 mSv with a median value of 6.6 mSv. Zuur [Z12] reported similar dose values from 12 institutions in the Netherlands, ranging from 1.0 to 8.8 mSv.

76. Sato [S2] carried out a survey on the radiographic technique and frequency of mammography in Japan. Of the 75 institutions surveyed, 45 utilized intensifying screens and film for mammography, 30 used a non-screen system and 20 did not have any special apparatus for mammography. There were approximately 2.9 exposures per examination, or 1.5 exposures per breast.

77. Gannon [G2] reviewed the equipment performance at 28 mammography centres in the United States. In this study the actual peak voltage was measured and compared to the dial reading on the xerox-mammography-type machines. In most cases the desired peak voltage was between 36 and 50 kVp. In only one case was the measured peak voltage that which was actually desired; in some instances the peak voltage differed by as much as 7 kV from that set on the machine. Such differences significantly affect image quality. The two-view (mediolateral and cranio-caudal) mid-line (3 cm depth) dose measured in a phantom ranged from 2.5 to 11.6 mSv.

78. The use of grids in mammography has been advocated to improve image quality and to reduce scattered radiation incident on the image receptor. Kirkpatrick [K11] measured the effect of such grids on patient dose. He showed that, although there was a gain in image quality, absorbed doses were approximately three times higher, unless there was a significant change in exposure parameters. Whether the improvement in image quality was worth the increased dose was not indicated, although the use of grids is usually restricted to circumstances where the thickness of the compressed breast exceeds 5 cm.

79. Measurement of absorbed dose from the newer technologies has also been a matter of concern. In the UNSCEAR 1982 Report, the large amount of literature reviewed indicated that the dose to the skin from a computerized tomography scan could be as high as 560 mSv, although in clinical practice the absorbed doses were mostly around 60 mSv. The dose distribution within the body from computerized tomography is markedly different from that from conventional radiography. In most radiography, the dose is highest on the incident side and lowest on the exit point; in most computerized tomography, the dose is lowest at the centre of the body section studied. The effective dose equivalent and absorbed dose from various computerized tomography procedures have been derived by Stieve [S31].

80. The x-ray beam of a computerized tomography unit is usually highly collimated, but the eye may be in or near the primary beam on scans of the brain or face, and the dose to the eye is of particular interest for radiation protection purposes. Lund et al. [L6] and Kronholz [K18] indicated, for brain computerized tomography, that although slice thickness and patient position have some effect on the absorbed dose in the lens of the eye, the greatest doses are those received when the scan is done with the gantry angled downwards in relation to the orbito-meatal (from the outer corner of the eye to the external ear canal) line. In this circumstance the eye is included in the primary beam. This positioning factor caused the dose to the lens of the eye to increase by a factor of 2-4 compared to standard orbito-meatal scans. Doses to the lens of the eye from cranial computerized tomography are in the range of the absorbed dose from other neuro-radiological procedures. Isherwood et al. [I5] indicated absorbed doses to the lens as follows: orbital hypocycloidal tomography, 120 mSv; petrous bone tomography, 100 mSv; cerebral angiography, 50-100 mSv; pneumo-encephalography, 20 mSv; and skull examination, 15 mSv. Panzer [P4] collected dose values from 120 facilities in the Federal Republic of Germany. Preliminary results show a large variation in the dose values (free-in-air) on the axis of rotation, from 10 to 200 mSv per slice, with a median value of 30 mSv. By calculations using Monte Carlo methods, the dose (free-in-air) can be converted into organ doses [D5].

81. The radiation doses to various organs for the types of computerized tomography scanners used in Japan have been published by Nishizawa et al. [N10, N11] and are given in Table 20. While the exact values depend upon the technique and the type of scanner, the values presented are in general consistent with those reported by other authors [B1, C8, E7, E8, G3, I5, M20, M25, S10, S11, S24, S35, W12]. McCrohan et al. [M16] surveyed 250 computerized tomography systems in the United States to determine the radiation dose from a head scan. For the typical adult scan the absorbed dose was 22-68 mSv; doses varied by a factor of two for the same manufacturer and model of machine. Beck et al. [B4] have devised a Monte Carlo model for absorbed dose calculations in computerized tomography.

82. There is a trade-off between image noise and radiation dose [T5]. All calculations used by the computer to construct the image are limited by the statistical distribution of the detected photons. Several attempts have been made to reduce the dose through various technical modifications. Dose reduction can be achieved by radiating and collecting data only during a portion of the scan cycle. Oppenheim [O5] found that artifacts caused the method to be of limited usefulness. More recently, Stanton et al. [S27] devised

a method that collects data over the entire scan but exposes the region of interest to a higher dose than other anatomical structures within the scan volume. This is accomplished through the use of a variable thickness filter; dose peak reductions of up to 80% are claimed for head scans. Moseley et al. [M37] discussed various methods of reducing radiation dose in the management of intracranial lesions that are clinically followed by use of computerized tomography, but they did not report any quantitative dose reduction factor. McCullough [M23] suggested that the performance of each computerized tomography scanner be specified and checked in order to ensure a typical level of performance and to provide a baseline value for a programme of quality assurance. Parameters tested usually include slice geometry, patient dosage, artifactual behaviour and contrast detail performance.

83. Digital medical radiographic systems are now becoming available in most developed countries. The contrast resolution of such instrumentation is limited primarily by quantum mottle. Rimkus et al. [R4] indicated that the number of meaningful levels of grey that are imaged will significantly affect the radiation dose. For example, if 128 meaningful visual shades of grey on an image require a dose of 17 mSv to the patient, simply raising the level of contrast resolution to 256 shades of grey will increase the dose by a factor of 5-10. However, since such contrast resolution is rarely needed for diagnosis, this is an area where unnecessary dose can be avoided.

84. The frequency of dental examinations was discussed in section I.A. Data on dental exposures are available from the Nationwide Evaluation of X-ray Trends (NEXT) survey in Canada [C2]. For a dental bite-wing posterior examination, a dose at skin entrance was recorded with a minimum of 0.56 mSv, a maximum of 43 mSv and a mean of 4.7 mSv. For periapical examinations, the maximum was 2.6 mSv, the minimum was 0.57 mSv and the mean was 2.2 mSv (standard error 1.1 mSv). Results from 200 dental facilities in the Federal Republic of Germany were reported by Panzer [P6]. Entrance doses for examinations of a molar tooth ranged from 2.5 to 45 mSv with a median value of 8.5 mSv. Comparison with earlier results (1970) showed a remarkable decrease in entrance doses.

85. In Japan [M11], the annual per caput doses for dental radiography were estimated to be 0.09 Sv (genetically significant dose) and 13 Sv (mean bone marrow dose). Iwai [I6] compared absorbed doses to the gonads and to bone marrow for both intra-oral and panoramic dental examinations and reported the total risk for intra-oral examinations to be lower than the dose for the less frequent panoramic examinations.

86. Radiation doses from dental x-ray examinations were discussed in detail in the UNSCEAR 1982 Report [U5]. The radiation exposure for dental films may be decreasing somewhat. The Nationwide Evaluation of X-ray Trends (NEXT) programme in the United States [U9] indicated that the mean dose at skin entrance from dental bite-wing posterior films was 9.1 mSv in 1973 and 4.3 mSv in 1981. There was an increase in the dose from pantomographic examinations, from 0.3 mSv in 1973 to 0.8 mSv in 1981.

87. Weighted dose equivalents in the United Kingdom have been calculated by Wall et al. [W3]. These values are 20 μSv for intra-oral examinations consisting of two films, 30 μSv for extra-oral examinations consisting of two films and 80 μSv for one pantomographic film. They estimated the collective weighted dose equivalent to the population of the United Kingdom to be 212 man Sv. The mean dose equivalent to various organs per dental examination is shown in Table 21.

88. Pellerin et al. [P10] reported on exposures in both phantoms and patients for various types of dental examinations in France. The intra-oral exposure was the most commonly used and delivered a maximum dose to the skin of about 15 mGy. The pantomographic view gives a picture of the entire dentition but delivers a dose of approximately 10 mSv to three intracranial "hot spots". Tingey [T2] has re-emphasized the need for quality control procedures to reduce the exposure factors and also to avert repeat examinations.

89. Dosimetry in panoramic examinations has also been studied in the Soviet Union by Trunov et al. [T8] and Kirko [K10] utilizing thermoluminescent dosimetry and anthropomorphic phantoms. The radiation dose was 15-20 μSv per film for examinations of the upper jaw and 25-30 μSv per film for examinations of the lower jaw. The thyroid doses were 40-180 μSv and gonadal doses were 13-150 μSv.

90. Hayami [H12] recently devised a Monte Carlo computer programme to estimate exposure to the head and thyroid for panoramic intra-oral x-ray tube radiography. With 55 kV (kilovolts) and 0.5 mAs (milliampere seconds), the energy imparted for a routine examination was 2.1 mJ to the head from each exposure of the mandible and maxilla, about 8.5 μJ to the thyroid from a mandibular radiograph and 1.7 μJ to the thyroid from a maxillary radiograph.

E. CAUSES OF DOSE VARIATION AND POSSIBILITIES FOR DOSE REDUCTION

91. Some possibilities for dose reduction are found by examining the causes of variation in dose for a given examination. Dose reduction cannot be taken as an ultimate goal in medical radiation since the images generated must have sufficient informational content to be of diagnostic value. An underexposed radiograph that cannot be interpreted is of no value to the patient even though the absorbed dose is low. Many aspects of image quality and its assurance were discussed at a seminar organized by the Commission of the European Communities [C10]. The actual assessment of priorities and analysis of cost versus benefit in this regard is beyond the scope of this Annex. Such analyses would be highly dependent on the availability of operating equipment and the knowledge of health care practitioners of a given country. There certainly are, however, some simple and low cost methods that can be used to substantially reduce absorbed dose. Russell [R10] has

presented one form of methodology that could be utilized for such assessments.

92. Wall et al. [W4] have discussed a number of the factors involved in dose reduction. There have been many changes in diagnostic radiology techniques over the past 20 years, many of which might be expected to have had a significant effect on patient doses. The trend towards faster films and the advent of highly sensitive rare-earth screens should have resulted in lower exposures per radiograph. However, the adoption of rare-earth screens has been very slow; for example, only five out of 21 hospitals surveyed in the United Kingdom [W4] used them at all, and then only for obstetric examination or casualty work. High cost and poor spatial resolution due to quantum mottle are the most common reasons for their poor acceptance. Use of such rare earth screens appears to be higher in Italy [C11]. The use of new materials (such as carbon fibre) for construction of table tops, grids and film cassettes has the potential to reduce patient dose by 30-50% [H19]. Dose reductions in pelvimetry have been marked in the United Kingdom and the United States, as a result of fewer examinations, fewer projections and the increased use of ultrasound.

93. An appropriate combination of radiography and fluoroscopy can result in dose reduction, particularly for examinations of the gastro-intestinal tract [S28]. Fluoroscopic screening times have not decreased [W4], and therefore the hoped for dose reduction owing to the increasing use of image intensifiers has not materialized in the United Kingdom. In some departments automatic brightness controls are allowing examinations to be conducted in ambient light rather than in a darkened room. This increases the absorbed dose to the patient. Maccia et al. [M1] have reported the percentage of the collective effective dose equivalent in France that is contributed by fluoroscopy (Table 22). It appears that about 5,000 man Sv are contributed by the use of fluoroscopy to position patients prior to routine film radiography.

94. The effect of gonadal shielding upon gonadal dose has been discussed by Poretti [P14]. Such shielding is particularly effective if the gonads are in the useful beam. Although gonadal shields are relatively inexpensive and easy to use, their use is not widespread. Wall et al. [W4] have reported that in the United Kingdom gonadal shielding was used for males only 35% of the time for hip and upper femur examinations, 26% of the time for lumbar spine examinations and 15% of the time for pelvis examinations.

95. One area that has received some attention, with resultant dose reduction, concerns the tailoring of the size and shape of the beam to the area of interest and to the film size [C11]. Many older medical x-ray machines have a circular beam, while the film is generally rectangular. Johnson [J7] point out that collimation of the primary beam has been an evolutionary process, whose stages are, at first, circular cones, then, variable rectangular collimators and, finally, positive beam limitation. In general, rectangular collimators are almost as good as positive beam limitation, but with circular cones there is almost twice as much radiation given as needed (Figure VI). The shift from circular to rectangular collimation for chest radiographs in the United States is shown in Figure VII and the resultant reduction in the amount of x rays utilized is shown in Figure VIII. The situation is somewhat different with fluoroscopy. In this case the collimators are usually rectangular while the image intensifier is circular. If the operator wishes to use the whole of the circular image, there is about 25% additional and unnecessary radiation.

96. Use of lower voltage for a given study will require higher entrance surface doses. Contento et al. [C11] have reported that in France softer x-ray spectra are used for a given examination than in Great Britain and Italy. The voltage and radiation output variation of x-ray machines have been studied by Henshaw [H13] and Pauly [P9]. They observed variations from the desired voltage, ranging from 5% to 20% or more and averaging approximately 10%. Belletti et al. [B7]

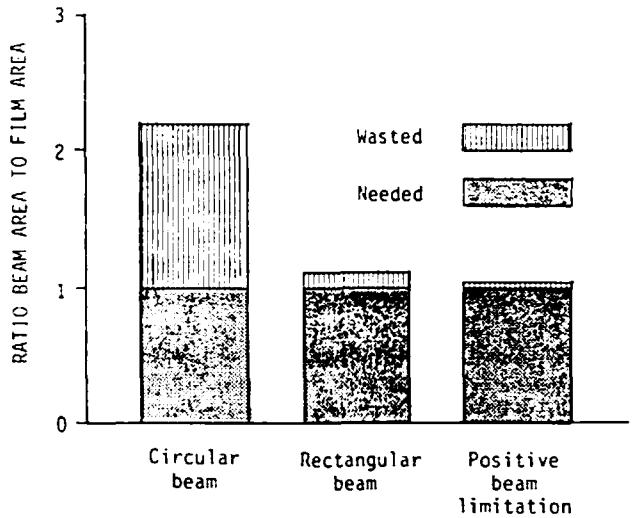

Figure VI. Mean ratio of beam area to film area for chest x rays in the United States, 1977-1983. [J7]

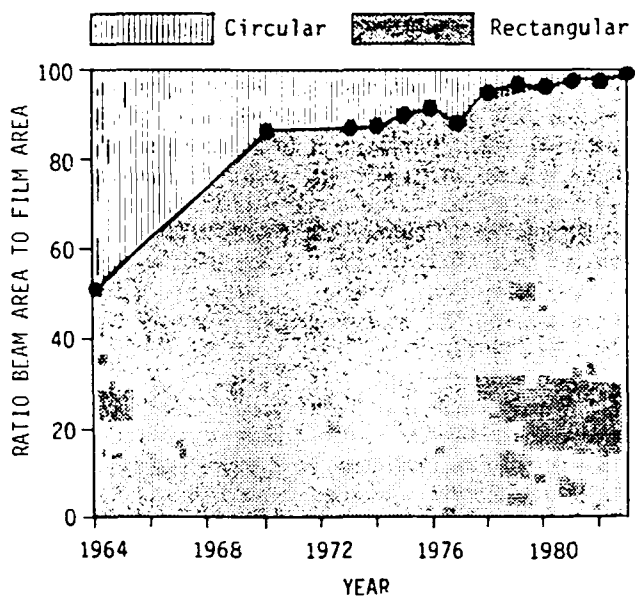

Figure VII. Trend in beam shape for chest x rays in the United States, 1964-1983. [J7]

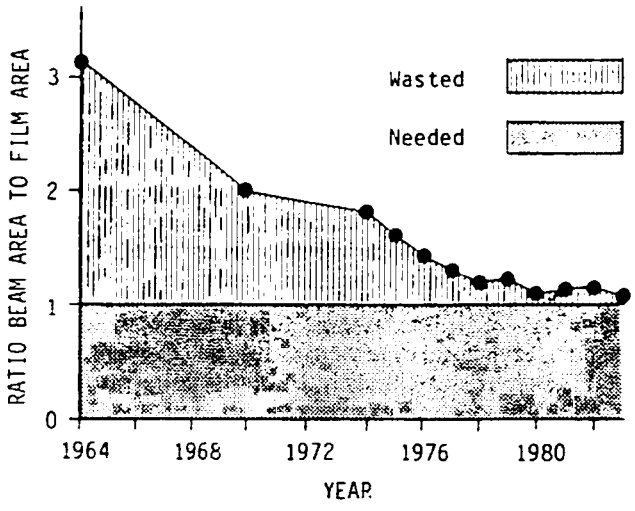

Figure VIII. Mean ratio of beam area to film area in the United States, 1964-1983.
[J7]

analysed the causes of repeat films. One of the more significant results was again the discrepancy between measured and selected peak voltage. Ten to 15 per cent of the machines examined were found to have a 10% difference between the set and measured values of peak voltage. Of all films that were spoiled, over 50% had been under- or over-exposed. Most spoilage was due to variations in the voltage produced by unstable generators, incorrect choice of either voltage or current, or malfunctions in film processing.

97. Practical recommendations to improve radiation protection in clinical mammography have been published [N3]. Breast compression is particularly important, not only to improve contrast and diminish motion unsharpness but also to reduce absorbed dose. Firm compression of the breast can reduce the absorbed dose by 25-50% while resulting in images of equal clinical usefulness. From an analysis of data from some 60 mammography installations throughout the United States [S17], it was concluded that the choice between xerographic and film-screen receptors is the most critical factor affecting breast exposure, followed by the choice of half-value layer and target material. Film-screen receptors without grids result in two to five times less absorbed dose than xeromammography. Panzer et al. [P5] have indicated that even a distinct increase in image detector sensitivity by switching to film-screen combinations did not always correspond to a comparable decrease in dose to the patient. Part of the reason for this may be that doses to obtain optimal images for various film-screen combinations for mammography vary by up to a factor of 2 [K12].

98. Breast phantoms have been utilized to assess absorbed dose from various imaging systems. Computation of absorbed dose is of course dependent on breast size, adiposity etc., but for analysis of detriment one needs to know the average size and composition of the breast in the population of interest. At the present time, research continues into alternative methods for breast imaging, such as thermography, ultrasonography, computerized tomography, magnetic resonance imaging and digital x-ray mammography. With the possible exception of ultrasonography, none of the other techniques has had any impact on the use of mammography.

