IONIZING RADIATION: SOURCES AND BIOLOGICAL EFFECTS

United Nations Scientific Committee
on the Effects of Atomic Radiation

1982 Report to the General Assembly, with annexes

UNITED NATIONS
New York, 1982

NOTE

The report of the Committee without its annexes appears as Official Records of the General Assembly, Thirty-seventh Session, Supplement No. 45 (A/37/45).

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

UNITED NATIONS PUBLICATION
Sales No. E.82.IX.8
06300P

ANNEX G

Medical exposures

CONTENTS

Introduction

1. Medical irradiation of the human body is done in the course of diagnostic x-ray procedures, in diagnostic nuclear medicine by internally administered radionuclides, and in radiation therapy. In many countries medical exposure gives the largest man-made contribution to the population dose. In developed countries such exposure may approach the contribution from natural sources, and much effort is devoted to minimize it. This Annex follows the trends in medical procedures giving rise to exposure and in relevant doses to patients and to the population; it also presents data on the distribution of doses among irradiated persons.

2. The Committee has reviewed information on the medical irradiation of patients in a number of reports since 1958 [U3, U4, U5, U6, U7]. Doses to patients from various medical procedures have been assessed, both in order to follow trends and to make it possible to see which procedures are most significant with regard to possible radiation risks. For any one procedure the dosimetric information is complex, with considerable variation of the absorbed doses in different organs. It is therefore not easy to find a simple basis for comparisons.

3. In its 1958 report, the Committee was mainly interested in exposures relevant to the risk of hereditary effects. The genetic significance of a gonadal dose depends on the child expectancy of the exposed individual. Therefore, the age distribution of patients subject to various radiological examinations must be considered in the assessments. This led the Committee

to the introduction of the genetically significant dose (GSD) (see Annex A), which was the quantity of primary interest in 1958. It was evident that the major part of the genetically significant dose was contributed by rather few types of examinations. At that time there was little biological ground for quantitative assessment of any somatic risk of a stochastic nature. The correlation between leukaemia and radiation exposure of the active bone marrow was being studied and the Committee included some assessments of mean marrow doses.

4. In its 1977 report [U7], the Committee made an effort to estimate mean doses to other tissues, e.g., thyroid, lung and breast. In the evaluation of the significance of such exposures, assumptions need to be made on the dose-response relationship for cancer induction in these organs. Because of the long latent periods involved, this would also strictly call for consideration of the age at exposure.

5. Some discussion of the possible development of a somatically significant dose equivalent is included in Annex A. However, refinement of this concept is felt to imply a precision of knowledge that is at present lacking. Development of the concept of a somatically significant dose equivalent is, however, considered to be useful to supplement the conventional information on the genetically significant dose because the emphasis that has been given to the latter might distort the relative importance of the various examinations from the point of view of total risk.

6. In 1977, the International Commission on Radiological Protection (ICRP) [I6] introduced a method for calculating a quantity later called effective dose equivalent, for the purpose of application of dose limits in radiation protection of workers (see Annex A). This method involved a weighting of the mean organ dose equivalents with factors derived to reflect the relative risk of cancer and severe hereditary effects from exposures of the corresponding organs. The effective dose equivalent, as defined by ICRP, is the sum of all the weighted organ dose equivalents.

7. The effective dose equivalent as calculated is independent of age and sex, because the organ weighting factors are average values for both sexes and all ages. It is obvious, therefore, that they are not based on the best estimate of risk for any given individual and that they are not intended to apply to population groups with sex- or age-distributions which substantially differ from the normal. It was not the original intention of ICRP that the effective dose equivalent should be calculated for patients.

8. In its effort to find a quantity that would indicate the significance, from the point of view of total risk, of the heterogeneous exposure of patients, the Committee found that the organ weighting factors that would be appropriate could only be estimated with great uncertainty and could not be shown to deviate substantially from the weighting factors used by ICRP, although for a different purpose. The Committee therefore decided to estimate the effective dose equivalent for patients and presents that quantity in this report, enabling dose comparisons which are believed to be more relevant than in previous reports, where only organ doses and the genetically significant dose were given. The reader is advised to interpret the results with caution because of the shortcomings of the concept when applied to medical exposures.

9. In particular, the effective dose equivalent would not satisfactorily reflect the true risk when applied to groups of patients with substantially reduced life expectancy (as in radiotherapy of some malignant disease) or with age- and sex-distribution grossly differing from those in a normal population (for example, in mammography or pelvimetry).

10. When effective dose equivalents are compared, it must therefore be recognized that they may over- or under-estimate the risk, depending upon the way in which the group of patients differs from a normal population. There is not yet sufficient information on the dose-response relationships for somatic stochastic effects to permit a reliable quantitative correction in such cases. For the total collective dose equivalent contribution from medical practice, specific calculations must ideally be made for the population of interest.

11. There is a very great potentiality for variation of individual organ doses, depending upon the value of a number of physical parameters that influence the dose per examination. It is also found that doses are in fact very different from hospital to hospital, depending upon the radiological technique and equipment. In order to assess average dose values representative for large population groups, it is therefore necessary to make extensive surveys. Data reported from single clinics, or calculated on the basis of some assumed practice, cannot usually be taken to be representative. These uncertainties influence the reliability of any dose estimates per caput for large regions of the world, such as the genetically significant dose and the per caput mean marrow dose as earlier assessed by the Committee, and of the effective dose equivalent.

12. Trends in frequencies of the various radiological procedures are reviewed in this Annex. Individual absorbed doses in the various organs per unit procedure, and the effective dose equivalent per type of procedure, are also compiled and discussed. Recent reports on exposure of patients have considered organ doses and the accuracy and precision of their measurements, and are reviewed here. Efforts have also been devoted to the compilation of biological data on the distribution of radionuclides administered to patients. Much of this information has been used to derive absorbed doses in organs, and effective dose equivalents, from the medical use of radionuclides [K2, K3].

13. Dosimetry of the tissues outside the treatment area during radiotherapy cannot be quantified in the same manner and to the same extent as in diagnostic exposure. This is mainly due to the lack of published information on absorbed doses in tissues outside the treatment area. For these reasons the chapter on the therapeutic use of radiation is rather more descriptive than quantitative.

I. DIAGNOSTIC X-RAY EXAMINATIONS

A. TRENDS IN FREQUENCY

1. General survey

14. In the 1977 report [U7] there was a brief review of the frequency of diagnostic x-ray examinations in various countries. Surveys made in Japan up to 1974, in Sweden up to 1974 and in the United States in 1964 and 1970, were analysed in terms of frequency of diagnostic

x-ray examinations by type. Since then new surveys have become available from Australia [S20], Finland [L7], Federal Republic of Germany [T8], Japan [H26], Poland [J5], Romania [F3], Sweden [N1, N11], the USSR [K11] and the United Kingdom [K12]. The data available have been expressed in terms of the annual per caput examination rate in order to allow comparisons between countries to be made. Various examinations have been grouped according to the organ or system examined.

15. The classification scheme for diagnostic radiological examinations, recommended by a joint ICRP/ICRU report [I14], is adopted in this report as a means of presenting statistics of x-ray diagnostic examinations. To that recommended classification scheme it was necessary to add three additional categories: x-ray examination of the breast (mammography), computed tomographic scanning (CT-scan) and other examinations not included elsewhere.

16. In industrialized countries, the frequency of various examinations per 1000 inhabitants is given in Table 1 which includes only the most recent data available [F3, H13, H14, H26, J5, K12, L7, M19, N11, S20, T8]. Earlier compilations are found in previous reports [U3, U7]. It is difficult to draw overall conclusions applying to countries whose reporting systems may not be comparable. However, existing data point to examination frequencies, per 1000 inhabitants, of between 300 and 900 in these countries, excluding dental examinations and mass miniature radiography, for which reporting is not consistent (however, see also paragraphs 28 and 29). The frequency of examinations of different anatomical sites estimated for various world areas, is given in Table 2. It is interesting to note that by far the most common types of examinations are those of the thorax and of the skeleton.

2. Survey of developing countries

17. Data on the availability of diagnostic radiological equipment, and on the frequency of diagnostic x-ray examinations in developing countries, are particularly difficult to obtain. The WHO has recently made major efforts to increase this knowledge by analysing the available sources [W11, W12] and by sending out a questionnaire which was worked out in co-operation with UNSCEAR [W13].

18. The current situation of radiodiagnostic services in each of five WHO regions, including most of the developing countries, is summarized in Table 3 [W12], which provides information about the distribution of the numbers of diagnostic x-ray equipment. The above data are not truly representative of the availability of the equipment in various regions because most of it is concentrated in urban areas, particularly in the larger cities, while the rural population has very limited access to such facilities.

19. The annual frequency of diagnostic x-ray procedures, as reported by WHO regional offices, is shown in Table 4, subdivided for various types of examination [W3, S8]. The total frequency of diagnostic x-ray examinations in developing countries is often between 100 and 200 per 1000 inhabitants, or lower, which is much less than in industrialized countries.

B. TRENDS IN TECHNIQUE AND EXPOSURE

1. Trends in reduction of exposure

20. In recent years, efforts, including testing and evaluation of various types of films and fluorescent screens, have been made in many countries to reduce unnecessary exposure of the patient. The results of these efforts are particularly good in regard to dental examinations [J1]. The data of Neuweg [N4], Johnson [J1], and Bunge [B19, B20], who reported average annual exposure during the 1970s, show little or no reduction in medical exposures for selected examinations.

21. Various technical improvements in diagnostic radiology, such as rapid films, more sensitive screens and image-intensifying television systems, may be presumed to reduce the dose to the patient, if applied correctly. However, a study of diagnostic procedures in Sweden from 1960 to 1975 revealed little decrease of the dose, despite technical improvements. On the other hand, the study showed a significant reduction of the dose for selected examinations, due to the introduction of high sensitivity screens and to a reduction of the number of films [G4].

22. Many data show that there is still a great variability in entrance doses for standard patients, brought about by the difference in sensitivity of the various detector systems used. According to several studies in the Federal Republic of Germany, the United Kingdom and the United States, the ratio between the lowest and highest entrance dose is about 1:100 [B19, J1, K30, U8, U9, W20, W21].

23. In 1971 a programme for a nationwide evaluation of the trends in the use of x rays, the NEXT project, was set up in the United States. The survey procedure allows estimation of radiation exposure to the patient and its variation in the course of time [J1, U9, U12, U13]. In addition, other parameters may be studied. For example, the ratio of beam-area to film-area (S_{beam}/S_{film}) used in the various projections was found to vary from 1.1 to 2 for various examinations. Few significant differences were found in the above ratio and in the exposure levels for different facilities or for different operators. The mean ratio for chest radiography decreased from 1.6 to 1.2 during the period 1973–1978. Hospitals and radiology facilities had significantly lower S_{beam}/S_{film} ratios than other groups (internal medicine, general practitioners, health agencies). Among operators, trained radiology technologists delivered lower values of the S_{beam}/S_{film} ratio and lower values of the exposure-area product than did non-trained personnel [W10].

24. In another case, improvements in the protection of patients during the period 1970–1975 resulted in a 15% decrease in the annual dose per individual averaged over the whole body, in spite of an increased frequency of examinations during the same time [Z2]. In other reports the mean gonad dose and the genetically significant dose did not change appreciably because the frequency of examinations giving the highest contribution to the gonadal dose was rather stable [K27, K28, T3, T4, T5, T6, T7].

25. Other studies indicate that many diagnostic facilities produce poor quality images, and give unnecessary radiation exposure, because of poor equipment performance [S4]. The introduction of quality assurance

programmes in diagnostic radiology and nuclear medicine, recommended by ICRP [I20] and WHO [W22], can be of great value in improving the diagnostic information content, thus leading to a reduction of radiation exposure.

26. A noteworthy reduction in the use of fluoroscopy has been reported from France [S34]. In that country, in 1976, there were some 13 000 fluoroscopic installations used for general medical purposes; by 1982 the number was 5000, of which 2000 were operated by specialists in cardiology and chest diseases. It is expected that the remaining 3000 fluoroscopic installations will have been eliminated by 1985 [P12].

2. Mass chest x-ray examinations

27. In most countries about 50% of all medical x-ray examinations are of the chest. There is a trend to abandon fluorography in favour of radiographic techniques. There is also a decline in mass chest x-ray examinations in some industrialized countries because the incidence of tuberculosis is declining; furthermore, there is now good evidence that early detection of lung cancer by radiological techniques is not associated with any significant improvement in the prognosis of the condition [B28, L9, S33].

28. Information from various countries and areas on gonad exposure from mass survey examinations of the chest was given in the 1962 report [U4], the frequency of examination per 1000 total population ranging from about 100–300 in most industrialized countries. At the time most surveys were performed by miniature radiography although in some countries examinations were still performed by fluoroscopy. Declining trends are now seen in the data reported from Sweden, the United Kingdom and the United States, where current frequencies are below 50 examinations per 1000 inhabitants. Other countries, however, still report frequencies above 300 examinations per 1000 inhabitants [F3, H14, K11, S20].

3. Dental examinations

29. Dental radiography is the most frequent type of diagnostic x-ray examination in many industrialized countries. There are however great difficulties in obtaining accurate statistical data on the frequency of dental x-ray examinations. In some countries the numbers are included in medical x-ray examinations and in others they are reported separately. Japan reports, for 1980, an annual frequency of 851 dental films per 1000 inhabitants; the corresponding value for the United Kingdom in 1977 is 212 dental films [K12, M19].

30. The radiation exposure caused by dental x-ray examinations may be reduced by increased filtration and collimation of the beam, adequate shielding of the head and by the use of faster films. In 1957 Baily [B1] was able to reduce the average facial exposure, in routine full-mouth set of 14 apical film examinations of adults, with 60-kVp x rays, from 5.9 mC kg^{-1} with no filtration to 4.1 mC kg^{-1} with 1 mm Al additional filter. Corresponding exposure values for the examination of children were 1.6 mC kg^{-1} with no filtration and 1.3 mC kg^{-1} with 1 mm additional Al filter. Because no collimation was used, the exposure to the thyroid was increased with additional filtration from 0.22 mC kg^{-1} to 0.28 mC kg^{-1} for adults and from 0.09 mC kg^{-1} to 0.13 mC kg^{-1} for children. In the same investigation the exposure to the bony structure per full-mouth set of 14 films ranged from 2 mC kg^{-1} to 6 mC kg^{-1} for adults, and from 0.8 mC kg^{-1} to 2.3 mC kg^{-1} for children, depending on operating voltage and added filtration [B1].

31. Bjärngard et al. [B9] studied the absorbed doses from full-mouth radiographic examinations. They reported absorbed doses in the lens of 15 mGy, in the thyroid of 5 mGy, and a maximum skin dose of 260 mGy. Further studies by the same group [B10] reported doses to the lens from 4 to 110 mGy, to the thyroid from 2 to 9 mGy, and maximum skin doses from 70 to 500 mGy. A study of the doses delivered in various anatomical sites of the head and neck from 14-film periapical examinations was carried out by Richards et al. [R3]. Values in this series that were comparable with the previous one were about 6 times lower, due to the use of faster films [R3, B10].

32. O'Shaughnessy and Mitchell [O1] performed a systematic study of the relative amounts of primary and secondary beam received by tissues, in relation to various changes made to the x-ray equipment and techniques (cone length, filtration, collimation). Collimation of the beam was the most important single factor in reducing unnecessary radiation.

33. A laboratory investigation was performed by Winkler [W9] to determine the reduction in exposure to be gained by the use of small rectangular x-ray beams restricted to the approximate size of the film, combined with a shield to absorb most of the radiation behind it. The absorbed dose during a 22-film intra-oral examination was reduced significantly with the use of a rectangular film holder. In the skin the absorbed dose was 11 $\pm$ 4 mGy without, and 4 $\pm$ 2 mGy with, film holder. Corresponding values for salivary glands were 5.3 mGy and 0.9 mGy, respectively, and for mandibular bone at the area of the third molar 21 mGy to 7.8 mGy. In the cornea of the eye the absorbed dose was reduced from 3.4 mGy without, to 0.2 mGy with, film holder.

34. Weissman and Sobkowski [W7] reported on a comparative clinical dosimetric evaluation of four intra-oral periapical radiographic survey methods, including the device proposed by Winkler [W9]. Their results showed that the absorbed dose to the cornea of the eye could be reduced from 8.6 mGy to 0.2 mGy by cone shielding and rectangular collimation of the primary beam. The absorbed dose in the thyroid was reduced from 0.6 mGy to 0.06 mGy. They concluded that radiographic methods using unshielded cones result in unnecessary irradiation without improvement of the image and should no longer be accepted.

35. The effect of adding accessories to a conventional x-ray machine to reduce patient exposure during full-mouth dental radiography was investigated by Yülek et al. [Y1, Y2]. Maximum reductions were observed at the eyes (80%) when the x-ray machine was protected by a cylinder of 1 mm Al and 0.1 mm Pb and the patient was made to wear 0.1 mm Pb-shielded glasses. With, in addition, a shield around the neck to protect the sites below the neck, reductions of absorbed doses amounted to 70.6% in the thyroid, 59.9% under the collar bone and 44.5% at the gonads [Y1, Y2].

36. Bushong et al. [B21] carried out measurements on patients undergoing full-mouth (18 films) examinations

at three different facilities. Skin exposure in the primary beam area was 1 mC kg^{-1} at the facility employing slow films and 65-kVp x rays. Ultra-speed films and 90-kVp x rays resulted instead in an average exposure of 0.2 mC kg^{-1}. Panographic examinations delivered average exposures of about 8 μC kg^{-1}. The study of Ice et al. [I1] compared radiation exposures from various types of position-indicating devices. Both at 65-kVp and at 90-kVp it showed that lead-lined cones are most effective in reducing patient skin exposure outside the useful beam in clinical dental radiography.

37. A study was also conducted by Alcox and Jameson [A2] of exposures at selected areas of the head and neck from conventional dental radiographic procedures. Their results indicated that the exposure at any specific area of the patient's face was much less than the exposure at the tip of the cone. Thyroid exposure, in particular, was around 0.3 μC kg^{-1} per film, which was about 1% of the exposure at the tip of the cone.

38. Absorbed doses in the marrow of the skull, mandible and cervical spine were measured by White and Rose [W8] during dental examinations of phantoms using intra-oral, panoramic and cephalometric radiography. Table 5 shows the mean dose equivalent to the marrow at different sites and for various types of examination. Mean absorbed doses to various organs and tissues from intra-oral and orthopantomographic examinations have been evaluated in detail by using phantoms [I18, J4, M4, S23].

39. Pantomographic radiology, which provides an image of all teeth from root to crown on a single film, has become increasingly used in the last few years. Its introduction, however, has led to a considerable increase in the number of patients examined [W17]. Pantomographic equipment from seven manufacturers has been investigated along with other procedures for obtaining similar information using conventional dental x-ray sets (Table 5). Absorbed doses in the head and neck region ranged from 0.1 to 0.8 mGy for the pantomographic technique and from 0.01 to 6.4 mGy for the conventional one. The mean values for the absorbed doses in the marrow were 0.05 and 0.08 mGy, respectively [B6]. Thus, the patient exposure for both techniques is of the same order of magnitude.

40. A study of the absorbed dose in panoramic view or full-mouth examination (11 intra-oral films) was performed on 22 patients [N12]. The average absorbed dose values from the panoramic view was 0.05 mGy and from a full-mouth examination 0.1 mGy. Corresponding absorbed dose values in the cheek were 0.09 mGy and 3.3 mGy, respectively, and in the skin 0.13 mGy and 3.5 mGy [N12]. In organs outside the beam the difference decreased and no significant difference was found in the gonads where the absorbed dose was about 0.01 mGy for both techniques.

4. Mammography

41. The number of mammography examinations is steadily increasing. Data have been reported from Sweden [N17] where the total number of examinations increased from 17 (1977) to 40 (1979) per 1000 women. In the same study the number of mammography examinations for screening purposes increased from 11 to 22 per 1000 women in the same period of time. Similarly, in the United States, the number of examinations in women of 35 years or older went from 30 to 72 and in women of 40–46 years of age rose from 56 to 136 per 1000 women over the same time. Screening of female breast for malignancy in the United States is treated extensively in a special report [N18].

