FROM THE DEPARTMENTS OF RADIATION PHYSICS, UNIVERSITY HOSPITAL, S-581 85 LINKÖPING, AND SAHLGRENSKA SJUKHUSET, S-413 45 GOTHENBURG, SWEDEN.

RADIATION EXPOSURE TO PERSONNEL IN DEPARTMENTS OF GYNAECOLOGIC ONCOLOGY IN SWEDEN

B. FORSBERG, P. SPANNE and S. HERTZMAN

Abstract

Radium-226 and cesium-137 are used at six departments of gynaecologic oncology in Sweden. A survey of radiation exposure (dose equivalents) to the personnel is reported. The measurements were performed with TL dosemeters. From dose distribution measurements, the dose equivalents in different parts of the body, related to different working procedures, were determined. Effective dose equivalents and collective dose equivalents were also estimated. The estimated collective dose equivalent for this category of personnel in Sweden was 1.3 manSv. The effective dose equivalent was less than the dose equivalent measured with dosemeters worn on the chest, and was less than half the annual limit set by ICRP.

Key words: Radiations, exposure to personnel; gynaecologic cancer, radium, cesium, dose equivalents, TL dosemeters.

Sealed sourses of radium (^{226}Ra) and cesium (^{137}Cs) are used in Sweden in six hospitals for treatment of gynaecologic cancers. Approximately 2500 treatments per year are performed and about 130 mg Ra-equ is used per treatment. Much of the work with the radioactive sources is still carried out manually, especially in the treatment of cancer of the corpus, where the Heyman packing method (6) is used. The medical staff of these departments, about 400 persons, is the category of radiologic staff in Sweden expected to receive the highest dose equivalents.

This report describes assessment of dose equivalents, effective dose equivalents, and collective dose equivalents, to the personnel of these departments. The survey was carried out by measurements of absorbed doses to the personnel with thermoluminescence dosemeters (TLD). Similar investigations have been reported (1, 3–5, 12, 17–20, 27, 28). The emphasis in those studies was on work in the operation theatre. The present investigation gives a picture of the dose equivalents to all categories of personnel working with radium/cesium. By using an LiF-TLD system with a low detection limit of 3 μGy (25), it was possible to measure absorbed doses also during single nursing procedures.

Treatment techniques

At Swedish departments of gynaecologic oncology, uterine cervical and endometrial cancers are treated with an intracavitary irradiation technique, the so-called 'Stockholm technique' or a modified form of it (6, 7, 13–16). The applicators have also been described in detail by THORÆUS (26). They are permanently loaded with ^{226}Ra or ^{137}Cs and vary in strength, typically between 30 and 150 mg Ra equ. The total activity used during one intracavitary treatment varies typically from 50 to 200 mg Ra equ.

An intracavitary irradiation treatment involves many different working procedures, during which the staff is exposed to radiation. One radiotherapist and two or three nurses or assistant nurses are involved in the insertion of the applicators. The personnel is also exposed when the radiotherapist, after the insertion, measures the dose rate along the anterior rectal wall and at the posterior wall of the urinary bladder. During the above-mentioned procedures, staff for anaesthetics is often present.

After application of the radiation sources the patient is transported to the radium ward where she lies with the applicators in place for 10 to 28 hours. During this time certain nursing procedures causing radiation exposure of the ward staff are carried out. At the end of the treatment, the applicators are removed and placed in a lead container. Finally the applicators are cleaned mechanically by a nurse and then brought back into the radium safe.

Accepted for publication 24 October 1986.

Table 1

Dose equivalent per unit equ mass of radium. Department No. 1

Working procedure	Staff category	Dose equivalent per unit equ mass of radium (μSv/mg)								
		Eyes	Chest	Pelvic region	Right					
					Wrist	Thumb	Fore-finger	Middle finger	Ring-finger	Little finger
Heyman packing	Radiotherapist	0.30	0.11	0.05	0.96	4.3	5.2	4.8		2.8
	Nurse	0.11	0.08	0.02	0.12	0.17	0.11			0.11
	Ass.nurse I	0.54	0.36	0.46	1.0	4.6	5.5	7.6		2.6
	Ass.nurse II	0.47	0.26	0.23	0.44	0.65	1.1			0.64
	Anaest.nurse	0.49	0.32	0.13	0.20		0.36			
	Ass.anaest.nurse	0.30	0.31	0.08	0.08		0.17			
All types of insertions including Heyman packing	Radiotherapist	0.33	0.16	0.14	1.4	3.6	4.6	4.2		2.7
	Nurse	0.19	0.17	0.10	0.25	0.29	0.29			0.24
	Ass.nurse I	0.52	0.51	0.52	1.5	4.1	5.0			3.4
	Ass.nurse II	0.38	0.28	0.18	1.1	1.8	2.7			1.0
	Anaest.nurse	0.36	0.28	0.08	0.20		0.34			
	Ass.anaest.nurse	0.34	0.23	0.05	0.30		0.37			
Transport between op.theatre and ward	Nurse or ass.nurse	0.09	0.12	0.13		0.20	0.15			0.19
Removal of sources	Nurse	0.35	0.25	0.14	0.69	1.6	2.0			1.5
	Ass.nurse	0.28	0.16	0.04	0.7	1.6	2.2			
Cleaning of sources	Ass. nurse	0.48	0.24	0.22	1.7	5.5	7.0	5.2	4.2	3.9