99. The effect of patient size on dose variation received in diagnostic radiology has been studied by Maillie [M4]. The thickness of the patient is more important at low potential (voltage), and the average absorbed dose from radiographs taken on individuals of various thicknesses may differ by as much as a factor of 4 or 5. As the peak voltage is raised, the variation due to body thickness is reduced to a factor of 2. Of course the thickness of the irradiated part is not the only factor that influences the doses to various organs: for example, a taller person will have some organs farther displaced from the useful x-ray beam than a shorter person. Increasing radiation quality (voltage) reduces entrance skin dose but increases absorbed dose to organs at depth. The percentage reduction in effective dose equivalent is much less than the corresponding reduction in entrance skin dose. This potential method of dose reduction should be weighed against possible disadvantages such as reduced image contrast.

100. Dosimetric methodology can be a significant cause of reported absorbed dose variation. Padovani [P1] has recently shown some limitations of the Monte Carlo methods when they are used to determine absorbed doses to various organs as a result of medical practice. Monte Carlo methods assume good practice (e.g., excellent collimation). In his survey in north-east Italy he found major differences between the absorbed dose to organs calculated by Monte Carlo methods and that measured by thermoluminescent dosimeters. Actual testicular doses for specific examinations were higher, by factors of 4-50, than Monte Carlo calculations would suggest. Similar findings were reported for absorbed doses to the breast and thyroid. These findings are probably due to the organs being near the field of interest and poor collimation being utilized.

101. Stieve et al. [S30] and others have repeatedly emphasized that training in the use, calibration and quality assurance of x-ray equipment is an essential part of any dose reduction programme. In many, if not most, countries, over one half of x-ray examinations are performed by persons with little or no formal training. Even in well-developed countries, many non-radiologist physicians perform x-ray examinations though they have little or no formal training in uses of x rays or of x-ray protection. Proper theoretical and practical training of all persons involved in the medical uses of radiation is one of the most important ways to achieve dose reduction [S30, V5]. Cohen [C9] attempted to generalize and assess the benefits of quality assurance programmes. He estimated that in a developed country a quality assurance programme would lead to a reduction of 50% in the per caput whole-body dose equivalent from diagnostic radiology, from approximately 1.0 mSv per year to 0.5 mSv per year.

102. Some of the possible methods of dose reduction and their quoted dose reduction factors are summarized

in Table 23. The largest dose reduction factors occur as a result of switching from chest fluoroscopy and photofluorography to chest radiography, with dose reduction factors of about 20 and 5, respectively. It should be mentioned that economic and other factors often dictate what equipment is available to be used. Certainly, in the correct clinical setting, chest fluoroscopy is preferable to no chest x-ray at all. The simplest and least expensive methods that do work and that do offer modest dose reductions are (a) installation of collimation on machines; (b) added beam filtration; (c) the use of gonadal and thyroidal shielding; and (d) proper film processing. The judicious use of radiographic examinations and the elimination of non-productive examinations, which are another area for potential dose reduction, have been the topic of several recent WHO reports [W19, W22]. Discussions have centred on the efficacy of screening or pre-operative chest x-rays, skull films after minimal head trauma, pre-employment examinations of the lumbar spine or the chest, and examinations of the genito-urinary system and sinuses in children [G8, G9].

F. MEASURES OF RISK

103. The genetically significant dose (GSD) for a population has been used as a measure of the genetic detriment to be expected from a practice. It is defined as "the dose which, if given to every member of the population, would produce the same genetic detriment as the actual doses received by the various individuals." In some countries, such as China, gonadal doses and GSD may be greater than had been previously estimated. Apparently fluoroscopy is used in some provinces of China to check for the presence and location of intra-uterine contraceptive devices. Zheng et al. [Z10] have reported that mean skin doses for such examinations measured with TLDs was 8 mSv. In other countries there are problems in determining gonadal doses because of the lack of good data regarding the presence of collimation. As was mentioned earlier, in India and Bangladesh 20-40% of the machines have no functional collimation. Many genetically significant dose surveys have been performed and were summarized in both the UNSCEAR 1977 Report [U4] and the UNSCEAR 1982 Report [U5]. Since then, Sohrabpour et al. [S19] reported that in the Islamic Republic of Iran the genetically significant dose in 1980 was estimated to be 93 μSv, with the male and female contributions being 57% and 43%, respectively. In the province of Manitoba, Canada, the genetically significant dose was calculated in 1979 by MacEwan [M3] to be 260 μSv.

104. Kumamoto [K22] indicated that the genetically significant dose from mass chest x-ray examinations in Japan in 1980 was 0.17 μSv. The genetically significant dose due to computerized tomographic examinations in Japan in 1979 was estimated to be 1.1 μSv.

105. In France in 1982 the annual genetically significant dose was estimated to be 0.29 mSv [B10]. This represents a 64% increase from 1957. Table 24 also shows that the genetically significant dose for females is more than twice that of males (0.20 mSv versus 0.09 mSv). Examinations of the pelvis/hip and intravenous urography contributed almost 60% of the genetically significant dose. Fluoroscopy accounted for only 10%, while x-ray examinations contributed 90%.

106. Figure IX indicates a very high gonadal dose in French children under one year, which is apparently due to mandatory screening for hip dysplasia. The average dose equivalent to the female and male gonads from various examinations is shown in Tables 25 and 26, respectively.

107. Genetically significant doses in various countries are shown in Figure X and Table 27. It is clear from these data that the average gonadal dose (as well as skin dose) often varies between countries by a factor of 3 or more. Poretti [P14] has reported on both gonadal dose and genetically significant dose in Switzerland, where the GSD rose from 0.19 mSv in 1971 to 0.23 mSv in 1978. He also calculated the dose to the gonads with and without gonadal shielding for

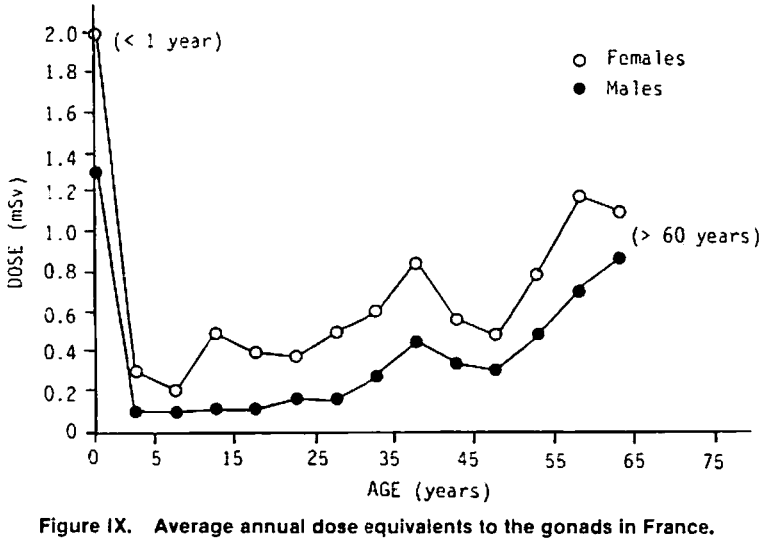

Figure IX. Average annual dose equivalents to the gonads in France. [B10]

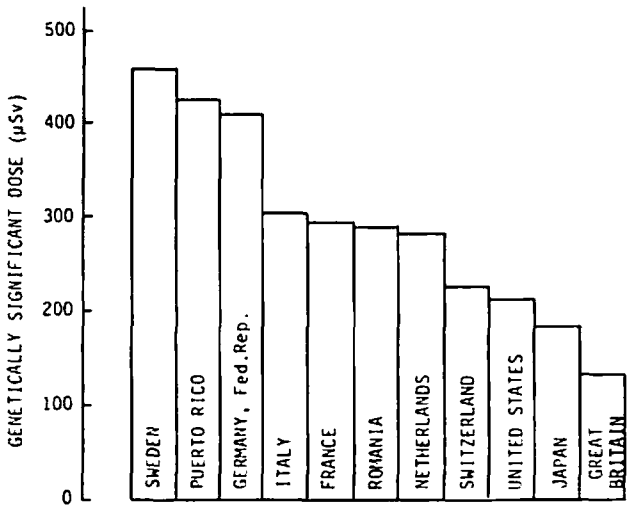

Figure X. Annual genetically significant dose in various countries.
[B10]

four common examinations. Gonadal shielding reduced gonadal doses by a factor of 2-10, depending upon the examination and on the distance of the gonads from the area of interest being radiographed.

108. According to estimates made by Kudritsky et al. [K19, K20] for the Russian Soviet Federative Socialist Republic, the trend is towards a gradual increase in the mean per caput gonadal dose. During 1970-1980, this increased by nearly 50%, probably owing to an increase in the number of special examinations and in examinations of the digestive organs and the osteo-articular system. The value of the genetically significant dose also changed. It increased by 0.06 mSv during the decade, mainly as a consequence of examinations involving radiation of the pelvic region (Table 28).

109. The genetically significant dose includes only absorbed dose that can be expected to affect the progeny; it does not take into account the somatic effects in the exposed population. Examples of the limitations of the genetically significant dose concept in practice have been given by Kaul et al. [K4]. In cases of a simultaneous increase in both the rate of examinations involving ionizing radiation in a given population and the number of alternative procedures applied in paediatric examinations in the same population, the genetically significant dose may lead to a misinterpretation of population exposure. Kaul et al. [K4] have therefore recommended that when sources of radiation exposure are being compared, the genetically significant dose should be indicated with estimates of somatic radiation exposure. The authors also pointed out significant limitations in the use of the genetically significant dose, particularly in countries where the age distribution changes with time. Under such circumstances the genetically significant dose alone is an unreliable indicator of the state and trend of medical radiation exposure; comparative evaluations of mean radiation exposure in different populations will also be of limited value. The latter point will become more important over the next several decades, when the world's population is expected to age markedly.

110. Stochastic risk estimates of various types for Japan have been published by Hashizume [H3, H4]. Annual per caput bone marrow dose in Switzerland was reported by Poretti [P14] as 0.63 mSv in both 1971 and 1978. The average active mean bone marrow dose to the United States population from radiological procedures in 1980 was about 1.3 mSv if the method of Shleien et al. [S9] is used for calculation. This compares with 0.83 mSv in 1964 and 1.0 mSv in 1970. Estimates of mean per caput marrow doses are very dependent upon the modelling parameters utilized. While the relative contribution by examination type does not change appreciably according to the method, the numerical quantity obtained is significantly different [R8, S9].

111. Beentjes et al. [B6] reported that the annual per caput "somatic effective dose" in 1980 in the Netherlands from diagnostic radiology was about 0.5 mSv and that the average somatic dose per examination was approximately 0.8 mSv. The somatic effective dose was defined as the uniform whole-body dose that would cause the same somatic risk as the actual non-uniform dose from the x-ray examinations.

112. A somatic dose index has also been proposed [L7] that utilizes individual organ doses weighted according to sex-dependent factors for the relative radiation risk and not weighted for the gonads. Kaul et al. [K4] compared the ICRP weighting factors and the modifications occurring when the genetic risk is neglected: their conclusion is that excluding the genetic risk has an effect less than the uncertainty involved in the calculation of the absorbed dose to an organ.

113. Calculations of effective dose equivalent from diagnostic procedures must include an analysis of the dose distribution within the body. The dose equivalent in an organ, T, for a given radiographic examination must be obtained by the formula:

$$H_T = \Sigma_k n_k D_{T,k} Q \qquad (1)$$

where k is the type of view involved in the examination, n_k is the number of films for the view k; $D_{T,k}$ is the average absorbed dose in the organ for view k, and Q is the quality factor. Q is 1.0 for x rays used in diagnostic radiology.

114. The effective dose equivalent, H_E, for an examination of type I is obtained from the following equation:

$$H_{E,I} = \Sigma w_T H_{T,I} \qquad (2)$$

where w_T is the weighting factor for each organ given in ICRP Publication 26 [I2]. One main difficulty encountered by most authors has been in selection of the "remainder" organs as required by the ICRP definition, which may change from one examination to the next. The selections, however, are not consistent. Some potential solutions to this problem have been suggested by many groups, e.g., Stavitsky et al. [S29]. In many published articles in which effective dose equivalents have been reported, the methods for choosing remainder organs are not given.

115. Calculations of the effective dose equivalent for different types of examinations in Poland in 1976 and in Japan in 1979 were included in the UNSCEAR 1982 Report [U5]. Since that time, there has been one additional publication from Poland [J1], in which the effective dose equivalent per adult in 1976 was estimated to be about 1.7 mSv. Vano et al. [V4] reported an annual per caput dose equivalent of 0.8 mSv for Spain and a collective effective dose equivalent of 32,500 man Sv.

116. Reported annual effective dose equivalents for different examinations are shown in Table 29. Values generally range from 0.1 to 10 mSv.

117. From diagnostic x-ray examinations of the population in France in 1982, the collective effective dose equivalent was 86,000 man Sv, or an annual per caput effective dose equivalent of 1.6 mSv [B2]. In France the examination with the largest percentage contribution to the collective effective dose equivalent is intravenous urography, whereas in other countries, such as Japan and the United States, barium enemas and upper gastro-intestinal examinations play a larger role. Even from one highly developed country to another, the per caput effective dose equivalent may vary by up to a factor of 5. Some of these differences are certainly due to the number of examinations and to technical differences (beam quality, collimation etc.). In addition, however, Benedittini et al. [B10] indicate that there have been significant differences in the calculations of effective dose equivalents in specific organs by various authors. Benedittini et al. [B11] reported on the absorbed doses to patients from dental radiology in France in 1984. The collective effective dose equivalent was estimated as 2,000 man Sv and the per caput effective dose equivalent as 0.037 mSv. Although pantomographic examinations accounted for only 6% of the total number of examinations, their higher absorbed dose caused them to contribute 29% of the collective effective dose equivalent. Nikitin et al. [N8, N9] and Vorobyev et al. [V7] reported a per caput effective dose equivalent of about 1.5 mSv for the USSR. In 1981 the collective effective dose equivalent was estimated at about 400,000 man Sv.

118. It should be noted parenthetically that it is uncommon for a person to receive the "average" per caput effective dose equivalent calculated for the country in which he is living. Some authors have reported their findings as collective effective dose equivalents. Once this quantity has been derived for a given country, it can be divided by the population to obtain the per caput effective dose equivalent. Although in highly developed countries the frequency of diagnostic medical examinations may approach one examination per person per year, it is unlikely that more than 25-50% of people will actually have one examination in a given year. In less developed countries (health care levels II-IV), the situation is even more extreme, with perhaps only 1 person in 1,000 actually receiving an examination in a given year. Under such circumstances the person undergoing the examination would receive 1,000 times the average per caput effective dose equivalent or genetically significant dose, while 999 persons would receive no dose.

119. The energy imparted during a radiographic procedure has been suggested as an approach to estimating radiation risk. This method ignores the different sensitivities of individual body organs and calculates the energy imparted during a given procedure. It is attractive since it avoids the problem of calculating mean radiation doses to large organs [P8]. Bengtsson [B12] and Shrimpton [S13, S14] have already reported a reasonable correlation between the mean energy imparted and radiological risk. Over a range of two orders of magnitude in dose, mean energy imparted correlates with the quantity effective dose equivalent within factors of 2 or 3 [S14]. There is also a reasonable correlation between the energy imparted and the somatic effective dose. However, Huda [H15] has examined this approach with respect to computerized tomography scanning and concluded that it can lead to large errors in patient risk estimates.

120. Various other weighting factors can be utilized in an attempt to represent the impact of medical radiology in a more accurate fashion than can be done with the effective dose equivalent. As a first approximation, one could take the effective dose equivalent for the mean age of the population having a certain examination, multiply this by the specific rate for that examination and by absorbed dose. A second approximation would use the total age-specific weighted dose equivalent but would not use organ-specific risk factors. A third approximation could take sex into account as well by assuming a standard ratio of males to females having a specific examination. The greatest precision would be obtained by a fourth approximation which would apply age-specific and sex-specific weighting factors for each organ. Such weighting factors would be multiplied by the known dose to each organ for each examination type as well as each examination rate.

121. For a population of both sexes and a certain age distribution, the ICRP risk coefficient is normally utilized. To calculate the expected number of deleterious effects, n, after irradiation, Bengtsson et al. [B14] use the formula

$$n = RH_E N = RS \qquad (3)$$

where R is the risk coefficient, N is the number of individuals in the group and S is the collective effective dose equivalent. If age and sex are to be taken into consideration, one can have groups $i_{1-\infty}$. Additionally for each organ or tissue T, the risk in a given tissue per unit dose equivalent can be defined. One can then apply a series of risk factors for each tissue as a function of that tissue and age and sex of the individual. This would be expressed as r_{iT}. The probability of deleterious health effects in a given tissue would be expressed as the product of r_{iT} and H_E in that tissue. The probability of a deleterious effect in all tissues of a given individual in an age group would be given by

$$\bar{n}_i = \sum_T r_{iT} H_{Ti} \qquad (4)$$

Similarly, the expected number of deleterious effects for all persons in group i would be given as

$$\bar{n} = \sum_T r_{iT} H_{Ti} N_i \qquad (5)$$

where r_{iT} is the risk coefficient in tissue T, H_{Ti} is the dose equivalent in tissue T and N_i is the number of individuals in group i. In a similar fashion, the expected number of deleterious effects produced by examinations of type J in the total population would be given by

$$\bar{n}_J = \sum_i \sum_T r_{iT} H_{Ti} N_{iJ} \quad (6)$$

This could also be written as

$$n_{iJ} = S^*_J R \quad (7)$$

where S^*_J is the collective reference population dose for examination J. r_{iT}/R could also be termed "f factor" rather than weighting factor.

122. This appears to be quite precise in theory although, as was pointed out earlier, there are many uncertainties in the exposure factors, the absorbed dose to various organs and, particularly, the tissue-specific risk factors in the presence of disease. The risk factors used for this model were derived for continuous exposure of a working population and not for exposures received over a short time. Therefore, the risk derived is at best semi-quantitative. In a population with a very skewed age distribution, the use of collective effective dose equivalents may lead to an overestimation of detriment by a factor of between 1.5 and 3 [J8, M29]. The applicability of the concepts of effective dose equivalent and risk-weighted dose equivalent quantities to medical radiation have been examined by Drexler [D6], Ivanov [I8] and Kramer [K14].