42. The imaging media used in mammography may be medical x-ray films or various combinations of films and screens. Xerography is also a special method of imaging used for mammography, whereby the image is produced by the use of a photoconductive surface, electrostatic charges and xerographic-type processing. Owing to the "edge enhancement" effect of xerography, this technique is advantageous for the detection of certain types of breast diseases, such as dense fibrocystic conditions [U11].

43. A programme was established in the United States to reduce unnecessary examinations, to improve the image quality and to collect data on radiation exposure [J1]. This programme, known as BENT (Breast Exposure: Nation-wide Trends) made its first evaluation in 1976. The mean exposures for xerography, film-screen and non-screen medical and industrial film techniques have been reported by a number of investigators [A3, H2, J2, P1, U10, U11] and are shown in Table 6.

44. If current risk estimates for radiation carcinogenesis are to be applied to mammography, then the relationships between surface exposure and absorbed dose in tissues at risk should be considered. Information specifically related to mammography is available and several authors have adopted mid-breast dose as the critical parameter on which risk analyses should be based [E4, K1, P1, U10, Z1].

45. The most relevant indicator of the risk of mammography would be the energy imparted in the gland tissue of the breast, but before this quantity can properly be applied to the problem of risk assessment more information would be needed on the amount and distribution of the tissue at risk in individual cases. One could, however, assume very roughly that the linear density of the gland tissue might be 35 g/cm and its total mass 175 g, on the average. On these assumptions, the average absorbed dose per unit exposure to the glands of an average breast has been calculated for different radiographic techniques and found to vary between 1 and 4 mGy [H2].

46. The evolution of the mammographic technique is also summarized in Table 6. The average absorbed dose and the mid-breast dose are given for various systems [A3, K16, M16, P11, S24, U10]. There is a steady decrease in all dose values during the period of study. Some further reduction of absorbed dose might be achievable without compromising the mammographic image quality [S24]. These improvements would include photon energy control, scatter removal and improvement in detector response [M16].

47. The probability of an increase in five-year survival as a result of early detection and treatment of breast cancer has been used as a specific estimate of the benefit of mass application of mammography [K29]. Mammography increases the probability of diagnostic detection of stage I breast cancer by 3 times; the detection of stages II and III is however less efficient by comparison with other methods of examination [F5, G5, K29]. The five-year survival after treatment may be improved by 11%, following mammography. If this

benefit is then compared with the risk of developing fatal malignancies, it may be calculated to exceed the risk by a factor of 2 to 30 (according to the different techniques used) [K29].

5. Computed tomography

48. Diagnostic radiology has generally used methods for two-dimensional imaging of the body. Since 1971 a new tomographic method has been introduced in which a finely collimated x-ray beam is used for scanning across the plane of interest at various discrete angles. The attenuation of the transmitted beam is recorded by a detector and the relevant data are processed by computer with a mathematical algorithm to generate a cross-sectional image of the body in terms of relative attenuation coefficients in the layer examined. Because of the paramount role of the computer in the imaging procedure the method is called "computed tomography" (CT) [B14].

49. Computed tomography is considered to be the greatest improvement in the diagnostic use of ionizing radiation since the discovery of x rays, and it overshadows other major technical achievements, such as tomography, image intensification, cine- and video-roentgenology. The value of CT-scanners was quickly recognized and technical developments have proceeded very rapidly.

50. The number of CT-examinations in Sweden from 1973 to 1979 is given in Table 7. In 1979, 8 head scanners and 7 whole-body scanners were in operation. The average number of examinations per head scanner was about 2050, and per whole-body scanner about 1300. In the same year about 2 head examinations and about 1 whole-body examination per 1000 population were performed in that country [N17]. In Japan, the frequency of CT-scanning examinations in 1979 was reported to be 0.44 for head examinations and 0.24 for whole-body scans, per 1000 population [N14].

51. If one images a uniform material, for example, a water bath, in a CT-scanner, one finds that the values of the attenuation coefficient μ are not all the same but are distributed approximately at random around an average value. The standard deviation of μ, designated as σ_μ, is called the noise of the apparatus; it is a very important measure of its performance, because the naturally-occurring variation of the attenuation coefficient between various normal tissues, and between normal and pathological tissues, is quite low. The noise depends on various parameters, such as the size of the patient or its body diameter, the mean energy of the photons and their energy spread, the width of the picture elements, the thickness of the scan and the skin dose [C4, C8, M6].

52. The x-ray beam of CT-units is highly collimated, particularly in a plane perpendicular to the axes of the trunk or the head. For single scans the x-ray beam is generally collimated to a length ranging from 3 to 15 mm perpendicular to the scan plane [M6]. For dual-scan CT-units the length is essentially double.

53. The eye may receive as much as 50 mGy for a complete CT-examination of the head [H30, I12]. The distribution of the skin doses varies with the angle of rotation. In the first-generation scanners having a 180° angle the highest absorbed doses for organs in the scan were around 35 mGy and the lowest about 0.5 mGy per scan. With other systems (360° rotation) a different distribution of the absorbed doses is obtained, and maximum doses in the skin can be as high as 560 mGy, although for normal clinical use they are around 60 mGy [B24, H21, H23, I13, K8, N3, N15, M6, P5, R2, S10, V1, W3]. Absorbed doses in the skin, the centre of the body and the gonads from CT-examinations are found in the following references: [B3, B13, H21, K8, K9, L8, M6, N5, P3, P4, W3, W18]. Organ doses and risk-weighted absorbed doses have been calculated by the Monte Carlo technique for head and whole-body scans. The data are given per slice and are normalized to exposure-free-in-air at the axis of rotation [K32]. Absorbed doses in various organs, and the average number of slices in different CT-scanning procedures, as derived by Stieve et al. [S15], are given in Table 8. A comparative study of doses from kidney CT-examinations, contrasted with conventional radiography, has been performed [K10, S18] and the results are given in Table 9.

C. ABSORBED DOSE IN THE PATIENT

54. The geometry in external irradiation is described by the projection and view — anterior/posterior (A/P), posterior/anterior (P/A), lateral (LAT) — x-ray field size at image receptor plane, x-ray field location relative to anatomical landmarks, and source-to-image-receptor distance. The conversion of exposure to absorbed dose in the body organs is obtained by using the tissue/air ratio. This is defined as the ratio of the absorbed dose at a given point in a tissue-equivalent phantom to the absorbed dose which would be measured at the same spatial point in free air within a volume of the phantom material just large enough to provide the maximum electron build-up at the point of reference [I5].

55. Estimation of organ doses from x-ray diagnostic procedures can be made either by direct measurements or by calculations. In vivo measurements are difficult and, with internal organs, phantom studies must be performed [J5, H15]. For calculations, the Monte Carlo method has been used extensively and the results of such estimates can be of considerable help in estimating the absorbed dose in various organs [K15, R6, R7].

56. Estimation of the effective dose equivalent depends on the availability of data about absorbed doses in the gonads, the breast, the red bone marrow, the lungs, the thyroid, the bone surfaces, the skin and up to five other most exposed organs or tissues [I6]. The distribution of organ doses measured or estimated for the same type of examination usually spans several orders of magnitude, with coefficients of variation ranging from 100 to 300%. This is in spite of considerable advances in the techniques of diagnostic radiology, many of which were actually expected to reduce the variability mentioned above [U9, U12, U13, W21].

57. Values of absorbed doses in diagnostic x-ray examinations are presented in various ways by different authors. Some authors report the absorbed dose in organs relative to the exposure or absorbed dose at the entrance surface [K15]. By measuring one of these values during a whole examination, the absorbed dose to various organs may thus be estimated individually. Most authors, however, report average absorbed doses in various organs, either per exposure or per full examination. Unless stated otherwise, all values in this report

refer to a full examination. The number of films used per full examination varies considerably and this makes it very difficult to estimate a good average [H1].

58. The absorbed doses in various tissues exposed in the course of diagnostic procedures, as reported from a large number of surveys conducted in different countries, are found in the following references: gonads [B5, F3, H27, J5, K30, L2, S20, U15, W15]; breast [B5, H15, J5, L2]; red bone marrow [B5, B18, C5, F3, H3, H11, H15, H27, J5, K30, L2, S9, S20, W5]; lungs [B5, H15, H27, J5, L2]; thyroid [B5, H15, H27, J5, L2]; bone surfaces [H15, J5]; skin [H15, J5, K30, S20]; remainder [H15, H27, J5, K30]; uterus and other organs [B2, H12, H30, I12, L2]. Great differences between various reports are due to different techniques. The reported organ doses for all types of diagnostic examinations range from less than 0.01 to about 50 mGy per examination.

59. Tabulation of all these data would have made the text unnecessarily complex. The Committee therefore decided to show, as an example, representative data from Japan and Poland, as supplied to the Committee by the delegations of those two countries. These are the only two series where reasonably complete values of the organ doses are available for calculating the effective dose equivalent (see section E). The relevant data are shown in Tables 10, 11 and 12.

60. These data show that there are inhomogeneities in the presentation, and, for those entries which are common, the differences in the values are very large. These differences must be attributed, to a great extent, to the variations in the techniques of exposure, and, in part, to the dosimetric techniques used. The extreme variability of the data base made it impossible for the Committee to carry out an independent assessment of effective dose equivalent which might have a more general applicability. It should be emphasized that the data from Japan and Poland cannot be considered representative of the situation applying in other countries.

D. GENETICALLY SIGNIFICANT DOSE EQUIVALENT

61. The genetically significant dose equivalent for a population is a widely used measure of the genetic detriment from medical irradiation. Its definition is found in Annex A, section II.B. Details of many GSD surveys have been given in the previous reports of the Committee and are summarized in the 1977 report [U7]. Since that time a few further data in various countries and areas have become available and are reviewed in this Annex [D5, H26, K21, S20, W21].

62. The variation with age in the frequency of all radiological examinations per 1000 population has been studied in the United Kingdom [D5]. The results indicate a general increase with age, with a superimposed increased frequency for very young children, teenagers and people in their early twenties. The increase in frequency for each age group and for both sexes relative to that found in 1957 is most marked for examinations of children and of old people (particularly women). A relatively larger increase in examinations of children and older people was also seen in the United States between 1960 and 1970 [U10].

63. The GSD from diagnostic radiology in National Health Service hospitals of the United Kingdom in 1977 was estimated to be 113 μSv, with a standard error of about 12 μSv, arising mostly from uncertainties in the frequency data. A summary of diagnostic radiology performed in 1977 in other hospitals and the contributions to GSD is given in Table 13 together with comparable data for 1957 [A6]. The GSD from all types of diagnostic radiology was estimated to be 118 μSv in 1977. Although this is somewhat lower than the figure of 141 μSv from the 1957 survey, the difference is less than twice the standard error of the mean GSD and therefore does not provide strong evidence of a decrease. The main contributions to the GSD in the United Kingdom in 1977 were examinations of the pelvis and lumbo-sacral area, upper femur and hip, urography, cystography and barium enemas. The contributions are broadly similar to those found in 1957, except that there has been a fall in the contribution from obstetric examinations from 45 to 6 μSv. On the other hand, there has been an increase by a factor of twenty in the contribution from cystography, largely due to an increase in the frequency of this examination [D5].

64. The variation with age in the frequency of all radiological examinations in Australia shows a pattern similar to that in the United Kingdom. The numbers of all x-ray diagnostic examinations per 1000 population were 209 under 2 years, 163 in the age group 2–14 years and 450 over 15 years, with a mean of 370. The examination rate of the foetus was 15.4 per 1000 population. The GSD from all x-ray diagnostic examinations in Australia during 1970 was estimated to be 149 μSv. The highest contributions were from urography, lumbo-sacral spine and obstetrical examinations [S20].

65. The most recent estimates of the GSD from medical examinations in Japan were based on a 1974 nation-wide survey of randomly sampled hospitals and clinics. The resultant annual GSD for 1979 was 150 μSv, which was approximately the same as that of 1974, although the annual number of examinations had increased in the meantime by about 30%. Table 14 shows a comparison between the 1979, 1974 and 1969 data. The GSD in the USSR due to diagnostic x-ray procedures was found to be 230 μSv per year, about two-thirds of which were attributed to radiography and the rest to fluoroscopy [K11].

66. On the basis of the data in Table 8 the annual GSD from CT-scanning in the Federal Republic of Germany was reported in 1977 at about 0.8 μSv. It was foreseen that this value might increase by a factor of 5 to 6 when optimal use of CT-tomography is reached [S15].

67. The most complete series on the GSD equivalent from diagnostic radiology has been reported from Japan. Table 15 summarizes the values for the various years and types of examination [H4, H5, H6, H7, H9, H10, H13, H14, H16, H17, H18, H19, H26, H27, H28, H35, M3, M4, M5, M19].

E. EFFECTIVE DOSE EQUIVALENT

68. The calculation of the effective dose equivalent from diagnostic procedures must take account of the technical parameters involved, i.e., beam quality, typical entrance exposure and the number of films for

each view. The expression of dose equivalent in an organ per examination is given by the formula

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

where k is the type of view involved in the examination (i.e., A/P, P/A or LAT); n_k is the number of films for view k in the examination in question; $D_{T,k}$ is the average absorbed dose in an organ for view k; and Q is the quality factor. This factor is taken to be unity for x rays used in diagnostic radiology.

69. The effective dose equivalent, $H_{eff,l}$ for an examination of type l is thus obtained from the following equation

$$H_{eff,l} = \sum_T w_T H_{T,l} \qquad (2)$$

where the weighting factors w_T are those given by ICRP [16] and reproduced in Annex A, Table 3. In the case of the weighting factor for skin, ICRP [17] recommended a value of 0.01 to be applied to the mean dose over the entire body surface. The average field size used in x-ray examinations covers about 5% of the body surface. Therefore the mean dose used in the calculation of the effective dose equivalent is only a small fraction of the absorbed dose in the skin at the entrance field.

70. The weighting factors w_T given by ICRP for various organs are average values for both sexes and all ages in a population with normal age distribution. The assumed variation of the individual risk of late stochastic effects with age has been shown in ICRP publication 27 [I19]. For patients undergoing diagnostic examinations, the age- and sex-distributions often deviate from those in a normal population. Considering all other uncertainties in dose and risk assessments, such deviations are not believed to invalidate the use of the ICRP weighting factors except in a few cases. The breast is an organ for which the risk assessment is particularly sensitive to the composition of the exposed group. The main risk relates to young women, but the ICRP weighting factor, being an average for men and women of all ages, would underestimate the risk for this category, e.g. for mammography patients. Older patients would run no risk of hereditary harm and little risk of radiation-induced cancer, because of the long latent periods. For patient groups with a high proportion of old individuals, the effective dose equivalent will therefore overestimate the risk.

71. The weighting factors w_T are given for the organs which are assumed to contribute most to the total risk at a given dose. In addition to the weighting factors specified for these organs, a weighting factor of 0.06 is allotted to each of the five other organs which are estimated to receive the highest doses. This is equivalent to applying a weighting factor of 0.30 to the average dose for these five organs (the "remaining" organs). In some cases, e.g., if these organs include the eyes and the brain, for which a weighting factor of 0.06 probably overestimates the risk, the contribution of the "remainder" to the effective dose equivalent may be too high.

72. The ICRP weighting factors are derived from assumptions of the risk of lethal cancer. The effective dose equivalent therefore reflects the risk of dying from cancer. If also non-lethal cancers were to be considered, they would have to be given a detriment weight in relation to lethal cancers. This involves a value judgement. The risk of additional non-lethal cancer is particularly high in the case of exposure of the thyroid and the breast. In case of examinations where these organs receive proportionally high doses, the effective dose equivalent will underestimate the total detriment.

73. The weighting factor for the gonads is derived from assumptions of the risk of severe hereditary effects in the first two generations of offspring. It will thus underestimate (by a factor of two) the total risk of hereditary harm in all generations.

74. Modified weighting factors could be derived to compensate for the over- and under-estimation of risk which will occur by the use of the ICRP weighting factors. However, if other factors are used, the derived quantity is no longer the effective dose equivalent, since this is linked, by definition, to the weighting factors given by ICRP. Since, in most cases, the errors are expected to be less than a factor of two, the Committee does not feel that such (apparent) precision would be justified. It would tend to give the false impression that it is possible to derive a quantity which would accurately indicate the true risk. It must be emphasized that any organ-weighted dose is only a very crude indicator of the real risk.

75. Calculations of the effective dose equivalent for different types of diagnostic x-ray examinations have been reported from Poland, 1976, and Japan, 1979. Recalculations of these data were submitted to the Committee in 1982 by the delegations of these two countries and are given in Table 16. They show large variations for individual examinations.

76. The total collective effective dose equivalent from diagnostic x-ray examinations in Poland in 1976 was reported to be 20 000 man Sv, which corresponds to about 600 man Sv per million people. Examinations of GI-tract, lumbar spine and urography give the highest contribution, with about 25% each [J5]. Very recent unpublished information submitted to the Committee by the delegation of Poland indicates that the value of 600 man Sv may be an underestimate.

77. The collective effective dose equivalent from diagnostic x-ray examinations in Japan, in 1974, was estimated to be 200 000 man Sv which corresponds to about 1800 man Sv per million population. Examinations of the stomach, which is a frequent examination in Japan [H15], gave by far the highest contribution.

78. The Committee had no other quantitative information from which to obtain a reasonable estimate of collective effective dose equivalent applying generally to the population of the world. The data from Poland and Japan differ by a factor of about 3. On the assumption that these data might be applicable to other areas, then the annual collective effective dose equivalent attributable to medical irradiation for diagnostic purposes might be of the order of 1000 man Sv per million population in industrialized countries. This is an annual per caput effective dose equivalent of 1 mSv. In developing countries, having a lower frequency of radiological examinations, the value would be correspondingly less.

F. SUMMARY

79. Data on the frequency of x-ray examinations have now been reported from many countries. Per 1000 total population, the number is found to vary between 300 and 900, excluding mass surveys and dental examinations.

80. Mass chest surveys show a decreasing trend, being below 50 per 1000 people in some industrialized countries, but in other countries still as high as 300 or more per 1000 people. Reports of dental x-ray examinations are not common, but the relevant value is probably in the region of 0.2–1 film per person per year in developed regions. There is an increase in the number of patients examined by pantomographic dental x ray; the exposure of these patients is comparable with that from conventional techniques.

81. Mammography techniques currently in operation result in a considerable reduction of the dose absorbed in breast tissue. This has stimulated interest in the examination, and the number of patients undergoing it is steadily increasing.

82. Computed x-ray tomography has introduced a new dimension in diagnostic radiology. Technical developments have taken place rapidly during the last decade. Recent figures point to an examination frequency of 1 to 3 per 1000 total population per year, two thirds of which are performed on the head. This technique has also resulted in a decrease of complex angiographic examinations and radioisotope tests. The net effect of such changes may be a lower exposure of the population.

83. Absorbed doses in various organs and tissues resulting from diagnostic x-ray examinations were found to be in the range of less than 0.01 to about 50 mGy per examination. The few available assessments indicate that the effective dose equivalent for the most common types of x-ray examinations ranges from about 0.05 mSv to about 10 mSv per full examination. In the absence of any other data, the Committee has tentatively, for the purpose of this report, used the round number of 1000 man Sv per million population as the annual collective effective dose equivalent for industrialized countries. In developing countries, where the frequency of radiological examinations is lower, the value would be correspondingly less.

84. Because of the differences in the classification of diagnostic x-ray examinations in various countries it is not easy to compare data from one country to another. There is therefore a need for an internationally accepted classification scheme for diagnostic x-ray examinations to be used in reporting frequencies and dosimetric data.

II. DIAGNOSTIC USE OF RADIOPHARMACEUTICALS

A. TRENDS IN FREQUENCY AND TECHNIQUES

85. The use of radionuclides in the field of diagnostic nuclear medicine has been rapidly increasing all over the world. Since this medical specialty began its development about 30 years ago, the frequency of examinations has steadily increased. Studies have indicated a continuing rate of growth, in the number of examinations performed, by about 25% per year during 1965–1975 in the United States, which has decreased to about 10–15% per year since that time [B16]. For some European countries the annual growth rate is now of the order of a few per cent [H36, H37, N2, R11, R12, S26, S27], while figures from Australia indicate an average growth rate of about 7% per year during 1970–1980.