During the application the radiotherapist works behind a lead shield, which protects most of the body. The eyes are protected by approximately 5 cm of lead glass. The other personnel in the operation theatre, including the anaesthetics staff, are normally protected up to the height of the chest by different lead shields. During some nursing procedures, including removal of applicators from the patient, lead shields are sometimes used.

Specification of radioactive sources

In order to estimate comparable dose equivalents without the influence of the frequency of treatments, to personnel at different hospitals where either cesium or radium or both are being used, it is necessary to relate the sources to each other (8, 11, 21). We have specified the radioactive sources by means of radium equivalent mass. This is the mass of radium filtered with 0.5 mm Pt, which gives the same exposure rate at 1 m distance as the source we want to specify.

Measurements

Measurement method. Extruded TLD-100 dosemeters, 0.9 mm thick and 4.5 mm in diameter and containing 38 mg of LiF, were used. The read-out unit (ALNOR TLD 1313 B) was optimized for low dose measurements (24, 25) and had a minimum detection limit of 3 μGy, defined as the absorbed dose, resulting in a signal-to-noise ratio of 3. The dosemeters were initially treated at 400°C for one hour and heated once in the read-out unit to obtain the sensitivity characteristic of the cooling rate in the read-out unit. The relative sensitivities of the dosemeters were determined by irradiating all dosemeters to the same absorbed dose, and the relative sensitivity constants obtained were used in the calculation of absorbed dose. This in connection with the low dose measurement technique made it possible to measure absorbed doses down to 30 μGy, with a precision of about 1 per cent (one standard deviation). The dosemeters were used for several measurements without any other high temperature treatment than the read-out cycle. After about 5 measurement cycles, a new 400°C treatment was performed for one hour in order to avoid sensitization effects. To minimize fading, the dosemeters were treated thermally at 100°C for 0.5 h after irradiation. For long measurement periods and when the dosemeters were used in other hospitals they were instead treated for 20 h in 80°C before the measurements started. With these thermal treatments the maximum uncertainty due to fading is less than 2 per cent.

Since TL dosemeters are not absolute dosemeters, they had to be calibrated in a known radiation field. We used a radium source (49.7 mg) for this purpose. The calculated dose rate was independently checked by TL dosemeters

Left					
Wrist	Thumb	Fore-finger	Middle finger	Ring-finger	Little finger
1.6	3.9	5.2	6.8	12.0	8.3
0.12	0.18	0.13			0.14
1.7	3.2	4.2			3.8
0.31	0.75				0.39
0.39		0.57			
0.17		0.39			
1.3	3.6	4.7	5.7	7.7	6.5
0.24	0.35	0.32			0.32
1.3	3.1	4.4			4.1
0.36	0.98	1.1			0.80
0.35		0.52			
0.37		0.49			
	0.19				
1.5	2.1	2.5			3.4
0.3	1.2	1.4			
1.8	2.6	3.5	3.1	3.0	2.6

calibrated against ionization chamber measurements. The differences were less than 5 per cent. Signals caused by environmental radiation were corrected for by using background dosemeters placed in the changing rooms of the staff. In this way differences in background radiation at different hospitals were taken into account. This background correction, however, underestimated the absorbed doses, since we subtracted the background signal from the whole measurement period independently of the working times of the staff. This underestimation was less than 0.1 mSv at 40 hours' work per week and 50 weeks of work per year.

Measurement strategy. The radiation exposure of individuals involved in radium work is as a rule inhomogeneous and measurements of absorbed doses in different parts of the body are necessary in order to determine effective dose equivalents. Detailed dose distribution measurements were therefore performed at two departments. Furthermore, at all six hospitals chest dosemeters were worn by all personnel (274 persons) during two 1-month periods. The categories of staff which from the detailed dose distribution measurements were found to get the highest dose equivalents also wore wrist dosemeters (111 persons) during the same periods.

