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PATIENT EXPOSURES AND RADIATION RISKS IN SWEDISH DIAGNOSTIC RADIOLOGY

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Medical exposure of patients gives in many countries the greatest artificial contribution to the radiation energy imparted to the population. In Sweden and other countries it equals approximately the contribution from natural sources of ionizing radiation, and much effort is being devoted to its minimization. A useful background for such efforts is knowledge of the radiation doses to patients. Radiation levels and their effects have been summarized by the United Nations Scientific Committee on the Effects of Atomic Radiation. The latest report was published in 1977 (UNSCEAR). Several recent symposia have also included the topic of patient exposures (IRPA 1977, IAEA 1974, Health Physics Society 1974, Bureau of Radiological Health 1977).

Most of the previous investigations, including a Swedish one (LARSSON 1958), have concentrated on gonad doses, against the background of possible genetic radiation effects. When radiation-induced leukemia had become recognized, several reports discussed the radiation doses to the bone marrow. In recent years, attention has also been drawn to other radiation-induced malignancies, but the corresponding organ doses have only rarely been analysed. In the present report the absorbed doses to the thyroid, the lung and the female breast are estimated. In addition data are given on bone marrow and gonad doses. Also included is the energy imparted to the patient which can be estimated from the simple measurement of exposure-area product (previously called integral dose). The energy imparted to patients in diagnostic radiology in Sweden has previously been estimated by CARLSSON (1964).

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Methods

The measurements were made in 13 Swedish hospitals, mainly in 1974, but also to some extent in 1973 and 1975. Approximately 1 000 patients were involved.

The radiographic techniques employed in those years were rather uniform throughout the country. Image intensifier television was generally used. Photography of the intensifier image was found to give a negligible part of the collective dose. Chest films were normally exposed without fluoroscopy. Image intensifiers were being introduced on a small scale for positioning in skeletal examinations and urography. Automatic exposure control was generally used in most examinations.

Of the many parameters influencing the dose, the type of intensifying screen should be specifically mentioned. The dominating screen-film combination would under optimum conditions require an exposure of 0.1 to 0.3 μCi/kg (0.4–1 mR) to give net density 0.9. Rare-earth screens were not used.

Examination of gall bladder, stomach and colon, and special examinations were performed by radiologists. Most other examinations were made by specially trained nurses or radiographers.

Measurements. Before measurements were started at a particular equipment, the potential difference across the roentgen tube was determined, using a penetrameter modified from ARDRAN & CROOKS (1968). The total filtration was then approximately determined from measurement of the first half value layer at one or two potential difference values representative of those commonly used with the particular equipment. Conversion from half value layer to filtration was made, using the tables for constant potential by WACHSMANN & DIMOTSIS (1956).

The exposure-area product was measured, using flat transparent ionization chambers (180 mm × 180 mm × 17 mm, manufactured by Physikalisch-Technische Werkstätten) placed on the beam limiting the diaphragm housing. Their calibration is traceable to the national Swedish radiation standards laboratory. The electrometer used was connected to a recorder enabling separation of the various exposure and fluorography periods in a single examination.The potential difference values and cassette sizes used were noted near the recorded trace.

The exposure was also measured at various points on the patient using thermoluminescent lithium fluoride dosemeters (3.2 mm × 3.2 mm × 0.9 mm ribbons manufactured by Harshaw Chemical Co.) read out on a standard reader (Teledyne model 2910). The dosemeters were calibrated at irregular intervals, lying on a wax phantom using a therapy tube at 90 kV with aluminium filtration of 4 mm. The same calibration factor was used for all radiation qualities. The error due to the energy dependence of the dosemeters was less than ± 5 per cent. The minimum detectable exposure was about 3 μCi/kg (10 mR) and the reproducibility of the dosemeter readings better than ± 6 per cent (95 % confidence). At examinations giving low exposures, one dosemeter was used to integrate the exposures from several examinations.

Calculations. The energy imparted is approximately proportional to the exposure-area product. For the conversion the data by CARLSSON were used, strictly applicable to a 20 cm water slab. In most of the examinations this should mean a good approximation. A thickness of 15 cm and 25 cm, respectively, would mean a change of the energy imparted per exposure-area product by about −7 and +4 per cent, respectively. If the primary beam is close to the laterally limiting surface of the body, the semi-infinite slab approximation used will overestimate the energy imparted by approximately 10 per cent. If the radiation beam is outside the surface, the overestimation will be even larger. With the types of examination concerned, this error is estimated to be less than 10 per cent.

Thyroid dose. A dosemeter (sometimes several) was placed on the laryngeal prominence (Adam's apple). The absorbed dose D in the thyroid was calculated from the measured exposure X using

$$D = CX \tag{1}$$

The factor $C = 32$ Gy kg C^{-1} (0.84 rad/R) represents a conversion from exposure to absorbed dose in muscle, and also contains a correction factor of 0.9 allowing for attenuation in interposed tissue corresponding to about 1 cm. The thyroid tissue as well as other soft tissues considered has been assumed to be equivalent to muscle with respect to radiation absorption. This introduces a systematic error which is less than 20 per cent in all cases excepting a few extremes, for instance at very low potential differences.

In a few examinations, part of the thyroid is directly irradiated in antero-posterior or lateral projections. The dosemeter may then represent the thyroid dose poorly because of the sharp dose gradient. Examinations of the dorsal spine and skull are included here. Usually the sharp gradient concerns only one of several projections, for instance in examinations of the cervical spine. This reduces the misrepresentation. An overall value of absorbed dose averaged over several individuals is probably representative of the mean thyroid dose, but individual values might be misleading due to the method of measurement.

Mammary dose. The dosemeters were normally placed on the skin in a position considered to be representative of the main part of the breast tissue. This was usually about 10 cm from the midline of the body and near the fourth or fifth rib. The dose was calculated using eq. 1 with $C = 29$ Gy kg C^{-1} (0.74 rad/R) containing an attenuation correction factor 0.8 corresponding to the average attenuation in 2.5 cm tissue. This factor is strictly not applicable to posterior irradiations, but its use was considered justified since posterior irradiation was estimated to give very small contributions to the total absorbed dose in the dosemeter.

In examinations of the stomach and gall bladder, the dosemeter was placed on the left and right breast, respectively, and the mean dose in both breasts was taken

as 0.6 of the dose in the breast where the dosemeter was placed. In chest examinations the dosemeter was placed on the breast which in the lateral projection was nearest to the roentgen tube, and the same factor of 0.6 was used to give the mean dose.

In urography the representativity of the normal dosemeter position was questioned. Therefore 3 dosemeters in different positions at a breast were used for the calculation of the mean breast dose at some laboratories. The normal position seemed to represent the mean absorbed dose with an uncertainty within a factor of 2, and no attenuation correction factor was applied. Nor was it applied in examinations of the small intestine and colon where secondary radiation from rather large distance should have given the main dose contribution.