86. Reasonably complete statistics are only available from a few countries (Australia, Austria, Denmark, Sweden, United States) [F6, K13, M8, N2, S13, S25, S26, S27, U16]. For Berlin (West) there are statistics for the period 1953–1975; per 1000 inhabitants the most recent figures on the number of examinations are: 1968, 10.3; 1970, 15.0; 1975, 32.1; 1978, 33.9 [H36]. There is also a value for Munich for 1978, 47.8 [R12]. In Austria the frequency in 1977 was reported to be 17.5 per 1000 inhabitants [F4, F6].

87. The examination frequency of various organs by radiopharmaceuticals (examinations per 1000 inhabitants) increased from 8.4 in 1971 to 13.6 in 1976 in Sweden [N2]. In the United States the examination rate increased from 3.7 in 1966 to 37 in 1975 [M8, U7, U16]. In Denmark it increased from 3.8 during 1973–1974 to a plateau of about 14 in 1978 and 1979 [S13, S25]. For some countries, the relative frequency of various nuclear medicine procedures is shown in Table 17 [K13, N2, M8, S13, S25, S27, U7, U16]. The data indicate that, in general, the relative frequency of examinations of liver, lungs and kidneys is approximately constant, the frequency of the thyroid examinations is decreasing, while that of bone examinations is increasing. The frequency of brain scintigraphy has decreased during recent years and has been replaced by computed tomography.

88. The annual frequencies of in vivo diagnostic nuclear medicine procedures per 1000 inhabitants in two countries, as reported by WHO, are shown in Table 18, while Table 19 gives the frequencies for a number of other countries, subdivided into the various types of procedure [W13].

89. The recent introduction of nuclides such as ^{99m}Tc has had a great impact on the development of nuclear medicine. In Annex F of the last report of UNSCEAR [U7] the trends for liver scanning, for which ^{198}Au colloid was being replaced by ^{99m}Tc colloid, were clearly demonstrated. The increased use of ^{99m}Tc is also evident in Table 20, together with the main trends for the most widely used radionuclides [N2]. The relative frequency of use of pharmaceuticals for various nuclear medicine procedures in the United States is also given in Table 20 [H16, M8]. Exhaustive data on the application of various radiopharmaceuticals in nuclear medicine are also available from Denmark and Sweden for the 1970s [M20, N2, S13, S25, S26, S27].

90. The scintillation gamma camera is the standard imaging instrument in nuclear medicine. The major reason for this is the excellent spatial resolution possible with the thin sodium iodide crystal when ^{99m}Tc is used. The increase in the number of gamma cameras installed in Europe is shown in Table 21 [P9]. These data should not be taken to infer that there has been an equal increase in the total number of procedures performed, since, in many instances, gamma cameras have simply been replacing rectilinear scanners. Newer techniques of single-photon and positron-emission

tomography have been developed, but, at present, these are predominantly used for research purposes.

B. DOSE ESTIMATES FOR RADIOPHARMACEUTICALS

1. Absorbed dose

91. Many biological parameters influence the mean absorbed dose to organs after administration of radionuclides. For the purpose of dose assessment, and for most radiopharmaceuticals in use, the relevant biological data are taken from animal experiments and are assumed to be applicable to man, when results from human studies are not available. However, these data are often incomplete and not suitable for the calculation of the effective dose equivalent. As in the case of external irradiation, this latter value should thus be taken as the best approximation to be obtained under the circumstances [R12, R13, R14, R18].

92. Physical methods for the calculation of the dose from internally-administered radionuclides are now well established. They are based on the concept of mean absorbed dose per unit cumulated activity (time integral of activity), as developed by MIRD [M10] and adopted by the ICRU [I16]. Experimental evaluation of organ doses from various radionuclides confirms the validity of the calculations [G1].

93. Table 22 gives, for various radiopharmaceuticals, the mean absorbed dose per unit administered activity in the most heavily exposed organs, in the gonads, and in the whole body and the effective dose equivalent per unit of activity of administered radiopharmaceuticals. The values have been estimated from data published by MIRD [M10], Kaul et al. [K2, K3, K20, K21, K23], Kereiakes et al. [K22], Roedler et al. [R4, R5, R11, R12, R13, R14] and from the recent Swedish compilation of doses from radiopharmaceuticals in medical use [N13]. Calculation of the effective dose equivalent has been made possible by a development of the MIRD concept to estimate the contribution from the activity in the "remainder" organs and tissues [C10, R15, R16, R17]. The values of effective dose equivalent are not applicable to therapeutic uses of radiopharmaceuticals.

94. With administered activity in the range of 100 to 800 MBq of various ^{99m}Tc-labelled radiopharmaceuticals the effective dose equivalent for the most common examinations is estimated to be in the range of 1 to 10 mSv per examination. For thyroid uptake measurements, with an average activity of 0.4 MBq of ^{131}I the effective dose equivalent is about 6.4 mSv per examination, assuming 35% uptake. For thyroid scintigraphy (activity 1.5 to 3 MBq of ^{131}I) the effective dose equivalent is about 85 mSv per examination. In Sweden, where thyroid examinations are still done with ^{131}I, this nuclide gives the most significant contribution (about 60%) to the collective effective dose equivalent.

2. Collective dose

95. A nation-wide survey was carried out in Japan in 1977 to collect data on the irradiation of the population from diagnostic uses of radiopharmaceuticals. The resulting genetically significant dose equivalent was about 3.6 μSv per year. The annual effective dose equivalent was estimated to be in the order of 20 μSv per person. With a population of about 10^8 people, this would result in an annual collective effective dose equivalent of about 2000 man Sv [H17].

96. In an attempt to estimate the collective effective dose equivalent from various radiopharmaceuticals in Sweden it was found that the most significant contribution comes from ^{131}I [P10]. By using reported values of the average administered activity per procedure and of the frequency of procedures, the Committee derived the following values of the collective effective dose equivalent, expressed in man Sv per million total population: Australia, 20; Denmark, 60; Sweden, 80; United States, 150 [F6, N2, M8]. These numbers are of the order of 2–15% of the collective effective dose equivalent from diagnostic x-ray examinations that the Committee has adopted in this Annex for industrialized countries.

III. THERAPEUTIC USE OF RADIATION

A. TRENDS IN FREQUENCY AND TECHNIQUES

1. External beam therapy

97. The IAEA, with assistance from the WHO, has published information on the use of high energy radiotherapy units and trained personnel in radiotherapy centres throughout the world [I2]. Owing to unavoidable delays in the flow of information and in data processing, the published information is often outdated by several years; moreover, it is often difficult to obtain complete data from all countries [W14].

98. For the year 1976 the total number of high-energy radiotherapy units installed in the world was reported as being 3117 in 2174 institutions. Some 4000 radiotherapists and 1600 physicists were estimated to be involved in this work. Of all the high energy units, 75.6% utilized ^{60}Co and 5.6 % ^{137}Cs, 6.9% were betatrons and 10.7% were linear accelerators. For the years 1970–1976 the percentage increase in a number of countries was between 20% and 50%, the higher rate applying to countries where few units were previously installed [I2].

99. Only limited data are available for the frequency of radiotherapy procedures. Table 23, from data published by the WHO [W13], gives the frequency of such procedures in three countries; this table also includes some data on the therapeutic use of radiopharmaceuticals.

100. Neutrons have been used in radiotherapy, from time to time, since their discovery. Summaries of the type and output of equipment used in a number of centres, and the numbers of patients treated, have been published [M22, S19, T2]. Research is currently being undertaken in some countries on the clinical use of π-mesons and heavy ions.

2. Brachytherapy

101. Brachytherapy designates the therapeutic use of encapsulated radionuclide sources applied in close vicinity of the tumour to be irradiated. In interstitial brachytherapy the source is implanted into the tumour mass. Intra-cavitary brachytherapy is performed by introducing the radiation sources into one of the body cavities. Data available from Japan on the frequency of use of brachytherapy, of the various nuclides and about the major categories of tumours treated, are reported in Table 24.

3. Therapeutic use of radiopharmaceuticals

102. Radioiodine has been used since 1946 in the treatment of hyperthyroidism and of thyroid carcinoma. Phosphorus-32 was introduced at about the same time for the therapy of polycythaemia vera and still remains the best therapeutic agent for this disease. On the other hand, the use of the same nuclide for the treatment of leukaemia has become less common with the discovery of other chemotherapeutic antileukaemic drugs.

103. Table 25 shows the annual number of treatments per million population in Sweden during the last several years using radiopharmaceuticals [N2]. There is a trend to a slight increase of thyroid treatments and a constant rate of treatments for polycythaemia vera. The use of ^{198}Au colloid for treatment of metastases in the pleural or peritoneal cavities has almost ceased and so has the treatment of rheumatic arthritis with other nuclides. The use of radiocolloids for therapy of diseases of the knee or other joints seems to have increased slightly. In Japan, treatments for thyroid diseases with ^{131}I were only about 56 per million in 1977 [H17]. In Berlin (West) the number of ^{131}I treatments per million inhabitants was reported as follows: 1968, 257; 1970, 188; 1975, 129; 1978, 305. For the same number of people ^{198}Au treatments were about 35 and ^{32}P treatments about 23, constantly over the years [K24, R19].

B. DOSE SPECIFICATIONS IN RADIOTHERAPY

1. General

104. The total absorbed dose of ionizing radiation at any point in a patient can be separated into a component from the primary beam and one from scattered radiation. The absorbed dose component from the primary beam is a function of attenuation and geometry. The absorbed dose component from scattered radiation depends upon the field size, beam quality and distance from the central axis. Several methods have been described to determine this component [B15, B25, N10].

105. For ^{60}Co radiation the total dose outside the primary beam is dominated by scattered radiation, while at 4 MVp the leakage contributes at least half the dose outside the beam at 30 cm from the beam axis [K17]. At energies above 10 MeV there is production of photoneutrons which contribute to the dose outside the primary electron beam [H41, M18, S29, S30].

2. Dose to the gonads

106. Table 26 shows the fraction of absorbed dose to the gonads at two different treatment field locations. The x-ray field size was 10 x 10 cm^2 at 100 cm source-to-skin distance (SSD) and the electron field was defined by a cone of 12 cm diameter at 120 cm SSD [N9]. Table 27 shows the average gonadal doses from ^{60}Co gamma radiation from various treatment conditions, as measured by thermoluminescent dosimetry. Extensive measurements of the absorbed dose to the gonads from ^{60}Co irradiation were also carried out by Novotny et al. in the Alderson phantom and in vivo [N8].

107. Most of the above measurements were carried out with treatment fields without filters and field-shaping devices. However, modern radiotherapy commonly makes use of field-shaping because of the considerable improvement in therapeutic gain that it allows. Measurements by Jetne [J3] showed that as much as 50% of the absorbed dose in the gonads during treatment of Hodgkin's disease may originate from scattering in field-shaping devices; similar effects have also been seen in other types of treatment [N6]. Thus, precautions should be taken to reduce this portion of the gonadal dose.

108. Extensive measurements of gonad doses in phantoms irradiated with a given surface dose have been reported for cobalt units, conventional x-ray units and 10-MV linear accelerators [H19]. These data have been summarized in Table 28.

3. Dose to other organs

109. The 1977 report of the Committee (Annex F) reviewed the available information on mean marrow dose. Since then bone marrow doses were evaluated in Japan, using dose distributions measured in phantoms and the technical factors of radiation therapy as used in that country [H19]. The per caput mean marrow dose was reported to be 540 μGy per year for males and 980 μGy per year for females [H19]. Table 29 gives the absorbed doses in various organs outside the treatment area, expressed per unit absorbed dose in the beam entrance surface. Per unit skin surface, these doses vary from less than 0.001 to 0.3 mGy per Gy of the entrance dose.

110. The absorbed doses outside the pelvic compartment in radium treatment of patients with cancer of the cervix have been studied [S28]. A series of measurements was performed in water phantoms simulating a standard adult, an adolescent (12-year-old) and a child (3-year-old). Encapsulated radium sources were positioned in the pelvis compartment and in an arrangement normally used in the treatment of carcinoma of the cervix. The results indicate that when a patient is treated with a standard radium technique the absorbed dose in the bone marrow is 10 Gy or higher for the pelvis, and between 1 and 5 Gy for the thighs and abdomen. Absorbed doses in the bone are about 0.1 Gy for thorax and legs and 0.01–0.1 Gy for head and feet. These doses are delivered in approximately 30 days. Several epidemiological surveys of leukaemia in patients with cancer of the cervix treated with radiation were reported [B26, H31, H33, K18], but the studies did not involve actual dose measurements.

4. Dose from therapeutic use of radiopharmaceuticals

111. The absorbed dose to the ovaries and to the uterus in the course of ^{131}I treatment of thyroid cancer or hyperthyroidism was estimated in one instance by in vivo measurements and by calculations. The calculated value per unit of administered activity amounted to 46 ± 19 and to 37 ± 18 μGy MBq^{-1} to the uterus and to the ovaries, respectively. The value measured inside the uterus cavity was 49 ± 29 μGy MBq^{-1} [B23]. Further data on the absorbed dose to various organs outside the treatment area per unit administered activity are summarized in Table 30 [K24].

5. Genetically significant dose equivalent

112. Recent data on genetically significant dose equivalent estimates in radiotherapy are summarized in Table 31. An average value applying at present in Europe might be in the order of 7 μSv a^{-1} [S2, S3, S4], while Australia and the United States report values around 23 μSv a^{-1} [S20, T1].The genetically significant dose equivalent may also be classified according to various parameters: Table 32 shows some values of GSD by type of disease in clinical departments or in private practice in Berlin (West) (1973) and in Munich (1971) [S2, S3, S4]. About 16% of the patients that had malignant disease were treated in private practice, and 84% in clinical departments; the child expectancy of this group was assumed to be zero. In a Japanese study performed in 1971 [H5] the genetically significant dose equivalent was classified by age and sex, for malignant and for benign conditions and the relevant findings are given in Table 33. Comparable figures for 1978 are given in the same table.

113. The genetically significant dose equivalent from brachytherapy has been estimated in Japan for 1971 on the basis of a nation-wide survey. In that year the number of brachytherapy treatments in the country was around 5 10^4, 60% of which were due to treatments of cancer of the cervix by ^{226}Ra and ^{60}Co gamma sources. The relevant genetically significant dose was estimated to be 0.12 μSv. For comparison, the GSD from x-ray diagnostic radiology amounted to 265 μSv and that from teletherapy to 9.8 μSv [H8, H35].

114. The effective dose equivalent has not been evaluated for patients receiving radiotherapy, for the following reasons: (i) the concept of effective dose equivalent is based on the assumption of "linearity", i.e., proportionality between dose and response. If organ doses exceed a few gray, the risk of non-stochastic effects becomes significant and the effective dose equivalent is no longer a reasonable indicator of risk. Such doses are given in the treatment field in radiotherapy; (ii) patients treated for malignant disease often have a short life expectancy, either because of age or as a result of the disease. This will invalidate the assumptions behind the choice of the organ weighting factors for the derivation of effective dose equivalent; (iii) few data are available on the actual dose distribution outside the target volume; (iv) in the therapeutic use of radionuclides, the metabolic data assumed in normal dose assessments may not be valid.

IV. CONCLUSIONS

115. The frequency of x-ray examinations (including mass surveys and dental examinations) is in the range of 300 to 900 per 1000 inhabitants per year in a number of industrialized countries, excluding mass surveys and dental examinations. In the same countries, examinations of the skeleton and the thorax prevail among the various organs examined. In developing countries, the frequency of examinations is often between 100 and 200 per 1000 inhabitants per year, skeleton and thorax being also most frequently examined. Mass chest surveys show a decreasing trend in most industrialized countries, while other types of examinations (dental pantomography, mammography and computed tomography) are becoming more frequent. New diagnostic techniques, such as ultrasound and nuclear magnetic resonance imaging, are being developed as alternatives to x-ray examinations. However, it is difficult to predict now whether these new technologies might result in a dose reduction from x-ray examinations in the future.

116. Improvements in radiological techniques may entail increases or decreases in radiation dose. In some instances, considerable gains in clinically important diagnostic information or therapeutic efficiency have been associated with moderate increases in dose. In other instances, the dose has been substantially reduced without loss of diagnostic or therapeutic value. In both cases, the objective has been to minimize the clinically necessary exposure.

117. The absorbed dose in the patient depends on many factors, such as geometry and beam quality. Estimation of organ doses may be done using the Monte Carlo method or by actual dosimetry measurements. The absorbed organ doses reported for diagnostic examinations have been reviewed, and they vary widely, often by as much as three orders of magnitude for the same examination in the same country. The reported organ doses for all types of diagnostic examinations range from less than 0.01 to about 50 mGy per examination. In developed countries the genetically significant dose equivalent from diagnostic radiology is of the order of 0.15 mSv per year.

118. The use of the effective dose equivalent has been expanded to include medical exposures, although the concept is unusable in some important diagnostic and radiation protection situations (e.g., mammography). The validity of applying the concept of effective dose equivalent to the other types of diagnostic examinations depends upon the actual age and sex distribution of patients for each particular type of examination. Such data are currently lacking for most countries. For this and other reasons (e.g., questionable applicability of ICRP weighting factors to the case of medical irradiation) the Committee cautions the reader about the interpretation and application of the results, but feels that the concept is more meaningful than the GSD for making comparisons with other sources.

119. Estimates of the effective dose equivalent have been made in two countries for different types of x-ray examinations. They range from less than 0.05 to about 10 mSv per full examination. These values are useful in comparisons of the detriment from different types of examination but were not used by the Committee to assess collective dose equivalents. For the purposes of this report, the Committee has used the round figure 1000 man Sv per million population as a tentative value for the annual collective effective dose equivalent from diagnostic x-ray examinations in industrialized countries. In developing countries, where the frequency of radiological examinations is lower, the value would be correspondingly less.

120. The above tentative value is subject to a number of uncertainties due mainly to the variability of the absorbed doses in various organs in the course of different radiological examinations, and to the wide variations that have been reported for the same type of examination. Future work may usefully be directed towards obtaining accurate additional data on the frequencies of examinations and on the doses absorbed in various organs and tissues so that firmer and more precise estimates of collective effective dose equivalents may be obtained.

121. The frequency of diagnostic nuclear medicine examinations in most industrialized countries is at present of the order of 10 to 40 per 1000 inhabitants per year. The rapid growth of these values that has taken place during the last decade appears now to be levelling off. In developing countries, frequencies in the range of 0.2 to 2 examinations per 1000 inhabitants per year are currently found.

122. In developed countries the use of ^{99m}Tc-labelled radiopharmaceuticals has replaced the use of longer-lived compounds for most imaging procedures. However, ^{131}I continues to be used for thyroid therapy and in some labelled compounds. Data on types of isotopes used in developing countries are not available.

123. The effective dose equivalent received by patients in the course of nuclear medicine diagnostic examinations with the most frequently used radionuclide, ^{99m}Tc, was found to be in the range of 1 to 10 mSv per examination.

124. The annual collective effective dose equivalent from the diagnostic use of radiopharmaceuticals may be estimated to be in the range of 20–150 man Sv per million of total population in industrialized countries, which is a small fraction of the collective effective dose equivalent from diagnostic medical x-ray examinations.

125. The number of high-energy radiotherapy machines installed in the whole world may at present be estimated at about 4000. About 4000 radiotherapists and 2000 physicists are estimated to work at present in radiotherapy centres in the world. While most developing countries are reported to use ^{60}Co-teletherapy and low-energy x-ray therapy units, developed countries are adopting increasing numbers of high-energy electron accelerators.

126. Absorbed doses in the target region during radiotherapy treatments are quite high, commonly 20–60 Gy given in fractionated courses. Absorbed doses in organs and tissues outside the target area depend on scattered and leakage radiation. They may vary from less than 0.001 to 0.3 mGy per Gy of radiation in the entrance surface.

127. The genetically significant dose equivalent due to radiotherapeutic treatments has been recently estimated in 4 countries to be between 0.7 and 23 μSv per year.

128. Since the contribution from diagnostic x-ray examinations dominates over all other components, the individual average effective dose equivalent from all medical exposure may be taken to be of the order of 1 mSv per person and year in developed countries (see paragraph 119). Differences in the radiological techniques, and in the spectrum of diseases over the whole population, may bring about considerable variations. On the assumption that the individual average may be proportional to the annual frequency of radiological procedures, the variation of the individual average dose equivalent could also be by a factor of three between various developed countries. If the frequency of diagnostic examinations in developing countries is taken to be one-tenth of that in developed countries (and that of radiotherapy still lower) it may be estimated on the same assumption that the individual average dose equivalent might be correspondingly lower. The value that might apply globally could, therefore, be 0.4 mSv per person and year.