G. WORLD-WIDE ESTIMATES OF DOSES FROM DIAGNOSTIC X-RAY EXAMINATIONS

123. In spite of the difficulties mentioned in the preceding section, an attempt is made here to derive per caput and collective effective dose equivalents from diagnostic x-ray examinations. The reported annual per caput doses for countries having various levels of health care are shown in Table 30. For health care level I countries, the effective dose equivalent and genetically significant dose agree reasonably well. In these countries the average per caput effective dose equivalent is approximately 1 mSv and the genetically significant dose is approximately 0.3 mSv. An analysis of diagnostic x-ray examination frequencies and contributions to absorbed doses in countries of health care level I is shown in Table 31. In previous UNSCEAR Reports it was been assumed that in less developed countries the collective effective dose equivalent would be lower, perhaps by an order of magnitude, due to the lesser frequency of radiological examinations. This would appear to be true according to literature on genetically significant dose in countries of health care levels II and III. However, most of these reports have not included fluoroscopy.

124. If the frequency of examinations is one tenth of that reported for countries of health care level I, and if fluoroscopy accounts for 30-70% of the total examinations, then the effective dose equivalent and genetically significant dose for countries of health care levels II, III and IV may in fact be comparable to those of level I countries. As was pointed out earlier, Zhang [Z4] estimated that in China chest fluoroscopy accounts for 70% of all examinations performed and that the associated absorbed dose is at least 15 times higher than that for chest radiography. It must be remembered in this connection that China accounts for approximately 20% of the world population.

125. Faced with these difficulties, the Committee has decided to calculate upper and lower limits for the effective dose equivalent and genetically significant dose for medical diagnostic radiography world-wide (Table 32). Calculations were performed by two methods. Method 1 is based on the frequency of examinations at various levels of development, and it assumes that the average doses for a given examination are comparable in countries of differing levels of health care. This method leads to a lower limit of approximately $1.8\ 10^6$ man Sv for the effective dose equivalent and of $0.5\ 10^6$ man Sv for the collective genetically significant dose equivalent. Method 2 assumes that although examinations are less frequent in countries of health care levels II, III and IV, the absorbed doses are 10 to 20 times higher than in level I countries primarily because of the extensive use of fluoroscopy and poorly calibrated machines. This method yields upper limits of $5\ 10^6$ man Sv for the collective effective dose equivalent and $1.5\ 10^6$ man Sv for the genetically significant collective dose.

126. Data on the effective dose equivalent and genetically significant dose from dental radiography are uneven and come only from countries of level of health care I. Since it appears that fluoroscopy is not widely used for dental purposes, one might assume that the per caput and collective doses for countries of health care levels II, III and IV are related predominantly to the frequency of examinations. The genetically significant dose from dental radiography in level I countries appears to be about 1/10,000 of that from medical diagnostic radiography. Estimations of the per caput and world wide effective dose equivalent and genetically significant dose for dental radiography are shown in Table 33. The annual collective effective dose equivalent world-wide from dental radiography is estimated to be about 17,000 man Sv with an annual genetically significant dose of 0.04 μSv.

H. OCCUPATIONAL EXPOSURE FROM DIAGNOSTIC RADIOGRAPHY

127. In the UNSCEAR 1982 Report [U5], occupational exposure was considered in a separate Annex. For this report, however, occupational exposures are considered along with the associated sources or practices. Evaluation of occupational exposures from medical radiation usage is complicated by the fact that the radiation usually comes from point sources close to the workers. Thus, the exposures are significantly non-uniform over the body because of the inverse square law as well as attenuation in the body. The effective dose equivalent cannot be easily inferred from one personal dosimeter on an individual, and this is especially true if the dosimeter is not in the

primary radiation fields striking the body. To make matters more complicated, the dosimeters are not always worn in the same position, although generally they are worn at the waist or neck. Often the recorded data do not indicate whether the worker wore the dosimeter inside or outside a protective lead apron. For these reasons it is very difficult to utilize average dose as measured by a dosimeter and to correct it to effective dose equivalent. Other difficulties are that minimum detectable levels vary as a function of dosimeter type and that the administrative decisions on whether to record the minimum detectable dose as zero or some other value are often arbitrary. Such decisions can have a major impact on estimation of the collective occupational dose, since in occupational exposure from medical radiation, a large percentage of workers receive doses at or near the minimum detectable level [D7]. The best that can be said is that for radiation qualities used for diagnostic x-ray procedures, the dosimeter usually measures a value that is 2-4 times higher than the effective dose equivalent [J12, M39], if a protective apron is not worn and if the exposure is relatively uniform. If a protective apron is worn and the personal dosimeter is placed on the outside (as is practice in the United States), then reported doses could be as much as 10 to 20 times higher than the effective dose equivalent.

128. As was discussed in the UNSCEAR 1982 Report [U5], another major complicating factor is accurate job classification of workers. While there is not usually a problem in differentiating between diagnostic radiologists and radiographers (technicians), the total number of workers in the field is sometimes expanded to include nurses, porters, aides, dark-room technicians etc., which can lead to erroneous calculations when determining mean annual individual dose. Many of these latter workers are not usually monitored since they usually receive very low doses. The number of unmonitored persons who occasionally perform x-ray examinations is unknown but is probably quite large, even in developed countries. The exact number of monitored workers engaged in performing diagnostic x-ray examinations varies widely from country to country. The range appears to be one monitored worker per 150-750 examinations annually [U4, U5, W17].

129. Data on occupational doses received from medical x-ray diagnosis are given in Table 34. In general, the average annual effective dose equivalents range from 0.1 to 3 mSv annually above natural background for radiologists and technologists. The dose distribution among the population of workers is markedly skewed, with a long tail of higher doses received by very few individuals. The highest exposures to radiologists, technologists and nurses occur during fluoroscopic procedures. Ameil et al. [A2, A3] and Tryhus et al. [T7] have reviewed the literature on absorbed dose to the radiologist during angiographic examinations. Doses were reported as follows: eyes, 0.01-0.5 mSv; thyroid, 0.03-0.5 mSv; waist (inside lead apron), 0.02 mSv; and hands, 0.05-1 mSv. Absorbed doses can be higher by a factor of 10 or more if the radiologist makes a manual injection (staying in the room during filming) or if there is an over-the-table x-ray tube. Gustafsson et al. [G10] have estimated that the effective dose equivalent to the radiologist performing angiography is about 0.03 mSv per examination.

130. It had been previously assumed by the Committee that lower estimates for occupational exposures would be appropriate for countries that had a lower frequency of examinations. This may not be the case, however, as is indicated by the recent data published by Wang [W10] and Zhang [Z9] for China, where average annual occupational doses for diagnostic medical workers are reported to be between 2.2 and 4.3 mSv. This figure is two to 10 times higher than the comparable figure in some countries of health care level I. There has, however, been remarkable progress in China (health care level II) in reducing the occupational doses over the past several decades. Wang [W10] reports that the average annual dose to diagnostic x-ray workers was 55.5 mSv before 1957, 8.7 mSv from 1957 to 1966 and 2.2 mSv from 1967 to 1980. The reason the doses still remain higher than in countries of health care level I is probably the extreme use of fluoroscopy and the lack of image intensification systems. The situation may be significantly worse in countries of levels of health care III and IV. Hussain [H22] reported on 311 x-ray installations in Bangladesh (level IV) and found that a majority of the installations had no shielded control booth, lead aprons or gloves. As was mentioned previously, almost one half of the machines had no functional collimation. In this Annex it will be conservatively assumed that the collective effective dose equivalent per million population is the same in countries of various levels of health care.

131. Information on occupational doses incurred as a result of dental radiography is very limited; however, the average annual doses are relatively low (Table 34), ranging from 0.02 mSv to 0.4 mSv annually in countries of health care level I. Dental practice generally contributes less than 1% to the collective effective dose equivalent from all occupational sources.

I. FUTURE TRENDS IN DIAGNOSTIC RADIOGRAPHY

132. It is instructive to postulate the future medical uses of radiation and the extent of their application and to examine potential areas of concern over the next 15 years. There is little doubt that, world-wide, the frequency and total number of procedures involving medical radiation will increase substantially [O4, U6]. There are three main reasons for this. First, there is the aging of the population, particularly in Europe. The Federal Republic of Germany, Switzerland, Italy and Greece are expected to have more than 20% of their populations over the age of 60 by the year 2000. The USSR and several other countries are expected to experience the same phenomenon, but to a lesser degree. As was indicated earlier, the older population accounts for a disproportionate number of medical diagnostic and radionuclide examinations as well as radiotherapy procedures.

133. The world's population is experiencing a marked contraction in the percentage of population between 0 and 30 years and a marked expansion in the percentage above the age of 30 [U6]. From 1950 to 1980, changes in the age distributions varied among the regions of the world. For example, the median age of the populations of Europe and the Soviet Union increased by about four years between 1950 and 1980 and that of Africa decreased by about 1.5 years. The median age for other regions decreased by about 2 years until the early 1970s and then began increasing, and it is now at the same level as it was in 1950. In contrast with past trends, the future is expected to be characterized by an aging of populations in all regions: the median age of the world population is expected to increase from 22.6 years in 1980 to 26.1 years in the year 2000 and to 30.8 years in the year 2025. The oldest populations in 2025 will be in Europe, East Asia, and Northern America. The youngest populations will be in Africa and Latin America, with median ages of 22.8 and 27.4 years, respectively.

134. Second, the total number of examinations will also undoubtedly increase simply as a result of population increase. The world's population was 2.5 billion in 1950 and 4.4 billion in 1980; it is projected to be 6.1 billion in 2000 and 8.2 billion in 2025. Even if the annual per caput effective dose equivalent and genetically significant dose remained the same, the collective doses would increase by over 60% from 1988 to 2025.

135. The population of the world had an annual growth rate of 1.7% in 1985. Throughout the nineteenth century and the first half of the twentieth century its annual growth rate was 0.5-0.8%. In the late 1960s, the world's population was growing at about 2% annually, and projections are that the growth rate will fall to 1.5% by the year 2000 and to 1% by 2025. It is important to note that while the rate of growth is declining, the annual increment to the world's population is increasing. The annual increment to the world's population in 1950 was 46 million, and in 1980 it was about 75 million. The annual increment is expected to peak at approximately 88 million near the end of the century and then decline somewhat by 2025. Although the global growth rate appears to be on the decline, there is marked difference between the more developed and less developed regions of the world. In the developed regions population is growing at an annual rate of 0.6%; in the less developed countries, it is growing at approximately 2%. As a consequence, the proportion of the world's population living in the less developed countries is expected to increase steadily.

136. Demographic trends also vary substantially from one part of the world to another. There is a rapid growth of the population in Africa, which is currently increasing at 3% per year and is expected to continue to increase at this rate until the end of the century. In 1950, the population of Africa accounted for about 8.7% of the total, but in 2025 it is expected to account for 19% of the total. Another rapidly growing area is Latin America, which has a growth rate of 2.5% per year or higher. Latin America's share of the total world population grew from 6.5% to 8.2% between 1950 and 1980, and by 2025 its share is expected to be 10.6%.

137. Third, the number and frequency of examinations will increase as a result of growing urbanization. At present, 41% of the population is classed as urban; in the year 2025, this percentage is expected to rise to 65%. As already discussed, urban populations have a much higher frequency of x-ray or radionuclide examinations than rural populations, the difference being an order of magnitude or more. If 50% of the world's population were urbanized by the year 2000, if the population aged as predicted and if the total population were 6 billion, the per caput doses and collective doses could be 50-100% higher than at present.

138. There are some countering factors in these projections. As the population ages, the assumed detriment would have less time to be expressed, and the use of an age-weighted dose equivalent would assume more importance. In simpler terms, although the number and frequency of examinations would increase, an older population would have less time to be at risk for the induction of stochastic effects. Moreover, in addition to depending on age, the genetically significant dose also depends on the reproduction rate. The gross reproduction rate in most developed countries is expected to remain fairly steady in the period 1980-2000, but it is decreasing in developing countries. This will be an additional factor to take into account when calculating the genetically significant dose. Overall, it can be assumed that the genetically significant dose will increase, but not as rapidly as the per caput or collective effective dose equivalent.

II. DIAGNOSTIC USE OF RADIOPHARMACEUTICALS

A. FREQUENCY AND TRENDS

139. Since the UNSCEAR 1982 Report, the Committee has obtained information from various countries on the number of in vivo diagnostic nuclear medicine examinations performed. This information is collected in Table 35. The frequency of all nuclear medicine examinations for countries of health care level I is in the range of two to 49 examinations per 1,000 population and for China (level II) it is 0.6 examinations per 1,000 population. Only in vivo diagnostic nuclear procedures are being considered in this chapter.

140. Malmstrom [M6, M7, M8, M9] reported statistics concerning nuclear medicine examinations in Sweden for the years 1979 through 1982. The total number ranged between 125,000 and 130,000 examinations annually (15 per 1,000 population).

141. The number of diagnostic nuclear medicine studies in the United Kingdom in 1982 was reported to be about 380,000, 84% of which were imaging

examinations. Bone scans were the most often performed procedure, although cardiac studies had increased 150-fold since 1973. Technetium-99m was the radionuclide used in 75% of the administrations, while iodine-131 was used in only 5%.

142. The number of diagnostic nuclear medicine procedures performed in the United States in different years is shown in Table 36. This Table documents the progressive increase in the frequency of diagnostic nuclear medicine procedures, both in absolute terms and per unit population. There was a rather sharp increase between 1970 and 1976, a plateau between 1976 and 1980 and another increase until 1982, with a sharp rise in cardiovascular and hepatobiliary imaging procedures. The only category in which a decline is evident is radionuclide brain scans. Similar trends have been reported in Denmark by Ennow [E2].

143. The percentage of each type of diagnostic nuclear medicine procedure may differ substantially from country to country. Table 37 shows that while thyroid imaging constitutes a large percentage of procedures in many Latin American countries, it constitutes only 9% of diagnostic radionuclide procedures in the United States, a variation that was also noticed and commented on in the UNSCEAR 1977 Report [U4]. A survey of radionuclide thyroid studies in the United States was reported by Parker et al. [P7], who identified substantial intra-country variation in methodology and radionuclide use. Technetium-99m pertechnetate was used for 54% of all thyroid scans and iodine-131 was used for only 9% of them. The rest of the thyroid scans were done with iodine-123. In summary, administered activity for a given examination varies by as much as a factor of 4 not only between countries but also within countries. The reasons for such variation are not known, but they may include training of the staff and, possibly, sensitivity of equipment.

144. The extrapolation procedure described in paragraph 10, which has been used to estimate world-wide medical diagnostic x-ray activity, can also be used to estimate nuclear medicine activity. A broad correlation exists between population per physician and annual nuclear medicine examinations per 1,000 population. There is also a strong relationship between population per physician and the population per scanner or gamma camera (Figure XI). The source terms and trends utilized to obtain averages for various levels of health care are shown in Tables 38 and 39. Estimates of annual examinations per 1,000 population for various levels of health care are shown in Table 40. It is estimated that there are approximately 24,000 gamma cameras or scanners world-wide and that approximately 24 million in vivo diagnostic radionuclide examinations are performed annually (Table 41). The number and type of nuclear medicine imaging devices in the United Kingdom have been reported by Wall [W8, W9]. The number of gamma cameras has markedly increased since 1974, while the number of rectilinear scanners has decreased.

B. AGE AND SEX DISTRIBUTION OF PATIENTS

145. For calculations of the genetically significant dose and related quantities it is necessary to know or assume the age and sex distribution of patients undergoing nuclear medicine procedures. Results of

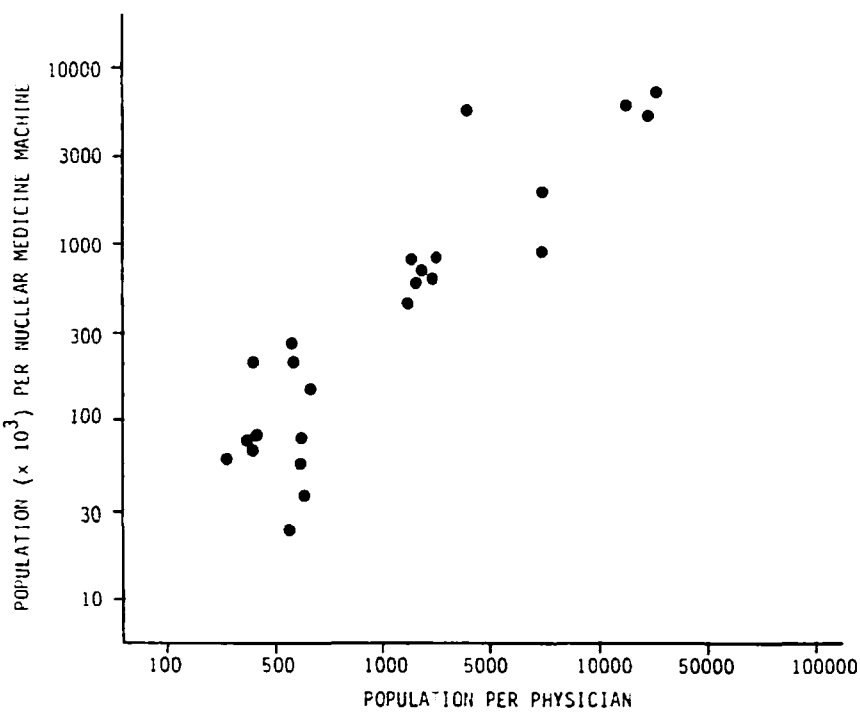

Figure XI. Correlation between population per physician and population per nuclear medicine machine in various countries.
[M28]

surveys performed in Poland in 1981 [S25] and the United States in 1980 [U10] are given in Table 42. About one third of the procedures in the United States are performed in persons over the age of 64 and approximately 70% of the procedures are performed in persons over the age of 45. This is true for most procedures, with the exception of thyroid and renal imaging procedures. In Poland the population receiving nuclear medicine examinations of all types is much younger.

C. IMPACT OF NEW TECHNOLOGIES

146. The impact of the new techniques has already been discussed briefly in section I.C, particularly the impact of computerized tomography on radionuclide brain scans and the possible impact of cardiovascular nuclear medicine procedures on invasive contrast studies. In view of the relatively high absorbed dose to the thyroid delivered in the course of examinations with iodine-131, many countries have begun to utilize either iodine-123 or technetium-99m pertechnetate. Unfortunately, iodine-123 is both difficult to obtain and expensive. The number of thyroid imaging procedures was rather stable in the United States over the period 1978-1982, and the number of thyroid ultrasound procedures performed is so far relatively small and does not appear to have significantly reduced the number of thyroid nuclear medicine procedures [M31]. Another area in which some replacement might be expected is radionuclide liver scans, which could be replaced by either hepatic ultrasound or hepatic computerized tomography. No data are available on the frequency of labelled monoclonal antibodies used predominantly for tumour detection.