Assuming that there was no great difference in working procedures between the two departments where detailed dose distribution measurements were made, and the remaining four departments, it was possible to estimate the dose equivalents in different parts of the body for personnel at these four departments from the chest and wrist measurements. It was especially interesting to determine the dose equivalents in the eyes and the fingertips, since these are limiting, regarding non-stochastic effects. Furthermore, the measurements of dose equivalents in the chest and wrist together with the dose distribution measurements made it possible to detect if any person had been close to or exceeded the limits set by ICRP.

Dose measurements. The dose distribution measurements included measurements of dose equivalents in the forehead (representative for the eyes), chest, pelvic region, wrists and the fingertips. In some cases, also the absorbed dose in the back of the pelvic region was measured. The dosemeters used on the fingertips were placed in black polyethylene bags and taped to the fingertips. Latex gloves were worn over the dosemeter package and the total thickness in front of the dosemeter was about 50 mg/cm^2. WHITTON & EVERALL (29) stated 5 to 40 mg/cm^2 to be the depth where the most radiation sensitive cell layers are situated. Thus the dose equivalents were slightly overestimated but this overestimation was less than 10 per cent.

For measurements of the absorbed dose in the chest and wrists, TLD badges used for routine personnel dosimetry were used. The build-up thickness was 480 mg/cm^2.

Results and Discussion

Individual dose equivalents

Dose distribution measurements

At two hospitals, measurements of absorbed doses in different parts of the body were performed for several working procedures. For those procedures where the hands were closest to the radioactive sources, i.e. the insertion and the cleaning of applicators, measurements of absorbed doses in all fingertips were made. For other procedures, three fingertips on each hand wore dosemeters. Tables 1 and 3 show the dose equivalent per unit equivalent mass of radium, in μSv/mg, for all staff categories at these two hospitals. Table 2 shows the dose equivalents, in μSv, during nursing procedures at department No. 1. The tabulated values are the mean of 6 to 8 measurements with exception of the values for the nursing procedures, which are the mean of 2 to 3 measurements. The spread around the mean values, corresponding to one standard deviation, is about 30 per cent.

By regression analysis the dose equivalents in the eyes and the fingertips, which are the organs receiving the highest dose equivalents, were correlated to the dose equivalents in the chest and wrist, respectively (cf. Table 4). This analysis was made for the staff categories which were most heavily exposed, i.e. the personnel in the operation theatre, and nurses cleaning the sources.

The ratios between dose equivalents in the finger which

Table 2

Dose equivalents during nursing procedures. Department No. 1

Nursing procedure	Amount of Ra in patient(s) (mg Ra equ.)	Time period (min)	Dose equivalents (μSv)							
			Eyes	Chest	Pelvic reg.	Back	Left thumb	Left fore-finger	Right thumb	Right fore-finger
Nurse										
Transport of 5 patients to rad.-protected room	823	11	78	102	108	29	154	160	161	127
Control of haemorrhage Administration of drugs	165 826	13	73	73	66	–	104	101	109	116
Control of haemorrhage Administration of drugs	55 165	3	8	5	8	–	9	11	10	12
Injection Change sheets Adjust CaD	190	12	47	68	84	–	284	288	192	234
7 h working period Administration of drugs Change sheets	605 35	15	42	41	41	17	48	49	50	47
Change sheets Administration of drugs	150 694	13	127	213	279	44	427	376	485	428
Transport of 2 patients to rad.-protected room. Information	205	6	30	58	59	18	59	55	75	58
Assistant nurse										
Change sheets Adjust CaD	190	5	26	37	34		73	71	64	63
7 h working period Change sheets Drink + newspaper	135 605	31	181	162	131	51	284	318	316	321
Transport of 2 patients to rad.-protected room. Drinks	205	5	25	23	20	6	30	30	32	28
Transport of 5 patients to rad.-protected room. Drinks + medicine.	823	18	97	84	70	30	145	144	135	132
Change sheets Control CaD Drinks	150	4	59	81	92	31	163	160	100	92

