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DOSIMETRIC INTERCOMPARISON AT THE SCANDINAVIAN RADIATION THERAPY CENTRES

I. Absorbed dose intercomparison

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A small reduction of the absorbed dose to the normal tissue has, for certain collections of patient data, been shown to prevent heavy reactions (MORRISON 1975, STEWART & JACKSSON 1975, SVENSSON et coll. 1975). On the other hand, an increase of the dose to the tumour of a few per cent may drastically improve the probability of tumour control (SHUKOVSKY 1970, 1974, MORRISON, STEWART & JACKSSON, TURESSON & NOTTER 1980). Furthermore, the difference between the dose level for tumour control and heavy reaction in normal tissue may sometimes be small. It is therefore generally accepted that a careful dosimetry is a necessity for the radiation therapy (cf. ICRU 1976).

In order to achieve a high accuracy in the absorbed dose given to every single patient, a calibration procedure must be worked out that is simple to use and can be applied to all types of radiation sources used in a country or region. It must be possible to carry out the procedure with the various dosimetry instruments and systems in use. A calibration protocol was introduced for the Nordic countries in 1972 (NACP 1972) and later improved (NACP 1980); the dosimetry for low energy electron radiation has recently been published (NACP 1981). The procedure recommended by NACP (1980), mainly based on ionization chamber measurements, has been tested by HOFMEESTER (1980) using a calorimeter. He obtained values that were only an average of 0.6 per cent higher using NACP (1980) for ^{60}Co gamma and roentgen rays between 4 and 20 MeV. MATTSSON et coll. (1982) obtained similar good agreement against the Fricke dosimeter.

Many international absorbed dose intercomparisons have been carried out in order to investigate if the procedures used in different centres, often based on different national protocols, result in satisfying agreement in the determination of absorbed dose (NAGL & SANIELEVICI 1967, SVENSSON et coll. 1971, ALMOND et coll. 1972, SVENSSON et coll. 1972, BJÄRNGARD et coll. 1980, ELLIS et coll. 1981). One or more of the authors have been involved in several of these reports. The absorbed dose stated by our group has always been within −1.3 per cent to +0.7 per cent of the mean value for all the different participants. Therefore, it is well proved that the absorbed dose determination, based on the NACP protocols, is in good agreement with the mean level obtained from measurements by well reputated laboratories.

In spite of good protocols large errors cannot be excluded, even at well-established departments, due to mistakes made by the staff or instrument failure. Such errors may be serious even if they appear only at one energy, field size and SSD combination. However, this type of error may be revealed in dosimetric intercomparisons including a large number of beam qualities at each department.

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Table 1

Radiation therapy centres in Sweden, Denmark and Norway. The numbers of machines and the photon and electron beam qualities in routine use at each centre

Centre	No. of machines	Photon beam quality (MV)	Nominal electron beam quality (MeV)
Sweden			
Malmö	2	6, 42	6, 8, 10, 15, 20, 25
Lund	4	^{60}Co, 6, 8	–
Borås	1	^{60}Co	–
Gothenburg	5	2×^{60}Co, 4, 5, 8, 16	5, 6, 8, 10, 12, 14, 17, 20
Jönköping	2	^{60}Co, 9	6, 9, 11
Linköping	3	4, 6, 12	7, 10, 12, 15, 18
Karlstad	2	^{60}Co, 12	7, 10, 12, 15, 18
Örebro	3	^{60}Co, 10, 42	6, 7, 8, 10, 8, 10, 12 15, 20, 25
Eskilstuna	2	^{60}Co, 8	6, 8, 10
Stockholm			
Södersjukhuset	2	2×^{60}Co	–
Karolinska Sjukhuset	6	2×^{60}Co, 4, 6, 8	6, 8, 10
Danderyd	2	2×^{60}Co	–
Uppsala	3	^{60}Co, 8, 8, 16	6, 8, 10, 12, 14, 17, 20
Gävle	2	^{60}Co, 8	5, 8, 11
Umeå	4	^{60}Co, 4, 10, 21, 32	10, 12, 14, 17, 19 21, 25, 30, 33
Denmark			
Odense	3	^{60}Co, 6, 8, 16	5, 6, 8, 10, 12, 14, 17, 20
Copenhagen	6	2×^{60}Co, 3×6, 32	11, 13, 15, 20, 25
Herlev	3	4, 8, 8, 16	6, 8, 10, 5, 6, 8, 10, 12, 14, 17, 20
Århus	4	^{60}Co, 6, 8, 16	5, 6, 8, 10, 12, 14, 17, 20
Ålborg	2	4, 10	6, 9, 12, 15, 18
Norway			
Oslo			
Ullevål Sykehus	2	5, 45	5, 10, 15, 20, 25, 30, 35
Det Norske Radiumhospital	7	2×^{60}Co, 4, 7, 8, 16, 8, 16	5, 6, 8, 10, 12, 14, 17, 20*
Bergen	3	^{60}Co, 8, 25	7, 10, 13, 16, 19, 22, 25, 28, 32
Total	73		