D. ABSORBED DOSE

147. The range of administered activities for some types of examinations in different countries is shown in Table 43. As with absorbed dose in diagnostic radiology, the administered activity follows a skewed distribution. There are some differences between countries in the average activity used for certain examinations. For example, in the United States administered activity for a technetium-99m pertechnetate thyroid scan is about four times higher than in other developed countries. Kaul et al. [K2] and Johansson et al. [J5] published data concerning the dosimetry of unsealed incorporated radionuclides and discussed the mathematical-physical and metabolic dose models.

148. The effective dose equivalent in the USSR in 1980 from diagnostic radionuclide examinations has been reported by Knizhnikov et al. [K13]. He has indicated that the per caput value is 0.04 mSv per year. In the following years, in spite of the increasing number of radionuclide examinations, the average dose decreased to a per caput value of 0.03 mSv due to expanded use of short-lived radionuclides [V7]. The collective effective dose equivalent from all radionuclide examinations was estimated to be about 8,700 man Sv for 1981 [V7]. Table 44 shows that the collective effective dose equivalent for all diagnostic nuclear medicine procedures in the United States in 1982 has been estimated at 32,000 man Sv (0.14 mSv per caput) [M30]. A more in-depth analysis of the effect of age- and sex-specific weighting factors has been performed by Johansson [J8, J9], who concluded that detriment was about 40% of that calculated from the effective dose equivalent.

149. The annual per caput effective dose equivalent for most developed countries ranges between 0.03 and 0.14 mSv (Table 44). This is due mainly to the use of iodine-131 and technetium-99m. The percentages of collective effective dose equivalent attributable to different radionuclides are shown in Table 45. There are large differences between countries.

150. Radiation dose estimates for orally administered radionuclides used in upper gastro-intestinal disease have been calculated by Siegel et al. [S18]. Patient exposure and radiation risk in Bulgarian diagnostic nuclear medicine has been reported by Poppitz [P13]. One of the main sources of exposure in this particular case was the iodine-131 used in thyroid studies.

151. As a result of the widespread use of radiopharmaceuticals labelled with iodine-131 and technetium-99m there has been an increasing interest in assessing the radiation dose from breast milk following administration of such compounds to nursing mothers. Many authors have discussed the subject [B13, B17, C4, O1, O2, T6, V1, W24]. The nature of the radiopharmaceutical significantly affects breast secretion, with technetium pertechnetate having as much as 10% of the activity in breast secretions [A1]. In almost all instances, the secretion rate in milk 24 hours after injection is insignificant. An important exception to this arises in the case of iodine-125 fibrinogen. Ahlgren et al. [A1] recommend that when nursing mothers have received this radiopharmaceutical, breast feeding should be stopped for three weeks.

152. The method of estimating average practice in countries of various levels of health care can be used to estimate the world-wide annual per caput doses and collective dose from nuclear medicine. Reported effective dose equivalents and genetically significant doses for countries of health care level I are shown in Table 46 and are used as source terms. Since data are limited or lacking altogether for countries of health care levels II, III and IV, the values for those levels have been estimated according to the frequency of examinations. This may result in a slight underestimate, however, because it may be that longer-lived radionuclides are being used in less developed countries. For example, technetium-99m has a short physical half-life, making the dose of the pharmaceutical lower than that of a similar pharmaceutical labelled with iodine-131. At the same time, the short half-life makes it impractical to use technetium-99m in some less developed areas. The annual per caput doses and collective effective dose equivalent for health care levels I-IV are shown in Table 47. The annual collective effective dose equivalent is estimated to be 74,000 man Sv; the genetically significant collective dose is estimated world-wide to be approximately 15,000 man Sv.

E. OCCUPATIONAL EXPOSURE FROM DIAGNOSTIC NUCLEAR MEDICINE

153. Over the past decade there has been rapid expansion in the use of nuclear medicine and particularly in the use of the many technetium-99m labelled radiopharmaceuticals. Since these are administered predominantly by injection, there is a potential for relatively high doses to the hands of the workers. Generally, lead-shielded syringes are recommended; however, they are not always used. Direct handling of thin-walled plastic syringes can result in skin doses of 0.012-0.25 mSv per hour per MBq. Following injection, the patient represents another source of exposure to the technologist.

154. The limited data concerning occupational doses incurred in the practice of diagnostic nuclear medicine are presented in Table 48. Mean annual individual doses are 0.3-2.0 mSv. Nuclear medicine contributes approximately 2% to the collective dose from all occupational sources. The number of monitored workers in the field of nuclear medicine varies widely among countries. On the average, there are 100-300 examinations carried out annually for each monitored worker in developed countries [U5, W17]. Certainly, one nuclear medicine technologist can perform as many as 1,000 in vivo studies annually; however, the monitored workers also include physicians, chemists, physicists, pharmacists and, in some instances, clerks.

III. THERAPEUTIC USES OF RADIATION

A. FREQUENCY AND TRENDS

155. Data on the use of radiotherapy are often confusing because of imprecise definitions. With teletherapy, a treatment course may extend over several weeks and include many irradiations or treatments. By contrast, brachytherapy and the use of radiopharmaceuticals for therapy usually entail only one or two applications. For the purposes of this Annex, a teletherapy course or a brachytherapy application will be referred to as a procedure. Some authors refer only to the number of patients treated; the use of their data may cause the frequency of radiotherapy to be underestimated, since some patients are re-treated for recurrent tumours. Additional confusion arises in the matter of patient numbers, since some patients may receive treatment for more than one body area. Since the UNSCEAR 1982 Report [U5], some data have become available on the number of therapeutic radiology treatments in various countries. Table 49 shows there was a slight annual increase in therapeutic radiology treatments in Canada from 1978 to 1981. The annual frequency of treatments is approximately 26 per 1,000 of population. The estimated number of different types of cases treated by radiotherapy in some western hemisphere countries is shown in Table 50.

156. Hashizume et al. [H5, H6, H7] have reported on the status of external beam radiotherapy in Japan, where 77,000 patients were treated in 1978 with 1.78 10^6 irradiations (treatments). The average number of irradiations per treatment course was 21, with an average of 2.4 fields per patient. About 55% of the treatments were done with cobalt-60 units, 38% with high-energy x rays, 6% with high-energy electrons and 1% with conventional x-ray units. More than 50% of the patients were over the age of 45, about 4% were under the age of 14 years, and less than 1% of patients were treated for non-malignant disease. Marayuma et al. [M13] reported that in Japan in 1983 a total of 38,900 brachytherapy procedures were performed, 36,300 (93%) of which were in females.

157. In United States hospitals [K15] the number of new patients per radiotherapy unit was about 300 annually from 1973 through 1979 and the number of new patients per 1,000 population rose from 1.46 to 1.73 during the same period. Trends in equipment have been discussed in both the UNSCEAR 1977 Report [U4] and the UNSCEAR 1982 Report [U5]. Although orthovoltage units are still common in some Latin American countries and in parts of Europe, they have been almost completely replaced in the United States by cobalt-60 units and high-energy accelerators. Table 51 shows that in the United States from 1975 to 1980, there has been an increasing use of high-energy accelerators while the number of cobalt machines has remained approximately stable.

158. By estimating average practice in countries at various levels of health care, it is possible to obtain a rough estimate of radiation therapy activity world wide. The known radiation therapy experience by level of health care is shown in Table 52. For most countries of health care level I, approximately 2,400 brachytherapy and teletherapy procedures are performed annually per million population. In most countries approximately 200 new patients are treated annually per machine. Using these source terms, it is possible to estimate radiation therapy activity by level of health care (Table 53). The estimated number of procedures and machines by level of health care is shown in Table 54. By this estimation method it appears that there are approximately 5 million patients treated by radiotherapy annually and approximately 18,000 machines in use world-wide. The annual genetically significant dose from radiation therapy in countries of health care level I is approximately 0.015 mSv (Table 55); estimates for countries of health care levels II, III and IV are also shown in the Table.

159. The future of radiotherapy is somewhat difficult to predict. Certainly as the population ages, expands and becomes more urban, both the need for and the availability of radiation therapy will increase. In addition, the spectrum of diseases will change with time. One of the diseases in which there has already been such a change (and which often is treated with radiation therapy) is lung cancer. Since 1950, the lung cancer death rate has doubled, and in some instances tripled, in many European countries [O4].

160. At present, the Committee has no information on the age distribution of the population receiving radiotherapy in various countries nor does it have

information on the percentage of patients who may be long-term survivors. There are few new data since the UNSCEAR 1982 Report on the uses of radiation therapy for benign diseases. Probably the most common use is administration of sodium iodide-131 for hyperthyroidism. The effective dose equivalent depends on the percentage of iodine accumulated by the thyroid, but in cases of hyperthyroidism the effective dose equivalent usually exceeds 15 mSv per MBq [J4]. Wall [W9] has indicated that in the United Kingdom in 1982, treatments for thyrotoxicosis constituted 2.0% (7,600) of all nuclear medicine procedures and had a mean administered activity of 367 MBq and a range of 120 to 1,550 MBq. Similar experience has been reported from Denmark in 1985 [E2]. Therapy with unsealed radionuclides represented 1.4% of all nuclear medicine procedures. Therapy for thyrotoxicosis accounted for 88% of therapeutic procedures and thyroid cancer, 11%. The remaining 1% was for therapy with other radionuclides (such as ^{89}Sr for prostatic metastases and ^{131}I metaiodobenzylguanidine, ^{32}P and ^{90}Y for other tumour types). The number of therapeutic procedures for thyrotoxicosis in Denmark doubled between 1977 and 1985 [E2]. Whether this is also happening in other countries is unknown. In Sweden between 1979 and 1982 about 3,300 therapeutic nuclear medicine procedures were performed annually [M4, M5, M6, M7]. This accounted for about 2.5% of all nuclear medicine procedures. Due to the high absorbed doses, particularly to the thyroid, where non-stochastic effects predominate, therapeutic procedures are not usually included in assessment of annual collective dose from nuclear medicine. Patients with either thyrotoxicosis or thyroid carcinoma are predominantly young and female and have long survivals compared to other patients undergoing radiotherapy. Some recent data from Sudan [S36] indicate that 10% of all radiotherapy treatments are for benign diseases, with the majority of these (8.5% of the total) being for thyroid disease.

161. Extensive literature exists on endometrial carcinomas occurring 10 or more years after pelvic irradiation for squamous cell carcinoma of the cervix or carcinoma of the ovary, and after radiation-induced menopause [C13, F3, M5, R6, U4, U5]. The relative importance of such delayed effects depends not only on the availability of radiotherapy in various countries but also on the incidence of these tumours in the various countries. Because the incidence rates of cancers of various types vary from country to country, the relative percentage of secondary tumour types and the number of long-term survivors could also vary even if radiotherapy were equally available.

162. As the prospects for long-term survival improve following therapy and the possibility of secondary radiogenic tumours increases, there has been renewed interest in dose levels outside the useful radiotherapy beam. This was briefly discussed in the UNSCEAR 1982 Report [U5]. In patients treated for Hodgkin's disease, the relative risk of a second malignancy is 5.2 times that of the normal population. The mean actuarial 15-year risk reported recently by Tucker [T9] was 17.6%, of which 13.2% was due to solid tumours. The risk of leukaemia, although elevated after radiation therapy alone (relative risk 11 compared to the normal population), was much higher after either adjuvant chemotherapy (relative risk 117) or chemotherapy alone (relative risk 130). Such risks will continue to confound long-term follow-up studies to assess radiation risk in these patients.

B. ABSORBED DOSE

163. The dose delivered outside the useful radiation beam is determined mainly by scattered radiation in the patient and to a lesser extent by radiation scattered in air. For x-ray therapy units and linear accelerators levels of leakage radiation through the housing of the source contribute only 0.1-0.2% of the dose rate inside the useful beam. For neutron generators, however, the value may be 10 times as high [G6]. Results obtained by Kase et al. [K1] suggest that the machine collimators contribute 20-40% of the dose to patients outside the treatment field and that local shielding of organs from scattered radiation generated in the machine collimators could reduce the risk of carcinogenesis by as much as a factor of 2. Hudson et al. [H18] have also examined dose levels outside the beam, with particular emphasis on the provision of radiation therapy to a pregnant patient. They observed that the shielding blocks themselves may contribute to scattered radiation and that this is most likely to occur if the block is positioned immediately adjacent to the main beam. If the shielding block is moved away from the main beam, a dose reduction of some 30% is possible. Williams et al. [W14] and Petoussi et al. [P12] have published tables that include Monte Carlo calculations of dose to various organs for different fields in radiotherapy. These results are extremely useful since doses to organs and tissues outside the irradiated volumes are not often quoted in the literature. Vasilev et al. [V4] have reported that when patients are being treated for benign diseases, appropriate selection of x-ray potential can result in improved precision of dose delivered as well as reduction of dose to areas not being treated.

164. The annual genetically significant dose from brachytherapy in Japan in 1983 is estimated to have been 13 mSv and the per caput mean bone marrow dose, 0.31 mSv [M13]. The genetically significant dose from all radiotherapy in Japan in 1978 was 0.7 μSv and the per caput bone marrow dose was 1.5 mSv. This amounted to decreases of 93% and 26%, respectively, compared to 1971 [H6].

165. Of course, the fields or body areas treated by radiotherapy vary widely from country to country, so a world-wide assessment of risk from this practice would require data not only on the number of patients and treatments but also on the tissues or fields irradiated. As an example, cancer of the lung and breast are very common in the United States, although overall, cancer is a less significant cause of death than heart disease. In contrast, Olivares [O3] pointed out that cancer is the leading cause of death in Lima, Peru, with stomach cancer being most common in

males and cancer of the cervix being most common in females. While the Committee recognizes such major regional differences, it feels that a complete discussion of them is beyond the scope of this Annex. For this reason and others, discussed earlier, the Committee has not attempted to calculate an effective dose equivalent from the practice of radiotherapy.

166. The optimization of radiotherapy is intimately connected with the quality assurance and optimization of cancer control programmes. Zaharia [Z1] has indicated that in Latin America the most serious obstacle to cancer control is very late diagnosis and referral for treatment. This is predominantly due to lack of awareness of the early signs and symptoms of cancer. For example, in Peru, 92% of the patients presenting for treatment of cancer were in stages II to IV. This is in contrast to Sweden, where more than 40% of the patients presenting were in stage I and more than 80% were in stages I or II [W20]. The World Health Organization has examined most of the aspects related to optimizing radiotherapy. It indicates that the need for radiotherapy may not be uniform in all countries because the cancer sites in patients referred to radiotherapy institutes may have different rates of occurrence. In most industrialized countries, approximately one third of all cancer patients need radiotherapy either alone or combined with surgery. Approximately one half need surgery either alone or combined with other therapies. About one quarter of all patients either do not obtain, or are too advanced for, specific therapy. In less developed countries, the distribution of treatment needs will be different if the distribution of cancer sites is different. For example, when comparing North America with Latin America, researchers have found that the death rates from cancers of the breast (highest in North America), cervix, uterus and larynx (higher in Central and South America) often differ by a factor of 3 or more [P3].

167. The World Health Organization has also indicated that there is a difference in the age distribution of cancer patients from developed countries to developing countries, and the genetically significant dose will vary accordingly. For example, the average age of patients diagnosed with cancer was 55.7 years for Europeans, 45.9 years for Asians, and 35.9 years for Africans. Of the age group 10-40 years, Africans constituted 40%, Asians 31%, and Europeans only 12% [W20].

168. The World Health Organization maintains a quality control and dose comparison programme for clinical dosimetry [W20]. In an IAEA/WHO dose intercomparison programme, radiotherapy institutes received thermoluminescent capsules by mail and were requested to radiate them under varying circumstances. Similar co-operative programmes exist in Europe and in the United States. It is interesting to note that, even in highly industrialized countries, 15% of the institutions made dosimetry errors of more than 10%. Such errors may significantly affect the number of cases cured as well as the complication rates of the radiation therapy. Similar dosimetry intercomparison programmes have been reported on by Greene et al. [G7].

C. OCCUPATIONAL EXPOSURE FROM RADIATION THERAPY

169. Occupational exposures during the practice of radiotherapy come from several sources. In general, with the use of external beam radiotherapy the rooms are very well shielded and the attendant staff receive little exposure. An exception to this is doses incurred when using either neutron beams or electron accelerators operating above 10 MeV. The neutrons cause the activation of nearby materials, which then constitute a source of radioactivity and exposure to the staff even after the primary beam has been turned off. LaRiviere [L1] and Hoffman [H16] have examined this problem, and it appears that 75% of the staff dose is due to photoactivation products in the treatment head. The remainder is due to other activation products in the room; however, induced activity in the patient is not a significant source. The exact occupational dose equivalent received by a worker in this manner is a function of the workload. This is measured by personal dosimeters and appears to be 0.3-2.0 mSv, annually. Tatcher et al. [T1] have examined patients treated in a fast neutron therapy facility to determine how much the (n, 2n) reaction and production of carbon-11 and oxygen-15 in the patient added to the technologists' exposure. They concluded that patients were the source of less than 10% of the occupational exposure of the technologist.

170. A main source of occupational exposure from radiotherapy is brachytherapy. This often involves the insertion or surgical implantation of radioactive wires, needles or seeds. Pre-loaded surface applicators are also sometimes used. There has been a trend towards utilizing after-loading devices whenever possible to reduce occupational exposure. This involves the pre-positioning of an applicator or holder on or in the patient and then inserting the radioactive material at a later time. The occupational dose received from brachytherapy is also very dependent on whether the source insertion is manual or automated in some manner. Once the sources have been inserted the radiation exposure of persons around the patient must be considered. Since such exposure may be non-uniform, a comparison with doses incurred from other more uniform sources may be difficult. Annual occupational absorbed doses from brachytherapy usually range from 2 to 5 mSv [U4, U5].

171. Table 56 presents the limited data that are available concerning occupational doses from the entire practice of radiotherapy. Average annual individual exposures are 1-3 mSv, but, as pointed out, they can be higher in those individuals intimately involved with brachytherapy [H16]. The reported personal dosimeter values for radiation therapy workers are undoubtedly closer approximations of the effective dose equivalent than for diagnostic radiology workers. This is because in radiation therapy the energy of the incident radiation is higher and because protective aprons are not worn. The number of monitored workers in radiotherapy is difficult to assess. At present, data are available only from the United States, where it appears that there is one monitored person for each 25-50 procedures annually.