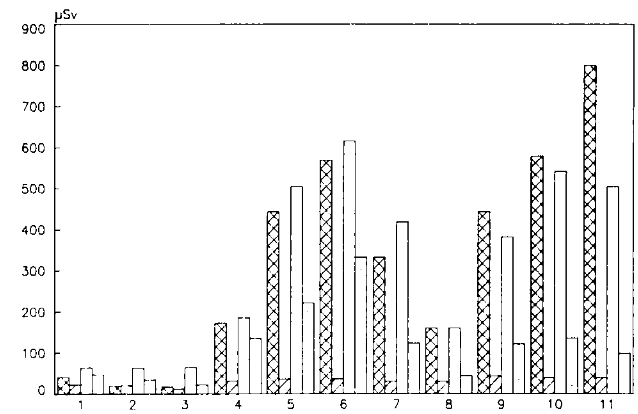

Fig. 1. Dose equivalents in different parts of the body and different staff categories at department No. 1 during one insertion of applicators. Radiotherapist (⊠), nurse (■), assistant nurse I (□), assistant nurse II (▦). Assistant nurse I is placed to the left of the radiotherapist and assists directly at the insertion. Assistant nurse II takes the applicators out of the radium safe, attaches threads to them and hands them to the nurse. 1—eyes, 2—chest, 3—pelvic region, 4—right wrist, 5—right thumb, 6—right forefinger, 7—right little finger, 8—left wrist, 9—left thumb, 10—left forefinger, 11—left little finger.

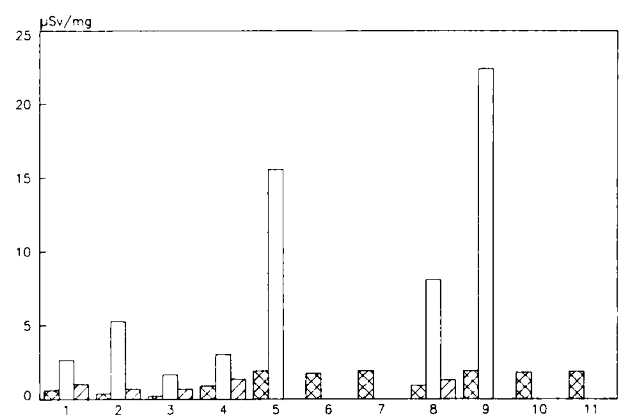

Fig. 3. Dose equivalents per unit mass of radium during the removal procedure at department No. 4. The numbers as in Fig. 1. Nurse with lead shield (⊠), nurse without lead shield (□), assistant nurse ■).

received the highest dose equivalent, and the wrist, and between the eye and the chest values, are shown in Table 4. The spread of the ratio finger/wrist, corresponding to one standard deviation, varied between 9 and 37 per cent, with an average of 23 per cent. Corresponding relative standard deviations for the ratios eyes/chest were 15 and 65 per cent with an average of 43 per cent. Similar dose distribution measurements have previously been made by BÄCKSTRÖM & RUDÉN (1), and they reported a ratio of 3.4 for eyes/chest values (in the present study 2.6 and 3.0) and 6.0 for finger/wrist values (in the present study 4.9 and

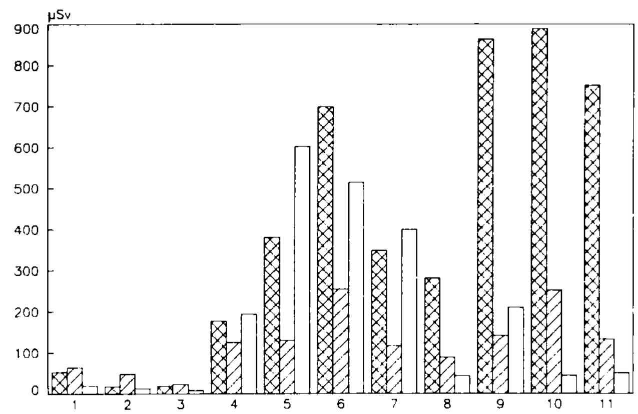

Fig. 2. Dose equivalents in different parts of the body and different staff categories at department No. 4 during one insertion. Symbols as in Fig. 1. Only one assistant nurse assists at the insertion.

3.5). The differences are caused by differences in staff experience, applicators, and cleaning methods.

The measurements at different procedures made it possible to determine the relative contributions to the collective dose equivalents and also to identify the procedures which caused the heaviest exposure of the staff.

Insertion of applicators. Under this heading Heyman packing, insertion of vaginal applicators and intra-uterine tubes are included. The dose equivalents are shown in Tables 1, 2 and 3. The average equivalent mass of radium per application was 123 mg for department No. 1 and 85 mg for department No. 4. The dose equivalents per insertion were also estimated (Figs 1, 2). Since at department No. 1, three persons besides the radiotherapist were taking part in the applications, but only two at department No. 4, and since they did not have exactly comparable tasks, a summation of the dose equivalents in the chest region was performed. This gave a ratio of these sums between the two departments of 1.4, while the ratio of the average equivalent mass of radium used per application was 123/85=1.4.