* Two identical accelerators for electron beams are used.

Nationwide surveys aiming at a more thorough check of ^{60}Co gamma and high-energy roentgen ray qualities in use at a department have been carried out in the USA (SHALEK et coll. 1976, SOARES & EHRLICH 1978, THOMPSON et coll. 1978, SAMULSKI et coll. 1981). An international survey is presently being carried out by the IAEA-WHO; results during 1970–75 are reported by EISENLOHR & JAYARAMAN (1977). In the Nordic countries one series of extensive measurements of this type has been performed (SVENSSON 1971). All these investigations have revealed unnecessarily, in some cases unacceptably large uncertainties in the determination of absorbed dose at certain departments.

Since the measurements by SVENSSON, the Nordic protocols have been adapted which can be expected to have resulted in an improvement in dosimetry. A new series of measurements at all the radiation therapy departments in Denmark, Sweden and Norway and at all the qualities in routine use by the clinics (excluding 5 machines which were under service and also all conventional roentgen ray units) has been performed and is now reported (Table 1). Measurements in Finland are not yet completed. All the 23 departments were visited, and all the dosimetric equipment was brought to the centres.

Statistical information

Besides the dosimetry measurements, data on the radiation units were collected. Table 1 includes the radiation therapy centres in Sweden, Denmark and Norway. The photon and electron qualities in actual use are reported. The number of accelerators has increased, from 16 in 1968 to 49 in 1980, while the number of ^{60}Co units (24) is almost constant. Some betatrons have been replaced by linear accelerators or microtrons. Low-energy electron beams are now available at more centres. The number of therapy sources per million inhabitants is given in Table 2.

All the departments used ionization chambers for the determination of absorbed dose. At the time of the investigation (1980) most of the departments still applied the method in NACP (1972), some had changed to NACP (1980), and only one used neither of these protocols. A recommendation for measurements in electron beams with energy, $\bar{E}_0$, below 10 MeV, was not available (NACP 1981). For this particular quality the protocol by HPA (1975) was used by some centres.

Experimental procedure

The procedure in the measurements followed that recommended in NACP (1980) and NACP (1981).

Table 2

Number of therapy sources and inhabitants in 1980

Country	No. of sources		Inhab-itants (million)	Sources per million inhab.
	^{60}Co	Accel-erators		
Sweden	17	26	8.3	5.2
Denmark	4	14	5.1	3.5
Norway	3	9	4.1	2.9
Total	24	49	17.5	4.2

Table 3

Comparison of the absorbed dose determined with ionization chamber (NACP 1980, 1981) and ferrous sulphate methods ($\varepsilon_m \times G = 352\times10^{-6}$ m^2 kg^{-1} Gy^{-1}, SVENSSON & BRAHME 1979). n gives the number of qualities investigated. $\bar{x}$ is the mean value, σ is the standard deviation of the ratios (ionization/ferrous sulphate-absorbed dose). The ferrous sulphate dosimeters were irradiated at the various centres and evaluated in Gothenburg

Quality		n	$\bar{x}$	σ
Photons	4–16 MV	5	0.998	0.008
Electrons	$\bar{E}_0<10$ MeV	5	1.000	0.006
	$\bar{E}_0\geq10$ MeV	9	0.993	0.011

The absorbed dose determination is therefore based on ionization chamber dosimetry. The ionization chamber method was checked against ferrous sulphate dosimetry. Such measurements were carried out by the present authors at some of the centres. The difference between the absorbed dose determined by the two methods was very small (cf. MATTSSON et coll. 1982), being generally less than one per cent (Table 3).