IV. SUMMARY

172. The present state of knowledge regarding the frequency of use of medical radiation and the associated absorbed dose is good for approximately 25% of the world's population. Data are fragmentary for another 25% of the population, and essentially no data exist for 50% of the population. For this reason, the Committee has developed an estimation procedure based on the good correlation that exists in most countries between population per physician and medical uses of radiation.

173. The main sources of uncertainty in the effective dose equivalent from medical diagnostic radiology are (a) the frequency of examinations and absorbed dose per examination, especially in the case of fluoroscopy; and (b) poorly calibrated or malfunctioning equipment. The effective dose equivalent from diagnostic medical examinations is far greater than that from dental or diagnostic nuclear medicine examinations.

174. The estimated world-wide per caput and collective effective dose equivalent and genetically significant dose from medical radiation are shown in Table 57. It would appear that the per caput annual effective dose equivalent is likely to be no lower than 0.4 mSv, but may be as high as 1.0 mSv. Similarly, the annual genetically significant dose may range from 0.1 to 0.3 mSv. The potential risk from medical radiation, if calculated from the effective dose equivalent for medical radiation, is probably an overestimate. This is particularly true in countries where the older portion of the population receives most of the medical irradiation.

175. The world-wide collective effective dose equivalent from medical radiation is estimated to be between $1.8\ 10^6$ and $5\ 10^6$ man Sv, and the genetically significant collective dose to be between $0.5\ 10^6$ and $1.5\ 10^6$ man Sv. Between 90% and 95% of both these values are attributable to medical diagnostic radiology. Dental radiography and nuclear medicine together contribute only 5-10% of the collective dose. In developed countries the contribution of diagnostic medical radiation to the collective effective dose equivalent is about 0.001 man Sv per examination.

176. There are many possibilities for dose reduction. In developed countries it may be possible to reduce the per caput effective dose equivalent to half its present value. In less developed countries the use of radiography rather than fluoroscopy, as well as the calibration and maintenance of equipment, would reduce the dose per examination, but the feasibility, cost and magnitude of these measures are unknown. One of the simplest and least expensive methods of dose reduction is appropriate collimation of the beam to conform only to the area of clinical interest. The genetically significant dose can be substantially reduced through the use of gonadal shielding, a practical, low-cost method. In spite of such measures, the collective effective dose equivalent may increase as x-ray examinations become more available in some countries, but this increase may in fact be medically appropriate. There have already been positive trends in dose reduction (including decreasing absorbed dose per examination as well as decreasing absorbed dose per patient without jeopardizing the desired clinical objective), particularly in well developed countries.

177. Occupational exposure from medical practices includes contributions from medical diagnostic radiology, dental radiography, nuclear medicine and radiation therapy. The sum of these for various countries is shown in Table 58. The average annual collective dose equivalent from medical occupational exposure is about 1 man Sv per million population. In both Canada and the United Kingdom, occupational exposure from medical practice represents about 10% of the collective dose equivalent from all occupational sources [U5]. In spite of the fact that the medical uses of radiation are increasing in most countries, limited trend data indicate that both annual individual doses and collective occupational doses are decreasing by 10-20% per decade. In the United States, for example, the number of occupationally exposed medical workers rose as follows: 300,000 in 1960; 400,000 in 1970; and 584,000 in 1980. During this time the annual collective dose equivalent decreased from 580 to 410 man Sv (Table 58). For developed countries the average occupational exposure is about 1 μSv per examination. The data also indicate that on average 150-750 examinations are carried out annually for each medical radiation worker.

178. The frequency and total usage of medical radiation is expected to increase over the next several decades as a result of (a) a general aging of the world's population; (b) an increase in the total number of people; and (c) a trend toward urbanization in the developing countries. By the year 2000, the collective dose will probably increase by 50% and by the year 2025 it may more than double.

179. Consideration of the following points would improve future assessments of exposures from the medical uses of radiation:

(a) collection of better data on the use of, and effective dose equivalents from, both mass miniature radiography and fluoroscopy in developing countries;

(b) continuing analysis of the aging and urbanization of population groups and its effect upon use of medical radiation;

(c) continued examination of the data for determining age- and sex-weighted dose equivalent values; and

(d) collection of data on the number of patients treated with radiotherapy and the proportion of long-term survivors in various countries.

Table 1

Annual frequency of common diagnostic x-ray examinations per 1000 population

Numbers in parentheses indicate per cent

Examination	Canada 1980 [C1]	China 1980 [Z5]	France 1981-1982 [B9, F1, M1]	Germany, Federal Rep. 1978 [U5]	Italy a/ 1983 [P1]
Skull and face	-	0.4 (0.1)	74.0 (8.9)	108.2 (12.4)	41.5 (5.6)
Cervical spine		1.0 (0.3)	23.5 (2.8)	-	26.7 (3.6)
Dorsal spine	113 a/ (11.1)	0.4 (0.1)	18.5 (2.2)	35.7 (4.1)	12.6 (1.7)
Dorsal lumbar sp.		-	33.6 (4.0)	21.9 (2.5)	-
Lumbosacral spine		3.5 (1.4)	13.3 (1.7)	-	36.4 (4.9)
Chest					
Radiographic	329.6 (32.4)	4.9 (1.9)	285.0 (34.1)	333.9 (39.6)	242.6 (32.6)
Photofluorogr.	-	-	-	-	80.9 (10.8)
Fluoroscopic	-	188.1 (72.6)	-	-	-
Mammography	2.7 (0.3)	-	4.8 (0.6)	27.9 (3.2)	6.7 (0.9)
Abdomen		0.4 (0.1)	29.6 (3.5)	4.1 (0.5)	22.3 (3.0)
GI tract and					
barium enema	132.3 (13.0)	9.2 (3.6)	35.3 (4.2)	67.8 (7.9)	46.0 (6.2)
Cholecystography		0.2 (0.1)	12.4 (1.6)	-	12.6 (1.7)
Urography	32.2 (3.2)	0.1 (0.1)	37.4 (4.4)	42.0 (4.9)	12.6 (1.7)
Hysterography		-	3.4 (0.4)	-	-
Pelvis and hip	-	1.5 (0.6)	62.2 (7.4)	49.0 (5.2)	40.1 (5.4)
Extremities	254.9 (25.1)	5.9 (2.3)	182.6 (21.9)	172.9 (20.2)	138.8 (18.6)
Computer tomography					
Head	-	-	-	-	5.2 (0.7)
Body	-	-	-	-	5.2 (0.7)
Others	151.3 (14.9)	43.4 (16.7)	19.4 (2.3)	-	14.1 (1.9)
Total (medical)	1016 (100)	259 (100)	835 (100) c/	863 (100) c/	744 (100)

Examination	Japan 1986 [M18]	Netherlands 1980 [B6]	Norway 1980-1983 [S3,S4]	Spain 1986 [V4]	Sweden 1979 [U5]
Skull and face	56.5 (4.8)	42.9 (6.6)	6.3 (1.0)	15 (3.1)	43.3 (8.8)
Cervical spine	41.2 (3.5)			)	
Dorsal spine	10.8 (0.9)	9.6 (1.5)	10.0 (1.6)	)	9.6 (1.9)
Dorsal lumbar sp.	52.5 (4.5)	-	0.6 (0.1)	) 97 (19.8)	17.8 (3.6)
Lumbosacral spine	14.4 (1.2)	30.8 (4.8)	27.0 (4.2)	)	2.6 (0.5)
Chest					
Radiographic	445.0 (38.1)	135.0 (20.8)	123.3 (19.2)	128 (26.0)	176.8 (35.8)
Photofluorogr.	-	123.1 (19.0)	84.4 (13.2)	-	-
Fluoroscopic	-	10.9 (1.7)	5.2 (0.8)	-	-
Mammography	1.3 (0.1)	8.4 (1.3)	2.5 (0.4)	14 (2.9)	6.4 (1.3)
Abdomen	82.9 (7.1)	12.7 (2.0)	8.0 (1.2)	45 (9.2)	11.7 (2.4)
GI tract and					
barium enema	174.9 (14.9)	19.7 (3.0)	33.1 (5.2)	40 (8.2)	32.6 (6.6)
Cholecystography	10.6 (0.9)	13.7 (2.1)	3.0 (0.1)	-	11.8 (2.4)
Urography	13.0 (1.1)	15.6 (2.4)	20.2 (3.2)	13 (2.6)	22.8 (4.6)
Hysterography	0.7 (0.1)	0.9 (0.1)	-	-	0.6 (0.1)
Pelvis and hip	12.7 (1.1)	33.6 (5.2)	46.4 (7.2)	15 (3.1)	36.4 (7.4)
Extremities	101.5 (8.7)	173.3 (26.7)	146.3 (22.8)	25 (5.1)	112.0 (22.7)
Computer tomography					
Head	-	-	7.4 (1.2)	7 (1.4)	1.2 (0.2)
Body	-	-	2.8 (0.4)		0.2 (0.1)
Others	154.0 (13.1)	18 (2.8)	115 (17.9)	91 (18.6)	8.0 (1.6)
Total (medical)	1172 (100) c/	648 (100)	641 (100)	490 (100) c/	494 (100) c/

Table 1, continued

Examination	Russian Federation 1980 [N9]	United Kingdom d/ 1983 [W6]	United States 1981 [M28]	Level I countries e/ (average)
Skull and face	52.2 (4.0)	39 (7.8)	36.1 (4.6)	50 (6)
Cervical spine	11.5 (0.9)	13 (2.7)	22.4 (2.8)	20 (2)
Dorsal spine	6.9 (0.5)	6 (1.2)	7.9 (1.0)	13 (2)
Dorsal lumbar sp.	17.4 (1.3)	-	-	25 (3)
Lumbosacral spine	4.6 (0.4)	24 (4.5)	56.8 (7.2)	25 (3)
Chest				
Radiographic	118.0 (9.0)	163 (32.9)	282.0 (35.7)	240 (30)
Photofluorogr.	525.0 (40.1)		-	25 (3)
Fluoroscopic	149.0 (11.4)		-	2 (1)
Mammography	-	5 (0.9)	5.7 (0.7)	7 (1)
Abdomen	-	21 (4.2)	34.8 (4.4)	55 (7)
GI tract and barium enema	181.0 (13.8)	20 (4.0)	55.1 (7.0)	70 (9)
Cholecystography	9.7 (0.7)	6 (1.3)	15.0 (1.9)	13 (2)
Urography	42.0 (3.2)	8 (1.7)	18.5 (2.3)	24 (3)
Hysterography	-	1	-	2 (1)
Pelvis and hip	10.0 (0.8)	22 (4.3)	20.7 (2.6)	38 (5)
Extremities	123.2 (9.4)	67 (13.4)	198.2 (25.1)	150 (19)
Computer tomography				
- Head	-	4 (0.8)	11.8 (1.5)	7 (1)
- Body	-	1	2.6 (0.3)	2 (1)
Others	58.0 (4.4)	89 (20.3)	22.5 (2.8)	32 (4)
Total (medical)	1308 (100)	488 (100)	790 (100)	800 (100)

a/ Northeast Italy only.
b/ Includes pelvis.
c/ Does not include mass screening.
d/ Great Britain only.
e/ Excluding China.

Table 2

Diagnostic x-ray examinations in the USSR [V7]

Examination	Number per 1000 population		Change
	1964	1981	
Fluoroscopy	439	220	-50%
Radiography	171	235	+37%
Photofluorography	183	503	+175%
Total	793	958	+21%

Table 3

Diagnostic x-ray machines in some western hemisphere countries

Country	1973 [P16]			1980 [I7]		
	Units	Population (thousands)	Units per 1000 population	Units	Population (thousands)	Units per 1000 population
Argentina	5170	24290	0.21	10000	27862	0.36
Chile	720	10309	0.07	1320	11104	0.12
Costa Rica a/	300	1896	0.16	124	2245	0.06
Ecuador	300	6726	0.04	345	8354	0.04
Mexico	3500	54300	0.06	3800	71910	0.05
United States	117151	209851	0.56	137000	227158	0.60

a/ Number of units reported in 1973 may include dental x-ray units.

Table 4

Diagnostic x-ray examinations by level of health care

Level of health care	Country	Annual examinations per 1000 population	Population per x-ray machine	Year	Reference
I	Argentina		2800	1978-1982	[I7]
	Canada	1016	3200	1980	[C1]
	Finland	958	-	1984	[T3]
	France	835	2700	1981-1982	[B9,M1,P11]
	Germany, Fed. Rep.	863	-	1978	[U5]
	Italy	744	3290	1983	[C11]
	Japan	1380	-	1986	[M18]
	Libyan Arab Jamal.	-	8000	1977	[C7]
	Netherlands	648	-	1980	[B6]
	Norway	641	-	1983	[S3, S4]
	Spain	490	4400	1986	[V4]
	Sweden	494	-	1979	[U5]
	United Kingdom	488	5000	1983	[W6, C11]
	United States	790	1800	1980	[M28]
	USSR	958	-	1981	[V7]
II	Bolivia	-	27000	1978-1982	[I7]
	Brazil	179	13400	1982	[C13]
	Chile	166	13000	1982	[C13]
	China	259	16400	1980	[Z4, Z5, S32]
	Colombia	211	14300	1978-1982	[I7]
	Costa Rica	270	19200	1981	[C13]
	Cuba	139	11000	1978-1982	[I7]
	Dominican Republic	20	80000	1981	[C13]
	Equador	36	-	1981	[C13]
	Islamic Rep.of Iran	180	-	1981	[S19]
	Mexico	70	15000	1980	[C13]
	Nicaragua	57	-	1981	[C13]
	Paraguay	-	41000	1978-1982	[I7]
	Peru	-	12000	1978-1982	[I7]
	Turkey	80	-	1978	[Y1]
	Uruguay	-	8800	1978-1982	[I7]
	Venezuela	-	10000	1978-1982	[I7]
III	Kenya	36	100000	1970	[C7]
	India	23	65000	1977	[C7]
	Liberia	80	70000	1977	[C7]
	Singapore	-	60000	1977	[C7]
	Sri Lanka	21	-	1979	[U5]
	Sudan	-	150000	1984	[S36]
	Thailand	34	-	1977	[C7]
IV	Ethiopia	-	300000	1977	[C7]
	Ghana	22	100000	1977	[C7]
	Côte d'Ivoire	40	190000	1977	[C7]
	Nigeria	25	90000	1977	[C7]

Table 5

Average diagnostic x-ray examinations by level of health care

Level of health care	Annual examinations per 1000 population	Population per x-ray machine
I	800	4000
II	150	20000
III	50	80000
IV	< 30	170000

Table 6

Estimated world-wide diagnostic x-ray examinations and machines in 1987

Numbers in parentheses indicate per cent of total

Level of health care	Population (millions)	Diagnostic x-ray machines (thousands)	Diagnostic examinations (millions)	Approximate examinations per machine
I	1300 (26)	330 (76)	1040 (75)	3000
II	1750 (35)	88 (20)	260 (19)	3000
III	1220 (24)	15 (3)	61 (4)	4000
IV	730 (15)	4 (1)	22 (2)	5500
Total	5000 (100)	440 (100)	1380 (100)	

Table 7

Diagnostic x-ray examinations in some Latin American countries in 1981
(per cent)
[17]

Country a/	Nervous system	Chest	Neck	Digestive tract	Uro-genital	Extremities	Other
Chile	5	40	2	18	5	30	-
Costa Rica	6	22	1	9	8	36	18
Dominican Republic	10	33	2	19	5	30	1
Ecuador	3	26	4	8	5	35	19
El Salvador	10	38	3	6	6	26	11
Mexico	-	40	6	12	5	28	9
St. Lucia	-	50	5	7	5	22	11

a/ All countries are of health care level II.

Table 8

Diagnostic x-ray examinations by level of health care
(per cent)

Examination	Level of health care a/			
	I	II	III	IV
Head and neck	8	9	8	
Chest	33	36	50	
Abdomen and digestive tract and gallbladder	18	13	6	
Urogenital	4	6	4	
Extremities	19	27	23	
Other	18	9	9	
Sample size (number of countries)	(12)	(7)	(2)	(0)

a/ Information for health care level IV not available.

Table 9

Estimated percent of urban and rural populations receiving diagnostic x-ray examinations in some Latin American countries in 1981 [I7]

Country	Urban	Rural
Chile	15	2
Costa Rica	5	2
Dominican Republic	15	10
El Salvador	9	-
Mexico	20	2
St. Lucia	6	3

Table 10

Annual frequency of diagnostic x-ray examinations per 1000 population a/

Country	1955-59	1964	1969-70	1974-76	1977-79	1980-83	Reference
Canada					987	1016	C1
China b/				146	208	259	S22,Z4,Z5
France	150					835	B9, B10
Germany, Fed.Rep.					863		U5
Japan	259		641	729	1328		U4, U5
Netherlands			810			648	U4, B6
Norway	609					641	S4, S5
Sweden	430	650			494 c/		U4
Turkey					80 d/		Y1
United Kingdom	300	310	400		440	496	U4,K5,W6
USSR		793	911	1094		1272	V7, N9
USSR e/			1065	1192		1339	K13, K19
United States		637	717			790	M28

a/ Includes mass screening and fluoroscopy unless otherwise indicated.
b/ Refers to Shangdong Province; frequency for Beijing (1983): 671 [Z11].
c/ Does not include mass screening.
d/ Does not include fluoroscopy.
e/ Russian Federation.

Table 11

Dental radiography, 1975-1987
[B8, B11, C11, H20, M10, M14, P11, U4, U5, W6]

Level of health care	Country	Films per 1000 population	Procedures per 1000 population	Population per machine a/
I	Argentina			3900
	France	540	-	1800
	Italy	118	70	
	Japan		800	1700
	Poland		44	
	Sweden	1800		
	United Kingdom	255	165	
	United States	1650	456	1000
	Rounded average		250	2500
II b/	Chile		3.9	21000
	Costa Rica			6500
	Ecuador			9400
	Mexico			80000
III	Sri Lanka		0.8	

a/ Data provided are difficult to evaluate for number of dental machines since standard radiographic machines are often used.
b/ Data for health care level II countries from [I7].

Table 12

Estimated world-wide dental radiography, 1980

Level of health care	Films per 1000 population	Procedures per 1000 population	Population per machine	Estimated total procedures (millions)
I	1000	250	2500	330
II	-	4 (50) a/	20000	7 (87)
III	-	0.8 (16)	-	1 (19)
IV	-	(8)	-	0.3 (6)
Total				340 (440)

a/ Numbers in parentheses refer to estimates for levels II-IV based on diagnostic radiologic activity. These estimates may be high by an order of magnitude.