In examinations of the thoracic and lumbar spine, the lateral exposure may give rise to large dose differences between the two breasts. Unfortunately, the dosemeters were not systematically placed on the breast receiving the higher dose. The mean value over all laboratories should still represent an average breast dose, but individual results exhibit a large spread which may have been enhanced due to the positioning of the dosemeters, and are thus not quoted.

Lung dose. From the exposure-area product (when the lungs were in the primary beam), the number and type of exposures, the field size and the mammary dose, an approximate dose averaged over all of the lung tissue was calculated, taking into consideration the approximate volume of lung irradiated, radiation quality etc. The average attenuation in the thorax was assumed to equal that of 12 cm polymethylmetacrylate at a.p. or p.a. projection and 17 cm at lateral projection. The calculation was made assuming a typical case based on data from all laboratories, and no attempt at detailed calculation was made in the individual cases.

Bone marrow dose. Detailed calculations of the mean absorbed dose to the whole active bone marrow were only made in a few cases. Instead, the hypothesis was set up that the mean marrow dose to adults in many examinations could be estimated to a good approximation from the exposure area product XA using

$$D = kXA \tag{2}$$

where $k = 58$ Gy kg $m^{-2}C^{-1}$ (0.015 rad/(Rdm²).

This hypothesis is based on the assumption of an approximately uniform distribution of the bone marrow over a projected body area of 0.2 m² in a.p. or p.a. projections and a mean ratio of absorbed dose at the bone marrow site and exposure at the surface of 11.6 Gy kg C^{-1} (0.3 rad/R). The latter was derived from data by ELLIS et coll. The relative dose at lateral exposures was estimated to be 1.5 times lower than at a.p. or p.a., whereas the projected area should be correspondingly smaller, so approximately the same conversion factor k should apply irrespective of projection. The hypothesis was not expected to hold to any good approximation in irra-

diations involving arms and legs, in which cases it was not tested. A first test against detailed calculations in several cases of lung exposures and dental examinations showed an agreement within ± 20 per cent. Even if this was fortuitous it encouraged further tests which could not, due to lack of time, be made in the same detail. It was decided not to use the suggested approximation in examinations where any indication was found that it would fail by more than a factor of 2. This was the case only in a few types of examination. In lumbar spine examinations one half of the value of k was used, and in urography one fifth. In gall bladder examinations the alleged marrow dose is believed to be an overestimate, but the varying practices regarding the exposures make a better estimate impossible. In stomach examinations the alleged dose is also believed to be an overestimate. With the mentioned exceptions eq. 2 could be used for the estimation of mean marrow dose.

Testes dose. A dosemeter was placed in 2 to 3 cm of thin plastic tubing and taped to the inside of the thigh near the scrotum on male patients. The absorbed dose to the testes was calculated from eq. 1 using

$$C = 32 \text{ Gy kg } C^{-1} \text{ (0.84 rad/R)}. \quad (3)$$

Ovary dose. Excepting colon examinations, a dosemeter was placed in 20 cm of thin plastic tubing, and its first 15 cm inserted into the rectum. The distance between the dosemeter and uterus and ovaries was probably about 5 to 10 cm. The basis for the dose calculation was eq. 1 with $C = 36$ Gy kg C^{-1} (0.93 rad/R). No further correction was applied for examinations of the colon, in which the dosemeter was placed in the top of the special tube used to prevent release of the enema. Approximately uniform irradiation of the ovaries, uterus and dosemeter site was assumed. In some hysterosalpingographies the dosemeter was most often in a position between the ovaries and the radiation source. In these cases the measured dose was divided by 3 as an approximate correction for attenuation in interposed tissue. A corresponding multiplication by 3 was made in other examinations of the same kind in which the radiation had an opposite direction. In examinations of the lumbar hip and spine and in urography a similar multiplication by 2 was made, and in pelvimetry 1.3 was used. The gall bladder examinations were difficult to assess and no correction was made. The alleged ovary dose appears to be rather approximate.

Calculation from the exposure-area product, field sizes, and number of exposures was made in examination of dorsal spine, pelvis and small intestine.

No well-founded estimate of ovary dose was made relating to hip examinations.

Results and Discussion

The absorbed doses to the individual patients are extremely variable. As an extraordinary example, the testes dose in lumbar spine examinations varied between 0.2 mGy and 50 mGy, i.e., the highest value is 250 times the lowest. In most cases the extremes are found within a factor of 10. A large number of factors influence the

resulting absorbed dose. It is obvious that characterization by single numbers, for instance mean values, must involve large approximations. Several thousand measurements on about a thousand patients were made in 13 hospitals. This enables assessment of the mean absorbed dose in a given body organ at a given type of examination with an overall accuracy of about ± 50 per cent. A warning is thus in place concerning too far-reaching conclusions, for instance relating to time trends of patient doses.

The discussion centers around five major points: (1) The spread of doses between individuals, an anlysis facilitates the understanding of sampling errors, (2) the possibility of dose reduction, deduced from the variations of dose between groups of patients examined under different conditions, (3) estimates of collective doses, (4) estimates of the genetically significant dose, and (5) estimates of risk for late radiation effects.

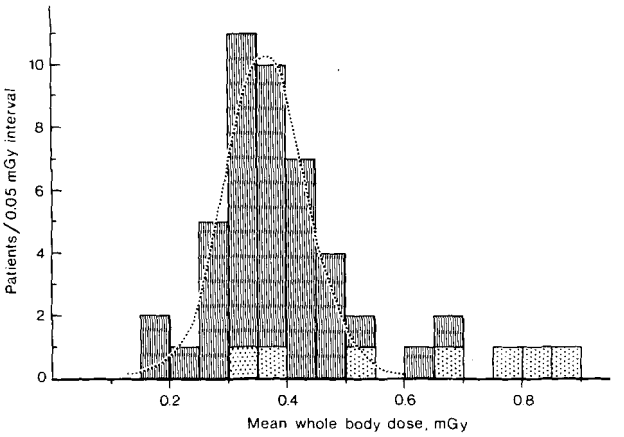
Accuracy of dose estimates. Before entering into a discussion on these points, the limitations of the primary dose estimates must be discussed.

The physical measurements upon which the patient dose estimates were based could be made routinely with an accuracy of about ± 10 per cent. Calculations of absorbed dose at the dosemeter site or of energy imparted, assuming a patient with a density similar to that of water, add an error of about the same magnitude or less. The major uncertainty in the estimate of the dose to an individual patient lies in the transformation from dose at the dosemeter site to actual organ dose. It is sometimes possible to position the dosemeter at a quite representative position. This applies to the thyroid and the testes, where the transformation averaged over several patients may be accurate to perhaps 20 per cent, although an error by a factor of 2 might be possible in single patients.

The other organs are larger or further away from the dosemeter, and the representativity of the dosemeter site consequently poorer. The position of the organ in relation to the dosemeter may depend strongly on the positioning of the patient. The breast, for instance, may be strongly displaced to the side when the patient is resting on one side. Attenuation in interposed tissue amounts to about a factor of 2 for each 5 cm, and no strict determination of corresponding correction factors was made. The mean dose in these organs (breasts, lungs, bone marrow and ovaries) should thus have an uncertainty of about a factor of 2 or less, as an average over several patients. In individual patients the uncertainty may be still higher.

