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INTERCOMPARISON OF NORDIC EXPOSURE SECONDARY STANDARDS FOR SOFT ROENTGEN RAYS

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The calibrations at the National Standards Laboratories in the Nordic countries are based mostly on exposure secondary standards. As a part of a Nordic cooperation on standardization of dosimetry, exposure standards for different energy ranges are compared and recently an intercomparison of therapy level exposure secondary standards at ^{60}Co gamma radiation was reported (JÄRVINEN & LINDBORG 1982). In the present work an intercomparison of exposure secondary standards for soft roentgen rays is reported.

Although the accuracy required in the dosimetry of soft roentgen rays seems to be less than in the dosimetry of higher energy roentgen rays, there were certain reasons to prefer soft roentgen rays as the next choice of energy range in the intercomparison program. The use of medium energy roentgen rays (generating potential 100–300 kV) in radiation therapy is decreasing rapidly, while the use of soft roentgen rays seems to remain. The commercially available ionization chambers which are used as exposure secondary standards for soft roentgen rays are more fragile and unstable than ionization chambers used at other energies. The description of the radiation quality in exposure half value layers (HVL) is more complicated at soft roentgen rays due to the very small thicknesses needed as well as the sensitivity to impurities in the filters.

The two radiation qualities used in the intercomparison (generating potentials 10 kV and 25 kV) are given in Table 1. The measurements were made at the National Institute of Radiation Protection (NIRP) in Sweden late 1981. Denmark, Finland and Norway took part in the intercomparison.

Equipment and Method

The ionization chambers used as exposure secondary standards are given in Table 2. All chambers are made by the same manufacturer (Physikalisch-Technische Werkstätten, PTW, Germany). The chambers are equal except for the Danish chamber, which has an air volume about ten times smaller.

The Swedish standard is defined by the two chambers given in Table 2, and the mean value of exposure obtained by them represents the true value. The Swedish standard is traceable to the International Bureau of Weights and Measurements (BIPM) while the others have been calibrated at the National Physical Laboratory (NPL) in England.

The roentgen beams were generated by a constant potential generator (Tunzini Sames Type KS 140) connected to a roentgen tube (Machlett type OEG-60S) with a tungsten target and beryllium window of 1.5 mm. Due to the relatively small instability of the output of the tube the measurements were made without a beam monitor. The HVL values were determined using aluminium filters of high purity

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(99.99%). The systematic uncertainties of the HVL values were estimated to be ±5 per cent.

The intercomparison was carried out by calibrating the secondary standards of Denmark, Finland and Norway against one of the Swedish secondary standards. The calibration was performed following the routine established in the laboratory and by the person who usually performs the job. The relative exposure rate at a point 500 mm from the tube window in the centre of the roentgen beam was first determined by one of the Swedish standard chambers. The standard chamber was then replaced by the chamber to be calibrated, and the current from the chamber was measured. Thereafter the relative exposure rate was again determined by the same standard chamber. This procedure was repeated after new alignments of the chambers. Because of lack of time the second Swedish standard was not used except in the calibration of the Norwegian chamber, where it was used in the second independent calibration. No corrections were applied for the ambient temperature and the atmospheric pressure, because the three measurements in each calibration were made at the same point in the room within a few minutes giving rise to only negligible changes in temperature and pressure.

The current from the ionization chambers were measured with a precision current measuring device developed at the laboratory (SAMUELSON & BENGTSSON 1973). The systematic uncertainty and the statistical uncertainty (at the 95% confidence level) of the current values were both expected to be less than ±0.1 per cent.

The calibration factor N_X of the chamber at 22°C and 101.3 kPa was calculated from:

$$N_X = N_{X,s}(I_{s,1}+I_{s,2})/2I$$

where $N_{X,s}$ is the calibration factor of the Swedish secondary standard at 22°C and 101.3 kPa and $I_{s,1}$ and $I_{s,2}$ are its currents at the two measurements. I is the current from the chamber to be calibrated. The currents $I_{s,1}$, $I_{s,2}$ and I were taken in the actual temperature and pressure and they were corrected for leakage currents only.

Table 1

Radiation qualities used in the intercomparison. The inherent filtration of the roentgen tube was 1.5 mm Be and the diameter of the radiation beam 10 cm

Generating potential (kV)	Additional filtration (mm Al)	mm Be	HVL (mm Al)
10		2	0.041
25	0.377	2	0.24

Table 2

Ionization chambers used as exposure secondary standards

Country	Type	Serial number
Denmark	Nuclear Enterprises 2523/3	171057
Finland	Nuclear Enterprises 2536/3	R17787
Norway	Nuclear Enterprises 2536/3	R17786
Sweden	PTW 7241/UI/k	R17696
Sweden	PTW 7241/UI/k	R17918

Results

The results are summarized in Table 3. Systematic uncertainties in the intercomparison which may contribute more than 0.1 per cent are given in Table 4. Systematic uncertainties relate partly to possible differences between the radiation beams at BIPM and NIRP, and partly to the calibration technique used at NIRP. Although the ambition has been to have the radiation beams at NIRP very similar to those at BIPM, some differences are expected, especially in the photon spectrum, in the beam size and in the field homogeneity.