The cylindrical ionization chamber used for the basic measurements was a Baldwin-Farmer 0.6 cm^3, type 2505, with graphite wall. This chamber was used for measurements at the reference depth for all photon beams and for electron beams with energies at the phantom surface higher than $\bar{E}_0=10$ MeV. The calibration was carried out at the National Institute of Radiation Protection (Sweden) in air-kerma free in air in a ^{60}Co gamma beam. Repeated calibrations were made at both the Danish and Norwegian standard laboratories in connection with measurements at centres in Copenhagen and Oslo. The agreement was within 0.3 per cent (cf. also JÄRVINEN & LINDBORG 1981). Constancy checks were carried out at all centres with a ^{90}Sr source; the standard deviation was 0.13 per cent and the maximum deviation from the mean value was 0.3 per cent.

All results for electrons below $\bar{E}_0=10$ MeV are based on measurements with a plane-parallel chamber (the NACP chamber, MATTSSON et coll. 1981). The absorbed dose to air calibration factor, N_D, for the plane-parallel chamber was determined against the Farmer chamber in a high-energy electron beam as described in NACP (1981). The reproducibility of the plane-parallel chamber was checked in a ^{60}Co gamma beam against the cylindrical chamber; such measurements were made at each centre. The standard deviation of the ratio of the signal for these two chambers was 0.4 per cent.

Random errors in reproducing the set-up of the equipment at the therapy source have been estimated to be ±1 mm for the positioning of the phantom surface at the SSD (in most cases 100 cm), and ±0.5 mm for the positioning of the chambers in the phantom. The comparison between the ionization and ferrous sulphate dosimetry indicated (Table 3) that the overall random uncertainties generally should be less than about ±0.5 per cent.

Absorbed dose comparison

^{60}Co gamma beam

The absorbed dose in the water phantom at the reference depth, i.e. 5 cm on the central axis, was determined with the cylindrical chamber. Eq. (11) in NACP (1980) was used for the absorbed dose calculation and data for the stopping-power ratio and the perturbation correction were taken from Table 6 in the same publication. These measurements were carried out at a field-size of 10 cm × 10 cm and at the normal treatment distance in use at each therapy unit.

The procedure used in practice by the centres is to calibrate the beam for the dose-rate at the depth of dose maximum (5 mm) in a water phantom. Therefore, the ratio between the absorbed dose at 5 and 50 mm depth had to be determined. Three different methods were used—based on measurements with an ionization chamber, a diode and a liquid ionization chamber—and the agreement between them was better than about ±0.3 per cent.

All the absorbed dose values stated by the centres are within about ±3 per cent, with a mean value very close (within 0.1%) to that determined by us

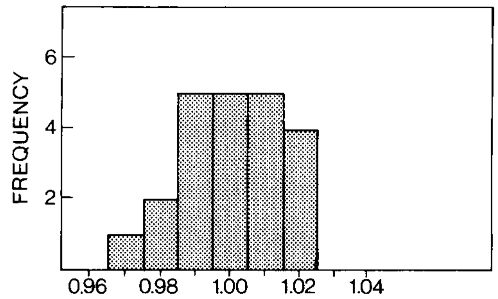

Fig. 1. The frequency at the different centres of determined to stated absorbed dose for ^{60}Co gamma beams for 10 cm × 10 cm field size. Δ is the difference between the highest and lowest values of determined to stated absorbed dose. n=22. $\bar{x}$=1.001. σ=0.014. Δ=0.047.