129. A precise estimate of the collective effective dose equivalent from medical exposure is not possible at present owing to the lack of appropriate information from most countries and the lack of applicability to certain categories of exposure such as radiation therapy. The Committee would like to express the wish that in the future, medical irradiation statistics be reported in such a way that some evaluation of the genetically significant dose equivalent and of the effective dose equivalent may be possible.

Table 1

Annual frequency of diagnostic x-ray examinations
in various countries expressed in number of examinations per 1000 inhabitants

	Type of examination	Australia (1970) [S20]	Finland (1975) [L7]	Germany, Fed. Rep. (1978) [T8] M	F	Total	Japan (1979) [H13,H14,H26,M19] M	F	Total	Poland (1976) [J5] M	F	Total	Romania (1977) [F3] M	F	Total	Sweden (1977) [N11]	United Kingdom (1977) [K12] M a/	F a/	Total
01	Hip and upper femur	8.7	403.3 b/	4.1	7.7	11.8	6.3	9.0	15.3	23.3 c/	29.3 c/	52.6 c/	3.1	2.0	5.1	19.2	8.2	10.7	9.9
02	Femur	13.5		-	-	-	3.2	1.7	4.9				15.5	9.2	24.7	4.0	5.7	7.3	6.5
03	Pelvis	7.6	-	15.7	22.0	37.3	1.9	2.8	4.7	-	-	-	3.3	1.8	4.1	13.2	12.9	18.3	15.6
04	Pelvimetry	0.7	-	-	-	-	-	1.0	1.0	-	-	-	-	-	-	1.6	-	-	-
05	Lumbo-sacral	15.2		-	-	-	-	-	-				18.2	18.8	36.9	2.6	6.5	6.6	6.5
06	Lumbar spine	8.8		9.3	12.6	21.9	27.8	23.8	51.6				-	-	-	17.8	10.8	12.8	11.8
07	Urography	12.0	21.7	21.7	20.3	42.0	9.6	5.2	14.8	5.6	5.3	10.9	3.6	3.5	7.0	18.5	10.2	7.7	8.9
08	Retrograde pyelography	0.8	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	-	-	-
09	Urethrocystography	0.6	-	-	-	-	5.8	2.6	8.4	-	-	-	-	-	-	3.2	1.0	1.0	1.0
10	Stomach and upper G.I.T.																		
	(a) Radiography	1.6	127.4	29.7	38.1	67.8	66.8	52.7	118.7	-	-	-	5.3	2.9	8.2	17.5	10.1	10.1	10.1
	(b) Fluroscopy	17.1	-	-	-	-	71.4	58.4	129.8	19.8	16.9	36.7	64.4	43.5	107.9	-	-	-	-
	(c) Mass survey	-	-	-	-	-	21.3	15.6	36.9	-	-	-	-	-	-	-	-	-	-
11	Small intestine	6.8	-	-	-	-	3.6	4.4	8.0	1.0	1.1	2.1	10.8	8.9	19.7	15.1	5.0	6.7	5.8
12	Abdomen	14.3	-	1.2	2.9	4.1	17.6	17.4	35.0	8.3	8.9	17.2	-	-	-	11.7	15.2	18.4	16.8
13	Abdomen (obstetrical)	2.6	-	-	-	-	-	1.5	1.5	-	-	-	-	-	-	2.2	-	1.2	0.6
14	Hysterosalpingography	1.0	-	-	-	-	-	1.1	1.1	-	0.5	0.5	-	0.4	0.4	0.6	-	0.8	0.4
15	Cholecystography	9.4	-	-	-	-	16.7	17.9	34.6	3.7	8.9	12.6	2.6	5.8	8.4	11.8	4.6	10.1	7.3
16	Chest (lungs, heart)																		
	(a) Radiography	118.8	382.2	168.7	165.2	333.9	194.3	140.6	334.9	88.6	81.7	170.3	29.0	15.4	44.4	159.6	140.4	120.3	130.4
	(b) Fluoroscopy	1.4	-	-	-	-	2.4	1.8	4.2	4.0	2.4	6.4	229.3	142.5	371.8	-	-	-	-
	(c) Chest mass miniature	146.7	-	-	-	-	165.5	135.5	301.0	174.0	154.9	328.9	214.1	219.7	433.8	-	-	-	26
17	Head	40.9		51.4	56.8	108.2	33.5	25.6	59.1	39.8	39.0	78.8	16.8	20.2	37.0	43.3	45.2	39.4	42.3
18	Dorsal spine	7.3		16.5	19.2	35.7	3.2	3.5	6.7	-	-	-	12.6	11.2	23.8	9.6	4.0	5.8	4.9
19	Thorax	13.4	63.7	-	-	-	12.1	7.6	19.7	-	-	-	6.1	4.0	10.1	17.2	8.3	9.8	9.0
20	Arm and hand	37.4		36.7	41.9	78.6	18.9	9.4	28.3	32.6	21.2	53.8	9.3	5.9	15.2	46.0	50.1	39.1	44.6
21	Lower leg and foot	28.5		46.2	48.1	94.3	31.8	29.0	60.8	29.9	23.3	53.2	27.5	18.3	45.8	66.0	55.2	47.4	51.3
22	Dental	80.9	170.0	32.4	89.5	71.9	248.0	311.0	559.0	18.5	25.4	43.9	16.5	18.3	34.9	2.1	6.1	6.9	6.5
23	Breast	0.3		0.6	27.3	27.9	-	1.2	1.2	-	-	-	-	-	-	6.4	-	1.7	0.8
24	CT-scan	-	-	-	-	-	7.6	4.9	12.5	-	-	-	-	-	-	-	1.3	1.3	1.3
25	Other	-	21.2	-	-	-	16.3	15.6	31.9	0.6	0.6	1.2	6.1	5.8	11.9	6.0			23.0

a/ National Health Service, per 1000 males and females, respectively.
b/ Including all skeleton and bones.
c/ Including whole femur, lumbo-sacral and lumbar spine examinations.

Table 2

Relative frequency of diagnostic x-ray examinations in various areas

Type of examination	Africa [SB] Type of hospital: General and university	Africa [SB] Type of hospital: Regional and district	Africa [SB] Type of hospital: Small rural	Japan 1979 [H26]	Australia 1970 [S20]	Europe a/ 1977 [F3, J5 N11, K12]	United States 1970 [U8]
Head and neck	7.6	4.3	3.6	7.0	6.0	7.9	7.7
Thorax	37.9	53.8	58.5	43.2	58.9	50.2	52.0
Digestion organs	7.5	1.2	0.1	18.4	5.2	7.7	10.4
Urogenital organs	11.6	2.9	3.3	7.7	4.7	7.0	11.0
Skeleton, extremities	35.4	37.8	34.5	24.7	25.2	27.2	18.9

a/ Poland, Romania, Sweden and United Kingdom.

Table 3

Percentage of the population with availability of diagnostic x-ray machines in WHO regions [W11]

(Number of countries is given in parentheses)

Number of x-ray machines per 10^6 persons	Thousands of persons per x-ray machine	Region (WHO classification): Africa	America	Eastern Mediterranean	South-east Asia	Western Pacific
> 100	> 10		24.4 (9)	1.9 (2)	0.2 (1)	0.2 (1)
99-50	11-20		55.0(11)			71.0 (3)
49-33	21-30	1.0 (1)	6.8 (3)	6.2 (4)		3.7 (1)
32-20	31-50	0.7 (2)	7.3 (5)	6.4 (4)		20.4 (3)
19-13	51-75	19.6 (3)	0.5 (2)	15.2 (5)	92.6 (1)	4.7 (1)
12-10	76-100		0.7 (2)	18.1 (2)		
9.9-6.7	101-150	22.8 (2)		41.1 (4)		
6.6-5	151-200	6.6 (1)	2.4 (1)		5.3 (2)	
< 5	> 200	49.3 (8)	3.0 (2)	11.1 (2)	1.9 (1)	

Table 4

Annual frequency of diagnostic x-ray procedures as reported by WHO Regional Offices [W13] expressed in number of examinations per 1000 population

	Type of examination	Barbados 1978	Brazil 1978	Chile 1978	Colombia 1978	Cuba 1978	Fiji 1978	Guatemala 1978	Sri Lanka 1979
01	Hip and upper femur	] 11.3	-	2.5	0.15	1.4	-	2.4	1.43
02	Femur		-	15	-	-	-	-	1.07
03	Pelvis	-	-	7.9	-	-	-	-	-
04	Pelvimetry	-	-	-	-	-	-	-	0.07
05	Lumbo-sacral	14.9	-	-	30.0	9.2	-	0.26	-
06	Lumbar spine	-	-	6.9	-	9.4	-	-	-
07	Urography	6.2	38.0	5.1	30.0	27.2	1.77	-	0.14
08	Retrograde pyelography	0.42	-	0.35	-	-	0.17	-	0.07
09	Urethrocystography	4.1	-	0.19	-	20.1	11.1	-	0.40
10	Stomach and upper G.I.T.	6.9	15	17	-	21.9	65	0.16	0.11
11	Small intestine, colon, etc.	2.2	-	6.4	1.59	10.5	1.36	0.02	0.30
12	Abdomen	0.15	0.68	7.9	-	6.1	0.02	1.11	0.28
13	Abdomen (obstetrical)	6.1	] 7.0	0.23	-	17.4	4.6	0.25	0.32
14	Hysterosalpingography	1.04		0.7	-	3.0	0.25	-	-
15	Cholecystography	2.1	-	17.2	0.11	13.8	1.48	0.06	0.07
16	Chest (lungs, heart)	91.0	42.0	45.9	78.9	-	0.03	0.56	12.9
17	Head	24.0	0.4	14.7	7.3	-	6.7	0.97	0.33
18	Dorsal spine	0.51	-	4.2	63.0	-	-	-	0.43
19	Thorax	12.0	-	-	0.46	-	0.62	2.7	0.48
20	Arm and hand	-	-	6.4	-	-	-	-	-
21	Lower leg and foot	-	-	0.4	-	-	-	-	-
22	Dental	-	-	3.9	-	-	39.0	-	0.8
23	Breast	-	-	-	-	-	-	-	-
24	CT-scan	-	-	-	-	-	-	-	-
25	Other	0.13	77.0	3.6	0.35	0.54	-	0.07	1.78

Table 5

Mean bone marrow dose equivalent (μSv) at different sites for various radiographic dental examinations [W8]

Site	Panorex	Pan-elipse	Ortho-pantomo-graph	Intra-oral	Collimated intra-oral	Lateral cephalo-metric
	4 films 75-kVp 14 mA	80-kVp 15 mA	80-kVp 15 mA	21 films 80-kVp 15 mA	21 films 80-kVp 15 mA	20 exp. 70-kVp 200 mA
Mandible	141	318	239	8500	2820	188
Calvaria	59.6	122	93.1	91.2	101.8	129
Cervical spine	131	237	532	1160	24.1	151

Table 6

Data on the evolution of mammography technique [A3, H2, J2, K16, M16, S24, U10]

Year x-ray unit introduced	Target	Focal spot (mm)	Filtration	Film/focus distance	Detector system	Absorbed dose in the breast	
						Average	Mid-plane
Before 1969	W	3.2	Inherent	70	Industrial film	16	8.5
1971	Mo	1.0	0.7 Al	44	Electrostatic	8.2	5.5
1972	Mo	1.0	0.003 Mo	44	Screen-film	2.8	1.7
			or 0.5 Al		Direct film	16.9	-
1975	Mo/W	1.8	1.1 Al	60	Electrostatic	4.1	3.3
1976	Mo/W	1.8	1.5 Al	60	Screen-film	1.2	0.65
1977	W	0.15	0.03 Mo	30	Screen-film	1.5	0.7
	W	0.15	0.2	94	Electrostatic	0.75	0.6

Table 7

Number of CT-examinations per 1000 population in Sweden [N17]

Type of examination	1973	1974	1975	1976	1977	1978	1979
Head	0.03	0.20	0.33	0.51	1.22	1.94	2.00
Whole-body	-	-	-	0.01	0.21	0.54	1.00
Total	0.03	0.20	0.33	0.52	1.41	2.48	3.00

Table 8

Effective dose equivalent and absorbed dose in gonads, eyes, and thyroid from various CT scanning procedures [S15]

Dose in organ or tissue	Head (8-14 slices)	Thorax (10-18 slices)	Abdomen (18-20 slices)
Effective dose equivalent (μSv)	40-100	60-110	80-120
Absorbed dose (μGy)			
Gonads (M/F)	1/5	1/1	10-50/10-150
Eyes	4000-6000	-	10
Thyroid	40-200	140	3-10

Table 9

Comparison of absorbed dose in skin and gonads from CT-scanning examinations of the kidney or from conventional urography [S18]

	CT-scanning (average of 10 patients)	Urography
Absorbed dose in skin (mGy)	31	166
Gonad dose (M/F) (mGy)	0.02/0.46	0.95[a]/12.7

a/ With gonad shielding 0.06 mGy.

Table 10

Doses in organs and tissues from various diagnostic x-ray examinations in Japan

The data were supplied to UNSCEAR by the delegation of Japan, 1982[a], as derived from [H27]

Type of examination		Average dose equivalent H_T (mSv) in the various tissues per full x-ray examination (radiography)						
		Gonads	Breast	Red bone marrow	Lung	Thyroid	Bone surface	Mean of other five organs or tissues
01	Hip and upper femur	2.7	0.0004	0.018	0.0014	0.002	0.054	0.52
03	Pelvis	0.5	0.0006	0.3	0.003	0.003	0.9	0.9
06	Lumbar spine	0.09	0.006	0.4	0.9	0.009	1.0	1.9
07	Urography	0.11	0.007	0.6	0.12	0.009	1.8	2.7
09	Urethrocystography	2.6	0.0011	0.34	0.0011	0.002	1.0	0.9
10	Stomach and upper G.I.T.							
	(a) Radiography	0.05	0.11	2.8	1.8	0.03	8.4	2.8
	(b) Photofluorography	0.06	0.6	2.5	4.0	0.17	7.5	5.5
11	Small intestine	2.9	0.0014	3.4	0.06	0.004	10.3	5.1
12	Abdomen	0.18	0.0018	0.8	0.004	0.002	2.3	0.9
15	Cholecystography	0.01	0.007	0.7	0.04	0.006	2.5	0.9
16	Chest (lungs, heart)							
	(a) Radiography	0.0001	0.3	0.07	0.3	0.10	0.2	0.12
	(b) Tomography	0.2	35	0.7	16.3	0.014	2.0	3.9
	(c) Photofluorography	0.0006	0.5	0.3	0.9	0.05	1.0	0.13
17	Head	0.001	0.03	0.3	0.09	0.13	0.8	0.17
24	CT-scan (head)	0.006	0.3	2.5	0.4	2.7	7.4	1.3

a/ These values should be used for males, as those for females are slightly different, mostly for the gonads.

Table 11

Doses in organs and tissues from various diagnostic x-ray examinations in Japan

The data were supplied to UNSCEAR by the delegation of Japan, 1982[a], as derived from [H27]

Type of examination		Average dose equivalent H_T (mSv) in the various tissues per full x-ray examination (fluoroscopy)						
		Gonads	Breast	Red bone marrow	Lung	Thyroid	Bone surface	Mean of other five organs or tissues
01	Hip and upper femur	0.4	0.0001	0.11	0.0004	0.0006	0.015	0.15
03	Pelvis	0.04	0.0001	0.06	0.0005	0.0005	0.17	0.17
06	Lumbar spine	0.004	0.0004	0.04	0.06	0.006	0.07	0.14
07	Urography	0.07	0.002	0.3	0.04	0.003	0.6	1.0
09	Urethrocystography	0.10	0.0004	0.12	0.0004	0.0008	0.4	0.3
10	Stomach and upper G.I.T	0.05	0.3	5.3	4.8	0.08	22	7.4
11	Small intestine	4.7	0.004	12.2	0.17	0.01	28.6	14.3
12	Abdomen	0.06	0.0008	0.11	0.0018	0.001	0.3	0.4
15	Cholecystography	0.015	0.014	0.4	0.07	0.01	1.2	1.7
16	Chest (lungs, heart)	0.0001	0.08	0.02	0.08	0.03	0.05	0.03
17	Head	0.0000	0.0002	0.002	0.0008	0.0011	0.007	0.0015

a/ These values should be used for males, as those for females are slightly different, mostly for the gonads.

Table 12

Doses in organs and tissues from various diagnostic x-ray examinations in Poland

The data were supplied to UNSCEAR by the delegation of Poland, 1982, as derived from [J5]

Type of examination	View	Dose equivalent (mSv)						
		Gonads	Breast	Red bone marrow	Lungs	Thyroid	Bone surface	Liver a/
Mass miniature radiography (70-kVp; HVL 2.9 mm Al)	P/A	<0.01	0.11	0.46	0.75	0.20	0.83	0.07
Chest radiography (70-kVp; HVL 2.9 mm Al)	P/A	<0.01	0.03	0.11	0.18	0.05	0.20	0.02
Chest tomography (70-kVp; HVL 2.9 mm Al)	A/P	0.02	46.0	2.0	15.0	25.0	3.6	4.15
Stomach and upper G.I.T. (fluoroscopy) (90-kVp; HVL 4.2 mm Al)	P/A	3.75	1.3	6.2	6.4	0.6	11.1	4.0
Urography (80-kVp; HVL 3.6 mm Al)	A/P	8.95	2.3	3.3	9.85	0.22	5.95	45.0
Cervical spine (fluorography) (70-kVp; HVL 2.9 mm Al)	A/P	<0.01	5.2	0.68	1.9	13.5	1.2	0.03
Dental (fluorography) (60-kVp; HVL 2.0 mm Al)	A/P	0.02	0.01	0.08	0.01	0.01	0.14	0.01
Humeral joint (fluorography) (60-kVp; HVL 2 mm Al)	A/P	<0.01	0.71	0.02	0.09	0.30	0.04	<0.01
Hip joint (fluorography) (80-kVp; HVL 3.6 mm Al)	A/P	5.0	0.09	0.47	0.38	<0.01	0.85	4.4
Cholecystography (70-kVp; HVL 2.9 mm Al)	P/A	0.97	0.20	2.75	1.55	0.02	4.95	1.4
Cholangiography (70-kVp; HVL 2.9 mm Al)	P/A	0.92	0.34	3.60	1.85	0.02	6.50	2.05
Sinuses (fluorography) (70-kVp; HVL 2.9 mm Al)	P/A	<0.01	0.02	1.7	0.08	0.33	3.05	<0.01
Lumbo-sacral spine (fluorography) (80-kVp; HVL 3.6 mm Al)	A/P	2.35	0.85	0.8	2.20	0.03	1.50	12.5

a/ As representative of the remainder.

NOTE:

1. The data refer only to adult patients (above 14 years of age).
2. Examinations in adults account for 91.7 % of all x-ray examinations in Poland.
3. The examinations included in the table account for 78.5 % of the total number of x-ray examinations of adults in Poland in 1976.
4. For the application of the ICRP weighting factors and procedure for calculation of the effective dose equivalent the data are averaged for both sexes.
5. As a first approximation the absorbed dose in the liver was assumed to represent the dose for the "remainder" of tissues.
6. In the case when absorbed dose in a given organ was lower than 0.01 mSv, the value 0.01 mSv was taken for calculation of the effective dose equivalent.

Table 13

Summary of diagnostic radiology performed in the United Kingdom showing contributions to the genetically significant dose equivalent (comparison of the 1957 and 1977 national surveys)
[D5]

Type of examination and/or type of institution	1957		1977	
	Thousands of examinations	GSD (μSv)	Thousands of examinations	GSD (μSv)
The Armed Services	412	4.1	418	2.2
Hospitals not in the National Health Service	286	2.4	323	1.7
Private medical radiology	100	0.8	250 a/	1.3
Mass miniature radiology	4770	0.1	1400	-
Other	288	1.0	135	-
Total	5856	8.4	2526	5.2
Hospitals in the National Health Service	13000	132.4	21338	112.6
Total (excluding dental)	18856	140.8	23864	117.8
Dental	2000	0.1	5750	0.3
Total (including dental)	20856	140.9	29614	118.1

a/ Including chiropractors.