The systematic uncertainty caused by the relatively poor accuracy of the HVL values were investigated by re-evaluating the results using calibration factors for HVL=0.037 mm Al. The new calibration factor deviates less than 0.2 per cent from the first and it is believed that a systematic uncertainty related to the HVL values is about ±0.1 per cent. From Table 3 it can be seen that the ratio of the two independent determinations of N_X at NIRP is very nearly the same both in the case of the Norwegian calibration where two different Swedish standards were involved and the other calibrations. Therefore, a calibration factor obtained from a comparison against only one Swedish standard instead of two is believed to increase the systematic uncertainty less than ±0.2 per cent. The maximum systematic uncertainty from Table 4 becomes ±0.8 per cent.

Since one of the aims of the intercomparison was to detect unexpected systematic uncertainties in the standards, such as long term instabilities or changes

Table 3

Results of the intercomparison

	10 kV HVL 0.041 mm Al			25 kV HVL 0.24 mm Al		
	Denmark	Finland	Norway	Denmark	Finland	Norway
Ratio of the two independent determinations of N_X at NIRP	0.999	1.001	1.001	1.002	0.999	0.998
N_X (NIRP)/N_X (NPL)	0.997	0.989	0.990	0.997	0.989	0.990

Table 4

Systematic uncertainties in the intercomparison which contribute at least 0.1 per cent

Cause of uncertainty	Uncertainty (per cent)
Differences in the radiation beam between BIPM and NIRP	
Photon spectrum	±0.3
Beam size	±0.1
Field homogeneity	±0.1
Calibration technique at NIRP	
HVL	±0.1
Use of only one standard chamber	±0.2
Total	±0.8

in the spectral sensivity of the standards, these are not included in the list of the systematic errors (Table 4) of the intercomparison.

The most essential statistical uncertainty in the calibration is the short term instability of the Swedish exposure standards. Results of regular constancy checks with the Swedish standard chambers over four years (two chambers) and six years (two chambers) have shown a mean value of 1.000 during a year (ratio: (measured value)/(original value)) with a standard deviation of ±0.5 per cent calculated from the twelve mean values observed during a year. Considering some other uncertainties, a statistical uncertainty of ±0.8 per cent is arrived at (95% confidence level) for the calibration techniques (KUPFER et coll. 1977).

Discussion

The calibrations at the NPL were made in April 1976, May 1976 and April 1977 for the Norwegian, the Finnish and the Danish standard, respectively. In spring 1979 the NPL replaced their old primary standard for therapy level low energy roentgen rays by an entirely new free air chamber, which in an intercomparison with the BIPM primary standard yielded an agreement better than 0.2 per cent (CCEMRI 1979). The NPL introduced a correction factor which should be applied to calibration factors obtained before spring 1979 in order to get factors that would have been obtained by calibration against the new primary standard (NPL 1979). This correction has been applied to the calibration factors N_X from NPL, and the values then correspond to the new primary standard at the NPL. The Swedish standard chambers were calibrated at the BIPM in 1976 and in 1979. The latter calibration revealed a drift of 0.5 per cent for both chambers.

From the last line of Table 3 it is seen that all differences between the standards became equal to or less than one per cent.

The differences are close to the estimated systematic and statistical uncertainties and they are not regarded as significant. Greater differences would have been expected because of the fragile construction of the ionization chambers and the rather long period, four to five years, since their last calibration at the primary standards laboratory. Another observation is that the evaluation at the two radiation qualities indicates no change in the energy response of the chambers. It is concluded that the long term stability of the secondary standards is sufficient for most calibration tasks in this energy range and a period of about five years seems acceptable between the calibrations against primary standards unless stability checks indicate otherwise.

SUMMARY

An intercomparison of exposure secondary standards for soft roentgen rays in use in the Nordic countries is reported. One of the standards was used as a reference standard against which all the other standards were cali-

brated. The statistical uncertainty in the calibrations was estimated to be 0.8 per cent (at the 95% confidence level) and the maximum systematic uncertainty in the intercomparison was estimated to be 0.8 per cent. The observed differences, at most about one per cent, were not considered significant. It was concluded that for this type of chambers a period of about five years is acceptable between recalibrations against a primary standard unless stability checks indicate otherwise.

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REFERENCES

CCEMRI: Comité Consultatif pour les Étalons de Mesure des Rayonnements Ionisants, Section 1–5ᵉ Réunion – 1977. Bureau International des Poids et Mesures, Pavillon de Breteuil, F-92310 Sèvres, France.

JÄRVINEN H. and LINDBORG L.: Intercomparison of Nordic therapy level exposure secondary standards for ^{60}Co gamma radiation. Acta radiol. Oncology 21 (1982), 203.

KUPFER T, LINDBORG L. and SAMUELSON G.: A Secondary standard laboratory for exposure calibrations in therapy X-ray beams. (In Swedish.) SSI Report No. 1977-013. National Institute of Radiation Protection, Box 60204, S-104 01 Stockholm, Sweden.

NPL: Technical Memorandum No. 5. Change in the primary standard of X-ray exposure for therapy-level medium energy X-rays (30–50 kV) and therapy-level low energy X-rays (8–50 kV). National Physical Laboratory, Teddington, Middlesex, TW11 OLW, U.K. 1979.

SAMUELSON G. and BENGTSSON L. G.: Precise and rapid measurements of small currents from high impedance sources. Rev. Sci. Instr. 44 (1973), 920.