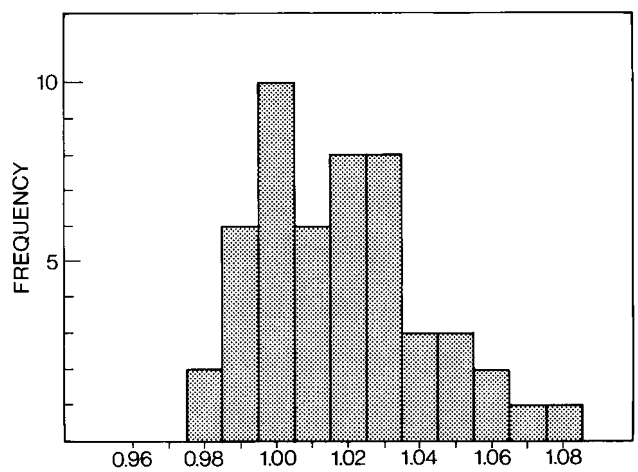

Fig. 2. The frequency of determined to stated absorbed dose for photon beams with accelerating potentials between 4 and 45 MV for 10 cm × 10 cm field size. Δ is the difference between the highest and lowest values of determined to stated absorbed dose. n=50. $\bar{x}$=1.017. σ=0.023. Δ=0.100.

Table 4

^{60}Co gamma beams, 10 cm × 10 cm field size. Number of determinations, standard deviation, and the difference between the highest and lowest values of the ratio of determined to stated absorbed dose. The ratios are divided into groups according to the dosimetric method used at the centre

Method used at the centre	n	$\bar{x}$	σ	Δ
NACP 1980	4	0.993	0.003	0.008
NACP 1972*	7	0.994	0.018	0.043
NACP 1972**	9	1.007	0.009	0.027
Other methods	2	1.010	–	0.014

Measurements carried out with
* The centre of the ionization chamber at the reference point.
** The effective point of measurement at the reference point.

Table 5

Photon beams, 4 to 45 MV, and 10 cm × 10 cm field size. Number of qualities, mean values, standard deviations, and the difference between the highest and lowest values of the ratio of determined to stated absorbed dose. The ratios are divided into groups according to the dosimetric method used at the centre

Method used at the centre	n	$\bar{x}$	σ	Δ
NACP 1980	10	0.997	0.013	0.04
NACP 1972*	9	1.026	0.029	0.08
NACP 1972**	18	1.028	0.021	0.08
Other methods	13	1.013	0.017	0.05

Measurements carried out with
* The centre of the ionization chamber at the reference point.
** The effective point of measurement at the reference point.

(Fig. 1). A similar result was obtained by SVENSSON.

Three types of errors turned out to be very common in the determination of absorbed dose at ^{60}Co. The stop-clock registered a time somewhat shorter than the real irradiation time for most units. A correction for time error was often not carried out. For most units this error was about 0.01 min and was never larger than 0.02 min. The effective point of measurement of the chamber was used by some departments, but C_λ from NACP (1972) applies to the centre of the chamber (Table 4). Finally, the air pressure was often measured with inaccurate barometers giving errors as large as 10 mbar. The effect of these last two types of errors have been evaluated. They caused errors of up to about 2 per cent in the absorbed dose in some places. A small reduction of the spread of the values in Fig. 1 was obtained if correction for these two errors were made. The uncertainty was fairly independent of the dosimetry procedure that had been used by the centres (Table 4).

In conclusion, good agreement was obtained between the absorbed dose stated by the centre and that determined by us. However, simple precautions such as re-calibration of the reference ionization chamber, more accurate temperature and pressure measurements and careful setting-up of the

