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Technical note

Analysis of the long-term stability of the output of electron beams generated by the Novac11™ IORT accelerator

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ABSTRACT

Aim: The aim of the study was to analyze the long-term stability of electron beams generated by the Novac11™ IORT accelerator.
Background: Novac11™ (NRT®) is a mobile electron accelerator designed to irradiate small areas of tissue, up to 10 cm in diameter, with electron beams during surgical procedures. It is characterized by a great mobility guaranteed by a number of degrees of freedom enabling irradiation in the conditions of an operating theatre.
Materials and methods: Over the period of January 2013 and September 2016, the measurement sessions of the output of clinically used beam qualities (6, 8 and 10 MeV) were carried out 41 times. Because of the unsatisfactory long-term stability, an extra procedure of tuning of the magnetron, suggested by the manufacturer, was introduced in October 2015, 15 measurements were performed since then. The output of the Novac11™ accelerator was measured in the reference conditions recommended by the IAEA Report 398, the measurements of the charge in the ionization chamber at the reference depth were carried out with a Dose1™ electrometer and a plane-parallel chamber PPC05™ from IBA®.
Results: The introduction of the tuning of the magnetron procedure resulted in satisfactory long-term stability of the measured outputs below 2%.
Conclusions: After the introduction of the STV parameter tuning procedure, the long-term stability of the Novac11™ output increased considerably and is within the values declared by the manufacturer.

1. Introduction

The technique of intraoperative radiotherapy is increasingly used in the treatment of cancer patients, in breast cancer in particular. It is used for irradiation of the tumour bed after tumourectomy in order to decrease the risk of local recur-

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Table 1 – The values of the correction factors for incomplete saturation, polarization and beam quality and their uncertainties.

Nominal energy [MeV]	6 MeV	8 MeV	10 MeV	Uncertainity of the correction factor [%]
Incomplete saturation (K_{SAT}) [1]	1.002	1.007	1.011	0.06
Polarization (K_{POL}) [1]	0.992	0.991	0.994	0.21
Beam quality (K_Q) [1]	1.045	1.035	1.29	1.70

rence. It is very important because over 90% of recurrences appear in the breast quadrant in which the primary tumour was localized [1].

Intraoperative radiotherapy is also used in head and neck tumours, gastrointestinal tumours, in soft tissue sarcomas and recurrences of solid tumours [1]. In the daily practice of our department, intraoperative radiotherapy is most often used in the irradiation of the nipple-areola complex after subcutaneous nipple sparing mastectomy.

Novac11^{TM} (NRT) is a mobile accelerator designed to irradiate small areas of tissue (up to 10 cm in diameter) during a surgical procedure with electron beams. It is characterized by great mobility guaranteed by six degrees of freedom: rolling and rotation of the wheel, two planes of rotation of the modulator part, and two planes of rotation of the head. It is equipped with a set of transparent circular collimators (transparency facilitates considerably machine positioning) of 3, 4, 5, 6, 7, 8 (80 cm long, clinical collimators) and 10 cm in diameter (10 cm is a reference collimator, 100 cm long). The accelerator generates electron beams of nominal energy 4, 6, 8, and 10 MeV. The maximal dose rate is 39 Gy/min for nominal energy 10 MeV. Maximal dose per pulse is approximately 7.2 cGy/pulse, and differs between the available nominal energies. Novac11^{TM} is developed from the Novac7^{TM} model [2].

In August 2016, there were about 15 Novac11^{TM} models installed around the world. Therefore, so far there have been no publications dealing with their dosimetry parameters, such as the long-term stability of the output.

In this paper, the results of routine dosimetry controls performed before every treatment are presented.

2. Materials and methods

The output of the Novac11^{TM} accelerator was measured in the reference conditions recommended by the IAEA Report 398 [3]. The measurements were carried out with a reference collimator (10 cm diameter, 100 cm length), at a reference depth Z_{REF} for every nominal energy used clinically (6, 8, 10 MeV). The Z_{REF} values were determined according to the recommendations of the IAEA Report 398, namely by the measurement of the ionization curve which was later recalculated to the percentage depth dose (PDD). The measurements were carried out in the PTW MC^2 field analyzer, with a plane-parallel ionization chamber Advanced Marcus (PTW). The measurements of the charge in the ionization chamber at the reference depth were carried out with a Dose1 electrometer and a plane-parallel chamber PPC05 from IBA. This particular measuring equipment was selected because of the very high dose rate of the accelerator. The ionization chambers commonly used in conventional radiotherapy cause many problems because they require very high correction factors for incomplete saturation.