In the estimates marked with an asterisk in Table 5 it is not unlikely that the uncertainly might exceed a factor of 2, because of uncertainties in calculations or scarcity of primary data.

Spread of doses between individuals. The individual patient's dose is influenced by several factors: his body size and constitution, the performance of the equipment used, the education and training of the personnel and the method of examination. An example of the distribution of average whole body absorbed dose in chest



Distribution of the mean whole body dose at chest examinations in one hospital. The dotted boxes indicate patients for whom 3 exposures were made, against normally two. The dashed curve is a normal distribution fitted to the two-exposure observations. 2 exposures. 3 exposures.

examinations is given in the Figure. The same equipment and personnel was used for all patients. A significant deviation from the normal distribution was found at large patient doses. With some patients three exposures were required, whereas with most patients two were sufficient. If the three-exposure cases are exluded, a good fit to a normal distribution is obtained. This illustrates that basically a well defined distribution may be present when the number of parameters is limited, but as further parameters are introduced the distribution may become odd. The average whole body dose in stomach examinations at one hospital with given equipment and personnel followed closely a normal distribution, but the energy imparted deviated slightly. Neither the chest nor the stomach examinations fitted a log-normal distribution. A general conclusion from this is a warning against simplifying assumptions about the frequency distributions of patient doses.

Individual organ doses may exhibit a quite significant spread, (standard deviation above 100%) and strongly depend on for instance the care exercised in field size adjustment. The energy imparted is often less variable, as is the mean absorbed whole body dose. Showing the least spread, the latter was chosen for some calculations of patient dose variations. With a given set of examinations using given personnel and equipment, the whole body dose in examinations of individual patients showed a relative standard deviation of about 40 per cent. Returning to the cited example concerning chest examinations, two-exposures gave a standard deviation of 31 per cent while it was about 37 per cent when three exposures were used. The difference is barely significant, but it hints that the standard deviation may increase as more variables are introduced. Similar hints arise from the observation that patient doses from examinations performed by an experienced radiologist may have much less spread (and also lower mean whole body dose) than those by the less experienced radiologist. Percentage standard deviations of the mean whole body dose below 20 per cent and above 60 per cent were observed in about 10 per cent of all sets of examinations.

Table 1

Unusually wide spread of individual doses in some examination types at one hospital with the same personnel (10 examinations) or at all hospitals considered, indicated by the ratio of the mean and the median value

Examination type or organ examined	Dose to	Mean/median		Explanation
		One	All	
Hip	Whole body	1.5		Highest dose 2 times second highest due to one additional exposure.
	Testes	1.7		Highest dose 4 times second highest due to one additional exposure.
Lumbar spine	Testes	3		Highest dose 3 times second highest. Occurred in two hospitals.
Lumbar spine	Ovaries		1.4	Doses at one hospital 2 times higher than average.
Urography	Breast	1.7		Highest dose 5 times second highest, possibly due to additional exposure.
	Thyroid	1.7		Possibly variations in body weight and number of exposures.
Stomach	Thyroid	5		Highest dose 30 times second highest. Fluoroscopy started at the mouth.
Stomach	Ovaries	4		Highest dose 10 times second highest. Occurred in 2 hospitals.
Colon	Testes	3		One group of doses about 10 times higher than the rest.
Cholecystography	Whole body	1.5	1.3	Examination often discontinued because of incomplete contrast filling.
Thoracic spine	Testes	3		Highest dose 5 times second highest.
Thoracic + lumbar spine	Testes	2		Highest dose 6 times second highest due to one patient weighing 144 kg.
Thoracic + lumbar spine	Whole body	2		Highest dose 3 times second highest due to one patient weighing 144 kg.

The instances of wider spread are particularly interesting. Several causes add to the total spread. It is therefore tempting to expect a normal distribution of the doses. Exceptionally high and also sometimes very low recorded doses indicate, however, very skewed distributions. A mean or median value and a standard deviation then give a very incomplete idea of the distribution. One example concerns a set of lumbar spine examinations, where 11 examinations gave testes doses below 6 mGy, one gave 15 mGy and one 45 mGy. Another pertains to urography, where the central mammary dose was in 12 examinations below 7 mGy and in one 30 mGy. Exclusion of the highest value in these cases reduces the mean to about one-half.

The deviations from the normal distribution can also be illustrated by the difference between median and mean value. As a rule the mean whole body dose is

between 0.9 and 1.3 of the median, supporting the hypotheses of a fairly normal distribution. In a number of cases the difference between median and mean was larger (Table 1).

Possibilities of dose reduction. A major reason for determining patient doses is the hope for results implying possibilities of dose reduction. The existence of a wide spread of the dose to different groups of patients leads to the hypothesis that with suitable measures the dose in every group of patients can be reduced to that of the group exhibiting the lowest dose.

Significant efforts may be made towards reducing the dose of all groups to a value below a maximum acceptable dose. This decision may in any particular case be based on a measurement of the mean dose to a sample group of patients. The sample mean will have a statistical uncertainty which has to be kept reasonably small. To give an example, the double standard error of the mean value will be about 25 per cent if this mean is based on measurements on 10 patients and the standard deviation of a single measurement is 40 per cent, which is typical in the case of mean whole body doses. In this case, a measured mean dose 25 per cent above the maximum acceptable does not necessarily imply that the true mean is unacceptable; nor need a value 25 per cent below the maximum be acceptable. Whether dose reduction measures should be initiated depends on such things as the cost of these measures, the cost of further measurements which would lower the uncertainty, and the strength of the recommendation to keep the doses below the maximum acceptable. To aid such decisions, the possibilities of reducing the uncertainty interval of the sample measurement will now be discussed. It is important to point out that such a reduction is not intended to improve the estimate of the collective dose.

Table 2 illustrates a number of sets of measurements, including several of the sets exhibiting the widest spread of individual doses. If all examinations performed at a certain laboratory during a limited time period are analysed, the double standard error of the mean value of the set often approaches 100 per cent. Frequently the set includes a single, strongly deviating observation. Such observations get reduced significance if a log-normal distribution is assumed (GADDUM 1945). The mean value of the logarithms corresponds to the geometrical mean of all observations and this is assumed to represent more 'normal' observations. It was found that with the small number of observations made in a practical situation, another definition of normal observations gives about the same (within 35 %) mean value as the geometrical mean while being more easily understandable. The two middle quartiles of the observations, rejecting the 25 per cent highest and the 25 per cent lowest observations were used (Table 2). In comparison with using all observations the double standard error of the mean value was never significantly increased. In many cases it was significantly reduced, and at most it amounted to 80 per cent.