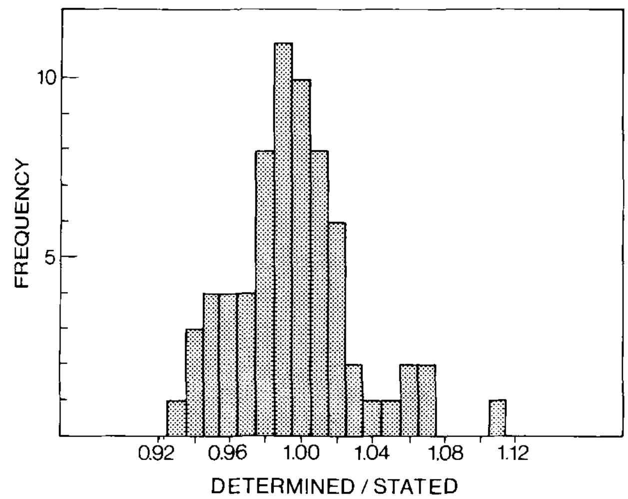

Fig. 3. The frequency of determined to stated absorbed dose for electron beams with $\bar{E}_0 \geq 10$ MeV for the reference field size (in most cases 10 cm × 10 cm). Δ is the difference between the highest and lowest values of determined to stated absorbed dose. n=68. $\bar{x}=0.996$. $\sigma=0.034$. $\Delta=0.178$.

Table 6

Electron beams, $\bar{E}_0 \geq 10$ MeV, and 10 cm × 10 cm for most of the beams. Number of qualities, mean values, standard deviations, and the difference between the highest and lowest values of the ratio of the determined to stated absorbed dose. The ratios are divided into groups according to the dosimetric method used at the centre

Method used at the centre	n	$\bar{x}$	σ	Δ
NACP 1980	16	0.975	0.026	0.087
NACP 1972	45	0.993	0.024	0.121
Other methods	7	1.061	0.027	0.081

measuring equipments can reduce the spread even more.

High-energy roentgen rays

In principle the same method was used to determine the absorbed dose to dose-maximum for high-energy roentgen rays as for ^{60}Co gamma beams. The appropriate values for $(s_{w,air})_u$ and $p_{u,graphite}$ were used. The comparison between determined and stated values appears in Fig. 2. The spread (from −2% to +8%) is considerably larger for roentgen rays than for ^{60}Co gamma beams.

One part of this difference is due to the fact that different dosimetric protocols were in use at the centres, i.e. NACP (1972), NACP (1980) and other methods (Table 5). It is well established that systematic errors may be obtained if the C_λ from NACP (1972) or ICRU (1969) are used. The expected errors are of the order of 2 to 3 per cent which agree well with the results in Table 5. The mean value given in Fig. 2 will change from $\bar{x}=1.017$ to $\bar{x}=1.004$ if corrections for the change in protocols and for air pressure measurements are applied. However, there is still a fairly large spread in the determined to stated values; the standard deviation only decreases from 0.023 to 0.021. Several parameters were checked in order to try to identify the reasons. It was found that the spread was independent of the age of the accelerator and of the accelerating potential. It was also shown that the spread was about the same with Varian and Philips accelerators (other types were too few for an analysis). The only reasonable explanation for the spread is a change in the response of the accelerator monitor between the calibration by the centre and our measurement.

$\bar{E}_0 \geq 10$ MeV. The frequency distribution of the absorbed dose determined by us to that stated by the centre appears in Fig. 3. The spread of the values is fairly large; even larger than for high-energy roentgen rays. The reason seems to be that the centres make larger errors in the choice of $(s_{w,air})_u$ and p_u with electron than with photon radiation. It seems that the centres using the recommendations from NACP (1980) have a smaller spread than centres using NACP (1972), but other factors dominate the uncertainty (Table 6). The discrepancies are particularly high if none of the protocols are followed. The mean value, $\bar{x}$, for those centres using NACP (1980) is only 0.975 compared with the expected value of unity. The reason is that the centre N1 (Table 10) is included. This centre seems to have an error in the calibration factor used for their reference instrument.