Table 13

Age and sex distribution of diagnostic x-ray examinations
(per cent)

Examination	Age and sex	Norway 1983 [S3, S4]	United Kingdom 1983 [W6]	United States 1980 [U10]
Skull and face	< 15 male	10.0	10.9	11.2
	female	7.2	6.8	7.1
	both	17.2	17.7	18.3
	15-29 male	12.2	13.1	20.1
	female	8.6	8.6	14.8
	both	20.8	21.7	34.9
	30-44 male	10.0	9.8	8.7
	female	9.4	9.3	8.9
	both	19.4	19.1	17.6
	45-64 male	13.6	11.5	7.3
	female	12.6	13.0	9.0
	both	26.2	24.5	16.3
	> 64 male	7.4	6.8	5.1
	female	8.8	10.2	7.8
	both	16.2	17.0	12.9
	All ages male	53.2	52.1	52.4
	female	46.8	47.9	47.6
	both	100.0	100.0	100.0

Examination	Age and sex	China a/ 1980 [Z4, Z5]	Norway 1983 [S3, S4]	Poland 1978 [N5]	United Kingdom 1983 [W6]	United States 1980 [U10]
Chest	< 15 male	10.4	5.8	7.3	3.7	4.6
	female	6.5	4.0	6.0	2.4	3.4
	both	16.9	9.8	13.3	6.1	8.0
	15-29 male	14.1	4.7	9.2	6.9	7.4
	female	13.3	4.3	7.7	7.0	7.5
	both	27.4	9.0	16.9	13.9	14.9
	30-44 male	12.4	7.1	9.6	8.5	6.7
	female	12.4	7.5	9.1	8.1	8.1
	both	24.8	14.6	18.7	16.6	14.8
	45-64 male	14.1	18.7		16.4	14.6
	female	9.9	17.1		13.4	14.4
	both	24.0	35.8	26.0	29.8	29.0
	> 64 male	4.0	15.9	25.1	16.4	15.6
	female	2.9	14.9	51.1	16.5	17.7
	both	6.9	30.8		32.9	33.3
	All ages male	55.0	52.2	52.1	52.6	49.9
	female	45.0	47.8	47.9	47.4	51.1
	both	100.0	100.0	100.0	100.0	100.0

a/ Chest fluoroscopy, which constitutes 95% of all chest examinations in China.

Table 13, continued

Examination	Age and sex	Norway 1983 [S3, S4]	Poland 1978 [N5]	United Kingdom 1983 [W6]	United States 1980 [U10]
Abdomen	< 15 male	4.5	4.0	4.7	4.5
	female	2.9	2.9	4.6	3.8
	both	4.7	6.9	9.3	8.3
	15-29 male	5.4	9.3	8.4	8.2
	female	6.2	13.0	10.9	10.2
	both	11.6	22.3	19.3	18.4
	30-44 male	7.1	10.9	6.3	7.9
	female	7.0	13.4	8.8	8.3
	both	14.1	24.3	15.1	16.2
	45-64 male	17.2		12.0	14.2
	female	11.9		12.0	14.2
	both	29.1	24.3	24.0	26.5
	> 64 male	19.6	22.2	14.2	13.6
	female	21.2	46.5	20.1	17.0
	both	40.8		34.3	30.6
	All ages male	50.8	48.5	45.6	48.4
	female	49.2	51.5	56.4	51.6
	both	100.0	100.0	100.0	100.0

Examination	Age and sex	China 1980 [Z4, Z5]	Norway 1983 [S3, S4]	Poland 1978 [N5]	United Kingdom 1983 [W6]	United States 1980 [U10]
Upper GI (barium meal)	< 15 male	2.1	3.2	0.9	0.9	1.4
	female	0.9	2.4	0.7	0.4	1.5
	both	3.0	5.6	1.6	1.3	2.9
	15-29 male	13.7	8.4	9.8	6.6	6.0
	female	9.2	5.4	7.5	4.9	9.2
	both	22.9	13.8	17.3	11.5	15.2
	30-44 male	15.8	10.2	14.0	13.4	8.4
	female	9.9	8.6	12.4	12.5	11.9
	both	25.7	18.8	26.4	25.9	20.3
	45-64 male	21.7	18.8		18.2	14.3
	female	15.8	16.2		15.0	18.7
	both	37.5	35.0	29.3	23.2	33.0
	> 64 male	6.7	12.2	25.4	9.8	11.3
	female	4.2	14.4	54.7	18.3	17.2
	both	10.9	26.6		28.1	28.6
	All ages male	60.0	52.8	54.0	48.9	41.5
	female	40.0	47.2	46.0	51.1	58.5
	both	100.0	100.0	100.0	100.0	100.0

Examination	Age and sex	Norway 1983 [S3, S4]	Poland 1978 [N5]	United Kingdom 1983 [W6]	United States 1980 [U10]
Barium enema	< 15 male	0.2	4.5	0.4	1.1
	female	0.2	5.9	< 0.1	1.1
	both	0.4	10.4	0.4	2.2
	15-29 male	5.0	4.0	3.5	3.5
	female	6.6	6.4	5.8	6.9
	both	11.6	10.4	9.3	10.4
	30-44 male	8.2	9.5	4.9	5.5
	female	13.2	7.3	11.3	10.8
	both	21.4	16.8	16.2	16.3
	45-64 male	15.2		14.8	13.6
	female	23.6		17.2	21.2
	both	38.8	28.3	32.0	34.8
	> 64 male	10.7	34.1	15.2	14.1
	female	17.1	62.4	26.9	22.2
	both	27.8		32.1	36.3
	All ages male	39.3	46.3	38.8	37.8
	female	60.7	53.7	61.2	62.2
	both	100.0	100.0	100.0	100.0

Table 13, continued

Examination	Age and sex	Norway 1983 [S3, S4]	United Kingdom 1983 [W6]	United States 1980 [U10]
Biliary tract	< 15 male	< 0.1	< 0.1	0.3
	female	0.2	1.1	0.6
	both	0.2	1.1	0.9
	15-29 male	2.8	1.5	4.5
	female	7.0	9.1	12.1
	both	9.8	10.6	16.6
	30-44 male	7.2	8.2	8.1
	female	05.9	10.0	15.9
	both	23.1	18.2	24.0
	45-64 male	13.8	11.8	14.0
	female	27.0	33.2	20.1
	both	40.8	45.0	34.2
	> 64 male	8.3	8.5	9.6
	female	17.8	12.6	14.7
	both	26.1	21.1	24.3
	All ages male	32.1	30.0	36.6
	female	67.9	70.0	63.4
	both	100.0	100.0	100.0

Examination	Age and sex	Norway 1983 [S3, S4]	Poland 1978 [N5]	United Kingdom 1983 [W6]	United States 1980 [U10]
Urogram	< 15 male	4.4	6.6	6.5	1.8
	female	9.9	10.4	3.9	2.7
	both	14.3	17.0	10.4	4.5
	15-29 male	5.4	7.9	8.1	7.1
	female	7.5	9.9	8.5	9.7
	both	12.9	17.8	16.6	16.8
	30-44 male	8.0	11.0	9.9	9.0
	female	9.3	10.5	5.3	11.6
	both	17.3	21.5	15.2	20.6
	45-64 male	16.6		24.2	15.6
	female	13.5		7.7	15.5
	both	29.1	25.8	31.9	31.1
	> 64 male	17.4	17.9	19.1	15.0
	female	7.8	43.7	6.8	12.0
	both	25.2		25.9	27.0
	All ages male	52.0	51.3	67.8	48.5
	female	48.0	48.7	32.2	51.5
	both	100.0	100.0	100.0	100.0

Examination	Age and sex	Norway 1983 [S3, S4]	Poland 1978 [N5]	United Kingdom 1983 [W6]	United States 1980 [U10]
Lumbosacral spine	< 15 male	2.0	2.4	3.6	1.1
	female	2.3	2.7	1.9	1.1
	both	4.3	5.1	5.5	2.2
	15-29 male	13.0	6.0	5.8	16.2
	female	8.6	5.1	8.3	9.5
	both	21.6	11.1	14.1	25.7
	30-44 male	13.0	11.5	13.2	13.6
	female	12.2	14.4	13.7	11.1
	both	25.2	25.9	26.9	24.7
	45-64 male	15.2		12.3	12.5
	female	16.9		14.4	15.1
	both	32.1	25.4	26.7	27.6
	> 64 male	6.6	32.5	11.0	6.6
	female	10.2	57.9	15.8	13.2
	both	16.8		26.8	19.8
	All ages male	49.8	45.3	54.1	50.0
	female	50.2	54.7	54.1	50.0
	both	100.0	100.0	100.0	100.0

Table 13, continued

Examination	Age and sex	Norway 1983 [S3, S4]	Poland 1978 [N5]	United Kingdom 1983 [W6]	United States 1980 [U10]
Pelvis and hip	< 15 male	9.2	18.6	5.6	4.3
	female	10.8	27.1	7.5	3.7
	both	20.0	45.7	13.1	8.0
	15-29 male	4.2	4.7	6.1	8.2
	female	4.2	3.9	6.6	5.6
	both	8.4	8.6	12.7	13.8
	30-44 male	4.4	5.3	8.2	5.6
	female	8.0	6.0	6.5	5.1
	both	12.4	11.3	14.7	10.7
	45-64 male	10.8		10.4	10.2
	female	20.0		13.6	13.1
	both	30.8	14.1	24.0	23.3
	> 64 male	8.4	20.3	9.9	12.6
	female	20.0	34.4	25.6	31.6
	both	28.4		35.5	44.2
	All ages male	37.0	42.7	40.2	40.9
	female	63.0	57.3	59.8	59.1
	both	100.0	100.0	100.0	100.0

Examination	Age and sex	Isl.Rep. of Iran 1980 [S19]	Norway 1983 [S3, S4]	Poland 1978 [N5]	United Kingdom 1983 [W6]	United States 1980 [U10]
All diagnostic examinations	< 15 male	9.0	-		6.7	5.5
	female	6.7	-		4.6	4.2
	both	15.7	-		11.3	9.7
	15-29 male	21.6	-		10.7	12.1
	female	10.7	-		8.3	9.8
	both	32.3	-		19.0	21.9
	30-44 male	16.0	-		9.9	8.1
	female	11.0	-		8.5	9.1
	both	27.0	-		18.4	17.2
	45-64 male	12.4	-		13.9	12.1
	female	7.5	-		13.2	14.1
	both	19.9	-		27.1	26.2
	> 64 male	3.2	-		7.6	10.5
	female	1.4	-		15.6	14.5
	both	4.6	-		23.2	25.0
	All ages male	63.0	50.9	48.8	48.3	
	female	37.0	49.1	51.2	51.7	
	both	100.0	100.0	100.0	100.0	

Table 14

Cardiac imaging procedures in the United States
(thousands)
[N1]

Examination	1972	1973	1980
Angiography		200	504
Coronary and left ventriculography		200	504
Echocardiography	0		1400
Radionuclide blood pool	11	25	580
Radionuclide infarct scan	2		580
Radionuclide scan perfusion/ischemia thallium	0		580

Table 15

Head x-ray and radionuclide examinations in the United States
(thousands)
[E6]

Examination	1964	1970	1972	1973	1978	1980
Head CT			0	<10		1600
Skull	2500	3600				3700
Pneumo-encephalogram		48				2
Arteriogram	121					315
Radionuclide brain scan			1250		1546	867
Radionuclide cisternogram			12			16

Table 16

Mammography examinations in the United States
(thousands)
[N1]

	1964	1970	1980
Number in hospitals	53	199	1000
Number in surgeries	13	47	260
Total	66	246	1260
Per 1000 female population	0.6	2.4	11

Table 17

Skin dose in the primary beam per film a/
(mSv)

Examination (projection) b/	Canada [C2]	Italy [I1]	Poland [J1]	United Kingdom [H2,S16]	United States [U9]
Skull (LAT)	2.1 (0.8- 8.9)	4.3 (2.6-19.6)	- -	2.3 -	2.3 (0.1-36.1)
Chest (P/A)					
Radiographic	0.17 (0.04-3.15)	0.69 (0.07-16.8)	2.0	0.22 (0.10-0.90)	0.21 (0.03-7.1)
Photofluorographic	-		7.7	1.2	-
Abdomen (A/P)	6.2 (0.6-39.9)	-	27.0	8.4	6.2 (0.4-86.4)
Retrograde pyelogram (A/P)	6.6 (3.7-74.5)	13.1 (2.9-39.8)	-	-	6.8 (0.8-61.9)
Cervical spine (A/P)	1.8 (0.5-4.4)	-	16.8	-	2.2 (0.1-33.6)
Thoracic spine (A/P)	3.2 (1.9-20.3)	-	-	6.2	6.8 (0.8-42.6)
Lumbar spine					
(A/P)	5.3 (0.7-36.1)	12.3 (12.4-36.5)	27.7	9.2	7.5 (0.4-98.0)
(LAT)	-	-	-	22.8	-

a/ Values expressed as median, numbers in parentheses refer to range when available.

b/ A/P and P/A and LAT refer to beam entrance and exit on the body. For example, on a P/A chest radiograph the beam is incident upon the posterior thorax and exits on the anterior thorax.

Table 18

Mean number of radiographs and fluoroscopy screening time by examination in France, 1982
[M1]

Examination	Mean number of films	Fluoroscopy screening time (s) a/	Examinations involving fluoroscopy (%)
Cervical spine	3.7	53	37
Thoracic spine	43.	34	33
Lumbar spine	4.8	47	41
Sacro-lumbar spine	4.8	82	56
Pelvis, hip	2.2	26	25
Abdomen	2.4	34	29
IV urography	10.7	83	52
Hysterography	4.9	96	73
Cholecystography	5.7	73	67
Skull	3.2	29	24
Barium enema	9.5	187	76
Barium meal	9.5	267	81
Thorax	1.5	17	10
Cerebral angiography	46	482	40
Thoracic angiography	24.2	455	86
Abdominal angiography	37.7	302	78
Inferior limbs angiography	14.3	78	60
Phlebography	10.1	182	15
Obstetrical abdomen	3.4	53	57
Pyelography	5.2	75	54

a/ For static examinations, such as lumbar spine, cervical spine, abdomen etc., fluoroscopy is mostly used for centring the patient.

Table 19

Radiation doses to neonates receiving diagnostic examinations in the United Kingdom
(sample size 85 infants)
[R5]

Gestation (weeks)	Mean birth weight (kg)	Mean number of films per infant	Mean number of CT scans per infant	Mean marrow dose (mSv)
26-27	0.83	6.7	0.5	2.47
28-29	1.15	10.5	0.3	1.65
30-31	1.49	11.3	0.6	2.17
32-33	1.80	3.6	0.3	1.05
34-35	2.23	2.8	0	0.05
36-37	2.60	4.1	0	0.08
38-39	2.38	3.3	0	0.06
40-41	3.39	2.4	0	0.04
42	3.42	1.5	0	0.03

Table 20

Organ doses from computerized tomography scans in Japan [N10]

Organ	Mean absorbed dose (mSv)		
	Cranial	Upper abdominal	Lower abdominal
Ovary	0.0043	0.18	9.50
Testes	0.004	0.17	0.175
Bone marrow	1.41	1.74	2.60
Brain	25.0	0.06	0.06
Sublingual gland	1.45	0.45	0.04
Thyroid	9.60	0.54	0.043
Breast	0.15	14.8	0.21
Stomach	0.04	7.60	0.43
Lung	0.18	6.80	1.13
Liver	0.04	5.80	0.38
Upper large intestine	0.006	0.26	12.0
Lower large intestine	0.006	0.26	12.0
Rectum	0.005	0.16	9.20
Eye (right)	28.0	0.15	0.03

Table 21

Organ doses from dental radiography in the United Kingdom [W3]

Organ	Mean dose equivalent per examination (mSv)		
	Intra-oral (2 films)	Extra-oral (2 films)	Pantomography (1 film)
Gonads	0.002	0.001	< 0.005
Breast	0.01	0.005	0.01
Bone marrow	0.025	0.02	0.05
Lungs	0.002	0.001	0.01
Thyroid	0.01	0.01	0.07
Bone surface	0.12	0.10	0.20
Brain	0.10	0.03	0.50
Salivary glands	0.03	0.70	1.1
Sinuses	0.50	0.05	0.20

Table 22

Collective effective dose equivalent from diagnostic x-ray examinations in France, 1982
[M2]

Examination	Collective effective dose equivalent (man Sv)	Accounted for by fluoroscopy (%)
Cervical spine	1680	18 a/
Thoracic spine	2100	16.5 a/
Lumbar spine	8580	13 a/
Sacro-lumbar spine	3400	7 a/
Pelvis, hip	5350	3 a/
Abdomen	4120	6.5 a/
IV urography	20580	11.5 a/
Hysterography	810	17
Cholecystography	4860	34.5
Skull	4990	10 a/
Barium enema	8210	21.5
Barium meal	7460	31.5
Thorax	4110	3 a/
Cerebral angiography	1780	15
Thoracic angiography	680	70.5
Abdominal angiography	5590	34
Inferior limbs angiography	280	15
Phlebography	940	37
Obstetrical abdomen	930	8 a/
Pyelography	370	24

a/ Examinations in which fluoroscopy is only used for positioning the patient prior to film radiography.

Table 23

Procedures to reduce collective dose equivalent in diagnostic x-ray examinations

Area	Procedure	Entrance dose reduction factor	Reference
All types	Elimination of medically unnecessary procedures	1.2	[C9]
	Introduction of quality assurance programme (general) a/	2.0	[C9]
Radiography	Decrease in rejected films through QA programme	1.1	[G1, P15]
	Increase of peak kilovoltage	1.5	[W13]
	Beam collimation	1.0-3.0	[J7, M35]
	Use of rare earth screens	2-4	[K21, N7, S8, W2]
	Increase of filtration	1.7	[K21,M34,W13]
	Rare earth filtration	2-4	[T10]
	Change from photofluorography to chest radiography	4-10	[J1, M38, N6]
	Use of carbon fibre materials	2	[H17]
	Replacement of CaWO4 screens with spot film technique	4	[K21]
	Entrance exposure guidelines	1.5	[L2]
	Gonadal shielding	2-10 b/	[P14]
Pelvimetry	Use of CT topogran	5-10	[S27]
Fluoroscopy	Acoustic signal related to dose rate	1.3	[A4]
	Use of 105 mm camera	4-5	[R9]
	Radiologist technique	2-10	[R9]
	Variable aperature iris on TV camera	3	[L3]
	Change from chest fluoroscopy to radiography	20	[S32]
	High and low dose switching	1.5	[L3]
Digital radiography	Decrease in contrast resolution	2-3	[R4]
	Use of pulsed system	2	[R4]
Computed tomography (head)	Gantry angulation to exclude eye from primary beam	2-4 c/	[I5]
Mammography	Intensifying screens	2-5	[N3, S17]
	Optimal compression	1.3-1.5	[N3]
	Filtration	3	[H1]

a/ The role of proper training in radiation protection is extremely important. Dose reduction factors in this regard may be large, however they are difficult to quantify.
b/ To gonads.
c/ To eye.