The table permits comparisons within nine pairs of technicians, radiologists or hospitals. If all examinations are included, three pairs are found in which the ratio

Table 2

Examples of differences in mean exposures in certain organs between various sets of examinations. The comparison is made on the basis of exposure at the dosemeter site or mean body exposure in units of mR. Little attention should be given to the absolute values. The notation 680_{690} indicates an exposure of 680 mR with 690 mR as the double standard error of the mean value. The hospitals where the examinations were made and the staff members who performed the examinations are represented by numbers in the third column

Examination type or organ examined	Dose	Hospital or examiner	No. of exam.	Exposure		
				Arithmetic mean, mR		Geometric mean, mR
				All examinations	Middle quartiles	
Lumbar spine	Testes	Technician 1	13	680_{690}	280_{40}	300
		Technician 2	6	57_{11}	55_{11}	56
Lumbar spine	Ovaries	Hospital 1	12	260_{60}	260_{20}	240
		Hospital 2	6	640_{280}	650_{270}	560
Lumbar spine	Testes	Hospital 1	20	140_{140}	53_{6}	51
		Hospital 2	6	41_{21}	38_{18}	34
Urography	Breast	Technician 3	11	170_{60}	170_{30}	141
		Technician 4	13	600_{400}	400_{70}	450
Urography	Thyroid	Technician 5	5	47_{13}	44_{13}	45
		Technician 6	8	73_{39}	61_{37}	55
Urography	Ovaries	Technician 3	9	430_{120}	430_{60}	380
		Technician 4	11	680_{140}	710_{60}	640
Stomach	Ovaries	Radiologist 1	8	290_{460}	67_{45}	58
		Radiologist 2	21	84_{28}	71_{20}	58
Colon	Testes	Radiologist 1	11	$3\,100_{2\,100}$	$2\,100_{1\,700}$	1 400
		Radiologist 3	6	580_{510}	350_{60}	420
Cholecystography	Whole body	Hospital 2	10	220_{70}	210_{60}	190
		Hospital 3	16	110_{40}	100_{20}	90

of the highest and the lowest dose is significantly exceeding 1 (it is about 2). If only the two middle quartiles are included, the confidence of the significance for these three pairs is increased, and two more pairs are added. In either case, 1.6 is the lowest ratio significantly different from unity. This supports the belief that a reliable comparison of the normal dose to groups of patients can be made using the two middle quartiles. However, a warning is indicated against too optimistic a view on demonstrable differences between sets of measurements. Many observations, of the order of 100, will be required to demonstrate clearly differences below 25 per cent between normal groups of individuals. In evaluating possibilities of dose reduction, it must be carefully considered whether differences by a factor of 2 or less are really significant.

These observations have a bearing also on the follow-up of dose-reducing measures. It is suggested that a possible dose reduction be considered either on a sample of the continuous flow of patients using the middle quartiles of the observations, or on patients selected according to pre-determined criteria restricting some of the most important causes of dose variations, for instance the body weight or the number of films exposed.

While such procedures may facilitate relative comparisons, they may be strongly misleading as to absolute dose levels. Table 2 shows that the mean dose of the normal group may be less than one-fourth of the mean dose in the group. For the assessment of collective dose or risk, it is very important that the odd observations are not excluded.

With these limitations of the data thus established, the mean values of all measured doses are presented in Table 3. It must be borne in mind that these represent only approximately the mean values of the populations from which the sets of examinations are drawn. The table also gives the lowest mean value recorded for one hospital, and the highest, as fractions of the overall mean. This indication of the spread in the results is given only if measurements were made in at least 2 patients at each hospital, and at least 3 different hospitals were involved.

The hypothetical possibilities of dose reduction may be examined using Table 3. The ratio of the highest and the lowest mean group dose is in the range 1.5 (energy imparted, dorsal spine examinations) to more than 60 (testes dose, dental intraoral exposures). Since the significance of ratios of 2 or below is questionable, only ratios of 3 or more will be discussed (Table 4). Half of all observed ratios relating to energy imparted and thyroid and mammary dose are around or above 3, the corresponding figure for ovaries and testes being 4 and 10, respectively. It may thus quite safely be concluded that significantly reduced patient doses are generally possible. As a first approximation, it may be estimated that the doses might be reduced from the overall mean value to the lowest value observed at any hospital. It is scarcely probable that this dose is too low to give sufficient information, since almost all of the radiology is supervised by well trained radiologic specialists. Often the overall radiation level can be reduced, as indicated by the energy imparted. Frequently, careful attention to shielding can significantly reduce the dose to various organs involved. If the lowest observed value could be attained, the data in Table 3 indicate that it should be possible, using available techniques, to reduce the energy imparted, thyroid dose, mammary dose and ovary dose to the Swedish population to about one-half and the testes dose to less than one-third of the present average level.

Collective doses. The Swedish Board of Health and Welfare collects quite detailed information on the frequency of various types of radiologic examinations, excluding the bulk of dental and mass miniature chest examinations. To calculate the collective dose their statistics from 1973 were used, multiplied by 1.34 to correct for an

Table 3

Mean values of all measured doses. The ratios min/mean and max/mean refer to the lowest recorded mean value for one hospital and the highest, as fractions of the overall mean. Results with an indication of their spread are given only if at least 2 patients were included at each of 3 or more hospitals

Examination type or organ examined	Energy imparted (mJ)			Absorbed dose (mGy)					
				Thyroid			Breast		
	min/ mean	mean	max/ mean	min/ mean	mean	max/ mean	min/ mean	mean	max/ mean
Hip and femur (upper third)	0.71	120	1.21		—			—	
Pelvis	0.46	87	1.38		—			—	
Lumbar spine	0.51	410	1.78	0.58	0.16	1.42	0.37	1.20	2.3
Urography	0.71	510	1.16	0.51	0.38	1.40	0.13	5.40	1.79
Stomach and duodenum	0.29	310	1.49	0.51	0.29	4.2	0.44	1.00	2.2
Small intestine		210			—			—	
Colon	0.63	600	1.56	0.58	0.10	2.3	0.83	0.27	1.53
Hysterosalpingography	0.56	90	2.6		—			—	
Cholecystography, cholangiography	0.46	90	1.08	0.66	0.03	1.33	0.35	0.15	3.7
Thoracic spine	0.83	210	1.21	0.55	13.0	1.23	0.62	1.70	2.1
Lungs (full size) ribs	0.61	21	1.35	0.35	0.17	2.3	0.54	0.55	1.58
Lungs (photofluorography)	0.50	73	3.0		1.00			2.00	
Lungs plus heart	0.55	40	1.28	0.48	0.24	1.38	0.45	0.61	1.41
Dental (intraoral single exposure)	0.15	2	3.5	0.4	0.03	3		0.005	
Cervical spine	0.62	18	1.27	0.35	1.40	1.57		—	

estimated loss at certain hospitals and other installations. In addition, were used estimates on dental and mass miniature chest examinations, made in cooperation with various bodies involved, military as well as civilian. The resultant frequencies per 1 000 population given in Table 5 are believed to be correct within about ± 10 per cent. The frequency of pelvimetry is based on a separate estimate with about the same accuracy.