Three balancing factors explained this equality: Firstly, at department No. 1, many of the insertions were made with cesium sources, while at department No. 4 only radium was used. Since the gamma rays from cesium are attenuated more than the gamma rays from radium, this resulted in lower dose equivalents per unit equivalent mass of radium in the chest region to the staff at department No. 1. Secondly, the mean application time per unit equivalent mass of radium was probably shorter at department No. 1, since the mean activity per applicator was higher at this department. This reduced the dose equivalent to this staff. Thirdly, however, the higher number of persons involved in an application at department No. 1 acted in the opposite direction and increased the contribution to the collective does equivalent to the staff. The total amount of work at both departments was about

Table 3

Dose equivalent per unit equ mass of radium. Department No. 4

Working procedure	Staff category	Dose equivalent per unit equ mass of radium (μSv/mg)								
		Eyes	Chest	Pelvic region	Right					
					Wrist	Thumb	Fore-finger	Middle finger	Ring-finger	Little finger
Heyman packing	Radiotherapist	0.77	0.21	0.25	2.0	5.1	9.4	6.5	5.4	4.9
	Nurse	0.85	0.59	0.26	1.7	1.6	3.4			1.4
	Ass.nurse I	0.28	0.19	0.12	3.6	8.0	7.3			5.6
	Anaest.doctor	0.50	0.54	0.22	0.51	0.62	0.74			0.43
	Anaest.nurse	0.71	0.24	0.11	0.54	0.2	0.43			0.82
All types of insertions including Heyman packing	Radiotherapist	0.62	0.21	0.22	2.1	4.5	8.2	5.8	4.6	4.1
	Nurse	0.76	0.56	0.27	1.5	1.5	3.0			1.4
	Ass.nurse I	0.23	0.16	0.1	2.3	7.1	6.1			4.7
	Anaest.doctor	0.45	0.43	0.16	0.47	0.65	0.69			-
	Ass.anaest.nurse	0.63	0.29	0.13	0.49	0.47	0.54			-
Transport between op.theatre and ward	Nurse or ass.nurse	0.33	0.25	0.23	0.32	0.39	0.47			0.35
Different nursing procedures										
Nursing of patient	Nurse or ass.nurse	0.09	0.12	0.10	0.12	0.16	0.17			0.15
Changing of infusion bottle	Nurse	0.12	0.10	0.11	0.14	0.18	0.28			0.15
Injection	Nurse	0.36	0.43	0.23	0.65	0.6				0.98
Changing of bed-pan	Ass.nurse	0.60	0.43	0.50	0.68	0.8	0.78			
Removal of sources	Nurse*	0.62	0.39	0.21	0.90	1.9	1.7			1.9
	Ass.nurse**	1.0	0.69	0.68	1.4					
Cleaning of sources	Nurse or ass.nurse	0.42	0.16	0.11	2.6	6.5	8.7	8.3	7.1	6.0

* Using lead shield.
** Not using lead shield.

Table 4

Ratio between dose equivalents in different parts of the body

Working procedure, staff category	Department No. 1		Department No. 4	
	Eyes/ chest	Finger/ wrist	Eyes/ chest	Finger/ wrist
Insertion				
Radiotherapist	3.2	4.9	2.6	3.9
Nurse	1.3	1.4	1.4	2.3
Ass.nurse I	1.3	3.6	1.4	2.9
Ass.nurse II	1.5	2.9	–	–
Cleaning				
Ass.nurse	2.6	4.9	3.0	3.5

Correlation coefficients for the ratio eyes/chest vary between 0.62 and 0.92. Corresponding coefficients for the ratio finger/wrist were 0.79 and 0.96.

Left					
Wrist	Thumb	Fore-finger	Middle finger	Ring-finger	Little finger
3.7	11.5	11.3	12.1	10.2	9.6
1.2	1.4	3.2			1.6
0.68	3.3	0.8			0.6
0.71	0.63	0.88			0.45
0.50	0.70				0.81
3.3	10.2	10.5	10.9	8.8	8.8
1.0	1.7	3.0			1.6
0.51	2.5	0.5			0.6
0.54	0.59	0.63			-
0.74	0.59	0.72			-
0.32	0.45	0.51			0.49
0.14	0.19	0.16			0.19
0.10	0.19	0.12			0.25
0.58	0.88	0.90			0.9
0.75	0.95	0.88			0.9
0.9	1.9	1.8			1.9
1.3					
3.2	7.0	8.8	7.6	6.8	6.1

the same. Hence individual persons at department No. 1 were unnecessarily exposed.

Feige & Schlesinger (4) performed dose measurements on fingers during Heyman packing. For the radiotherapist, they reported 8 μSv/mg (max 14 mSv/mg) compared with 12 μSv/mg in the present investigation. Lax (17) reported 10 μSv/mg in the radiotherapist and 8 μSv/mg in the operation nurse, both values concerning the most exposed finger. Our values were 12.1 μSv/mg and 8 μSv/mg, respectively.