Table 14

Summary of diagnostic radiology in Japan and genetically significant dose equivalent (comparison between the years 1969, 1974 and 1979)
[H26]

	1969	1974	1979
Total number of examinations	$6.4\ 10^7$	$7.3\ 10^7$	$9.6\ 10^7$
Number of examinations per 1000 population	621	664	830
Genetically significant dose (μSv)	257	165	150

Table 15

Genetically significant dose equivalent from diagnostic x-ray examinations in Japan

[H4,H5,H6,H7,H9,H10,H13,H14,H16,H17,H18,H19,H26,H27,H28,H35,M3,M4,M5,M19]

Type of medical irradiation	GSD (μSv)					
	1960	1969	1974	1975	1979	1980
x-ray radiography	174	152	111	-	100	-
x-ray photofluorography						
Chest	5.7	7.9	-	0.32	-	-
G.I.T.	-	0.4	-	1.5	-	-
x-ray fluoroscopy	50	105	-	-	49.9	-
Dental intra-oral radiography	-	-	0.13	-	-	0.08
Dental orthopantomography	-	-	0.00088	-	-	0.01

Table 16

Estimates of the effective dose equivalent (mSv) from various diagnostic x-ray examinations in Japan and Poland

The data were supplied to UNSCEAR by the delegations of those two countries, as derived from [H27] *and* [J5]

Type of examination		Japan [H27] 1979		Poland [J5] 1976
		Radiography	Fluoroscopy	
01	Hip and upper femur	0.84	0.16	2.71
03	Pelvis	0.46	0.07	-
06	Lumbar spine	0.78	0.06	4.87
07	Urography	0.98	0.38	17.85
09	Urethrocystography	0.99	0.14	-
10	Stomach and upper G.I.T.			
	(a) Radiography	1.67	-	-
	(b) Fluoroscopy	-	4.15	4.2
	(c) Photofluoroscopy	2.77	-	-
11	Small intestine	2.98	7.81	-
12	Abdomen	0.48	0.16	-
15	Cholecystography	0.44	0.61	1.36
	Cholangiography	-	-	1.75
16	Chest (lungs, heart)			
	(a) Radiography	0.13	-	0.06
	(b) Fluoroscopy	-	0.04	-
	(c) Photofluoroscopy	0.29	-	0.22
	(d) Tomography	8.57	-	11.05
17	Head			
	(a) Conventional	0.13	0.001	0.32
	(b) CT-scan	1.09	-	-
	Cervical spine	-	-	1.54
22	Dental	-	-	0.023
	Humeral joint	-	-	0.14

a/ The data refer only to adult patients (above 14 years of age) and are averages for the two sexes.

Table 17

Relative frequency (per cent) of diagnostic nuclear medicine procedures in various countries

Type of examination	Australia		Denmark					United States		
	1970 [K13]	1980 [L10]	1973 [S13]	1975/76 [S25]	1977 [S26]	1978 [S27]	1979 [S27]	1966 [U7]	1977 [M8]	1978 [U16]
NERVOUS SYSTEM										
Brain scintigraphy	24.2	18.4	17.6	19.25	20.26	16.50	14.29	8.6	47.3	23.2
Regional brain perfusion imaging	-	-	-	1.51	1.90	1.31	1.80	-	-	-
Cisternography	0.5	-	-	0.14	0.11	0.11	0.14	-	-	-
Craniopharyngeoma imaging	-	-	-	-	-	-	-	-	-	-
NECK ORGANS										
Salivary glands	-	-	-	-	0.14	-	0.04	-	-	-
Thyroid-uptake	27.2	1.5	10.4	8.60	6.00	5.21	4.90	41.6	5.3	1.0
Thyroid-scintigraphy	9.2	9.0	7.8	6.39	8.16.	8.31	9.1	21.0	6.6	8.5
Parathyroid scintigraphy	-	-	-	0.01	-	-	-	-	-	-
THORAX										
Lung scintigraphy (per fusion)	13.1	11.3	2.16	4.0	3.7	3.88	3.58	3.2	7.2	12.8
Lung ventilation study	-	3.4	-	0.89	0.3	0.6	0.54	-	3.1	4.1
Cardiovascular imaging	-	-	-	0.12	0.08	0.45	0.23	-	-	2.9
Myocardial scintigraphy	-	1.7	-	0.15	0.49	-	-	-	0.7	-
AV shunt	-	-	-	-	-	-	-	-	-	-
DIGESTIVE TRACT ORGANS										
Liver-spleen	12.9	21.5	5.06	8.35	8.54	8.44	8.57	8.4	14.6	21.1
Liver-gallbladder	-	1.7	0.25	0.52	0.84	0.81	0.89	-	0.6	0.8
Liver-pancreas	0.9	-	0.09	0.1	0.07	0.03	0.03	-	0.7	-
Spleen	0.4	-	-	0.31	0.35	0.36	0.51	-	-	0.2
Stomach and GI-blood or protein loss	0.6	0.1	-	0.97	1.73	1.18	1.08	-	-	-
Vitamin B12 absorption	1.0	0.3	4.18	3.16	2.27	2.07	1.86	23.0	-	-
UROGENITAL ORGANS										
Renography	1.6	0.5	5.4	19.66	17.22	17.6	17.6	-	0.9	0.4
Kidney GFR test	-	-	2.1	3.32	3.5	4.02	4.04	-	0.6	-
Kidney scintigraphy (dynamic and static)	1.6	1.4	15.5	5.66	4.79	5.94	5.71	-	1.8	3.5
Kidney, ureter, bladder	-	-	-	0.52	0.55	0.97	0.81	-	-	-
Adrenal glands imaging	-	-	-	0.09	0.05	0.07	0.06	-	-	-
Placenta imaging	1.8	-	-	0.86	0.48	0.30	0.21	-	-	-
SKELETON AND MARROW										
Skeleton scintigraphy	1.2	24.4	2.9	7.08	11.3	14.43	17.65	0.9	5.8	17.2
Scintimetry of joints	-	-	-	0.04	0.05	0.06	0.2	-	-	-
Bone marrow imaging	0.1	-	-	0.01	0.05	0.01	<0.01	-	-	-
Ca-metabolism	-	-	-	-	-	-	-	-	-	-
OTHER										
Deep vein thrombosis	1.0	-	-	0.07	0.31	0.48	0.33	-	-	-
Iron kinetics	0.4	-	0.29	-	0.04	0.04	0.03	-	-	-
Lymph scintigraphy	0.1	0.1	-	0.04	0.18	0.36	0.2	-	-	-
Blood cell survival time and plasma volume	1.0	0.8	-	1.99	1.59	1.48	1.72	14.0	-	-
Peripheral circulation	-	-	-	4.29	3.06	2.71	3.12	-	-	-
Whole-body profile	-	2.0	-	-	0.03	0.02	0.02	-	-	-
Other	1.4	0.1	6.2	0.83	1.27	1.72	0.87	-	1.5	3.1
Number of all types of examinations										
Total in thousands	52.0	117.3		57.8	68.3	72.7	71.7			8000
per 1000 population	4.1	8.0	3.8	11.4	13.4	14.3	14.1	3.71		36.7

Table 17, continued

Type of examination	Sweden [N2]							
	1971	1972	1973	1974	1975	1976	1977	1978
NERVOUS SYSTEM								
Brain scintigraphy	9.06	9.4	11.19	12.9	13.19	14.04	13.3	13.3
Regional brain perfusion imaging	-	-	-	-	-	-	0.29	0.38
Cisternography	-	-	-	-	-	-	0.25	0.19
Craniopharyngeoma imaging	-	-	-	-	-	-	0.01	-
NECK ORGANS								
Salivary glands	-	-	-	-	-	-	0.01	0.02
Thyroid-uptake	17.24	17.7	15.81	12.7	10.73	9.2	8.22	4.86
Thyroid-scintigraphy	19.83	14.9	14.95	14.6	12.6	11.8	11.11	11.99
Parathyroid scintigraphy	-	-	-	-	-	-	0.03	0.02
THORAX								
Lung scintigraphy (per fusion)	1.97	2.5	2.55	2.9	3.05	3.87	4.21	4.44
Lung ventilation study	2.64	2.5	3.15	2.8	1.28	2.40	2.00	0.77
Cardiovascular imaging	-	-	-	-	-	-	0.34	0.4
Myocardial scintigraphy	-	0.03	0.045	0.08	0.23	1.16	1.01	1.02
AV shunt	-	-	-	-	-	-	0.16	0.18
DIGESTIVE TRACT ORGANS								
Liver-spleen	10.94	11.34	11.35	12.0	12.91	11.9	13.0	14.0
Liver-gallbladder	-	-	0.005	0.07	-	-	0.15	1.1
Liver-pancreas	0.27	0.13	0.51	0.59	0.84	0.72	0.47	0.59
Spleen	-	-	-	-	-	-	1.18	0.09
Stomach and GI-blood or protein loss	-	-	-	-	-	-	0.096	0.25
Vitamin B12 absorption	3.93	4.3	3.4	2.5	2.61	2.21	1.86	2.0
UROGENITAL ORGANS								
Renography	20.39	22.0	24.03	23.3	26.34	22.95	17.68	16.7
Kidney GFR test	-	-	-	-	-	-	4.46	5.15
Kidney scintigraphy (dynamic and static)	1.35	1.7	1.26	1.8	0.99	1.09	1.76	1.02
Kidney, ureter, bladder	-	-	-	-	-	-	0.20	0.20
Adrenal glands imaging	-	-	-	-	-	-	0.11	0.12
Placenta imaging	-	-	-	-	-	-	0.4	0.25
SKELETON AND MARROW								
Skeleton scintigraphy	1.21	1.5	3.7	5.3	7.06	10.01	11.8	14.82
Scintimetry of joints	-	-	-	-	-	-	1.15	0.91
Bone marrow imaging	-	-	-	-	-	0.08	0.08	0.1
Ca-metabolism	-	-	-	-	-	-	0.07	-
OTHER								
Deep vein thrombosis	0.27	0.89	0.08	0.46	0.84	1.68	1.25	1.53
Iron kinetics	0.65	0.57	0.64	0.74	0.6	0.24	0.52	0.55
Lymph scintigraphy	0.19	-	0.18	0.17	0.06	0.012	0.054	0.06
Blood cell survival time and plasma volume	3.15	2.4	2.34	2.5	2.28	2.05	1.89	2.67
Tumour and abscess imaging	-	-	-	0.22	0.39	-	0.20	0.01
Peripheral circulation	0.58	0.2	0.5	0.36	0.07	0.01	0.29	1.16
Whole-body profile	-	-	-	-	-	0.33	0.82	0.81
Other	6.9	5.13	3.53	4.0	3.93	4.1	0.9	1.03
Number of all types of examinations								
Total in thousands	66.9	71.2	88.4	95.7	98.9	112	114	120
per 1000 population	8.29	8.79	10.9	11.7	12.1	13.6	13.8	14.5

Table 18

Frequency of in vivo diagnostic nuclear medicine procedures per 1000 population in two countries according to a WHO survey, 1979 [W13]

Country	Year	Frequency per 1000 population
Burma	1972	0.16
	1973	0.17
	1974	0.18
	1975	0.20
	1976	0.20
	1977	0.24
	1978	0.22
Cuba	1976	0.79
	1977	0.85
	1978	0.81

Table 19

Annual frequency of diagnostic nuclear medicine procedures for 1978 as reported by WHO Regional Offices [W13]

(Annual number of examinations per million population in parentheses)

Type of examination	Burma	Colombia	Cuba	Guatemala	Peru	Sri Lanka
	Number of population (in millions)					
	33	25.7	9.6	6.6	17	14.2
NERVOUS SYSTEM						
Brain scintigraphy	268 (8.1)	220 (8.56)	567 (59)	147 (22)		40 (2.8)
Regional brain per fusion imaging					2000 (118)	
Cisternography		1 (0.03)				
Craniopharyngeoma imaging					31 (1.8)	
NECK ORGANS						
Thyroid-uptake	2776 (84)	1700 (66)	3230 (336)	466 (71)	19500 (1147)	4051 (285)
Thyroid-scintigraphy	1468 (44.5)	1200 (47)	2004 (209)		5330 (313)	1222 (86)
THORAX						
Lung scintigraphy (perfusion)	3 (0.1)	80 (3)	48 (5)	4 (1)	393 (23)	
Cardiovascular imaging		115 (4.5)				
Myocardial scintigraphy	15 (0.5)					
DIGESTIVE TRACT ORGANS						
Liver-spleen	1774 (53.8)	680 (26)		115 (17)	2205 (130)	34 (2.4)
Liver-gallbladder			270 (28)			50 (13.5)
Liver-pancreas			43 (4.5)			
Spleen			72 (7.5)			
Vitamin B12 absorption	8 (0.24)		67 (7.0)		10 (0.6)	
UROGENITAL ORGANS						
Renography	993 (30)	150 (5.8)	980 (102)		340 (20)	500 (35)
Kidney GFR test		315 (12)				
Kidney scintigraphy (dynamic,static)	47 (1.4)	195 (7.6)		2 (0.3)	446 (26)	1 (0.07)
Placenta imaging	143 (4.3)	30 (1.2)			74 (4.4)	
SKELETON						
Skeleton scintigraphy	9 (0.27)	120 (4.7)	64 (6.7)		550 (32)	
OTHER						
Iron kinetics			57 (5.9)		10 (0.6)	
Lymph scintigraphy					5 (0.3)	
Red cell survival time or volume	65 (2.0)		140 (14.6)		43 (2.5)	10 (0.7)
Tumour scintigraphy	4 (0.1)		17 (1.8)			
Other			234 (24.4)		20 (1.2)	

Table 20

Relative frequency (per cent) of radiopharmaceuticals administered in diagnostic nuclear medicine procedures

Radio-nuclide	Chemical form	Australia		Denmark				Sweden			United States	
		1970 [K13]	1980 [L10]	1976 [S25]	1977 [S26]	1978 [S27]	1979 [S27]	1976 [N2]	1977 [N2]	1978 [N2]	1976 [M8]	1978 [U16]
^{3}H	water, labelled compounds	0.08	-	0.97	0.17	1.14	0.37	0.4	0.32	0.31	-	-
^{14}C	labelled compounds	-	0.05	0.46	0.4	0.38	0.32	0.54	0.51	0.55	-	0.05
^{18}F	fluoride	0.7	-	0.03	0.1	-	-	-	-	-	-	-
$^{22,24}Na$	chloride	0.08	-	0.19	0.17	0.08	0.04	0.09	0.04	0.04	-	-
^{32}P	phosphate	0.3	0.04	<0.01	<0.01	0.01	<0.01	0.04	0.03	0.01	-	0.03
^{42}K	chloride	-	-	0.23	0.08	0.01	0.04	-	<0.01	-	-	-
$^{45,47}Ca$	chloride	-	-	0.46	0.77	0.47	0.76	0.04,0.09	0.04,0.03	0.03	-	-
^{51}Cr	chromate, RBC	2.0	1.0	3.5	4.0	4.35	4.27	4.32	4.9	5.6	-	0.04
^{55}Fe	citrate	-	-	-	-	-	-	0.04	0.2	0.24	-	-
^{57}Co	cyanocobolamin, bleomycin	0.6	0.8	1.46	1.42	1.28	1.16	1.35	0.98	1.29	-	0.19
^{58}Co	cyanocobolamin (vit. B-12)	0.4	0.5	1.84	0.94	0.86	0.79	0.88	0.88	0.81	-	0.01
^{59}Fe	citrate	0.45	0.03	0.13	0.04	0.04	0.03	0.2	0.33	0.31	-	-
^{64}Cu	ion	-	-	0.29	-	-	-	-	-	-	-	-
^{65}Zn	ion	-	-	-	-	-	-	0.08	0.06	0.06	-	-
^{67}Ga	citrate	-	2.0	0.54	0.64	0.77	0.32	0.01	0.13	0.06	2.8	2.8
^{68}Ga	citrate	-	-	-	-	-	-	-	-	0.04	-	0.4
^{75}Se	selenomethionine	0.85	0.03	0.1	0.07	0.03	0.03	0.73	0.46	0.34	-	-
$^{81}Rb/^{81m}Kr$	gas	-	-	-	-	0.16	0.1	-	0.05	<0.01	0.14	-
^{82}Br	bromide	-	-	0.12	0.13	0.01	-	-	-	-	-	-
^{85}Kr	gas dissolved in saline	-	-	0.02	-	-	-	-	<0.01	<0.01	-	-
^{85}Sr	chloride	-	-	49.8	-	-	-	0.83	0.78	0.64	-	-
^{87m}Sr	chloride	0.5	-	-	-	-	-	-	-	-	-	-
^{99m}Tc	pertechnetate, labelled compounds, colloid and particles	53.3	89.0	-	56.2	56.7	57.8	45.8	49.8	54.5	80.5	81.7
^{111}In	DTPA	-	0.02	-	0.06	0.09	0.14	0.03	0.6	0.19	-	0.09
^{113m}In	DTPA, colloid and particles	2.8	0.1	0.93	0.52	0.31	0.25	0.54	0.01	0.29	4.1	-
^{123}I	iodide, labelled compounds	-	-	0.12	-	0.11	0.06	0.05	0.08	0.1	0.01	0.8
^{125}I	iodide, labelled compounds	1.35	0.3	6.5	7.73	7.92	7.61	10.5	8.42	8.56	-	0.19
^{127}Xe	dissolved in saline	-	0.02	0.01	0.01	0.1	0.17	-	-	-	-	-
^{131}I	iodide, labelled compounds	31.1	0.9	26.5	22.1	21.4	21.0	29.7	27.9	23.04	8.0	8.38
^{132}I	iodide	-	-	1.31	0.56	0.55	0.41	-	-	-	-	-
^{131}Cs	iodide	0.35	0.3	-	-	-	-	-	-	-	-	-
^{133}Xe	gas and dissolved in saline	0.02	3.4	4.15	3.88	3.49	4.29	2.91	2.62	2.2	3.1	3.8
^{169}Yb	DTPA	0.3	-	0.06	0.03	0.01	0.01	0.1	0.04	-	-	0.05
^{197}Hg	chlormeodrin, BMHP	1.55	-	0.35	0.01	-	-	0.03	-	-	0.03	-
^{198}Au	colloid	0.85	-	-	-	-	-	0.19	0.16	0.06	-	-
^{201}Tl	chloride	-	1.6	-	-	0.04	0.01	0.47	0.66	0.75	-	-
^{203}Hg	chlormeodrin	0.02	-	-	-	-	-	-	-	-	0.07	-

Table 21

Estimated installations of scintillation cameras and population per scintillation camera in Europe 1978 with annual growth rate from 1977 to 1978 [P9]

Country	Population in millions	Installed scintillation cameras 1978	Growth of installations as compared to 1977 (%)	Population per scintillation camera (1000)
Austria	7.51	34	26	220
Belgium	9.84	63	5	160
Bulgaria	8.81	3	50	2940
Czechoslovakia	15.15	28	4	540
Denmark	5.1	37	6	140
Finland	4.75	28	17	170
France	53.28	134	7	400
German Dem. Rep.	16.76	8	14	2100
Germany, Fed.Rep.of	61.32	498	44	120
Greece	9.36	13	44	720
Netherlands	13.94	104	22	130
Hungary	10.69	3	50	3560
Italy	56.7	86	32	660
Norway	4.06	22	10	180
Poland	35.01	11	10	3180
Portugal	9.8	4	0	2450
Romania	21.85	7	0	3120
Spain	37.11	35	25	1060
Sweden	8.28	69	8	120
Switzerland	6.34	45	10	140
United Kingdom	59.06	206	26	290
Yugoslavia	21.91	23	64	950

Table 22

Mean absorbed dose in the most heavily exposed organs, in the gonads and in the whole body and effective dose equivalent per unit of administered activity [K2, K3, M10, N13, R5]