Table 5 also includes the overall mean doses per examination (including all extreme values) from Table 3 as well as some results (based on the present measurements) which were not included in Table 3. These can be used for estimation of collective dose only if the hospitals visited can be assumed to represent the whole population of hospitals. To some extent this may be justified, since an effort was made to select hospitals with good as well as bad practices according to the evaluation. However, it was often found to be incorrect and the systematic error in the collective dose due to incorrect sampling of the hospitals may be considerable. It may, however, be small in comparison with the statistical error of the results. If the sampling had been

Table 3 (*cont.*)

Absorbed dose (mGy)												
Lungs			Bone marrow			Ovaries			Testes			
min/ mean	mean	max/ mean	min/ mean	mean	max/ mean	min/ mean	mean	max/ mean	min/ mean	mean	max/ mean	
—				2.50			—			0.63	15.00	2.3
—				1.90			1.90			0.23	3.10	2.3
<1.00				4.10		0.49	6.20	2.1		0.09	1.80	2.3
<1.00				2.40		0.57	8.80	1.33		0.18	3.30	3.0
<0.50				4.20		0.15	0.56	2.1		0.58	0.16	1.63
—				3.50			1.80				—	
<0.20				9.40		0.57	7.00	1.99		0.29	5.30	3.9
—				1.70		0.53	5.90	1.67			—	
<0.10				1.53		0.54	0.24	2.3		<0.50	0.06	3.7
8.00				4.70			<1.00				—	
0.8				0.29			—				—	
3.5				0.9			<0.1				<0.1	
1.2				0.54			—				—	
0.001				0.01		<0.1	0.0001	6		<0.1	0.0001	6
—				0.38			—				—	

random, the overall mean would typically have a double standard error of about 40 per cent. The calculated collective dose for a certain organ summed up for all types of examinations may be in error somewhat but not much less, since different hospitals were sampled for different types of examinations.

In several cases Table 5 has been supplemented by doses from the estimate in the ICRP publication on patient protection (ICRP 1970), or estimates based on knowledge of the techniques used. As a rule these supplementary data only weakly influence the collective dose. The classification follows essentially that of the ICRP–ICRU (1957) except for the splitting of three categories into two classes each, considered justified by the examination frequency and dose conditions. Thus the small intestine group was divided into small intestine and colon, the chest group into chest and chest plus heart and the skull and cervical spine group into its two types. Special examinations such as more extensive angiographies were considered to have an insignificant influence upon the collective dose; therefore they were included in other groups, for instance nephroangiography in the urography group.

The cerebral angiographies formed a borderline group which is particularly mentioned in Table 5 because of its rather large influence on the collective marrow dose. Examinations on children were not treated separately since they represent only about 10 per cent of all examinations. Some examinations for which no dose data are available, for instance fluoroscopy at femoral neck operations, are estimated to represent less than a few per cent of the total collective dose.

The collective dose for all of Sweden will be 8 100 times the collective dose per 1 000 population.

The results in Table 5 show that collective doses to an organ can seldom be ascribed to one dominating type of examination. There is one outstanding exception to this rule, namely photofluorography of the chest. This type of examination contributes about 15, 40, 60 and 10 per cent to the collective thyroid, mammary, lung and bone marrow dose, respectively, but only 10 per cent to the collective energy imparted. When this was observed in the preliminary compilation of patient dose data, a special scheme was devised in 1974–75 to minimize the spread of patient doses at this type of examination. Using a mail dose measurement system and follow-up by some form of personal contact, the spread was reduced by a factor of 2 or more. The collective dose due to photofluorography of the chest should by these measures have decreased by about 30 per cent.

The annual collective dose from all examinations is of interest as it can be used to give a mean population dose. The mean dose to the various organs is given in Table 6, where also the mean whole body dose is given, obtained from the energy imparted and assuming a mean body weight of 75 kg. The annual mean whole body dose overestimates the annual mean organ dose by a factor in the range 1.1 to 1.9.

Using information on film consumption given by the suppliers, it was calculated that the overall mean value of energy imparted to patients per unit film area was 0.39 J/m^2. This figure does not apply to dental radiography, photofluorography or photography of the intensifier image.

Genetically significant dose. A comparison with the previous estimate by LARSSON (1958) of genetically significant dose is interesting. A similar thorough analysis was not possible but an attempt to trace changes in relation to Larsson's figures was made. Five factors influence the gonad dose: the total number of examinations, the dose per examination, the age distribution of the individuals examined as well as that of the population, and the child expectancy distribution. The latter has probably undergone little change since LARSSON's investigation performed 1955. The number of children born per 1 000 inhabitants has changed by less than 10 per cent from 1955 to 1973, and the age distribution of the mothers has been relatively stable with shifts between adjacent 5-year age groups comprising far less than 10 per cent of the total number of children born (Statistical abstract of Sweden, 1974). It is assumed that similar changes relating to the fathers have also been small.

The age distribution of the population has changed significantly, with about 45

Table 4

Highest observed ratios of the radiation load to groups of 5–20 patients examined under different conditions, e.g. different hospitals or personnel. All radiation doses were not recorded in all patients. Only ratios of 3 or more are entered

Examination type or organ examined	Ratio of highest and lowest group				
	Energy imparted	Mean absorbed dose to			
		Thyroid	Breast	Ovaries	Testes
Hip					3.7
Pelvis	3.0				10
Lumbar spine	3.5		6.2	4.3	26
Urography			14		17
Stomach	5.1	8.2	5.0	14	
Colon		4.0		3.5	13
Hysterosalpingography	4.6			3.2	
Cholecystography			11	4.3	>7
Thoracic spine			3.4		
Lungs (full size)		6.6			
Lungs (photofluorography)	6.0				
Lungs plus heart			3.1		
Cervical spine		4.5			
Dental intraoral	23	7.5		>60	>60

per cent increase of the population in the age group 25 to 29 years. The total number of future children expected from the Swedish population has also changed, increasing by about 10 per cent between 1955 and 1973. The population has increased by 10 per cent, closely corresponding to the increased child expectancy; these cause no change in the genetically significant dose.

The examination frequency has increased considerably. For genetically significant examinations in which the gonads may be exposed to the primary beam, the number of examinations per inhabitant has increased by a factor of 2.0 (1.6–2.6), and it is assumed, lacking data, that the sex distribution has remained the same through the years.

The ovary dose in these examinations was in 1974 about 0.8 (0.2–1.4) of the 1955 dose, and for testes it was about 0.7 (0.2–1.7). These dose data include several of the present approximate estimates not based on measurements. It must further be pointed out that the measured testes doses varied greatly, the double standard error of the mean value of the dose at a certain examination type being about 100 per cent. The ovary doses had a double standard error of about 50 per cent.