$\bar{E}_0 < 10$ MeV. The result for the low-energy range appears in Fig. 4. Also in this case, the scatter is considerable. However, one exception is the results from Denmark (Table 7). The difference between their highest and lowest values is only 5 per cent, while corresponding differences for Sweden and Norway are 12 and 15 per cent, respectively. One reason appears to be that in Denmark plane-parallel chambers and the procedure by HPA (1975) were used in the low-energy region and thus perturbation

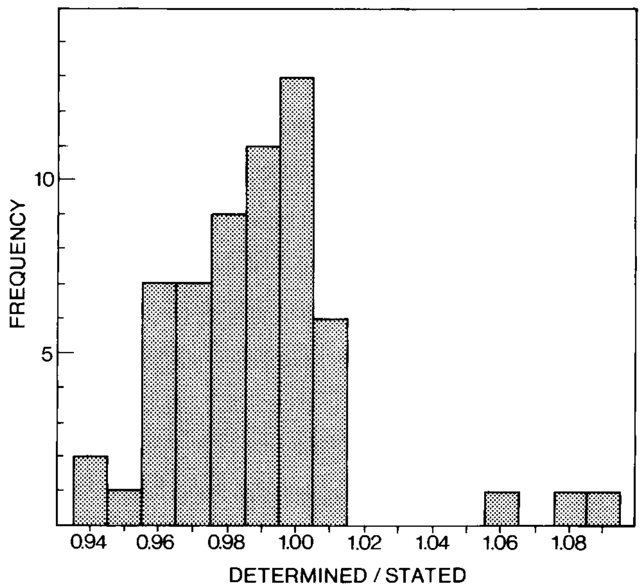

Fig. 4. The frequency of determined to stated absorbed dose for electron beams with $\bar{E}_0$<10 MeV and for the reference field size (in most cases 10 cm × 10 cm). Δ is the difference between the highest and lowest values of determined to stated absorbed dose. n=59. $\bar{x}$=0.989. σ=0.027. Δ=0.150.

corrections did not need to be applied (plane-parallel chambers are recommended for the low-energy range in NACP 1981). However, there is a systematic difference between NACP (1981) and the HPA methods resulting in about 2.5 per cent difference in dose determination (JOHANSSON & NAHUM 1980). In Table 7 the mean value for Denmark is 1.9 per cent lower which agrees fairly well with this prediction. The dose values (Table 8) would be 1 to 3 per cent too low if NACP (1972) was used instead of NACP (1980). The result $\bar{x}$=0.983 confirms this fact. The reason is that the perturbation correction factors given for cylindrical chambers in NACP (1972) were too small (JOHANSSON et coll. 1978).

Absorbed dose at an arbitrary depth and field-size

A separate investigation was made to determine the errors in dosimetry at an arbitrarily chosen field size and depth for photon beams. The staff of the departments were asked to state the absorbed dose for a 6 cm × 12 cm field at 15 cm depth in water for a given setting on the accelerator dose-monitor or ^{60}Co machine stop-clock. Measurements were then carried out at that point to determine the absorbed dose. As expected the spread, σ, and the maximum variation, Δ, of the ratios for determined to stated absorbed dose increased compared with those for dose maximum depth and 10 cm × 10 cm field size (Table 9). The reason is the additional uncertainties in the field size correction factors (most departments use 10 cm × 10 cm as a reference field) and in the relative depth-dose data.

Table 7

Electron beams, $\bar{E}_0$<10 MeV, and 10 cm × 10 cm for most of the beams. Number of qualities, mean values, standard deviations, and the difference between the highest and lowest values of the ratio of the determined to stated absorbed dose. The ratios are divided into groups according to the country

Country	n	$\bar{x}$	σ	Δ
Sweden	29	0.990	0.023	0.12
Denmark	18	0.981	0.016	0.05
Norway	12	0.999	0.043	0.15

Table 8

Electron beams, $\bar{E}_0$<10 MeV, and 10 cm × 10 cm for most of the beams. Number of qualities, mean values, standard deviations, and the difference between the highest and lowest values of the ratio of the determined to stated absorbed dose. The ratios are divided into groups according to the dosimetric method used at the centre

Method used at the centre	n	$\bar{x}$	σ	Δ
NACP 1980*	15	0.990	0.027	0.120
NACP 1972	24	0.986	0.019	0.066
Other methods	20	0.991	0.034	0.131

* Some hospitals use a cylindrical ionization chamber.