Radionuclide and compound	Type of administration	Mean absorbed dose per unit administered activity (μGy/MBq)				Effective dose equivalent (μSv/MBq)
		Tissues most heavily exposed	Testes	Ovaries	Whole body	
^{3}H water	i.v.	whole body, 15	15	15	15	15
	oral	colon, 33; G.I.T., 30			15-22	15
^{3}H inulin	i.v.	kidneys: normal, 1 no outflow, 1300	0.1	0.1	0.1	1
^{11}C monoxide	inhalation or i.v.	heart, 23; lungs, 9-12	2.5	2.5	3	5
^{14}C inulin	i.v.	kidneys: normal, 8 no outflow, 11000	1	1	1	11
^{13}N ammonium	i.v.	lung, 49; kidneys, 5	3	3	2.5	10
fluoride	i.v.	skeleton 30-60; bone marrow, 50	5-12	5-12	5-20	21
^{22}Na chloride	i.v. or oral	skeleton,6200; bone marrow,4400	3200	3200	3100	3100
^{24}Na chloride	i.v. or oral	bone marrow, 450; skeleton, 410	340	350	400	340
^{32}P phosphate	soluble i.v.	skeleton,7600; bone marrow,8000	1300	1300	2200	1700
	oral	colon, 5400; G.I.T., 2000			1900	2400
	insoluble oral	colon, 21000; G.I.T., 1500			1300	2700
^{42}K chloride	i.v.		220	220	250	220
^{45}Ca chloride	i.v.	skeleton, 19000; bone marrow, 5900	300	300	2600	1400
	oral	colon, 6300; G.I.T., 130			520	670
^{51}Cr chromate	oral	colon, 160; G.I.T., 30	3.5	41	6.3	35
chrom III ion	i.v.	skeleton, 90; bone marrow, 70	70	70	65	45
erythrocytes	i.v.	spleen, 1500; kidneys, 240	80	100	140	210
denatured erythrocytes	i.v.	spleen, 3400-24000; kidneys,140	17	25	50	400
ethylene diamine triacetate		kidneys: normal, 0.007 no outflow, 1500	0.2	0.8	0.5	2
^{55}Fe ion	i.v.	bone marrow; 4000; liver, 1000	91	230	250	550
^{57}Co vitamin B12	oral	liver, 25000; kidneys, 4300	30	1100	3500	2900
bleomycin	i.v.	kidneys, 100; liver, 50	20	28	15	29
^{58}Co vitamin B12	oral	liver, 85000; kidneys, 10000	500	2600	5000	5900
^{59}Fe ion complex	i.v.	spleen, liver, 17000 bone marrow, 13000	12000	6300	6400	12000

Table 22, continued

Radionuclide and compound	Type of administration	Mean absorbed dose per unit administered activity (μGy/MBq)				Effective dose equivalent (μSv/MBq)
		Tissues most heavily exposed	Testes	Ovaries	Whole body	
^{67}Ga citrate	i.v.	colon, 190; bone marrow, 160	65	76	70	110
^{68}Ga citrate	i.v.	intestine, 57; colon, 46	11	13	14	23
DTPA a/	i.v.	bladder, 500; kidney, 54	13	23	10	41
^{75}Se L-seleno methionine	i.v.	liver, kidney, 6800; pancreas, 3200	3000	1400	2200	2900
^{82}Br bromide	i.v.		440	410	370	430
^{85}Sr chloride	i.v.	skeleton, 5500; bone marrow 4500	850	1100	1500	1000
^{87m}Sr	i.v.	skeleton, 20; bone marrow, 10	4	4	4	7
^{99m}Tc pertechnetate	i.v.	ventricle, 68; thyroid 35	2	6	4	11
	oral	colon, 110; G.I.T., 55	1	25	5	25
albumin	i.v.	liver, 35; heart, 21	7	8	3	6
denatured red blood cells	i.v.	spleen, 150; pancreas, 43	< 1	1	5	53
dimercaptosuccinate	i.v.	kidney cortex, 280; kidney av.185	3	5	4	16
DTPA a/		kidneys:normal, 10; no outflow 420	3	6	5	7
red blood cells		spleen, 30; lungs, 25			9	7
phosphate complex	i.v.	skeleton, 14; kidneys, 9	5	6	3	7
iminodiacetate complex,	i.v.	gallbladder, 45; liver, 25	1	9	4	20
colloides	i.v.	liver, 92; spleen, 56	< 1	2	5	13
macroaggregates	i.v.	lungs, 50; thyroid, 23	2	2	3	16
plasmin	i.v.	spleen, 51; liver, 40	4	6	7	13
^{111}In ion	i.v.	liver, 880; bone marrow, 850			73	210
leucocytes	i.v.	spleen, 2800; liver, 610			140	330
bleomycin	i.v.	liver, 210	31	45	45	47
DTPA a/	i.v.	kidneys: normal, 15; no outflow, 7600			94	490
thrombocytes	i.v.	spleen, 6700; liver, 170				
^{113m}In ion	i.v.		4	4	4	4
aerosol	inhalation	lungs, 200	< 1	< 1	2	30
denatured red blood cells	i.v.	spleen, 1100; pancreas 21	1	2	5	72
DTPA a/	i.v.	kidneys: normal,50; no outflow 710	4	5	2	15
colloid	i.v.	liver, 140; spleen, 42	1	2	3	14
^{123}I iodide	i.v.	thyroid (35%), 5200; ventricle, 53	3	8	9	170
albumin	i.v.	spleen, 42; lungs, 29	16	18	17	21
o-hippurate	i.v.	kidneys: normal,10; no outflow 1500	3	4	2	15
^{125}I iodide	i.v.	thyroid (35%),330000; liver, 140	8	12	190	10000
albumin	i.v.	spleen, 550; lungs, 400	170	210	220	290
fibrinogen	i.v.	spleen, 260; lungs, 170	44	53	60	95
o-hippurate	i.v.	kidneys: normal,10; no outflow 7500	1	2	2	11
^{131}I iodide	i.v.	thyroid (35%), 530000; ventr., 340	26	38	260	16000
albumin	i.v.	spleen, 800; lungs, 670	460	480	480	680
macroaggregates	i.v.	lungs, 1900; liver, 410	120	120	50	360
o-hippurate	i.v.	kidneys: normal,10; no outflow 4500	3	4	3	16
^{127}Xe gas	inhalation	broncus epith., 14; lungs, 1			0.2	0.3
in saline	i.v.	lungs, 6; fat tissue, 1	0.3	0.4	0.4	0.5
^{133}Xe gas	inhalation	broncus epith., 30; lungs, 3	0.3	0.4	0.4	0.3
in saline	i.v.	lungs, broncus, 25; fat tissue 3	0.3	0.4	0.4	0.7
^{169}Yb DTPA a/	i.v.	kidneys: normal, 28; no outfl.32000	13	17	7	43
^{198}Au colloid	i.v.	liver, 11000; bone marrow, 730	10	38	380	1000
^{201}Tl ion	i.v.	colon, 220; kidneys, 200	750	100	35	94

a/ DTPA = diethylenetriaminepentaacetate.

Table 23

Frequency of radiotherapy procedures in 1978 as reported from some WHO regional offices [W13]

(Annual frequency per million population in parentheses)

Radiotherapy procedure	Burma	Indonesia	Sri Lanka
	Millions of population in 1978		
	33	146.9	14.2
External beam			
Cobalt-60 teletherapy		955 (6.5)	4454 (314)
x-ray therapy 100-150 kV			171 (12)
Brachytherapy			
Interstitial			
Gold-198 seeds			6 (0.4)
Radium-226 needles			118 (8.3)
Intracavity			
Radium-226 tubes		148 (1.0)	221 (15.6)
Applicators			
Radium-226 moulds			31 (2.2)
Strontium-90 eye applicators			11 (0.77)
Radiopharmaceuticals			
Thyroid cancer: iodine-131	4 (0.1)		
Thyreotoxicosis: iodine-131	165 (5)		22 (1.6)
Polycythaemia vera: phosphorus-32			2 (0.1)

Table 24

Data on the annual frequency of brachytherapy in Japan [H9]

		1971	1979
Treatments (number per million)	Female	400	217
	Male	54.5	16.2
	Total	454.5	233.2
Radiation source (relative frequency, %)	^{226}Ra	50.3	38.5
	^{222}Rn	2.3	a/
	^{137}Cs	7.2	16.0
	^{60}Co	28.5	38.5
	^{90}Sr	11.7	6.0
	^{90}Y	-	1.0
Source position (relative frequency, %)	Mouth	12.0	4.1
	Maxilla	1.6	3.2
	Neck	0.6	
	Breast	0.7	
	Cervix	60.0	85.5
	Femur	0.2	-
	Other	24.9	7.2

a/ Radon-222 has not been used for brachytherapy in Japan since 1976 because production has been stopped due to radiation protection problems.

Table 25

Annual number of treatments and relative frequency of various treatments with radiopharmaceuticals in Sweden during the years 1971-1978
[N2]

Radio-pharmaceutical	Disease or site treated	Annual number of treatments per million population (relative frequency in per cent of all treatments in brackets)							
		1971	1972	1973	1974	1975	1976	1977	1978
^{131}I	Thyroid diseases	249.8 (82.5)	271.0 (84.1)	297.3 (85.3)	300.1 (88.0)	298.4 (87.8)	387.1 (90.1)	357.6 (88.58)	350.3 (89.6)
^{32}P	Polycythemia vera	40.6 (13.4)	36.0 (11.2)	38.8 (11.1)	31.5 (9.22)	31.5 (9.3)	31.0 (7.2)	33.8 (9.38)	32.3 (8.3)
^{198}Au	Pleura and abdomen	2.4 (0.8)	1.9 (0.57)				0.4 (0.09)	1.44 (0.36)	0.96 (0.24)
^{32}P, ^{90}Y	Rheumatic arthritis	3.1 (1.0)	4.0 (1.23)	0.3 (0.07)	0.1 (0.04)	0.3 (0.07)			
^{198}Au, ^{90}Y	Knees and joints	1.8 (0.6)	3.5 (1.07)	4.4, (91.2)	3.3 (0.97)	5.0 (1.47)	6.9 (1.56)	9.1 (2.08)	5.9 (1.50)
^{90}Y	Pleural and perime-diastinal carcinoma	3.9 (1.3)	4.9 (1.53)	0.5 (0.14)	4.6 (1.36)	3.8 (1.11)		1.08 (0.27)	0.36 (0.09)
^{90}Y	Cystic craniopharyngeoma	1.3 (0.4)	0.4 (0.11)		1.5 (0.43)	0.6 (0.18)	1.0 (0.23)	1.08 (0.27)	1.2 (0.31)
^{32}P	Mycosis fungoides		0.5 (0.15)						
^{32}P	Metastasis, generalized carcinoma		0.13 (0.04)					0.24 (0.06)	
^{198}Au	Spinal cord cyst		0.1 (0.03)						

Table 26

Percentage of absorbed dose in ovaries and testes of the total treatment dose at maximum build-up at two different field locations
[N9]

(The last two columns give the gonad doses resulting from 45 Gy maximum absorbed dose in the treatment region)

Treatment region	Type of radiation	Percentage dose		Absorbed dose (mGy) with 45 Gy at maximum in treatment region	
		Ovaries	Testes	Ovaries	Testes
Mediastinum $10 \times 10\ cm^2$	45 MV x ray	0.15	0.2	68	90
	10 MV x ray	0.2	0.24	90	110
	45 MeV electron	0.3	0.2	135	90
	18 MeV electron	0.05	0.09	23	41
Paraaortal lymph nodes $10 \times 10\ cm^2$	45 MV x ray	0.4	0.1	180	45
	10 MV x ray	0.6	0.4	270	180
	45 MeV electron	0.15	0.07	68	32
	18 MeV electron	0.03	0.02	14	9

Table 27

Average percentage gonadal doses for various treatments using cobalt-60
[N8]

Type of treatment	Site or condition	Average CGD a/ (cm) field size (cm^2)	M	F	Percentage dose calculated M	F	Measured M	F
Head fields	Nose, middle ear, sinuses, paratoid, brain, CNS, pituitary, antrum	50	70	60	0.085	0.115	0.096	0.128
Neck fields	Pharynx, larynx, thyroid, upper oesophagus, upper postcricoid	100	60	50	0.130	0.200	0.195	0.254
Thorax fields	Bronchus, lung	150	40	30	0.445	0.900	0.468	0.850
	Lower oesophagus	130	50	40	0.252	0.395	0.220	0.382
	Breast	120	-	40	-	0.345	-	0.377
	Shoulder	200	60	50	0.150	0.225	0.170	0.210
Mante fields	Hodgkin's disease	850	40	30	1.200	3.250	1.150	3.300
		850	50	40	0.450	1.200	0.550	1.010
Abdominal fields	Stomach, bowel	120	30	20	0.850	2.200	0.915	2.410
	Lymphoma	220	30	20	1.150	3.400	1.250	3.280

a/ CGD = centre-of-the-field to gonad distance.

Table 28

Absorbed dose in the gonads of males and females per 1 Gy at the surface due to primary beams plus scatter radiation and from generalized leakage radiation
[H19]

Irradiation position	Male ^{60}Co gamma rays		200 kV x rays		10 MV x rays		10 MeV electrons		50 kV x rays	
	a/	b/	a/	b/	a/	b/	a/	b/	a/	b/
Head	0.21	-	0.043	-	0.487	-	0.25	-	0.005	-
Neck	0.35	-	0.075	-	0.54	-	0.385	-	0.015	-
Chest	0.475	0.0025	0.068	0.01	0.44	0.0015	0.5	-	0.016	-
Abdomen	0.382	0.006	0.06	0.018	0.29	0.0026	0.414	-	0.015	-
Ovaries	-	-	-	-	-	-	-	-	-	-
Pelvis	0.638	0.129	0.062	0.104	0.16	0.0043	0.657	0.002	0.015	0.028
Thigh	0.483	0.135	0.06	0.06	0.067	0.0274	0.507	0.0017	1.68	0.041
Testes	845	0.37	808	0.1	796	0.265	785	-	495	0.18
Lower leg	0.2	-	0.05	0.01	0.22	-	0.23	-	0.015	-
Foot	0.15	-	0.05	-	0.23	-	0.18	-	0.01	-

Irradiation position	Female ^{60}Co gamma rays		200 kV x rays		10 MV x rays		10 MeV electrons		50 kV x rays	
	a/	b/	a/	b/	a/	b/	a/	b/	a/	b/
Head	0.18	-	0.027	-	0.302	-	0.218	-	-	-
Neck	0.34	0.003	0.03	0.01	0.34	0.001	0.38	-	-	-
Chest	0.42	0.009	0.33	0.027	0.228	0.006	0.44	-	-	-
Abdomen	0.32	0.032	0.02	0.067	0.08	0.023	0.32	0.002	0.001	
Ovaries	460	0.64	165	1.11	607	0.48	1.8	-	30.6	-
Pelvis	0.38	0.075	0.03	0.2	0.05	0.05	0.37	0.005	0.01	-
Thigh	0.384	0.0072	0.026	0.022	0.096	0.005	0.4	0.001	0.01	-
Testes	-	-	-	-	-	-	-	-	-	-
Lower leg	0.16	-	0.02	-	0.175	-	0.065	-	-	-
Foot	0.075	-	0.02	-	0.11	-	0.045	-	-	-

a/ Gonad dose due to primary plus scatter radiation, in mGy per Gy at the surface of beam entrance.
b/ Gonad dose due to generalized leakage radiation, in mGy per Gy and cm^2 of the beam entrance surface.

Table 29

Absorbed dose in various organs outside the treatment area per unit absorbed dose in the surface of the beam entrance for 10 MV x ray radiotherapy

Irradiation position	Absorbed dose from scatter radiation in (mGy Gy^{-1} cm^{-2})						
	Thyroid	Breast	Stomach	Lungs	Bladder	Testes	Ovaries
Head	0.05	0.004	0.0004	0.015	-	-	-
Neck	-	0.009	0.0035	0.1	0.0002	0.1	0.001
Thorax	0.04	0.02	0.03	0.09	0.0008	0.002	0.006
Abdomen	0.004	0.03	0.17	0.11	0.007	0.004	0.023
Pelvis	0.001	0.003	0.07	0.005	0.16	0.03	0.31
Thigh	-	0.001	0.01	0.001	0.25	0.12	0.005

Table 30

Absorbed dose in various organs outside the treatment area per unit administered activity in radiopharmaceutical therapy [K24]

Administered radiopharmaceutical	Type of disease	Organ	Absorbed dose per unit administered activity (mGy/MBq)
^{131}I-iodide	Hyperthyroidism	Gonads	0.08
		Bone marrow	0.19
^{32}P-phosphate	Polycythemia vera	Gonads	0.14
^{198}Au-colloids	Malignant intraperitoneal and intrapleural infusions	Gonads	0.08
		Bone marrow	1.62
^{32}P-lipiodol F (with I-131 for scintigraphic localization of lymph nodes)	Malignant lymphoma	Lung	22.9
^{198}Au	Joint diseases	Regional lymph nodes	176
		Lymphocytes	2.7
		Liver	0.14
		Total body	0.35
^{90}Y	Joint diseases	Regional lymph nodes	246
		Liver	0.14
		Total body	0.35

Table 31

Genetically significant dose equivalent values (μSv) for radiation therapy reported at different times from various countries

Country	Year				Ref.
	1970	1971	1973	1978	
Australia	23	-	-	-	[S21]
Germany, Fed.Rep.of	-	-	6±2	8±3	[S2,S3,S4]
Japan	-	7	-	0.7	[H5, H19]
United States	-	23±1	-	-	[T1]

Table 32

Genetically significant dose equivalent value (μSv a^{-1}) and its percentage distribution, in Berlin (West) and in Munich [S2, S3, S4]

Type of disease	Berlin (West) (1973			Munich (1971)		
	Private GSD=1.7	Clinic GSD=6.5	Total GSD=8.2	Private GSD=1.9	Clinic GSD=4.1	Total GSD=6.0
Haemangioma	1.6	41.5	10.0	2.9	83.7	57.5
Arthrosis and arthritis	9.0	8.0	8.6	72.1 17.7	2.3	30.1
Keloid	71.0	7.0	57.7		6.0	4.5
Spleen or kidney transplants		10.5				
Anal region	13.0	31.0	23.7		0.1	
Other benign conditions	4.0	2.0		7.3	7.7	7.9
Malignant diseases	0	0	0	0	0	0

Table 33

Annual genetically significant dose equivalent from external beam therapy in Japan, by age and sex of the patients and by the nature of the conditions requiring radiotherapy

Age class	Annual genetically significant dose equivalent (μSv)				Ref.
	Male		Female		
	Benign	Malign	Benign	Malign	
0-14	0.41	0.39	3.10	0.61	
15-29	0.06	0.97	3.40	0.22	
30-44	0.01	0.29	0.02	0.11	
> 45	0	0	0	0	
Total 1971	0.48	1.65	6.52	0.94	[H5]
Total 1978	0.03	0.36	0.08	0.58	[H19]

REFERENCES

A2 Alcox, J. Patient exposures from intra-oral radiographic examinations. J. Am. Dent. Assoc. 88: 568–579 (1974).

A3 Andersson, I., L. Andrén, M. Nilsson et al. Reduction of absorbed dose in radiography of the breast. Acta Radiol., Diagn. 18: 264–268 (1977).

A6 Adrian. Radiological hazards to patients. Second report of the Committee under Lord Adrian. HMSO, London, 1960.

B1 Baily, N.A. Patient exposure to ionizing radiation in dental radiography. Radiology 69: 42–45 (1957).

B2 Baker, M.L. and J.F. Vandergrift. Fetal exposure in diagnostic radiology. Health Phys. 37: 237–239 (1979).

B3 Bassano, A., C.C. Chamberlein, J.M. Mozley et al. Physical performance and dosimetric characteristics of line Δ-scan 50 whole-body/brain scanner. Radiology 123: 455–462 (1977).

B5 Bengtsson, G., P.G. Blomgren, K. Bergman et al. Patient exposures and radiation risks in Swedish diagnostic radiology. Acta Radiol., Oncol. 17: 81–105 (1978).

B6 Bengtsson, G. Maxillo-facial aspects of radiation protection. Focused on recent research regarding critical organs. Dentomaxillofac. Radiol. 7: 15–14 (1978).

B9 Bjärngard, B. Radiation doses in oral radiography. I. Measurements of doses to gonads and certain parts of head and neck during full mouth roentgenography. Odont. Revy. 10: 355–366 (1959).

B10 Bjärngard, B. Radiation doses in oral radiography. II. The influence of technical factors on the dose to the patient in full mouth roentgenography. Odont. Revy. 11: 100–112 (1960).

B13 Brasch, R.C., D.P. Boyd and C.A. Gooding. Computed tomographic scanning in children, comparison of radiation dose and resolving power of commercial CT scanners. Am. J. Roentgenol. 131: 95–101 (1978).