The dose equivalents in the eyes were about the same in the anaesthetics staff and in the radiotherapist. The distance to the sources was larger for the anaesthetics staff than for the radiotherapist, but the radiotherapist was shielded behind lead glass, which compensated for the closer distance.

Transport to treatment rooms. The dose equivalents in the chest region per unit equivalent mass of radium were of the same order of magnitude as estimated for insertion or cleaning procedures. The dose equivalents are directly related to the transport times. Transport time is not simple to change in existing departments, but this factor should be taken into account when new departments or rebuilding of old departments are planned.

Nursing procedures. Tables 1, 2 and 3 show dose measurements made during single nursing procedures at departments Nos 1 and 4. At department No. 1, also the absorbed dose during 7 hour ward personnel shifts was recorded (5). Since at department No. 1 lead shields were used, but not at No. 4, a difference in the observed ratio between the dose equivalents in the eyes and in the pelvic region would have been expected. The absence of such a difference can be explained by a non-optimized design of the lead shields.

Removal of applicators. When the applicators were removed from the patients (Fig. 3) a lead shield was usually used by the nurse. However, at three out of seven measurements at department No. 4, no lead shield was used. On one of these three occasions suture threads were removed and a dose equivalent in the chest region ten times as high as the usual value was recorded.

Cleaning of applicators. Dose distribution measurements at the cleaning procedure are shown in Fig. 4. As expected, the dose equivalents in the fingertips were high. Measurements of dose equivalents in the fingertips of a nurse or assistant nurse at different procedures (Fig. 5) showed that the highest dose equivalents were received during the cleaning procedure.

Assessment of maximum annual dose equivalents in the chest region

During two one-month periods the staff used extra TL chest dosemeters in parallel with the normal personal dosemeters. From these measurements the annual dose equivalents for 1983 were estimated from knowledge of the used equivalent mass of radium during the measurement months and during the whole of 1983. The uncertainty in the derived dose equivalents was estimated to be less than 30 per cent. The fact that the staff sometimes forgot to use the dosemeters, and the applied background correction, explain this uncertainty.

The maximum estimated annual dose equivalent among the nurses in the ward and the nurses or assistant nurses in the operation theatre was 25 mSv during 1983. The majority of the staff got less than 15 mSv in the chest region.

Assessment of maximum annual dose equivalents in the eyes

By using the chest dose measurements and the ratios of the dose equivalents in the eyes and the chest in Table 4, it is possible to conclude that no person working with gynaecologic radiation therapy is likely to exceed ICRP's annual limit for the dose equivalent in the eyes.

Table 5

Estimated maximum dose equivalent to fingers

Department No.	Max. dose equivalent in the wrist measured during 2 months (mSv)	Estimated max. dose equivalent in fingers during 1983 (mSv)
1	7.7	230
2	19.1	410
3	20.9	270
4	5.1	190
5	13.2	350
6	17.9	650
Limit (ICRP)		500

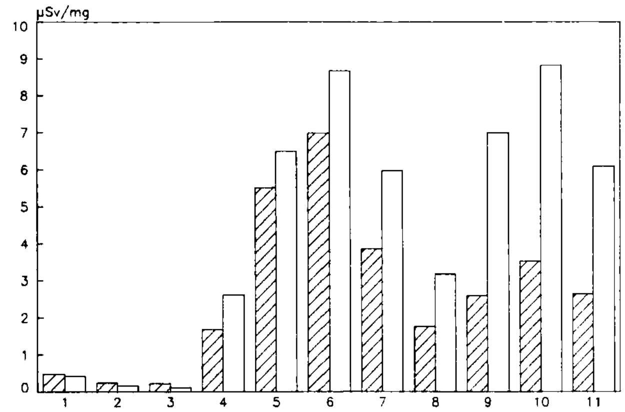

Fig. 4. Dose equivalents per unit equivalent mass of radium during the cleaning procedure. The numbers as in Fig. 1. Department No. 1 (■), department No. 4 (□).

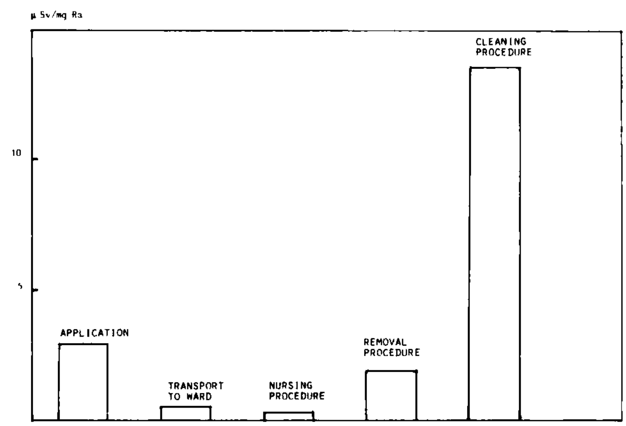

Fig. 5. Dose equivalents in fingertips of a nurse at different working procedures.