Table 2 – Percentage values of the uncertainties of output measurements for various beam energies.

Nominal energy [MeV]	6 MeV	8 MeV	10 MeV
Uncertainity of output [%]	2.72	2.00	2.01

The PPC05 chamber was specially designed and adapted for measurements of high dose rates – according to Laitano et al. [4], a high dose rate is defined as dose per pulse between 2 and 12 cGy/pulse. In our case, the maximal dose rate is 39 Gy/min (65 cGy/s; 7.2 cGy/pulse), according to manufacturer [5], PPC05 chamber can be used up to 3000 Gy/s in continuous irradiation or 15 Gy/pulse in pulsed irradiation. The correction factor for polarization for the PPC05 chamber was established according to the Report 398 [3].

While preparing measurements of stationary electron accelerators, the correction factor for incomplete saturation should be established according to the IAEA Report 398 [3] and Boag [6] method of two-voltage analysis. However, Laitano et al. [4] compared the absorbed dose in both low- and high-dose-per-pulse electron beams with ferrous sulphate chemical dosimetry (method independent of the dose per pulse), and suggested alternative method of determining the k_{SAT} parameter for high-dose-per-pulse electron beams, which forced us to establish k_{SAT} for PPC05 ionization chamber according to above theory. For further information and formulas, we recommend reading Laitano et al. [4].

The measurements of the beam output for every nominal energy were performed five times. The measurements were carried out for exposures corresponding to 300 monitor units (MU). The results of the measurements were averaged and, on this basis, the dose was established, taking into account the correction factors for incomplete saturation, beam quality, polarization, temperature and pressure and the calibration coefficient of the ionization chamber ($N_{D,W}$). Using the PDD curves for each energy, the dose at the d_{max} depth was recalculated (d_{max} – the depth of the maximum dose for each beam energy) [7]. By dividing 300 MU by the dose at the d_{max} depth, the beam output for each nominal energy was calculated, expressed in MU/Gy units.

The values of the output measurements carried out during the period January 2013–September 2016 (41 measurements) were averaged for particular beam energies. The standard deviation was calculated and its absolute value was used as the measure of the long-term stability of the output.

The uncertainty of the mean value was calculated using the exact differential method. The following uncertainties were taken into account: incomplete saturation – K_{SAT}, polarization K_{POL}, beam quality – K_Q, temperature and pressure – $K_{p,T}$, and uncertainty of the measurement of the charge in the ionization chamber, and also the uncertainty resulting from the standard deviation of the output results. The