B14 Brooks, R.A. and G. DiChiro. Theory of image reconstruction in computed tomography. Radiology 117: 561–572 (1972).

B15 Brown, L.H., G.K. Svensson and B.E. Bjärngard. Analytical description of the spatial distribution of scattered dose. Paper presented at the 20th Annual Meeting of the American Association of Physics in Medicine (AAPM), San Francisco, 1978.

B16 Brunner, P., A. Dwyer, G. Watkins et al. Public health impact of nuclear medicine practice. Proceedings of the Ninth Annual National Conference on Radiation Control. DHEW(FDA)78-8054 (1978).

B18 Bundesminister des Innern, Federal Republic of Germany. Umweltradioaktivität und Strahlenbelastung, Jahresbericht 1974. Bonn, 1976.

B19 Bunge, R.E. Three years of the nation-wide evaluation of x-ray trends (NEXT). An analysis presented at the Health Physics Society Meeting, June, 1976. U.S. Department of Health, Education and Welfare (1977).

B20 Bunge, R.E. Five years of the nation-wide evaluation of x-ray trends. U.S. Department of Health, Education and Welfare (1978).

B21 Bushong, S.C. Reduction of patient exposure during dental radiography. Health Phys. 21: 281–284 (1979).

B23 Briere, J. and B. Philippon. Absorbed dose to ovaries or uterus during a I-131-therapeutic treatment of cancer or hyperthyroidism: comparison between in vivo measurements by TLD and calculations. Health Phys. 30: 643–646 (1979).

B24 Bhave, D.G., C.A. Kelsey, J. Burstein et al. Scattered radiation doses to infants and children during EMI head scans. Radiology 124: 379–380 (1977).

B25 Brown, L.H., G.K. Svensson and B.E. Bjärngard. Scatter decrement values for rectangular fields. Med. Phys. 7 (1981).

B26 Boice, J.D. and G.B. Hutchison. Leukemia in women following radiotherapy for cervical cancer: ten-year follow-up of an international study. J. Natl. Cancer Inst. 65: 115–129 (1980).

B28 Boucot, K.R. and W. Weiss. Is curable lung cancer detected by semiannual screening? in: Proc. of Annual Meeting of American Medical Association. 1972.

C4 Cohen, G. and F.A. DiBianca. The use of contrast-detail-dose evaluation of image quality in a computed tomographic scanner. J. Comput. Assist. Tomogr. 3: 189–195 (1979).

C5 Committee on the Radiological Hazards to Patients. Final report of the Committee. HMSO, London, 1960.

C8 Cohen, G. Contrast-detail-dose analysis of six different computed tomographic scanners. J. Comput. Assist. Tomogr. 3: 197–203 (1979).

C10 Coffey, J.L. and E.E. Watson. Calculating dose from remaining body activity: a comparison of two methods. Med. Phys. 6: 307–308 (1979).

D5 Darby, S.C., G.M. Kendall, S. Rae et al. The genetically significant dose from diagnostic radiology in Great Britain in 1977. NRPB-R-106 (1980).

E4 Ewton, J.R., R.J. Shalek and R.L. Egan. Estimated radiation dose during mammography. Cancer Bull. 14: 116–117 (1962).

F3 Fulea, C., S. Ramboiu and S. Salagean. Medical irradiation of the population in Cluj-Napoca (Romania) 1977. La Santé Publique Rev. Int. Bucarest (1980).

F4 Frischauf, H. Report of the increase of the genetically significant dose from nuclear medicine examinations in Austria (in German). Nuclear Med. Dept. First Medical University Clinic, Vienna, Austria (1980).

F5 Frischbier, H.J. and K. Würthner. Critical comments on risk/benefit discussion in mammography from a clinical point of view. Vorsorgemedizin und Strahlenschutz (Risk/Benefit-analysis). Forschung und Praxis XVIII: 95–100 (1977) (in German).

F6 Frischhauf, H., K. Kletter and R. Dudczak. Radiation doses from nuclear medicine procedures. Austrian Federal Ministry of Health and Environmental Protection. Report 5/80. Vienna, Austria (1980).

G1 Grönberg, T., B. Persson and S.E. Strand. Experimental evaluation of organ doses from exposure to Tc-99m, I-123 and I-131. p. 493–496 in: Proceedings of the Fourth International Congress of IRPA, Paris, 1977.

G4 Gustafsson, M. Radiation doses and correlated late effects in diagnostic radiology. Ph. D. Thesis. University of Lund, Sweden, 1980.

G5 Gur, D. and S. Donald. Evaluation of benefits and risks of breast cancer screening. Radiology 124: 261–262 (1977).

H1 Halm, A. Escalation in non-productive radiography. Int. Soc. Radiogr. Radiol. Tech. Newsl. 13: 11–14 (1978).

H2 Hammerstein, G.R., D.W. Miller, D.R. White et al. Absorbed dose in mammography. Radiology 130: 485–491 (1979).

H3 Hashizume, T., Y. Kato, T. Maruyama et al. Population mean marrow dose and leukaemia significant dose from diagnostic medical x-ray examinations in Japan. 1969. Health Phys. 23: 845–853 (1972).

H4 Hashizume, T., Y. Kato, T. Maruyama et al. Genetically significant dose from diagnostic medical x-ray examinations in Japan. 1969. Health Phys. 23: 827–843 (1972).

H5 Hashizume, T., Y. Kato, Y. Kumomoto et al. Genetically significant dose from beam therapy in Japan. 1971. Health Phys. 26: 449–459 (1974).

H6 Hashizume, T., Y. Kato, Y. Kumomoto et al. Population mean marrow dose and leukaemia significant dose from beam therapy in Japan. 1971. Health Phys. 26: 461–467 (1974).

H7 Hashizume, T., T. Maruyama, K. Nishizawa et al. Comparison of genetically significant doses from medical uses of ionizing radiations and radionuclides in Japan. Proceedings of the First World Congress of Nuclear Medicine, World Federation of Nuclear Medicine and Biology. Kyoto, 1974.

H8 Hashizume, T., T. Maruyama, K. Nishizawa et al. Estimation of population dose from brachytherapy in Japan. Nippon Acta Radiol. 35: 1022–1031 (1975).

H9 Hashizume, T., T. Maruyama and Y. Kumamoto. Estimation of population dose from diagnostic medical examinations in Japan, 1974. 1. The number of radiographs, radiographic and fluoroscopic examinations. Nippon Acta Radiol. 36: 47–55 (1976).

H10 Hashizume, T., T. Maruyama and Y. Kumamoto. Estimation of population dose from diagnostic medical examinations in Japan, 1974. 2. Estimation of genetically significant dose. Nippon Acta Radiol. 36: 208–214 (1976).

H11 Hashizume, T., T. Maruyama and Y. Kumamoto. Estimation of population dose from diagnostic medical examination in Japan, 1974. 3. Per caput mean marrow dose and leukaemia significant dose. Nippon Acta Radiol. 36: 215–224 (1976).

H12 Hashizume, T., T. Maruyama and Y. Kumamoto. Estimation of population dose from diagnostic medical examinations in Japan, 1974. 4. Dose estimation of foetus exposed in utero to diagnostic x rays. Nippon Acta Radiol. 36: 645–651 (1976).

H13 Hashizume, T., Y. Kato, T. Maruyama et al. Estimation of population doses from stomach mass screening, 1975. Nippon Acta Radiol. 37: 590–599 (1977).

H14 Hashizume, T. and T. Maruyama. Estimation of population doses from chest mass screening, 1975. Nippon Acta Radiol. 37: 6 (1977).

H15 Hashizume, T. and T. Maruyama. Estimation of stochastic risk from medical x-ray diagnosis. Nippon Acta Radiol. 39: 170–173 (1979).

H16 Hashizume, T., T. Maruyama, Y. Tateno et al. Estimation of population doses from medical uses of radiopharmaceuticals in Japan, 1977. 1. The number of medical examinations using radiopharmaceuticals. Nippon Acta Radiol. 39: 267–276 (1979).

H17 Hashizume, T., T. Maruyama, H. Yamaguchi et al. Estimation of population doses from medical uses of radiopharmaceuticals in Japan, 1977. 2. Estimation of genetically significant dose, per caput mean bone marrow dose and leukaemia significant dose. Nippon Acta Radiol. 39: 747–760 (1979).

H18 Hashizume, T., H. Matsuzawa, T. Maruyama et al. Estimation of population doses from radiation teletherapy. 1. The number of irradiations, fields and patients. Nippon Acta Radiol. 40 (1980).

H19 Hashizume, T., H. Matsuzawa, T. Maruyama et al. Population doses from beam therapy in Japan, 1978. Part 2. Estimation of genetically significant dose per caput mean bone marrow dose and leukaemia significant dose. Nippon Acta Radiol. 40 (1980).

H21 Hobday, R. and R.P. Parker. Radiation exposure to the patient in computerized tomography. Br. J. Radiol. 51: 926–927 (1978).

H23 Horsley, R.J. and V.G. Peters. Radiation exposure from EMI-scanner-multiple scan. Br. J. Radiol. 49: 810–811 (1976).

H26 Hashizume, T., T. Maruyama, Y. Noda et al. Stochastic risk estimation from medical x-ray diagnostic examinations. 1. The number of radiographs and fluoroscopic examinations. Nippon Acta Radiol. 41 (1981).

H27 Hashizume, T., T. Maruyama, Y. Noda et al. Stochastic risk estimation from medical x-ray diagnostic examinations. 2. Risk estimates of individuals from x-ray diagnosis. Nippon Acta Radiol. 41 (1981).

H28 Hashizume, T., T. Maruyama, Y. Noda et al. Stochastic risk estimation from medical x-ray diagnostic examinations. 3. Population doses and population risks from x-ray diagnostics. Nippon Acta Radiol. 41 (1981).

H30 Heaton, B. and Susan Millard. Radiation dose to critical organs of staff and patients during neuroradiology. Br. J. Radiol. 52: 880–892 (1979).

H31 Hutchison, G.B. Late neoplastic changes following medical irradiation. Radiology 105: 645–652 (1972).

H33 Hutchison, G.B. Leukemia in patients with cancer of the cervix uteri treated with radiation. A report covering the first 5 years of an international study. J. Natl. Cancer Inst. 40: 951–982 (1968).

H35 Hashizume, T., T. Maruyama and K. Nishizawa. Population doses from brachytherapy in Japan 1979. Nippon Acta Radiol. 40: 878–884 (1980).

H36 Hinz, G. und W. Pietzsch. Entwicklung der Nuklearmedizin in Berlin (West) 1953–1975. STH-Bericht 10/76 (1976).

H37 Hinz, G. und H.D. Roedler. Anwendungshäufigkeit und Strahlenrisiko nuklearmedizinischer Untersuchungen unter besonderer Berücksichtigung des Radiojodtests. STH-Bericht (1981).

H41 Heaton, H.T. and R. Jacobs (eds.) Proceeding of a conference on neutrons from electron medical accelerators. U.S. Dept. of Commerce, National Bureau of Standards, Special Publication 554 (1979).

I1 Ice, R.D., W.J. Updegrave and E.I. Bogucki. Influence of dental radiographic cones on radiation exposure. J. Am. Dent. Assoc. 83: 1297–1302 (1971).

I2 International Atomic Energy Agency. Directory of High-Energy Radiotherapy Centres. IAEA, Vienna, 1976.

I5 International Commission on Radiological Protection. Report of the Task Group on Reference Man. ICRP publication 23, Pergamon Press, Oxford, 1975.

I6 International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection. ICRP publication 26. Pergamon Press, Oxford. Ann. ICRP 1: No.3 (1977).

I7 International Commission on Radiological Protection. Statement from the 1978 Stockholm Meeting of the ICRP. ICRP publication 28. Pergamon Press, Oxford. Ann. ICRP 2: No. 1: 1–22 (1978).

I12 Isherwood, I., I.M. Young, K.W. Bowker et al. Radiation dose to the eyes of the patient during neuroradiological investigations. Neuroradiolpgy 10: 137–141 (1975).

I13 Isherwood, I., B.R. Pullan and R.T. Ritchings. Radiation dose in neuroradiological procedures. Neuroradiology 16: 477–481 (1978).

I14 International Commission on Radiological Protection (ICRP) and International Commission on Radiological Units and Measurements (ICRU). Joint Study Group report on exposure of man to ionizing radiation from medical procedures. Med. Biol. 2: 107–151 (1957).

I16 International Commission on Radiation Units and Measurements. Methods of assessment of absorbed dose in clinical use of radionuclides. ICRU report 32 (1979).

I18 Iwai, K. Stochastic risk estimates from dental radiographic examinations in Japan 1980. Jap. Soc. Dental Radiol. 21: 19–31 (1981).

I19 International Commission on Radiological Protection. Problems involved in developing an index of harm. ICRP publication 27. Pergamon Press, Oxford. Ann. ICRP 1: No. 4: 1–24 (1977).

I20 International Commission on Radiological Protection. Protection of the patient in radiodiagnosis. Revision of ICRP publication 16 (in preparation, 1982).

J1 Johnson, D.W., F.G. Rueter, R.E. Bunge et al. National evaluation of x-ray trends, 1973–1978. Proceedings of the Health Physics Society Fourteenth Mid-Year Topical Symposium (1980).

J2 Jenssen, J.E. and P.F. Butler. Breast exposure: nationwide trends: a mammographic quality assurance program — results to date. Radiol. Technol. 50: 251–257 (1978).

J3 Jetne, V. Gonadal doses in radiation therapy of malignant disease. in: Proceedings of the Eighth Nordic Meeting on Clinical Physics (E. Petursson, ed.). Reykjavik, Iceland, 1975.

J4 Jung, T. Gonadal doses resulting from panoramic x-ray examinations of teeth. Oral Roentgenology 19: 745–753 (1965).

J5 Jankowski, J. Evaluation of the risk of neoplasm induction in the Polish population in result of x-ray radiation applied for medical purposes. Studia i Materialy Monograficzne No. 3 (1980) (In Polish).

K1 Karlsson, M., K. Nygred, G. Wickman et al. Absorbed dose in mammary radiography. Acta Radiol., Ther., Phys., Biol. 15: 252–258 (1976).

K2 Kaul, A., K. Oeff, H.D. Roedler et al. Die Strahlenbelastung von Patienten bei der nuklearmedizinischen Anwendung offener radioaktiver Stoffe. Informationsdienst für Nuklearmedizin, Klinikum Steglitz der Freien Universität Berlin (1973).

K3 Kaul, A., K. Oeff, H.D. Roedler et al. Radiopharmaceuticals-biokinetic data and results of radiation dose calculations. Informationsdienst für Nuklearmedizin, Klinikum Steglitz der Freien Universität Berlin (1973).

K8 Krauss, O. and H. Schuhmacher. Measurement of the absorbed dose to the patient by computerized whole-body x-ray tomography with aid of thermoluminescence dosimeters in an Alderson-Phantom. Radiology 16: 288–293 (1976) (in German).

K9 Krauss, O. and H. Schuhmacher. Absorbed dose to the patient by computerized whole-body x-ray tomography. p. 1095–1098 in: Proceedings of the Fourth International Congress of IRPA, Paris, 1977.

K10 Kaude, J. and G. Svahn. Absorbed gonad and integral doses to the patient and personnel from angiographic procedures. Acta Radiol., Diagn. 15: 454–464 (1974).

K11 Knizhnikov, V.A., R.M. Barkhudarov, F.M. Lyass et al. Collective radiation dose to the USSR population as the result of the medical use of sources of ionizing radiation. Med. Radiol. 3: 40–45 (1980) (in Russian).

K12 Kendall, G.M., S.C. Darby, S.V. Harries et al. A frequency survey of radiological examinations carried out in national health service hospitals in Great Britain in 1977 for diagnostic purposes. NRPB-R104 (1980).

K13 Keam, D.W. Genetic and mean bone-marrow doses from medical use of unsealed radioisotopes. ARL/TR-023 (1980).

K15 Kramer, R. Ermittlung von Konversionsfaktoren zwischen Körperdosen und Gamma-Bestrahlung. GFR-S-556 (1979) (in German).

K16 Kainberger, F. and W. Kallinger. Comparative measurements of the radiation dose in mammography with two different systems. Röntgenpraxis 32: 93–100 (1979) (in German).

K17 Kase, K.R., G.K. Svensson and T.S. Chen. Radial distribution of scattered and leakage radiation dose for radiotherapy equipment. in: Biomedical Dosimetry: Physical Aspects, Instrumentation and Calibration. IAEA, Vienna, 1981.

K18 Kohn, H.I., J.C. Bailar and C. Zippin. Radiation therapy for cancer of the cervix: its late effect on the lifespan as a function of regional dose. J. Natl. Cancer Inst. 34: 345–361 (1965).

K20 Kaul, A. and H.D. Roedler. Dosimetrie. in: Nuklearmedizin — Funktionsdiagnostik und Therapie (D. Emrich, ed.). Georg Thieme Verlag, Stuttgart, 1979.

K21 Kaul, A., K. Henrich and H.D. Roedler. Radionuclide biokinetics and internal dosimetry in nuclear medicine. Laricera Clin. Lab. 10: 629–660 (1980).

K22 Kereiakes, J.G. and M. Rosenstein. Handbook of Radiation Doses in Nuclear Medicine and Diagnostic x-ray. CRC Press, 1980.

K23 Kaul, A., H.D. Roedler and G.J. Hine. Internal absorbed dose from administered radiopharmaceuticals. in: Medical Radionuclide Imaging. IAEA, Vienna, 1977.

K24 Kaul, A. Strahlenschutz bei nuklearmedizinischer Therapie. Der Nuklearmediziner 2: 328–338 (1979).

K27 Kudritsky, Ju.K. and V.D. Serebrjannikov. Peculiarities of changes of the level of radiation safety for patients and population of the RFSFR during x-ray examinations in IX five-year plan. Proceedings of the VIIIth All-Russian Scientific Conference on Radiation Hygiene. Leningrad, 1978.

K28 Kudritsky, Ju.K., V.D. Serebrjannikov, A.I. Kuznetsov et al. Heightened requirements for providing radiation safety for patients and population in standardization of x-ray examinations. Radiation Hygiene. LIRH, Leningrad, (1980).

K29 Kudritsky, Ju.K., V.D. Serebrjannikov, E.B. Kisel'gof et al. Some ways of hygienic estimation of radiation safety level during mammography. Radiation Hygiene. LIRH, Leningrad (1980).

K30 Kramer K. and L. Widenman. Organ doses for different radiation qualities in diagnostic radiology. Gesellschaft für Strahlen- und Umweltforschung report (1981).

K32 Kramer, R., R. Veit and G. Drexler. Body dose conversion factors for computerized tomography. p. 79–91 in: Biomedical Dosimetry: Physical Aspects, Instrumentation and Calibration. IAEA, Vienna, 1981.

L2 Laws, P.S. and M. Rosenstein. A somatic dose index for diagnostic radiology. Health Phys. 35: 629–642 (1978).

L7 Lehtinen, E. and E. Vauramo. How many x-ray examinations are needed in Finland? Research Report. Department of Medical Physics, Tampere, Finland.

L8 Löhr, H., H. Vogel, H. Wroblewski et al. Radiation exposure and radiation risks from body scanners. Fortschr. Röntgenstr. 132: 667–671 (1980) (in German).

L9 Lewis, W.W. Mobile X-ray units: a critical look. National Tuberculosis and Respiratory Disease Association. NTRDA Bulletin, October (1971).

L10 Lokan, K.H. Communication (1982).

M3 Maruyama, T. and T. Hashizume. Estimation of population doses from dental radiography in Japan, 1974. Jap. Soc. Dent. Radiol. 17: 52–63 (1977).

M4 Maruyama, T., Y. Noda and T. Hashizume. Determinations of organs doses during intra-oral dental x-ray examinations and orthopantomographic examinations. Jap. Soc. Dent. Radiol. 18: 271–277 (1978).

M5 Maruyama, T., Y. Noda and T. Hashizume. Risk estimation from dental diagnostic x-ray examinations. Jap. Soc. Dent. Radiol. 19: 1–7 (1979).

M6 McCullough, E.C. and J.T. Payne. Patient dosage in computed tomography. Radiology 129: 457–463 (1978).

M8 McIntyre, A.B., D.R. Hamilton and R.C. Grant. A pilot study of nuclear medicine reporting through the medically oriented data system. DHEW(FDA) 76-8045 (1976).