Assessment of maximum annual dose equivalents in the fingertips

To estimate dose equivalents in the fingertips, which are most heavily exposed to radiation, the ratio between the measured dose equivalent in the fingertip receiving the highest dose equivalent and in the wrist was calculated for every measurement. The mean of those ratios was then calculated for the working procedures which gave the highest dose equivalents (Table 4) at all hospitals. With knowledge of these ratios and the recorded dose equivalents in the wrist during the two month period, it was possible to derive the maximum dose equivalents in the fingertips during the measurement period. The relation between the equivalent mass of radium used during the measurement period and during 1983 gave the annual dose equivalents in the fingertips. The dose equivalents in the fingertips, together with the maximum dose equivalents in the wrist, are shown in Table 5. During one month a dose equivalent of 27 mSv was derived for a radiotherapist. This is about 5 per cent of the annual limit (500 mSv). The highest dose equivalent during two months was 20.9 mSv which is about 20 per cent of the limit. The annual dose equivalent for the same person amounted to about 300 mSv, which is less than the annual limit. The results in Table 5 indicate that a few persons were close to exceeding the annual limit. Thus, something should be done to reduce the dose equivalents in the fingers. The main contribution arises from the cleaning procedure. Therefore, a replacement of the manual cleaning with some sort of an automatic cleaning machine should be valuable. This is the only way to significantly reduce the dose equivalents in the fingers for this staff category if an afterloading method is not introduced. For all other categories the only way to considerably reduce the dose equivalents would be the introduction of such a method.

Effective dose equivalents

ICRP (9, 10) recommends that in order to limit stochastic biologic effects caused by ionizing radiation it is necessary to limit the effective dose equivalents. The reason for this is that the risk at the dose limit is assumed to be the same, irrespective of whether the body is uniformly or non-uniformly irradiated. ICRP has given weight factors for different organs, which must be used when calculating the effective dose equivalent (H_E). In a calculation of H_E, the spatial distribution of absorbed dose in the body also has to be known. In radium work this distribution will to a great extent depend on the working procedures.

The average organ dose equivalents used for calculation of H_E were derived from phantom measurements and found to be 85 per cent of the entrance dose equivalent for the brain, 90 per cent for thyroid, lungs, red bone marrow and the gastro-intestinal tract, and 65 per cent for ovaries. The phantom measurements were made using a radium source, which means that the effective dose equivalents caused by cesium sources will be overestimated.

H_E was calculated by means of the percentages given

Table 6

H_E and H_B per unit equ mass of radium (µSv/mg)

Working procedure	Staff category	Department No. 1		Department No. 4	
		H_E	H_B	H_E	H_B
Heyman packing	Radiotherapist	0.09	0.11	0.23	0.21
	Nurse	0.05	0.08	0.40	0.59
	Ass.nurse I	0.37	0.36	0.14	0.19
	Ass.nurse II	0.24	0.26	–	–
	Anaest. nurse or doctor	0.20	0.32	0.32	0.54
	Ass.anaest.nurse	0.17	0.31	0.21	0.24
All types of insertions incl. Heyman packing	Radiotherapist	0.16	0.15	0.24	0.21
	Nurse	0.12	0.16	0.38	0.56
	Ass.nurse I	0.39	0.45	0.12	0.16
	Ass.nurse II	0.27	0.34	–	–
	Anaest.nurse or doctor	0.15	0.20	0.27	0.45
	Ass.anaest.nurse	0.16	0.28	0.22	0.29
Transport between operation theatre and ward	Nurse or ass.nurse	0.10	0.12	0.22	0.25
Nursing procedure:					
Changing infusion bottle	Nurse			0.05	0.06
Injection	Nurse			0.08	0.12
One 7-hour pass	Nurse	0.06	0.07		
	Nurse	0.29	0.31		
	Nurse	0.23	0.28		
Removal av sources	Nurse	0.18	0.25	0.21	0.39
	Ass.nurse	0.10	0.16	0.63	0.69
Cleaning of sources	Ass.nurse	0.23	0.24	0.15	0.16