Table 9

Comparison between the ratios and their variations (defined in previous tables) for the reference field size (10 cm × 10 cm) at dose maximum depth (R_{100}) and for 6 cm × 12 cm at a depth of 15 cm. This investigation was carried out for ^{60}Co gamma and high-energy roentgen rays

Quality	Field size (cm)	Depth (cm)	n	$\bar{x}$	σ	Δ
^{60}Co gamma	10×10	R_{100}	22	1.001	0.014	0.047
^{60}Co gamma	6×12	15	15	1.016	0.024	0.088
4–45 MV	10×10	R_{100}	50	1.017	0.023	0.100
4–45 MV	6×12	15	48	1.029	0.026	0.120

Table 10

Comparison of the dosimetry at the different centres; each one given a code name (same symbols as in previous tables)

Hospital No.	No. of qualities	Determined to stated	
		$\bar{x}$	Δ
S1	5	1.005	0.049
S2	13	0.993	0.113
S3	5	0.993	0.031
S4	7	1.020	0.084
S5	11	1.001	0.104
S6	7	0.982	0.072
S7	5	1.009	0.088
S8	3	1.025	0.018
S9	9	1.011	0.045
S10	13	0.993	0.044
S11	2	1.018	–
S12	14	0.995	0.049
S13	2	1.001	–
S14	2	0.985	–
S15	1	1.011	–
DK1	9	1.010	0.112
DK2	15	0.997	0.076
DK3	12	1.001	0.073
DK4	12	1.000	0.045
DK5	7	1.004	0.031
N1	9	0.966	0.052
N2	12	1.053	0.101
N3	24	0.990	0.121
Total 23	199	1.000*	0.178**

* This value is a real mean value and not due to a normalization.
** The difference between the highest and lowest values (including all centres) of the ratio of the determined to stated absorbed dose.

Table 11

The dosimetric accuracy at different beam qualities (the symbols are the same as in previous tables)

Quality	n	$\bar{x}$	σ	Δ
^{60}Co	22	1.001	0.014	0.047
Photons				
4–45 MV	50	1.017	0.023	0.100
Electrons				
$\bar{E}_0$<10 MeV	59	0.989	0.027	0.150
$\bar{E}_0$≥10 MeV	68	0.996	0.034	0.178
Total	199	1.000		0.178

Discussion and Conclusion

The absorbed dose stated by the various centres relative to our measurements is given in Table 10. It can be noted that the mean values, $\bar{x}$, for the qualities investigated for each of the 21 centres are within ±2.5 per cent of our measured values; only two centres have higher differences (−3.4% and 5.3%). The total mean (Table 10) for all qualities and all departments agreed with our determination ($\bar{x}$=1.000). It can therefore be concluded that most departments should be able to exchange clinical experiences concerning radiation treatment, i.e. differences in local dose determination are small in this context.

However, it is remarkable that the dose statements within some of the departments have such a large spread. For 5 of the centres the difference between the highest and lowest values, Δ, was somewhat higher than 10 per cent. This is particularly serious as the experience in radiation treatments gained by the department using one beam quality may be invalid if a different accelerator is to be used for other patients or if the beam energy is changed. Furthermore, this difference may in reality be much larger as Table 10 only includes measurements for the reference field size; the uncertainty increases further when the absorbed dose for an irregular field size at an arbitrary depth in the phantom is to be determined.

It is also known that some departments re-calibrated their accelerator dose monitor before our visit. The actual situation may therefore be worse.

The uncertainties in the dose determinations for the different beam qualities for all the centres are summarized in Table 11. It is evident that the maximum spread is much larger for accelerators than for ^{60}Co gamma machines. The largest dose variation is found for $\bar{E}_0$>10 MeV with Δ=17.8 per cent.