M10 Medical Internal Radiation Dose Committee (MIRD). MIRD dose estimate reports Nos. 1–8. J. Nucl. Med. (1973–1976).

M16 Muntz, E.P., E. Wilkenson and F.W. George. Mammography at reduced doses: present performance and future possibilities. Am. J. Roentgenol. 134: 741–747 (1980).

M18 McCall, R.C. and W.P. Swanson. Neutron production and leakage from medical electron accelerators. in: Proceedings of the Fifth International Congress of IRPA, Jerusalem, 1980. Pergamon Press, Oxford, 1980.

M19 Maruyama, T., K. Iwai, T. Honjoya et al. Estimation of population doses from dental radiography in Japan 1980. Jap. Soc. Dental Radiol. 21: 9–18 (1981).

M20 Malmström, I. Nuclearmedicine examinations 1968–1979. SSI:1980-30 (1980).

M22 Minjnheer, B.J. and J. Broerse. Dose distributions of clinical fast neutron beams. p. 109–115 in: High-LET Radiations in Clinical Radiotherapy. (G.W. Barendsen et al., eds.). Pergamon Press, Oxford, 1980.

N1 National Central Bureau of Statistics, Sweden. X-ray examinations at hospital departments 1976. Statistical report HS-No. 6 (1978).

N2 National Institute of Radiation Protection, Sweden. Annual reports from 1971–1978 on the use of radiopharmaceuticals at Swedish hospitals. (1979).

N3 Nemec, H.W. and J. Roth. Über die Strahlenbelastung des Kopfes, insbesondere der Augenlinsen, bei der axialen Tomographie mit dem EMI-Scanner. Fortschr. Röntgenstr. 124: 526 (1976).

N4 Neuweg, M.E. Illinois' patient exposure limits — an update. p. 134–143 in: DHEW(FDA) 77-8021 (1977).

N5 Nishizawa, K., T. Iwata and Y. Furuya. Determination of gonad eye and bone marrow doses with EMI-5005 head and whole-body scans. Nippon Acta Radiol. 39: 144–151 (1979).

N6 Nilsen, T. Measurements and estimates of gonadal dose outside a treatment region at a 7 MeV linear accelerator. in: Proceedings of the Eighth Nordic Meeting on Clinical Physics (E. Petursson, ed.). Reykjavik, Iceland, 1975.

N8 Novotny, J. and M.S. Tarakanath. Radiation protection of the patient during radiotherapy. Strahlentherapie 152: 191–198 (1976).

N9 Nüsslin, F. and E. Hassenstein. Radioprotection of patients in radiotherapy: the gonadal doses resulting from treatments at electron accelerators. p. 1117–1120 in: Proceedings of the Fourth International Congress of IRPA, Paris, 1977.

N10 Nüsslin, F. and E. Hassenstein. Measurements on the radiation protection of patients irradiated with an 18 MeV electron accelerator. Int. J. Radiat. Oncol., Biol. Phys. (1979).

N11 National Central Bureau of Statistics, Sweden. X-ray examinations 1977. Statistical report HS-No.5 (1980).

N12 Norer, B. and P. Brunner. Die Strahlenbelastung bei Panoramaschichtaufnahme und Einzelbildstatus. Eine vergleichende Studie. Österr. Z. Stomatologie 77: 145–153 (1980).

N13 National Institute of Radiation Protection, Sweden. Compilation of radiation doses of radioactive compounds in medical use (B. Nosslin et al., eds.). (1980) (in Swedish).

N14 Nishizawa, K., T. Iwata, Y. Furuya et al. Estimation of stochastic risk from computed tomography examinations in Japan 1979. 1. The number of examinations and scans. Nippon Acta Radiol. 41: 45–49 (1981).

N15 Nishizawa, K., T. Maruyama, T. Iwata et al. Estimation of stochastic risk from computed tomographic examinations in Japan. 2. Organ or tissue doses by computed tomographic examinations. Nippon Acta Radiol. 41: 242–249 (1981).

N17 National Department of Health in Sweden. Preliminary X-ray statistics, 1979 (1981).

N18 National Council on Radiation Protection and Measurements. Mammography. NCRP Report No. 66 (1980).

O1 O'Shaughnessy, P.E. and D.F. Mitchell. Effect of altering physical roentgenographic factors on patient radiation dose levels. J. Am. Dent. Assoc. 69: 335–342 (1964).

P1 Palmer, R.C., R.L. Egan and B.J. Barrett. Preliminary evaluation of absorbed dose in mammography. Radiology 95: 395–397 (1970).

P3 Pauly, H., T. Schmidt and G. Hasl. Organ doses and integral doses in x-ray diagnosis of the chest and of the head. p. 1091–1094 in: Proceedings of the Fourth International Congress of IRPA, Paris, 1977.

P4 Pauly, H. Stochastic late effects after partial body irradiation in diagnostic radiology: evaluation of approximate data. Radiat. Environ. Biophys. 15: 21–23 (1978).

P5 Perry, B.J. and C. Bridge. Computerized transverse axial scanning (tomography): Part 3. Radiation dose considerations. Br. J. Radiol. 46: 1048–1051 (1973).

P9 Pretschner, D.P. Nuclear Medicine in Europe. Consideration of present and future trends. Eur. J. Med. 5: 175–184 (1980).

P10 Persson, R.B. Effective dose equivalent concept in radiopharmaceutical dosimetry. p. 616–624 in: Third International Radiopharmaceutical Dosimetry Symposium. DHEW(FDA) 81-8166 (1981).

P11 Panzer, W., G. Drexler and L. Widenman. Spectra and dose values in mammography. GSF-Bericht S-518 (1978) (in German).

P12 Pellerin, P. and J. Chanteur. Communication (1982).

R2 Rice, J.F. and T.E. Banks. Normal and high accuracy computed tomography of the brain: dose and imaging considerations. J. Comput. Assist. Tomogr. 3: 497–502 (1979).

R3 Richards, A.G., A. Arbor and R.L. Webber. Dental x-ray exposure of sites with the head and neck. Oral Surg., Oral Med., Oral Pathol. 18: 752–756 (1964).

R4 Roedler, H.D., A. Kaul, W. Berner et al. Development of an extended formalism for internal dose calculation and practical application to several biologically distributed radioelements. p. 515–541 in: Assessment of Radioactive Contamination in Man. IAEA, Vienna, 1972.

R5 Roedler, H.D., A.K. Kaul and G.J. Hine. Internal radiation dose in diagnostic nuclear medicine. Verlag H. Hoffman, Berlin, 1978.

R6 Rosenstein, M. Organ doses in diagnostic radiology. DHEW(FDA) 76-8030 (1976).

R7 Rosenstein, M. A computational method for organ doses in radiology. p. 465 in: Proceedings of the Fifth International Congress of IRPA, Paris, 1977.

R11 Roedler, H.D. and A. Kaul. Strahlenrisiko für den Patienten durch nuklearmedizinische Diagnostik in: Proceedings of a Symposium: Das Strahlenrisiko im Vergleich zu chemischen und biologischen Risiken. Georg Thieme Verlag, Stuttgart, 1981.

R12 Roedler, H.D. Strahlenexposition von Patienten bei diagnostischer Anwendung von Radionukliden. in: Strahlenschutz in Forschung und Praxis. (O. Messerschmidt, ed.). Georg Thieme Verlag, Stuttgart, 1981.

R13 Roedler, H.D. Accuracy of internal dose calculations with special consideration of radiopharmaceutical biokinetics. p. 1–20 in: Proceedings of the Third International Radiopharmaceutical Dosimetry Symposium. DHEW(FDA) 81-8166 (1981).

R14 Roedler, H.D. Strahlenexposition des Patienten durch Radiopharmaka — Grenzen der Genauigkeit von Dosisberechnungen. Thesis Dr. med. Freie Universität Berlin, 1977.

R15 Roedler, H.D., A. Kaul, W. Berner et al. Development of an extended formalism for internal dose calculation and practical application to several biologically distributed radioelements. p. 515–541 in: Assessment of Radioactive Contamination in Man. IAEA, Vienna, 1972.

R16 Roedler, H.D. Strahlenbelastung durch Radiopharmaka — Entwicklung eines mathematischen Dosiskonzepts und Ergebnisse von Neuberechnungen der Energiedosis. Thesis Dr. rer. nat. Freie Universität Berlin, 1974.

R17 Roedler, H.D. and A. Kaul. Dose to target organs from remaining body activity: results of the formally exact and approximate solution. p. 155–163 in: Proceedings of the Second Radiopharmaceutical Dosimetry Symposium. DHEW(FDA) 76-8044 (1976).

R18 Roedler, H.D. Radiation dose to the patient in radionuclide studies in: Medical Radionuclide Imaging. IAEA, Vienna, 1981.

R19 Roedler, H.D. and G. Hinz. Anwendung von radioaktivem Jod in der Diagnostik und Therapie. Proceedings of a Symposium on Diagnosis, Therapy and Ecology of Thyroid Diseases. STH-Bericht (1981).

S2 Saller, A. Strahlentherapie gutartiger Erkrankungen in Berlin (West). Statistische Untersuchungen über die Strahlenexposition der Bevölkerung durch die Therapie nicht maligner Erkrankungen. STH-Bericht 8/1979 (1979).

S3 Schmelz, I. Strahlentherapie in der Klinik. Statistische Untersuchung über die Strahlenexposition der Bevölkerung durch die Therapie nicht maligner Erkrankungen im Raum München. Inauguraldissertation. München, 1974.

S4 Schmelz, H.P. Strahlentherapie in freier Praxis. Statistische Untersuchung über die Strahlenexposition der

Bevölkerung durch die Therapie nicht maligner Erkrankungen im Raum W. Berlin. Inauguraldissertation. München, 1974.

S8 Seelentag, W. Compilation of data on the frequency of x-ray diagnostic procedures in various countries. in: Proceeding of the Fourth International Congress of Radiology, Rio de Janeiro, 1977.

S9 Shleien, B., T.T. Tucker and D.W. Johnsson. The mean active bone marrow dose to the adult population of the United States from diagnostic radiology. DHEW(FDA) 77-8013 (1977).

S10 Shrivastava, P.N., S.L. Lynn and J.Y. Ting. Exposures to patient and personnel in computed axial tomography. Radiology 125: 411–415 (1977).

S13 State Institute of Radiation Hygiene, Denmark. Annual report on the use of radiopharmaceuticals at Danish hospitals. Copenhagen, 1974 (in Danish).

S15 Stieve, F.E., T. Schmidt and N. Pietzsch. Strahlenexposition durch die Computertomographie. Röntgen-Bericht 6: 365–386 (1977).

S18 Swahn, G., L. Ekelund and G. Bankwall. Comparison of patient irradiation in kidney examination with CT-scanning and conventional urography in: Proceedings of Nordic Radiology Society Meeting in Stockholm, Sweden, 1979.

S19 Schmitt, G. Klinische Erfahrungen mit der Neutronentherapie. p. 60–65 in: Risiken und Nutzen der Strahlentherapie bösartiger Tumoren. Strahlenschutz in Forschung und Praxis. Band XIX (O. Messerschmidt and E. Scherer, eds.). Georg Thieme Verlag, Stuttgart, 1978.

S20 Swindon, T.N., N.D. Morris and S.B. Solomon. Contribution to the genetic and mean bone-marrow doses of the Australian population from radiological procedures. ARL/TR-017 (1980).

S21 Solomon, S.B. and N.D. Morris. Gonadal doses from radiotherapy. ARL/TR-020 (1980).

S23 Solomon, S.B. and N.D. Morris. The measurement of gonadal and bone-marrow doses from dental radiography. ARL/TR-022 (1980).

S24 Stanton, L., T. Villafana, J.L. Day et al. A study of mammographic exposure and detail visibility using three systems: Xerox 125, Min-R and Xonics XERG. Radiology 132: 455–462 (1979).

S25 State Institute of Radiation Hygiene, Denmark. Application of radiopharmaceuticals in Danish hospitals in the fiscal year 1975–1976. Copenhagen, Denmark, 1976 (in Danish).

S26 State Institute of Radiation Hygiene, Denmark. Application of radiopharmaceuticals in Denmark in 1977. Copenhagen, Denmark, 1978 (in Danish).

S27 State Institute of Radiation Hygiene, Denmark. Application of radiopharmaceuticals in Denmark in 1978 and 1979. Copenhagen, Denmark, 1980 (in Danish).

S28 Simon, N., M. Brucer and R. Hayes. Radiation and leukemia in carcinoma of the cervix. Radiology 74: 905–911 (1960).

S29 Swansson, W.P. Calculation of neutron yields released by electrons incident on selected materials. Health Phys. 35: 353–368 (1978).

S30 Swansson, W.P. Improved calculation of photoneutron yields released by incident electrons. Health Phys. 37: 347–358 (1979).

S33 Starbaro, J.A. Mobile x-ray units: Too much effort, too few results. National Tuberculosis and Respiratory Disease Association Bulletin, October 1971.

S34 Service Central de Protection Contre les Rayonnements Ionisants. SCPRI Activity report 1980 (1980).

T1 Terpilac, S.M., C. L. Weaver and S. Wieder. Dose assessment of ionizing radiation exposure to the population. Radiol. Health Data Rep. 12: 171–188 (1971).

T2 Tsunemoto, H., Y. Umegaki, S. Morita et al. Clinical trial with 30 MeV d-Be neutrons at NIRS hospital. Annual report 1977–78. NIRS-17: 57 (1978).

T3 Tselikov N.V. Population distribution by the number of roentgenologic procedures during a year. in: Hygienic estimation of radiation safety for personnel, patients and population in diagnostic application of ionizing radiation sources. LIRH, Leningrad (1977).

T4 Tselikov, N.V. Estimation of radiation exposure to population of Vorkuta and its region in roentgenologic examinations. in: Hygienic estimation of radiation safety for personnel, patients and population in diagnostic application of ionizing radiation sources. LIRH, Leningrad (1977).

T5 Tselikov, N.V. and Ju.K. Kudritsky. Possibility for specification of present estimations of the level of radiation exposure to population in roentgenologic examinations. in: Radiation Hygiene, volume 7, LIRH, Leningrad (1978).

T6 Tselikov N.V. Some peculiarities of distribution of roentgenologic procedures in population groups of various occupations. in: Tasks of hygienic science and practice in raising the efficiency and quality of state supervision on the control of peaceful use of nuclear power. Proceedings of the VIIIth All-Russian Scientific and Practical Conference on Radiation Hygiene. Leningrad, 1978.

T7 Thomas, E., V. D'Alotto, C.E. Nollman et al. Determination of absorbed dose in a computerized tomography scanner. Nucl. Instrum. Methods 175: 196–197 (1980).

T8 Tsavachidis, T., W. Pietzch and O. Huber. Report of the frequency of x-ray diagnostic examinations in the Federal Republic of Germany. STH-Bericht 7/1981 (1981).

U3 United Nations. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. Official records of the General Assembly, Thirteenth Session. Supplement No. 17 (A/3838). New York, 1958.

U4 United Nations. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. Official records of the General Assembly, Seventeenth Session. Supplement No. 16 (A/5216). New York, 1962.

U5 United States Department of Health, Education and Welfare. Survey of the use of radionuclides in medicine. BRH/DMRE-70-1 (1970).

U6 United Nations. Ionizing Radiation: Levels and Effects. A report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, with annexes. United Nations publication, Sales No. E.72.IX.17 and 18. New York, 1972.

U7 United Nations. Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation 1977 report to the General Assembly, with annexes. United Nations publication, Sales No. E.7.IX.I. New York, 1977.

U8 United States Department of Health, Education and Welfare. Population exposure to x rays, United States 1970. DHEW(FDA) 73–8047 (1973).

U9 United States Department of Health, Education and Welfare. Nation-wide evaluation of x-ray trends (NEXT). DHEW(FDA) 76-8056 (1976).

U10 United States Department of Health, Education and Welfare. Final reports of the National Cancer Institute ad hoc working groups on mammography screening for breast cancer and a summary report of their joint findings and recommendations. DHEW(NIH) 77-1400 (1977).

U11 United States Department of Health, Education and Welfare. The need for mammography screening, benefit-risk in mammography, mammography quality assurance program. p. 189–248 in: DHEW(FDA) 77-8021 (1977).

U12 United States Department of Health, Education and Welfare. Medical x-ray data (NEXT). DHEW(FDA) 78-8056 (1978).

U13 United States Department of Health, Education and Welfare. Dental x-ray data (NEXT). DHEW(FDA) 78-8057 (1978).

U15 United States Department of Health, Education and Welfare. Gonads doses and genetically significant dose from Diagnostic Radiology U.S., 1964 and 1970. DHEW(FDA) 76-8034 (1976).

U16 United States Department of Health, Education and Welfare. Nuclear medicine in the United States for the year 1978. DHEW(FDA) (1980).

V1 Villafana, T., J. Scouras, L. Kirkland et al. Health physics aspects of the EMI computerized tomography brain scanner. Health Phys. 34: 71–82 (1978).

W3 Wall, B.F., D.A.C. Green and R. Veerappan. The radiation dose to patients from EMI brain and body scanners. Br. J. Radiol. 52: 189–196 (1979).

W5 Weber, J. Red bone marrow doses in roentgen diagnostic. Thesis, University of Leiden, Netherlands, 1964.

W7 Weissman, D.D. and F.J. Sobkowski. Comparative thermoluminescent dosimetry of intraoral periapical radiography. Oral Surg., Oral Med., Oral Pathol. 29: 376–386 (1970).

W8 White, S.C. and T.C. Rose. Absorbed bone marrow dose in certain dental radiographic techniques. J. Am. Dent. Assoc. 98: 553–558 (1979).

W9 Winkler, K.G. Influence of rectangular collimation and interoral shielding on radiation dose in dental radiography. J. Am. Dent. Assoc. 77: 95–101 (1968).

W10 Wochos, J.F., N.A. Detorie and J.R. Cameron. Patient exposure from diagnostic x-rays: an analysis of 1972–1975 NEXT data. Health Phys. 36: 127–134 (1979).

W11 World Health Organization. The situation of diagnostic radiology in the developing world. WHO report RAD/80.1 (1980).

W12 World Health Organization. World situation of radiotherapy: 1979. WHO report RAD/80.2 (1980).

W13 World Health Organization. Frequency of various medical procedures involving the use of ionizing radiations 1978–1979. WHO report (1980).

W14 World Health Organization. Compilation of information on radiotherapy facilities. Radiation medicine extract from IAEA Directory of High-Energy Radiotherapy Centres, 1976 edition. WHO report 120 (1976).

W15 Wall, B.F., E.S. Fisher, P.C. Shrimpton et al. Current levels of gonadal irradiation from a selection of routine diagnostic x-ray examinations in Great Britain. NRPD-105 (1980).

W17 Wall, B.F., E.S. Fisher, R. Paynter et al. Doses to patient from pantomographic and conventional dental radiography. Br. J. Radiol. 52: 727–734 (1979).

W18 Wilson, B.C. and M.R. Sage. Radiation doses in computerized tomography. Med. J. Aust. 2: 30–32 (1979).

W20 Wall, B.F. and P.C. Shrimpton. Deliberations on a suitable quantity and technique for assessing the somatic risk for diagnostic radiology. in: Patient Exposure to Radiation in Medical x-ray Diagnosis. Gesellschaft für Strahlen- und Umweltforschung (1981).

W21 Wall, B.F. and P.C. Shrimpton. Methods and results of the recent assessment of the GSD from diagnostic radiology in Britain. in: Patient Exposure to Radiation in Medical x-ray Diagnosis. Gesellschaft für Strahlen- und Umweltforschung (1981).

W22 World Health Organization. Quality assurance in diagnostic radiology (1982).

Y1 Yülek, G.G., E. Soydan and Z. Ugur. Reduction of patient exposure during dental radiography. Health Phys. 36: 17–20 (1979).

Y2 Yülek, G. and E. Soydan. Determination of gonadal dose in diagnostic radiology in Turkey. Health Phys. 36: 695–698 (1979).

Z1 Zárand, P. and Z. Dèntek. Absorbed dose in xeromammography. Br. J. Radiol. 53: 114–119 (1980).

Z2 Zaharenko, Ju.S. Estimation of reserves in reducing exposure doses to population in medical roentgenologic examinations. Proceedings of the VIIIth All-Russian Scientific and Practical Conference on Radiation Hygiene. Leningrad, 1978.

back to first page