Table 24

Genetically significant dose in France in 1982
(mSv)
[B10]

Age (years)	Fluoroscopy		Radiography		Total		
	Males	Females	Males	Females	Males	Females	Total
< 1	0.002	0.001	0.017	0.028	0.019	0.029	0.048
1- 4	0.001	0.000	0.006	0.019	0.007	0.020	0.027
5- 9	0.001	0.002	0.008	0.016	0.009	0.019	0.028
10-14	0.002	0.001	0.009	0.040	0.011	0.041	0.052
15-19	0.003	0.002	0.008	0.032	0.011	0.034	0.045
20-24	0.003	0.003	0.010	0.027	0.013	0.030	0.043
25-29	0.002	0.002	0.007	0.019	0.009	0.022	0.031
30-34	0.002	0.001	0.004	0.007	0.006	0.008	0.014
35-39	0.001	0.000	0.002	0.002	0.003	0.003	0.006
40-44	0.000	0.000	0.001	0.000	0.001	0.000	0.001
> 45	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	0.017	0.013	0.072	0.190	0.089	0.202	0.295

Table 25

Average dose equivalent in the female gonads per examination
(mSv)

Examination	France a/ [M2]	Germany Fed.Rep. [H15]	Great Britain [W4]	Isl.Rep. of Iran [S19]	Italy [P1]
Cervical spine	0.01				
Dorsal spine	0.36				
Dorsolumbar spine	1.07	2.0	3.8		
Lumbosacral spine	1.28		8.39		3.85
Pelvis, hip		0.15 b/	0.75 b/	1.92	0.51 b/
	1.40	0.9	1.64 c/	1.31	23.8 c/
Abdomen, without preparation	1.36	1.5	0.84	1.56	2.33
IV urography	6.71	5.7	3.58	5.28	5.50
Hysterography	3.83			4.27	
Cholecystography	1.40			3.17	
Skull	0.05				
Barium enema	6.25		16.0	11.7	15.40
GI tract	1.70		3.60	0.73	1.51
Thorax	0.04			0.02	

Examination	Japan [H4]	Poland [J1]	Switzerland a/ [P14]	Turkey [Y1]	USSR [V7]	United States [R8]
Cervical spine					0.02	
Dorsal spine					0.13	
Dorsolumbar spine	1.62	1.6				4.05
Lumbosacral spine					2.8	6.4
Pelvis, hip	1.12 b/		1.2	11.0 b/		
	1.44 c/	1.0		1.58	15.0 c/	0.78
Abdomen, without preparation	0.72		0.6	1.40		2.72
IV urography	1.98	6.6		4.22	3.0	6.36
Hysterography	1.1			6.95		
Cholecystography	0.3	2.5		0.90		0.06
Skull	0.0007	0.01			0.0003	0.0001
Barium enema	9.7		10.20	38.0 d/	7.87	
GI tract	0.81	4.6		3.14	0.17 d/	0.45
Thorax	0.0005	0.01			0.02	0.0006

a/ Per film.
b/ Hip and upper femur.
c/ Pelvis.
d/ Includes fluoroscopy.

Table 26

Average dose equivalent in the male gonads per examination
(mSv)

Examination	France a/ [M2]	Germany Fed.Rep. [H15]	Great Britain [W4]	Isl.Rep. of Iran [S19]	Italy [P1]
Cervical spine	0.02			0.01	
Dorsal spine	0.15				
Dorsolumbar spine	0.60				
Lumbosacral spine	0.86	0.05		1.28	0.06
Pelvis, hip	1.48	0.1 b/	8.4 b/	1.02	
		2.5			
		1.7 c/	3.53		
Abdomen, without preparation	0.61	0.12	1.64	0.34	0.43
IV urography	2.46	0.5	4.3	1.10	2.27
Hysterography					
Cholecystography	0.93			0.11	
Skull	0.02			0.01	
Barium enema	3.70	0.58	3.4	1.30	2.33
GI tract	0.95		0.3	0.02	
Thorax	0.04			0.01	

Examination	Japan [H4]	Poland [J1]	Switzerland a/ [P14]	Turkey [Y1]	USSR [V7]	United States [R8]
Cervical spine					0.02	
Dorsal spine	0.004		0.004		0.10	
Dorsolumbar spine						0.07
Lumbosacral spine	0.09	3.40		0.72	1.4	0.43
Pelvis, hip	2.7 b/	0.9	3.0 b/	6.07	1.36	
	0.48 c/					0.57 c/
Abdomen, without preparation	0.18		0.06	2.22		0.16
IV urography	0.11	17.0	6.65	4.0	0.49	
Hysterography						
Cholecystography	0.01	0.08				0.0001
Skull	0.01	0.01			0.0003	0.0001
Barium enema	2.85			0.75	38.0 d/	0.58
GI tract		1.1		0.25	0.11 d/	
Thorax	0.0001	0.01			0.01	0.0001

a/ Per film.
b/ Hip and upper femur.
c/ Pelvis.
d/ Includes fluoroscopy.

Table 27

Contribution to the annual genetically significant dose from diagnostic x-ray examinations
(per cent)

Examination	France 1982 [M1,M2]	Isl.Rep. of Iran 1980 [S19]	Italy 1983 [P1]	Japan 1979 [H11]	Turkey 1977 [Y1]	United States 1980 [N1]
Skull	0.5	0.2	-	0.01	-	-
Cervical spine	0.5	-	-	-	-	-
Dorsal spine	2.5	-	-	0.02	-	-
Dorsal lumbar spine	5.0	)	-	-	-	-
Lumbosacral spine	2.4	) 25.7	19.0	8.9	5.1	22.5
Pelvis and hip	28.5	26.7	30.5	24.2	9.1	13.7
Abdomen	6.2	6.3	9.1	6.3	5.1	10.4
Urogram	29.8	10.4	14.7	3.5	33.1	12.5
Hysterography	0.7	2.6	-	2.5	19.5	-
Cholecystography	1.8	1.4	-	-	1.9	-
Upper GI (barium)	5.4	1.7	3.1	21.3	10.3	5.5
Barium enema	6.4	18.7	6.9	18.5	6.1	28.0
Chest	1.8	0.6	0.3	0.06	-	6.7
Other	8.5	5.7	16.4	14.9	9.8	0.7
Annual genetically significant dose (mSv) a/	0.30	0.09	0.25	0.15	0.05	0.22

a/ Additional values of the annual genetically significant dose: Canada, 0.26 mSv (1979) [M3]; Switzerland, 0.23 mSv (1978) [P14].

Table 28

Mean gonadal and genetically significant dose in the Russian Federation
[K19, K20]

Year	Annual per caput gonadal dose (mSv)	Genetically significant dose (mSv)
1970	0.33	0.13
1975	0.37	0.17
1980	0.45	0.19
1985	0.47-0.5	0.25-0.5

Table 29

Mean effective dose equivalent
for different diagnostic x-ray examinations
(mSv)

Examination	China	France a/	Italy	Japan	Spain	USSR	United States
	1981 [Z8]	1982 [M2]	1983 [P1]	1986 [M14,M18]	1986 [V4]	1982 [N9]	1980 [N1]
Skull	-	1.35	0.22	0.09	0.2	0.17 c/	0.13
Cervical spine	-	1.35	0.14	0.30	)	0.23 e/	0.20
Dorsal spine	-	2.24	1.34	-	) 1.0	3.55 e/	-
Dorsal lumbar spine	-	-	-		)	-	-
Lumbosacral spine	7.2	4.73	2.51	0.60	)	4.42 e/	1.27
Chest							
Radiographic	0.21	0.28	0.18	0.05	0.16	0.36	0.07
Photofluoroscopic	3.40	-	0.25	-	-	1.15	-
Abdomen	4.5	2.56	1.92	0.29	1.5	1.52	0.56
Upper GI			9.27				
Radiographic	-	6.73		1.2	)	1.52 b/	2.44
Fluoroscopic	-	-		-	)	9.45	-
Barium enema			8.97		) 10.2		
Radiographic	-	9.96		2.0	)	3.55	4.6
Fluoroscopic	-	-		-	)	14.40	-
Cholecystography	4.3	7.21	-	0.55	-	1.97	1.9
Hysterography	-	4.78	-	-	-	-	-
Urogram	-	10.42	7.07	0.70	7.0	2.51	1.6
Pelvis and hip	-	1.59	3.20	0.25	2.3	1.45	0.6
Extremities	-	-	-	-	0.1	0.01	0.1
Computer tomography	-	-		-	5.0		
Dental f/							

a/ Dose does not include component for bone marrow.
b/ P/A projection only.
c/ P/A and LAT projection.
d/ A/P projection only.
e/ A/P and LAT projection.
f/ Values of mean effective dose equivalent for dental x-ray examinations: Japan, 0.03 (intra-oral); 0.04 (extra-oral); USSR, 0.01 (intra-oral) [N9]; United Kingdom, 0.02 (intra-oral); 0.03 (extra-oral); 0.08 (pantomographic) [W4, S15].

Table 30

Annual per caput doses from diagnostic x-ray examinations by level of health care
(mSv)

Level of health care	Country	Year	Annual per caput effective dose equivalent	Annual genetically significant dose	Reference
I	Canada	1980		0.3	[M13]
	Finland	1978	0.7		[R2]
	France	1982	1.6	0.3	[M2]
	Germany, Fed.Rep.	1979		0.5	[S5,S6,S7]
	Italy	1983	0.8	0.3	[P1]
	Japan	1979	1.3	0.2	[U5]
	Netherlands	1980		0.3	[U4, U5]
	Romania			0.3	[U4]
	Poland	1976	1.7		[J1, J2]
	Spain	1986	0.8		[V4]
	Sweden	1985	0.6		[V3]
	Switzerland	1978		0.2	[P14]
	United Kingdom	1984	0.2	0.1	[H20, S16]
	United States	1980	1.3	0.3	[N1]
	USSR	1980/81	1.4	0.2	[K19, K20, N9, V7]
	Average		1.0	0.3	
II	China	1983	0.4	0.09	[Z11]
	Islam.Rep. of Iran a/	1980		0.09	[S19]
	Iraq a/			0.05	[U4]
	Turkey a/	1977		0.05	
III	India a/	1972		0.01	[U4]
	Thailand a/	1970		0.05	[U4]
IV	No data				

a/ Does not include fluoroscopy. If frequency of examinations is 1/10 of level I but fluoroscopy is 30-70% of the total, then the effective dose equivalent and the genetically significant dose may be comparable to those of health care level I.

Table 31

Diagnostic x-ray examination frequency and contribution to per caput absorbed dose in countries of level of health care I

Examination	Annual examinations per caput	Effective dose equivalent per examination (mSv)	Annual per caput effective dose equivalent (mSv)	Annual genetically significant dose a/ (mSv)
Skull	0.050	0.15	0.008	< 0.003 (<1)
Cervical spine	0.020	0.30	0.007	< 0.003 (<1)
Dorsal spine	0.013	1.00	0.013	0.006 (2)
Dorsal lumbar spine	0.013	1.00	0.013	0.006 (2)
Lumbosacral spine	0.025	1.50	0.038	0.045 (15)
Chest, radiographic	0.240	0.10	0.024	0.006 (2)
Abdomen	0.55	1.00	0.055	0.024 (8)
Barium meal and enema	0.070	8.0	0.560	0.066 (22)
Cholecystography	0.013	1.5	0.057	0.006 (2)
Urogram	0.024	3.5	0.084	0.060 (20)
Pelvis and hip	0.038	1.5	0.020	0.006 (2)
Extremities	0.157	0.10	0.016	-
Computer tomography	0.010	1.0	0.010	-
Other	0.096	1.0	0.096	0.030 (10)
Dental	0.250	0.03	0.008	< 0.003 (<1)
Total (rounded)			1.0	0.3

a/ Percentage given in parentheses.

Table 32

Estimated effective dose equivalent and genetically significant dose from diagnostic medical radiography world-wide

Level of health care	Population (millions)	Annual per caput effective dose equivalent (mSv)	Annual genetically significant dose (mSv)	Annual collective effective dose equivalent (thousands of man Sv)
METHOD 1 a/				
I	1300	1.0	0.3	1300
II	1750	0.2	0.07	350
III	1220	0.07	0.02	85
IV	730	0.03	0.01	22
Total				1760
METHOD 2 b/				
I-IV	5000	1.0	0.3	5000

a/ Method 1 assumes that in levels II-IV dose is related to the frequency and rate of examinations.

b/ Method 2 assumes that increased dose from fluoroscopy in levels II-IV countries makes absorbed dose comparable to level I.

Table 33

Estimated annual dose from dental radiography world-wide

Level	Population (millions)	Annual per caput effective dose equivalent (mSv)	Annual collective effective dose equivalent (thousands of man Sv)	Genetically significant dose (μSv)
I	1300	0.01 a/	13.0	0.08
II	1750	0.002	3.5	0.02
III	1220	0.0006	0.7	0.004
IV	730	0.0003	0.2	0.002
Total	5000		17.4	

a/ Data from Poland and United Kingdom [H20, K5, J1, U4, U5].

Table 34

Occupational exposures from diagnostic x-ray examinations
(mSv)

Category	Average annual dose equivalent (mSv)				Reference
	1974-1976	1978-1979	1980-1981	1984	
MEDICAL					
Radiologists					
Canada		0.4		0.25	U5,C3
Japan		0.3			M19
Norway			2.7		W17
Switzerland		0.6			U5
United Kingdom			0.51		H20
United States			1.7		N1
Technologists					
Canada		0.2		0.12	U5,C3
Japan		0.5			M19
United Kingdom			0.37		H20
United States			0.5		N1
Nurses					
Canada		0.4		0.15	U5,C3
Japan		0.2			M19
United Kingdom			0.35		H20
Aides, porters					
Canada		0.4		0.08	U5,C3
United Kingdom			0.14		H20
Physicists					
Canada				0.36	C3
Norway			0.74		W17
United Kingdom			0.14		H20
All medical workers					
Japan		0.5			M19
Poland a/	0.5-1.0				J3
United Kingdom			0.14		H20
DENTAL (all workers)					
Australia		0.1			U5
Canada	0.04	0.05		0.02-0.05	U4,U5,C3
France	0.5	0.4			U5
Switzerland		0.2			U5
United Kingdom				0.1	H20
United States b/			0.2		K23

a/ 1966-1978.
b/ Earlier values: 1.1 (1960); 0.6 (1970) [K23].

Table 35

Frequency of diagnostic nuclear medicine examinations
(per 1000 population)

Numbers in parentheses indicate percent of total

Examination	Australia	China	Denmark	
	1980 [U5]	1981 [Z6]	1981 [U5]	1985 [E2]
Brain	1.5 (18.4)	< 0.1 (0.3)	1.8 (14.3)	1.1 (7.4)
Biliary	0.1 (1.7)	-	0.1 (0.9)	0.2 (1.3)
Liver/spleen	1.7 (21.5)	0.2 (25.1)	0.8 (8.6)	1.0 (7.0)
Bone	2.0 (24.4)	< 0.1 (<0.1)	2.5 (17.7)	2.8 (19.3)
Pulmonary	1.2 (14.7)	-	0.6 (4.1)	1.1 (7.7)
Thyroid a/	0.8 (10.5)	0.4 (60.0)	2.0 (14.0)	1.7 (11.9)
Renal	0.2 (1.9)	< 0.1 (13.5)	2.5 (17.6)	4.8 (33.8)
Tumour/abcess	-	-	-	0.2 (1.6)
Cardiovascular	0.1 (1.7)	-	< 0.1 (0.2)	1.1 (8.0)
Other	0.4 (5.2)	< 0.1 (2.3)	3.2 (22.6)	0.3 (2.0)
Total	8.0 (100)	0.6 (100)	14.1 (100)	14.3 (100)

Examination	Poland 1981 [S25]	United Kingdom 1982 [W8, W9]	United States 1982 [U5]	b/
Brain	0.1 (5.5)	0.90 (15.0)	3.58 (11.0)	
Biliary	-	-	0.79 (2.4)	
Liver/spleen	0.3 (13.2)	0.88 (14.7)	6.27 (19.2)	
Bone	0.1 (2.9)	1.67 (27.8)	7.98 (24.5)	
Pulmonary	< 0.1 (0.4)	0.69 (11.5)	5.25 (16.1)	
Thyroid a/	1.2 (55.2)	0.41 (6.8)	2.98 (9.1)	
Renal	0.4 (19.1)	0.45 (7.5)	1.04 (3.2)	
Tumour/abcess	< 0.1 (0.4)	0.06 (1.0)	0.53 (1.6)	
Cardiovascular	< 0.1 (1.4)	0.18 (3.0)	4.19 (12.9)	
Other	< 0.1 (1.7)	0.76 (12.7)	-	
Total	2.2 (100)	6.0 (100)	32.6 (100)	

a/ Thyroid scans and uptakes.
b/ Additional reported values of total frequency: Canada (1981), 49.0 [C1]; Finland (1982), 17.7 [T3]; France (1982), 8.7 [B9].

Table 36

Annual number of diagnostic nuclear medicine examinations in the United States
(thousands)
[M28]

Examination	1966	1972	1973	1975	1978	1980	1982
Brain	62	1250	1510	2120	1546	1176	812
Hepatobiliary		26					179
Liver	60	455	535	676	1302	1349	1424
Bone	7	81	125	220	1160	1307	1811
Respiratory	23	332	417	597	1053	898	1191
Thyroid (uptake and scans)	454	647	460	627	699	606	677
Urinary		108	122	154	205	164	236
Tumour		10	14	22	166	130	121
Cardiovascular		25	33	49	160	558	950
Other	120	405	294	338	115	186	4
Total a/	726 (4)	3339 (16)	3510 (17)	4803 (22)	6406 (29)	6374 (29)	7405 (32)

a/ Figures in parentheses refer to number of procedures per 1000 population.