The trend of age distributions represents an even larger uncertainty. The age distributions 1974 were checked at two hospitals on about 1 000 patients of each

Table 5

Individual and annual collective doses. The figures marked with an asterisk represent crude estimates, the uncertainty of which might exceed a factor of 2. The total sum includes these figures, which contribute less than 20 % in any case except in the case of energy imparted, where the contribution is less than 30 %. The total excludes the figures given as upper dose limits (marked <). These contribute less than 10 %, except in the case of collective lung dose, where they contribute less than 20 %. The units mJ or mGy refer to the radiation load per examination, the units man × mJ or man × mGy per 1 000 to the radiation load per 1 000 Swedish inhabitants

Examination	No. of exam. per 1 000	Energy imparted		Thyroid dose	
		mJ	man × mJ per 1 000	mGy	man × mGy per 1 000
Hip and femur (upper third)	18.9	120	2 200	<0.01*	<0.19*
Pelvis	15.4	87.0	1 300	<0.01*	<0.15*
Pelvimetry	1.35	310	420	<0.10*	<0.14*
Lumbo-sacral	2.73	100*	270*	<0.01*	<0.03*
Lumbar spine	22.3	410	9 000	0.16	3.60
Urography	23.6	510	12 000	0.38	9.00
Retrograde pyelography	0.29	700*	200*	0.50*	0.15*
Urethrocystography	2.73	400*	1 100*	0.05*	0.14*
Stomach and duodenum	29.6	310	9 100	0.29	8.60
Small intestine	3.37	210	710	0.03	0.10
Colon	16.0	600	9 500	0.10	1.60
Abdomen	12.9	200*	2 600*	0.03*	0.39*
Abdomen (obstetrical)	1.40	150*	210*	0.02*	0.03*
Hysterosalpingography	0.80	90.0	72.0	<0.01*	<0.01*
Cholecystography, cholangiography	18.4	91.0	1 700	0.03	0.55
Thoracic spine	13.3	210	2 800	13.0	180
Lungs (full size), ribs	115	21.0	2 400	0.17	20.0
Lung (photofluorography)	110	73.0	8 000	1.00	110
Lung plus heart	46.6	40.0	1 900	0.24	11.0
Cervical spine	12.7	18.0	230	1.40	18.0
Shoulder, clavicle, sternum	16.3	40.0*	650*	<0.50*	<8.20*
Head, sinus	43.8	68.0	3 000	7.90	340
Cerebral angiography	1.18	680	810	3.00	3.50
Dental (intraoral single exposure)	1 500	2.00	3 000	0.03	45.0
Femur (middle and lower third)	5.90	50.0*	300*	<0.01*	<0.06*
Lower leg, knee	64.4	20.0*	1 300*	<0.01	<0.64
Arm	50.4	5.00*	250*	<0.01	<0.50
Total	2 150		75 000		750

Table 5 (*cont.*)

Mammary dose		Lung dose		Active bone marrow dose		Ovary dose		Testes dose	
mGy	man × mGy per 1 000	mGy	man × mGy per 1 000	mGy	man × mGy per 1 000	mGy	man × mGy per 1 000	mGy	man × mGy per 1 000
<0.05*	<0.95*	<0.10*	<1.90*	2.50	47.0	3.70*	70.0*	15.0	280
<0.05*	<0.77*	<0.10*	<1.50*	1.90	29.0	1.90	29.0	3.10	47.0
<0.10*	<0.14*	<0.50*	<0.68*	6.80*	9.4*	4.6	6.21	—	—
<0.05*	<0.14*	<0.10*	<0.27*	1.00*	2.70*	1.80*	4.90*	1.0*	2.70*
1.20	26.0	<1.00	<22.3	4.10	90.0	6.20	140	1.80	40.0
5.40	130	<1.00	<24.0	2.40	56.0	8.80	210	3.30	78.0
5.00*	1.50*	<1.00*	<0.29*	3.0*	0.87*	8.00*	2.30*	13.0*	3.80*
0.20*	0.55*	0.20*	0.55*	3.0*	8.20*	15.0*	41.0*	20.0*	55.0*
1.00	31.0	<0.50	<15.0	4.20	120	0.56	17.0	0.16	4.70
0.11	0.37	<0.20*	<0.67*	3.50	12.0	1.80	6.20	1.00	3.40
0.27	4.30	<0.20	<3.20	9.40	150	7.00	110	5.30	85.0
0.11*	1.40*	<0.20*	<2.60*	3.00*	39.0*	2.0*	26.0*	2.0*	26.0*
0.08*	0.11*	<0.15*	<0.21*	2.20*	3.10*	1.5*	2.10*	—	—
<0.05*	<0.04*	<0.10*	<0.10*	1.70	1.30	5.90	4.70	—	—
0.15	2.80	<0.10	<1.80	1.50	28.0	0.24	4.40	0.06	1.10
1.70	23.0	8.00	110	4.70	62.0	<1.00	<13.0	<0.20*	<2.70*
0.55	63.0	0.80	92.0	0.29	32.0	<0.03*	<3.45*	<0.03*	<3.45*
2.00	220	3.50	390	0.90	99.0	<0.1*	<11*	<0.1*	<11*
0.61	28.0	1.20	56.0	0.54	25.0	<0.05*	<2.30*	<0.05*	<2.30*
<0.1	<1.30	<0.1*	<1.30*	0.38	4.80	<0.01	<0.13	<0.01	<0.13
<0.50*	<8.20*	<0.10*	<1.60*	0.6*	9.80*	<0.01*	<0.16*	<0.01*	<0.16*
<0.10*	<4.40*	<0.10*	<4.40*	1.22	53.0	<0.01	<0.44	<0.01	<0.44
<0.10*	<0.12*	<0.10*	<0.12*	15.0	18.0	<0.10	<0.12	<0.10	<0.12
0.005	7.50	0.001	1.50	0.01	15.0	0.0001	0.15	0.0001	0.15
<0.01*	<0.06*	<0.01*	<0.06*	0	0	0.50*	3.00*	4.00*	24.0*
<0.01	<0.64	<0.01	<0.64	0	0	<0.01	<0.64	<0.01	<0.64
<0.01	<0.50	<0.01	<0.50	0	0	<0.01	<0.50	<0.01	<0.50
	540		640		920		680		650

Table 6

Mean annual collective dose per individual from medical exposure in Sweden 1974, the mean population dose

Organ	mGy
Thyroid	0.75
Breast	0.54
Lungs	0.64
Bone marrow	0.92
Ovaries	0.68
Testes	0.65
Whole body	1.00
Genetically significant dose	0.4

sex at each hospital, including urography as well as colon, hip and lumbar spine examinations. The latter comprised about 60 per cent of the 1955 genetically significant dose for both males and females. The fraction of all examinations in the ages between 16 and 40 years was about 30 per cent higher than 1955 for urography, and the difference seemed less for colon examinations. Hip examinations for females also showed little difference, but for males the sample gave only 40 per cent of the 1955 fraction of examinations of younger men. Lumbar spine examinations of young women were somewhat less common, but examinations of young males were about twice as numerous relative to 1955. In addition should be added the examinations of children below 16 years, on which very little information is available. The age distribution below 16 years was determined at one hospital only. Up to 25 per cent of the patients were below 16 years, but this is probably non-representative. However, it is possible that examinations of children have become comparatively more frequent, which may contribute to increase the genetically significant dose in some examinations by a factor of 2 and the overall dose by several tens of per cent. Adding together all this, it is estimated that the genetically significant dose for females has been enhanced by a factor of 1.2 (0.9–1.3) due to changed age distributions, and for males by a factor of 1.3 (0.4–2.0).