Some uncertainties in the dosimetry may depend on the accelerator type or construction. An investigation was carried out at all the accelerators to find out if the accelerator dose-monitor calibration depended on the gantry angle. This was only a problem for the oldest betatron in use. For this facility the calibration factor varied up to 5 per cent with the gantry angle. Another problem is the temperature and pressure sensitivity of the accelerator dose-monitor. There are a variety of constructions: sealed, semisealed and open monitor chambers. Not all departments with semisealed or open chambers

Table 12

Intercomparison of absorbed dose. Each investigator has made measurements at several centres for a large number of beam qualities. The frequency of results for determined to stated dose is given. The mean value is used as normalization

Reference	Quality	Method	Qualities	Frequency inside the dose limits ±5 per cent	Frequency inside the dose limits ±10 per cent	Region
SHALEK et coll. (1976)	^{60}Co, rtg ray	Visit, ion chamber	352	88	97	Part of USA
SOARES & EHRLICH (1978)	^{60}Co	Mailed, TLD	812	83	96	USA
EISENLOHR & JAYARAMAN (1977)	^{60}Co	Mailed, TLD	417	65	85	Whole world
EHRLICH & SOARES (1979)	e−	Mailed, ferrous sulphate	–	58	81	USA
SAMULSKI et coll. (1981)	^{60}Co, rtg ray	Visit, ion chamber	254	92	99	USA
SVENSSON (1971)	^{60}Co, rtg ray, e−	Visit, ion chamber	100	70	86	Scandinavia
Present investigation	^{60}Co, rtg ray, e−	Visit, ion chamber	199	89	99	Scandinavia

make corrections for air pressure changes in the daily routine. The temperature at the accelerator dose-monitor is not registered and changes in temperature during different working conditions during a day or period may occur. (The standard deviation for determined to stated dose values were about one per cent larger for those accelerators which had semisealed or open chambers than for sealed chambers.) The dose-rate in individual pulses is fairly large for some of the accelerators in the electron mode of operation and corrections for recombination may be as large as 5 per cent with a Baldwin-Farmer chamber. Some departments seem to have carried out inadequate corrections, a fact which contributes to the large spread in stated to determined dose values for electron beams.

The factors discussed may in a few cases lead to considerable errors. However, it is our firm belief that the large spread between the accelerator dose-monitor calibrations at different beam qualities is in most cases due to an insufficient checking or accelerator maintenance programme for the accelerators. The quality of this type of work does not seem to be dependent on the size of the department. A great improvement in the dosimetry would therefore be achieved if all departments applied a careful check and maintenance programme, for instance of the type suggested in NACP (1980).

Even if the spread appears to be fairly large a considerable improvement of the dosimetry has been observed in the Nordic countries since 1968. Compared with the previous set of measurements (SVENSSON) the spread is about one half; 86 per cent of the centres stated a dose value within ±10 per cent of the determined value in 1968 while 89 per cent were within ±5 per cent in 1980 (Table 12). However, a small part of this difference may be due to the fact that SVENSSON investigated various field sizes while the present investigation includes only the reference field-size.

The dosimetric accuracy in the Nordic countries appears from Table 12 to be somewhat better than that in other places. Furthermore, it should be taken into account that the other investigations only included ^{60}Co gamma units and sometimes also roentgen rays (mostly 4 MV) while a larger spread is generally obtained for electron beams as shown by EHRLICH & SOARES (1979) as well as in the present investigation. Also it should be observed that in the other investigations only centres which themselves wished to take part were included, while all centres were surveyed here. However, there seems still to be a fairly long way to go before the principle goal set by the CRP (Center of Radiological Physics, USA) is achieved, i.e. to ensure that the true absorbed dose calibration of therapy units is within ±3 per cent of that stated at all departments (SAMULSKI et coll.).

SUMMARY

A dosimetric intercomparison was carried out at all the centres in Denmark, Norway and Sweden. All the beam

qualities (except conventional roentgen rays) used in radiation therapy were investigated. The ratio of the absorbed dose measured by us to that stated by the centre was determined. The mean ratio and standard deviation with the reference field-size were for ^{60}Co gamma beams 1.001 ± 0.014, for roentgen ray beams (4–45 MV) 1.017 ± 0.023, electron beams with energy $\bar{E}_0<10$ MeV 0.989 ± 0.027, and electron beams with energy $\bar{E}_0\geq10$ MeV 0.996 ± 0.034. The difference between the highest and lowest ratios was 17.8 per cent. A systematic difference due to the application of different protocols (NACP 1972 and 1980) was found.

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