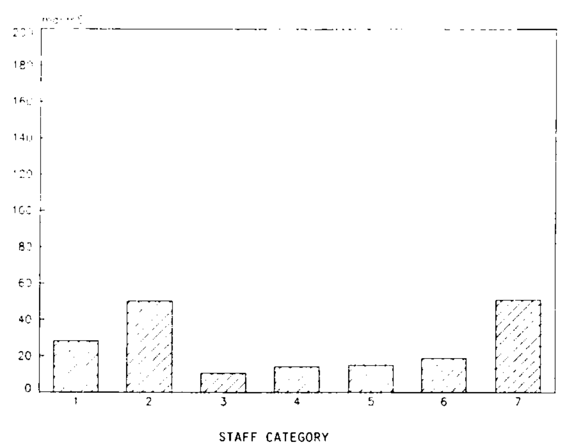

Fig. 6. Collective dose equivalent for different staff categories at department No. 1. Staff categories: 1—ward nurses, day, 2—ward assistant nurses, day, 3—ward nurses, night, 4—ward assistant nurses, night, 5—operation theatre radiotherapist, 6—operation theatre nurses, 7—operation theatre assistant nurses.

above and the following assumptions regarding the entrance dose equivalents: The mean value of the dose equivalents in the eyes, the chest and the pelvic region represented the dose equivalents in the red bone marrow and the bone surfaces. The mean value of the dose equivalents in the eyes and the chest was considered representative for the thyroid. The pelvic value was chosen for the gonads and the chest value for the lungs and the chest. Since the gastro-intestinal tract of the personnel is irradiated, four of the remaining tissues were given the pelvic value. The fifth remaining tissue was the brain, for which the eye value was used.

H_E and the dose equivalents, per unit equivalent mass of radium, in the chest, H_B, for different working procedures are shown in Table 6. It can be concluded that when using the H_B values for assessing H_E no underestimation of H_E is made. Hence the discussion regarding the dose equivalents in the chest is also valid for H_E.

H_E values per unit equivalent mass of radium derived from measurements by Lax (17) (radiotherapist 0.13 mSv/mg, nurse 0.15 mSv/mg, operation assistant 0.4 mSv/mg) are in agreement with our results.

Collective effective dose equivalents

It was shown that if H_E was replaced by the dose equivalent in the chest, H_B, no underestimation of H_E was made. Thus the collective dose equivalents, S_E, were approximated by

$$S_E \approx \frac{M_{1983}}{M_{2M}} \sum H_B$$

Table 7

Collective dose equivalent per unit equ mass of radium (manmSv/g) in patients at different departments

Department No.	manmSv/g
1	3.6
2	4.4
3	2.9
4	3.4
5	3.4
6	4.6

where

M_{1983} = equivalent mass of radium used during 1983.
M_{2M} = equivalent mass of radium used during the measurement period, 2 months.

The results for all departments showed that personnel at the ward contributed by approximately 60 per cent and the personnel in the operation theatre by 40 per cent to the total collective dose equivalent.

At department No. 1 (Fig. 6), S_E was estimated to be 170 manmSv. Compared with other radiologic disciplines at the same hospital, where $S_E \approx 22$ manmSv for the personnel at the department of diagnostic radiology and 17 manmSv for the nuclear medicine department, the department of gynaecologic oncology contributed with about 80 per cent to the total S_E.

The collective dose equivalent per unit equivalent mass of radium for the six departments appears in Table 7. The average for the whole country was 3.9 manmSv/g and during 1983 when a total of 335 g radium equ were used, 1.3 manSv. The corresponding value derived from the measurements by WALSTAM in 1957 (28) for the personnel at Radiumhemmet, Stockholm, was 16 manmSv/mg. Thus during thirty years the collective dose equivalent per unit equivalent mass of radium has decreased to one fourth.

During 1983, 2845 treatments were given in Sweden for gynaecologic cancers using radium and cesium. Thus each patient treatment on the average contributed with approximately 0.5 manmSv.

Conclusions

For personnel in Swedish hospitals working with radium and/or cesium in the field of gynaecologic oncology we conclude that: 1) the effective dose equivalent numerically is less than 25 mSv per annum; 2) the dose equivalents in the eyes are less than 75 mSv per annum; 3) dose equivalents in the fingertips in a few cases are close to or might even exceed 500 mSv per annum; a gross reduction of the dose equivalents in the fingers can only be obtained by the introduction of automatic cleaning machines and afterloading methods; 4) wrist dosemeters can be used to estimate the dose equivalents in the fingers; 5) the collective dose equivalent per unit equivalent mass of radium was estimated to be 3.9 manmSv/g, and for 1983 the contribution to the collective dose equivalent in Sweden was estimated to be 1.3 manSv; 6) the collective dose equivalents obtained by personnel dosimetry systems based on film are in agreement with results obtained in this investigation; 7) TL dosemeters are useful for studying working procedures from the point of view of radiation protection.

Request for reprints: Dr Börje Forsberg, Department of Medical Physics, Centrallasarettet, S-631 88 Eskilstuna, Sweden.

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