As a first approximation the separate factors may be multiplied to obtain the 1974 genetically significant dose. This would give $1 \times 1 \times 2.0 \times 0.8 \times 1.2 = 1.9$ and $1 \times 1 \times 2.0 \times 0.7 \times 1.3 = 1.8$ times higher values than those from 1955 for females and males, respectively. The approximation is very crude, since the spread of these changes in doses for males and females is very large, as well as the spread of changes in the age distributions for males.

A better approximation may be the application of the change factors to each type of examination, in spite of the large uncertainty associated with most of them. Such a calculation results in an overall change factor between 1955 and 1974 of 1.9 for

females and 1.1 for males. Considering the uncertainties involved, this is not inconsistent with the previous approximation, and it will be used for the calculation of the genetically significant dose.

The main contribution to the genetically significant dose from fetal irradiation in 1955 originated from pelvimetry. Since then, the examination technique has changed significantly and the fetal doses have been drastically reduced, to about 3 per cent of the previous values. No type of examination seems any longer to give any dominant contribution to the genetically significant dose, despite the fact that the pelvimetry frequency has increased about three-fold. Excepting the pelvimetries, the fetal dose is assumed to have followed the ovary dose of the mother. Calculation then gives the 1974 genetically significant dose as 0.4 of that from 1955.

Scaling of the data of LARSSON using his doses as recalculated according to the report by UNSCEAR (1962) then indicates the following contributions to the genetically significant dose in 1974: for males $0.203 \times 1.1 = 0.22$ mGy, for females $0.090 \times 1.9 = 0.17$ mGy and for foetuses $0.085 \times 0.4 = 0.03$ mGy. The total genetically significant dose in 1974 was according to this calculation 0.42 mGy, or 10 per cent above the 1955 value of 0.38 mGy. If the cruder approximation were used, the increase would instead have been 40 per cent, and this may serve to illustrate the uncertainties of the calculations.

Estimates of radiation risks. The following is an extremely simplified review of an extremely complicated topic. A thorough discussion is found in UNSCEAR (1977).

Acute effects. The radiation dose to a particular organ in a patient seldom exceeds 0.1 Gy at an examination (Tables 3–5). At some less common examinations such as cardioangiography the dose might exceed 1 Gy in rare cases. Acute radiation injury may follow single irradiation by a few Gy if large volumes are irradiated, and doses of almost 10 Gy are required at smaller volumes. If the radiation is delivered over an extended time period, still higher doses are required to produce acute radiation injury. Such injury is thus under normal conditions excluded in diagnostic radiology, even though it may occur as a result of insufficient attention to technical protection measures.

Long-term effects. A serious long-term health effect may occur in the individual patient in one of two forms: late tissue injury resulting from an exceptionally large number of examinations, or severe effects appearing a long time after irradiation, such as genetically related abnormalities in future generation children or induction of malignancy. The possibility of radiation-induced life-shortening is sometimes discussed. The dominant contribution hereto at the low doses encountered in diagnostic radiology originates from the enhanced malignant diseases. Such separate discussion of life-shortening is here omitted.

Considerable experience on the tolerance of normal tissue to irradiation has been collected in radiation therapy (RUBIN & CASARETT 1972). Extrapolation of those data to irradiation extended over longer periods than 100 days indicates that most tissues tolerate an absorbed dose of 10 Gy or more from localized irradiation without serious long-term injury. The injuries which may follow at lower doses are permanent sterilization, which might result from irradiation of the testes and ovaries, the much debated (RUBIN 1972) tolerance dose being about 5 Gy; progressive cataract following irradiation of the eye lens by 5 Gy; and injury to the human foetus at short-term irradiation with even lower doses. A life-time dose of 10 Gy is extremely unlikely, since this is about a hundred times the average life-time dose of an individual whose annual contribution follows the mean doses reported in Table 6. With the exceptions mentioned, the risk of late tissue injury will thus as a rule not constitute any important counterindication to radiography. These can be amplified further, in that temporary sterilization may follow testes doses much below 5 Gy, a fetal dose of about 0.1 Gy during organogenesis may double the probability of congenital injuries, and synergistic physical or chemical agents may lower the threshold of cataract formation.

The risk of malignancy induction and injury to future generations has recently been summarized by the International Commission on Radiological Protection, ICRP (1977). For the purpose of radiation protection, it may be assumed that even the smallest radiation dose carries a risk in proportion to the dose. The risk factors suggested by the ICRP have been used for the calculation of total risk per examination presented in Table 7. The ICRP gives risk factors also for endosteal tissue and for non-specified organs; these have, due to insufficient information been applied to the mean whole body dose.

Obviously this method of risk estimation is very crude, with for instance no regard to age and sex variations. Various limitations are discussed by the ICRP (1977).

If the estimates were correct, some heavy examinations (pelvimetry and examinations of the hip, colon, lumbar and dorsal spine, and the urinary tract) would carry an associated risk of 50 to 120 cases of serious late injury per million examinations performed. Most other examinations are found in the range 10 to 50 cases per million. Examinations of the cervical spine, shoulder, clavicle, and sternum, and lung (or lung plus heart) examinations using full-size film, fall between 2 and 10 cases per million, and below 2 are found examinations of the arms and legs, and single dental intraoral exposures.

From Table 7 it also appears that the magnitude of the risk is surprisingly well correlated with the energy imparted to the patient. The risk per joule is 0.0002 within a factor of 2 up or down, excepting examinations of the extremities. To some extent this is due to the application to the mean whole body dose of the risk factors for endosteal tissue and non-specified organs. This gives an alleged risk factor of 0.000 07 per joule even if no critical organs are exposed. At most examinations

Table 7

Example of an estimate of total risk of future serious injury. The table is based on the following number of serious injuries in the form of induced malignancy or future generation genetic injury per 1 000 Gy of absorbed dose in the relevant organ (ICRP 1977): Genetic injury manifest in future generations 4.2, mammary carcinoma 2.5, leukemia 2, pulmonary carcinoma 2, thyroid carcinoma 0.5, unspecific malignancy 5.5, total 16.7. The unspecific malignancies were weighted with the mean whole body dose