Table 37

Type and percent of diagnostic nuclear medicine examinations in some western hemisphere countries, 1981-1982
[I7]

Country	Thyroid	Hepatic/ Biliary	Brain	Bone	Lungs	Other
Brazil	50	10	15	10	5	10
Colombia	20	25	10	20	10	15
Ecuador	60	15	10	5		10
El Salvador	40	30	20	10		
Mexico	30	25	10	15	20	
Peru	50	15		25		10
United States	9	22	11	24	16	18

Table 38

Annual frequency of diagnostic nuclear medicine examinations
(per 1000 population)

Country	1970-1972	1973-1975	1977-1979	1980-1982	Reference
Australia	4			8	W8, U5
Austria			18		W8
Bulgaria				13	W8
Burma	0.1		0.2		U5
Canada				49	C1
China				0.6	Z5
Cuba	0.8		0.8		U5
Denmark		8	14	14 a/	U5,W8,E2
Finland				18	T3
France				9	B9
Japan			5	8	M15, H9
Poland				2	S25
Sweden	8	12	15	15	U5,W8
United Kingdom				7	W8
United States b/	16	11	29	31	M31
USSR				4	V7

a/ 1985 value.
b/ Earlier value: 4 (1966).

Table 39

Nuclear medicine examinations by level of health care

Level of health care	Country	Annual examinations per 1000 population	Population per scanner or camera (thousands)
I	Australia (1980) [U5]	8	75 a/
	Austria (1977) [W7]	18	57 a/
	Bulgaria (1980) [W7]	13	76 a/
	Canada (1981) [C2]	49	20 a/
	Denmark (1987) [E2]	14	71 a/
	Finland (1982) [T3])	18	-
	France (1982-87) [B9, P11]	9	160 a/
	German Dem.Rep.	8	122 a/
	Sweden (1982) [W8,U5]	15	50 a/
	United Kingdom (1982) [W8]	7	160
	United States (1982) [M25]	32	31 a/
	Rounded average	16	160
II	Bolivia	-	650
b/	Brazil	-	613
	China	0.6	
	Colombia	-	830
	Cuba	0.8	
	Ecuador	-	810
	Mexico	-	800
	Philippines	-	1600
	Uruguay	-	340
	Rounded average		800
III	Burma	0.2	
b/	India	0.1	4700
	Malaysia	-	1300
	Thailand [K17]	-	500
	Rounded average		2300
IV	Bangladesh		4750
b/	Indonesia		4000
	Nigeria [F4]	< 0.0001	-
	Pakistan		3600

a/ Estimated from the number of examinations, assuming 1000 examinations annually per machine [W8, W9].
b/ Except for referenced entries, the data were obtained between 1978 and 1984 and provided to UNSCEAR by the IAEA.

Table 40

Estimated average nuclear medicine examinations by level of health care

Level of health care	Annual examinations per 1000 population	Population per scanner or camera (thousands)
I	16	160
II	1.2 a/	800
III	0.4 a/	2300
IV	0.2 a/	4100

a/ Estimated from the number of machines, assuming 1000 examinations annually per machine [W7].

Table 41

Estimated world-wide diagnostic nuclear medicine examinations and number of machines

Numbers in parentheses indicate per cent of total

Level of health care	Population (millions)	Cameras or scanners	Annual diagnostic examinations (millions)
I	1300 (26)	20800 (89)	20.8 (89)
II	1750 (35)	2100 (9)	2.1 (9)
III	1220 (24)	500 (2)	0.5 (2)
IV	730 (15)	100 (< 1)	0.1 (< 1)
Total	5000 (100)	23500 (100)	23.5 (100)

Table 42

Age and sex distribution of patients undergoing diagnostic nuclear medicine examinations
[S25, U10]

Age and sex		Brain		Thyroid		Cardiovascular		Pulmonary	
		Poland	United States	Poland	United States	Poland	United States	Poland	United States
< 15	male	4.9	1.4	0.4	0.1	1.5	-	7.3	-
	female	4.4	1.3	2.2	1.3	0.9	-	1.6	-
	both	9.3	2.7	2.6	1.4	2.4	-	8.9	-
15-29	male	10.3	4.4	3.3	2.6	16.7	1.5	22.4	2.8
	female	8.1	2.6	20.4	14.0	6.3	0.8	5.4	5.3
	both	18.4	11.0	23.7	16.6	23.0	2.3	27.8	8.1
30-44	male	11.1	4.9	3.9	4.5	22.4	8.1	13.3	6.0
	female	11.4	7.7	30.2	23.0	7.1	4.3	11.9	8.8
	both	22.5	12.6	34.1	27.5	29.5	12.4	25.2	14.8
45-64	male	21.0	14.4	5.2	7.1	31.6	33.3	16.3	18.2
	female	15.5	15.1	29.7	28.5	6.4	20.4	6.4	18.9
	both	36.5	29.5	34.9	35.6	38.0	53.7	22.7	37.1
> 64	male	7.1	19.7	1.0	3.6	4.2	16.2	11.0	17.5
	female	6.2	24.5	3.7	15.3	2.9	15.4	4.4	22.5
	both	13.3	44.2	4.7	18.9	7.1	31.6	15.4	40.0
All ages	male	54.4	45.5	13.8	17.9	76.4	59.1	70.1	44.5
	female	45.6	54.5	86.2	82.1	23.6	40.9	29.9	55.5
	both	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Age and sex		Liver/spleen		Renal		Bone		All examinations	
		Poland	United States	Poland	United States	Poland	United States	Poland	United States
< 15	male	2.3	0.1	4.0	1.4	5.2	1.1	2.0	0.9
	female	2.4	-	5.6	2.1	3.2	0.9	3.3	0.7
	both	4.7	0.1	9.6	3.5	8.4	2.0	5.3	1.6
15-29	male	6.4	3.4	11.2	5.7	11.3	2.9	6.4	3.3
	female	6.9	3.1	9.4	5.7	11.6	2.3	15.4	4.9
	both	13.3	6.5	20.6	11.4	22.9	5.2	21.8	8.2
30-44	male	9.5	5.4	11.5	10.7	8.7	3.6	7.1	5.2
	female	10.5	5.7	12.9	10.0	15.0	6.4	21.7	8.7
	both	20.0	11.1	24.4	20.7	23.7	10.0	28.8	13.9
45-64	male	22.4	18.8	17.7	21.5	13.3	14.9	11.7	15.8
	female	21.5	21.7	17.4	15.8	22.9	23.9	24.0	21.6
	both	43.9	40.5	35.1	37.3	36.2	38.8	35.7	37.4
> 64	male	8.8	19.5	4.3	15.7	4.3	20.5	3.3	17.0
	female	9.3	22.3	6.0	11.4	4.5	23.5	5.1	21.9
	both	18.1	41.8	10.3	27.1	8.8	44.0	8.4	38.9
All ages	male	49.5	47.2	48.5	55.0	42.8	43.0	30.5	42.0
	female	50.5	52.8	51.5	45.0	57.2	57.0	69.5	58.0
	both	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 43

Average activity used for some common nuclear medicine examinations

Organ	Radiopharmaceutical	Average activity (MBq)			
		Germany Fed.Rep. [K2,K3]	Poland [S25]	Sweden a/ [M6]	United Kingdom a/ [W9]
Thyroid b/	^{99m}Tc-pertechnetate	37	37	81 (37-146)	75 (15-200)
	^{123}I-iodide	3.7	-	1.5 (0.7-1.9)	
	^{131}I-iodide	1.9	2.7	3 (1- 8)	
Liver/ spleen	^{99m}Tc-colloid	167	148	100 (75-191)	90 (37-200)
	^{198}Au-colloid	5.6		18.5	
Renal	^{131}I-Hippuran	1.5	1.2	4.5	28 (10-185) c/
	^{99m}Tc-DTPA	370		163 (40-560)	248 (37-555)
	^{99}Tc-glucoheptonate	370	136	370	
	^{99m}Tc-DMSA	111	192	177 (75-600)	102 (37-500)
Bone	^{99m}Tc-phosphate	555		409 (150-600)	520 (330-740)
Cardiac	^{99m}Tc-erythrocytes	740		540 (529-600)	658
	^{201}Tl-chloride	74		65 (42-350)	68 (40-100)
Lung	^{99m}Tc-microspheres	167		80 (42-110)	88 (37-222)
Brain	^{99m}Tc-DTPA	463		601 (337-750)	536
	^{99m}Tc-pertechnetate	463		403 (200-560)	490
	^{99m}Tc-glucoheptonate		592	403 (200-560)	570

a/ Numbers in parentheses indicate ranges where data are available.
b/ Additional values from the United States are 237 (37-555), 0.8 (0.3-1.6), 0.3 (0.04-0.4) for ^{99m}Tc-pertechnetate, ^{123}I-iodide and ^{131}I-iodide, respectively.
c/ Iodine-123.

Table 44

Annual collective effective dose equivalent for in vivo diagnostic nuclear medicine examinations
(man Sv)

Examination	China a/ 1981 [Z6]	Finland 1982 [T3]	Poland 1981 [S25]	Sweden 1983 [J8]	USSR 1981 [V7]	United Kingdom 1982 [H20]	United States 1982 [M30]
Brain	13	142	28	41	-	253	5280
Hepatobiliary	-	-	-	-	-	-	660
Liver/spleen	924	14	23	19	-	55	3420
Bone	4	45	-	81	-	319	7970
Pulmonary	-	7	4	9	-	34	1790
Thyroid	3740	203	1922	268	-	49	3980
Renal	1	-	5	1	-	8	730
Tumour/abcess	-	-	10	-	-	30	1480
Cardiovascular	-	10	3	-	-	54	6750
Other	12	13	24	121	-	148	-
Annual collective effective dose equivalent (total) (man Sv)	4700	430	2020	540	8700	950	32000
Annual per caput effective dose equivalent (mSv)	0.005	0.090	0.057	0.060	0.034	0.017	0.14

a/ Assumes that Shandong Province is representative.

Table 45

Radionuclide contribution to annual collective effective dose equivalents from diagnostic nuclear medicine
(per cent)

Radionuclide	China 1981 [Z6]	Finland 1982 [T3]	Poland 1981 [S25]	Sweden 1983 [J8]	United Kingdom 1982 [H20]	United States 1982 [M30]
Technetium-99m	-	51	2	33	89	68
Iodine-131	77	47	96	62	4	17
Other	23	2	2	5	7	15 a/

a/ Two-thirds of this is due to thallium-201.

Table 46

Annual per caput doses from diagnostic nuclear medicine examinations
(mSv)

Level of health care	Country	Year	Per caput effective dose equivalent	Annual genetically significant dose equivalent	Ref.
I	Australia	1980	0.02		[U5]
	Denmark	1985	0.05		[E2]
	finland	1982	0.09	-	[T3]
	Japan	1982	0.04	0.004	[M15]
	Sweden	1983	0.06		[J8]
	United Kingdom	1982	0.017	0.003	[H20]
	United States	1982	0.14	0.19	[M30]
	USSR	1981-1982	0.03-0.04		[V7, K13]
	Average		0.05 a/	0.01 b/	
II	China	1981	0.005		[Z6]
III	c/				
IV	c/				

a/ Population weighted average collective effective dose equivalent = 0.067 mSv.
b/ Assumes genetically significant dose is approximately 20% of effective dose equivalent.
c/ No data available.

Table 47

Estimated collective effective dose equivalent and genetically significant dose from in vivo diagnostic nuclear medicine

Level of health care	Population (millions)	Annual per caput effective dose equivalent (mSv)	Annual genetically significant dose (mSv)	Annual collective effective dose equivalent (thousands of man Sv)
I	1300	0.050	0.010	65.0
II	1750	0.004	0.0008	7.0
III	1200	0.001	0.0002	1.2
IV	730	0.0005	0.0001	0.4
Total	5000			74

Table 48

Average annual individual occupational doses for nuclear medicine technologists from diagnostic nuclear medicine

	Austria	Canada	France	Norway	United Kingdom
	1978 [U5]	1951-1983 [S20,S21]	1979 [U5]	1983 [W17]	1984 [H20]
Nuclear medicine technologists:					
Average annual dose (mSv)	0.4	2.0	0.5	0.6	0.3-1.4
Collective dose (man Sv)	0.4	-	1.2	0.3	-

Table 49

Radiation therapy treatments in Canada a/ [C1]

Type of treatment	Year		
	1978-1979	1979-1980	1980-1981
Superficial x ray	19 098	12 028	11 827
Deep x ray	109 702	20 925	29 392
Cobalt	333 355	274 470	244 422
Radium	2 202	2 199	1 289
Other	103 913	314 187	375 270
Total	568 270	623 809	662 197

a/ For eight provinces, which comprise approximately 91.5% of the Canadian population.

Table 50

Estimated annual number and type of cases treated by radiation therapy in some western hemisphere countries
[U7]

Country	New cancer cases treated	New cancer cases treated with radio-therapy	Type of case treated (%)					
			Breast	Lymph-phoma	Gynae-colog-ical	Dige-stive	Other cancers	Non-malig-nant
Columbia	3 000	2 000	11	8	31	17	7	5
Costa Rica	2 880	500						3
Ecuador	3 000	1 900		20	35	30	3-4	1-2
El Salvador	817	817	10		60		17	0
Mexico	580 000	50 000	15		20		9	1
Peru	10 000	6 000	15	10	65		8	2
United States	800 000	390 000						5
Venezuela	10 000	6 000	30		50	5	4	1

Additional values: head and neck, 10 (Venezuela); skin, 17 (Colombia) and 10 (Ecuador); lungs, 4 (Colombia) and 10 (Mexico).

Table 51

Number of megavoltage radiotherapy units in the United States and annual number of new patients per unit
[K15, R7]

Year	Cobalt	Linear accelerators and betatrons	New patients per unit
1975	970	407	227
1978	900	606	232
1980	980	801	233

Table 52

Radiation therapy experience by level of health care

Level of health care	Country	Year	Annual procedures per million population: Brachytherapy and teletherapy	Annual procedures per million population: Unsealed radionuclides	Machines per million population a/	Reference
I	Argentina	1981	-	-	14	[I7]
	Denmark	1985	-	205	-	[E2]
	France	1987	-	-	8	[P11]
	Germany, Fed.Rep.	1975	-	260	-	[U5]
	Japan	1983	1000	-	-	[H6, M13]
	Sweden	1978	-	375	-	[U5]
	United Kingdom	1984	2400	600	-	[D3]
	United States	1981	2400	-	10	[K14, R6]
	Average		~ 2400	~ 400		
II	Brazil	1981	-	-	2.5	[I7]
	Chile	1981	-	-	4.9	[I7]
	Ecuador	1981	-	-	2.3	[I7]
	Mexico	1981	-	-	1.2	[I7]
	Peru	1981	-	-	1.1	[I7]
	Venezuela	1981	-	-	2.4	[I7]
	Average		~ 600	~ 400		
III	Burma	1978	-	6	-	[U5]
	India	1976	125 b/	-	0.5	[M21]
	Sri Lanka	1978	350	2	-	[U5]
	Sudan	1985	70 b/	-	0.3	[S36]
	Average		100 b/		0.4	
IV	Indonesia	1978	7	-	-	[U5]

a/ Data also indicate approximately 200 new patients (or 250 total patients) per machine annually. Machines include teletherapy, cobalt and accelerators.
b/ Estimated based on 250 patients annually per machine.

Table 53

Estimated radiation therapy activity by level of health care
[M27]

Level of health care	Annual procedures per million population: Brachytherapy and teletherapy	Annual procedures per million population: Unsealed radionuclides	Machines per million population a/
I	2400	400	10
II	600	100 a/	2.5
III	100	16 a/	0.4
IV b/	50	8	0.2

a/ Estimates based on percentage of brachytherapy and teletherapy procedures.
b/ Estimates based on regression from nuclear medicine activity.

Table 54

Estimated worldwide radiation therapy procedures and machines [M27]

Level of health care	Population (millions)	Annual procedures or courses of treatment: Brachytherapy and teletherapy (thousands)	Annual procedures or courses of treatment: Unsealed radiotherapy (thousands)	Number of machines
I	1300	3120	520	13000
II	1750	1050	175	4400
III	1220	120	20	490
IV	730	40	6	150
Total	5000	4300	720	18000

Table 55

Estimated genetically significant dose from radiation therapy

Level of health care	Population (millions)	Annual genetically significant dose (mSv)
I	1300	0.015 a/
II	1750	0.0037
III	1220	0.0006
IV	730	0.0003

a/ Average of five reported values [H18, U5].

Table 56

Average annual individual occupational dose from radiation therapy (mSv)

Category	Australia 1978 [U5]	Canada 1984 [C3]	Norway 1983 [W17]	United Kingdom 1981 [H20]	United States 1975 [U5]
Beam therapy	0.8-1.5	-	-	1.0	-
Brachytherapy					
Radiotherapists	-	0.41	-	1.8	-
Anaesthetists	-	-	-	1.3	-
OR nurses	-	-	-	23.0	-
Ward Nurses	-	-	-	3.0	-
Laboratory staff	-	-	-	14.8	-
Mould room staff	-	1.23	-	1.5	-
Physicists	-	-	-	0.6	-
All workers	1.0-2.0	-	1.04	2.57	3.0
Collective dose (man Sv)	0.4	-	1.05	-	60

Table 57

Estimate of world-wide collective effective dose equivalent and genetically significant collective dose from medical uses of radiation
(thousands of man Sv)

Source	Annual collective effective dose equivalent	Annual genetically significant collective dose
Diagnostic medical	1800-5000	500-1500
Dental	17	0.14
Diagnostic nuclear medicine	74	15
Radiation therapy	-	27
Per caput (mSv)	~ 0.4-1.0	~ 0.1-0.3

Table 58

Occupational exposure from medical uses of radiation

Country	Year	Annual average dose (mSv)	Annual collective dose (man Sv)	Collective dose per million population (man Sv)	Reference
Canada	1974		10.5		U4
	1984	0.3	7.2	0.3	C3, W17
France	1974	1.3	29		U4
	1979			0.8	U5
Germany, Federal Rep.	1984	1.1	27	0.4	N12
Japan	1978	0.5	55	0.5	M19
Norway	1983	1.3	5.8	1.4	W17
United Kingdom	1984	0.7	28	0.5	H20
United States	1960	1.9	580		K23
	1970	1.1	500		K23
	1980	0.7	410	1.8	K23

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