Examination type or organ examined	Cases of serious injury		
	per million examinations	per 1 000 joule of energy imparted	per year in Sweden
Hip and femur (upper third)	53.4	0.45	8.2
Pelvis	21.0	0.24	2.6
Pelvimetry	57.0	0.18	0.6
Lumbo-sacral	15.5	0.16	0.3
Lumbar spine	60.1	0.15	10.9
Urography	83.3	0.16	15.9
Retrograde pyelography	116.2	0.17	0.3
Urethrocystography	109.8	0.27	2.4
Stomach and duodenum	36.3	0.12	8.7
Small intestine	29.0	0.14	0.8
Colon	89.8	0.15	11.6
Abdomen	29.8	0.15	3.1
Abdomen (obstetrical)	22.2	0.15	0.3
Hysterosalpingography	35.1	0.39	0.2
Cholecystography, cholangiography	10.9	0.12	1.6
Thoracic spine	54.1	0.26	5.8
Lungs (full size), ribs	5.31	0.25	4.9
Lungs (photofluorography)	20.1	0.27	18
Lungs plus heart	8.27	0.21	3.1
Cervical spine	3.27	0.18	0.3
Shoulder, clavicle, sternum	5.88	0.15	0.8
Head, sinus	11.9	0.17	4.2
Cerebral angiography	82.2	0.12	0.8
Dental (intraoral single exposure)	0.20	0.10	2.4
Femur (middle and lower third)	13.19	0.26	0.6
Lower leg, knee	1.56	0.08	0.8
Arm	0.46	0.09	0.2
Total			110

this will not be a dominating risk factor. Further, the list of organs associated with induction of malignant disease has been steadily growing with time, and it may be reasonable to make some allowance for possible future additions to the list.

To illustrate the uncertainties of the risk estimate, an independent estimate of

malignancy risk was made using risk data from the literature (National Academy of Sciences 1972, UNSCEAR 1977). This showed similar results with a risk factor of 0.000 1 per joule within a factor of 3 up or down. The difference to the estimate from Table 7 is only a factor of 2, and would have been even less if genetic risks had been included in this other estimate.

The collective risk to the Swedish population is also given in Table 7. If the estimates were correct, 110 cases of late injury would be induced by one years's radiographic diagnostic practice in Sweden. The main contributions would come, in order, from photofluorography of the lungs, urography and examinations of the colon and lumbar spine. The annual incidence of malignant disease in Sweden is above 30 000 cases, or about 3 600 cases per million inhabitants; the possible addition from radiographic diagnostic procedures is much less than one per cent.

Conclusion

The physical methods of patient dose measurements in the field enable an accuracy of about 10 per cent in routine measurements of the dose to the dosemeter or the energy imparted. In going from the dose in the dosemeter to the dose in the patient, about 10 per cent additional error occurs due to uncertainties in the composition of the soft tissues. In some cases practical problems of dosemeter positioning may add an error of more than a factor of 2 when the dosemeter must be placed far from the organ in which the dose is to be assessed.

However, as a rule simple physical measurements may give the organ dose within better than ± 50 per cent if the mean of a whole group of patients is considered. The representativity of the sample of patients may, however, be quite poor since the individual spread of patient doses is quite wide, with standard deviations up to 100 per cent. Even if the physical measurements were exact, an uncertainty of the order of ± 50 per cent (95 % confidence) is to be expected if the sample consists of 10 to 20 patients, a number which is attainable without too much practical difficulty. Estimates of collective dose involve rather large uncertainties from the sampling of hospitals, since large variations in patient dose from place to place were found, in several cases a ratio between the extremes exceeding 10. The estimates of the collective dose have an uncertainty of about a factor of 2, due to all the reasons mentioned.

The doses at given examinations are consistent with what would have been expected with the diagnostic techniques used. It is interesting that the gonad doses on the whole seem to have been significantly reduced since 1955, although the genetically significant dose has remained unchanged. The mean collective dose of about 1 mGy annually is approximately equal to the annual contribution from natural radiation sources.

The radiation risk does not exceed about one case of serious late injury per 10 000 examinations, and does not constitute any significant counterindication to

clinically indicated radiography. The collective risk of about 100 cases annually warrants, however, attempts at reducing the general exposure of the patients. In such attempts, patient dose measurements may be useful, as well as risk estimates. Then it is suggested to use the middle quartile mean to get less spread of the mean dose to a group of patients, and to use the energy imparted as a risk monitor with a risk factor of 0.0002 cases of late injury per joule of energy imparted to the patient.

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SUMMARY

Results are reported of measurements around 1974 on a thousand patients at 13 Swedish hospitals, and additionally at several photofluorographic and dental installations. Energy imparted as well as doses to the thyroid, breast, lung, bone marrow, ovary and testis have been calculated for many types of examination. Collective doses have been calculated and risk estimates made. The energy imparted corresponds to an annual mean body dose to the Swedish population of about 1 mGy (100 mrad), and the genetically significant dose was about the same as the 1955 total of 0.4 mGy; in both cases the uncertainty of the estimate is about ± 50%. The possibility of dose reduction by a factor of 2 or more using available techniques is demonstrated. The risk of future serious injury is estimated to 0.0002 cases per joule of energy imparted to the patient.

ZUSAMMENFASSUNG

Die Ergebnisse von Messungen um etwa 1974 bei etwa tausend Patienten von 13 schwedischen Krankenhäusern und zusätzlich verschiedenen Schirmbild und zahnärztlichen Einrichtungen werden berichtet. Die gegebene Energie sowie die Dosen von Thyreoidea, Brust, Lungen, Knochenmark, Ovarien und Testikeln wurden für verschiedene Arten von Untersuchungen berechnet. Die Kollektivdosis wurde berechnet und Risiko-Berechnungen vorgenommen. Die verabfolgte Energie entspricht einer jährlichen mittleren Körperdosis für die schwedische Population von etwa 1 mGy (100 mrad), und die genetisch signifikante Dosis von etwa 0,4 mGy war ungefähr dieselbe wie 1955. In beiden Fällen war die Unsicherheit der Berechnung etwa ±50%. Die Möglichkeit einer Dosisreduktion um einen Faktor von 2 oder mehr bei Verwendung befindlicher Techniken wird nachgewiesen. Das Risiko einer ernsthaften Schädigung in der Zukunft wird auf etwa 0,0002 Fälle per joule der diesen Personen verabfolgten Energie berechnet.

RÉSUMÉ

Les auteurs présentent les résultats de mesures de doses effectuées vers 1974 sur 1 000 patients dans 13 hôpitaux suédois, et, en outre, dans plusieurs installations de radiophoto-

graphie et de radiographie dentaire. Ils ont calculé pour de nombreux types d'examens l'énergie ainsi que les doses à la thyroïde, au sein, aux poumons à la moelle osseuse, à l'ovaire et aux testicules. Ils ont calculé des doses collectives et fait des estimations du risque. L'énergie absorbée correspond à une dose corporelle moyenne annuelle à la population suédoise d'environ 1 mGy (100 mrad) et la dose génétiquement significative a été environ la même que la dose totale en 1955 de 0,4 mGy; dans ces deux cas, l'incertitude de cette estimation est d'environ plus ou moins 50%. Les auteurs montrent la possibilité de réduire la dose par un facteur 2 ou plus en utilisant des techniques existantes. Le risque de lésion grave est estimé à 0,0002 cas par joule d'énergie communiqué au patient.

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