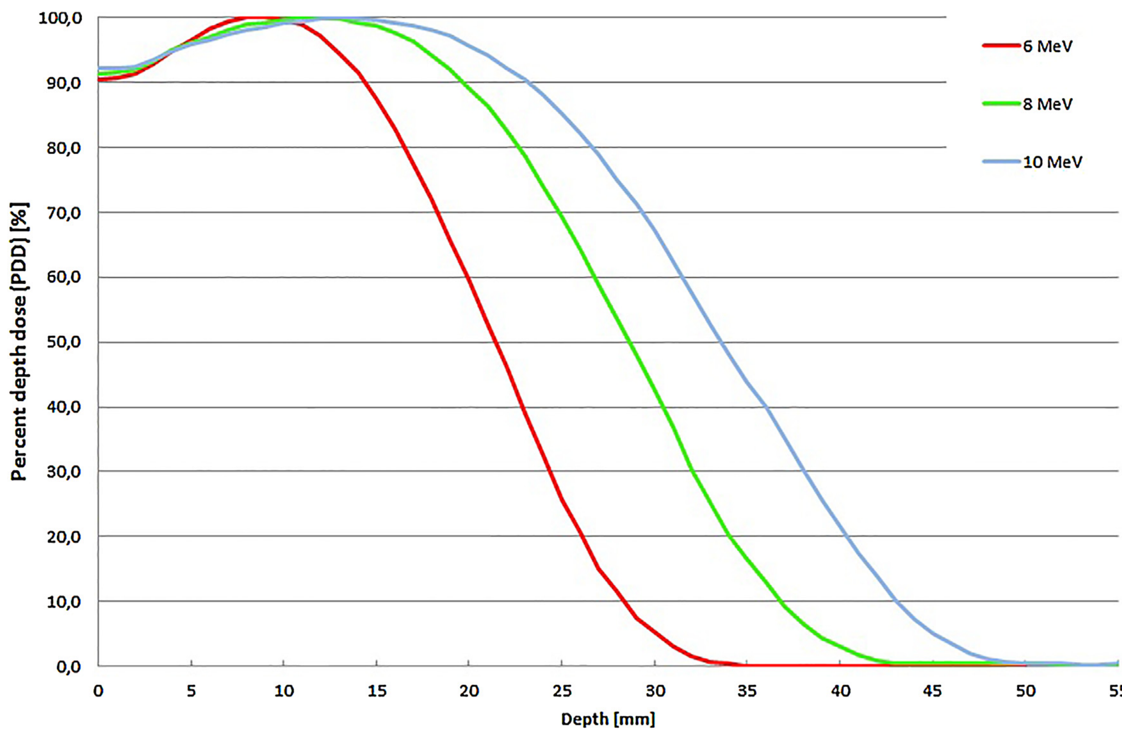

Fig. 1 – Percentage depth doses for 6, 8 and 10 MeV electron beams.

measurement uncertainty was calculated using the exact differential method [8]. In this calculation, the type A uncertainty related to the calibration coefficient was not taken into account because this uncertainty is already included in the uncertainties of the K_{SAT}, K_{POL} and K_Q factors.

The results of the measurements showed that the long-term stability is inferior to that claimed by the manufacturer. According to the Operation Manual, it should not exceed 2% [2]. The manufacturer service then suggested that the tuning of the Start Tune Value parameter should be added to the program of the measurements (The Start Tune Value is the initial value of the magnetron tuner). This modification was introduced in October 2015. The introduction of this tuning into the preparation of the accelerator for measurements considerably improved the reproducibility of the output measurements, however it has not effected the short-term stability. The results of the measurements are presented separately for the periods before and after October 2015.

3. Results

In Table 1 the values of the correction factors for incomplete saturation, polarization and beam quality for Novac11™ electron beams are presented.

The correction factor for temperature and pressure were calculated during each measurement session and the uncertainty was 0.06%. The uncertainty of the measurement of charge accumulated in the ionization chamber did not exceed 0.1%.

The standard deviation of the output values did not exceed 2% for nominal energy 6 MeV, and 1% for nominal energies 8 MeV and 10 MeV.

Table 3 – The mean output values and the standard deviations for Novac11™ electron beams before the introduction of the STV parameter tuning (27 measurements).

Nominal energy [MeV]	6 MeV	8 MeV	10 MeV
Mean output value [MU/Gy]	43.01	25.63	19.15
Standard deviation [%]	2.18	2.52	2.58

Table 4 – The mean output values and the standard deviation for Novac11™ electron beams after the introduction of the STV parameter tuning (14 measurements).

Nominal energy [MeV]	6 MeV	8 MeV	10 MeV
Mean output value [MU/Gy]	42.59	24.67	19.23
Standard deviation [%]	1.01	0.63	1.22

The final values of the uncertainties of the output for various beam energies are presented in Table 2.

In Fig. 1 the percentage depth dose curves for electron beam nominal energies used clinically (6, 8 and 10 MeV) are presented [7]. The source of the uncertainties concerning the ionization curves was the fluctuation of the dose rate. For the optimal settings of the device, this uncertainty did not exceed 0.2%.

In Table 3, the mean output values of the Novac11™ accelerator electron beams and their standard deviations are presented (absolute values). The results in Table 3 are from the period before the routine tuning of the STV parameter (Start Tune Value, initial value of the magnetron tuner) was introduced. In Table 4, the analogous results for the period after the introduction of the STV parameter tuning are presented. Dur-

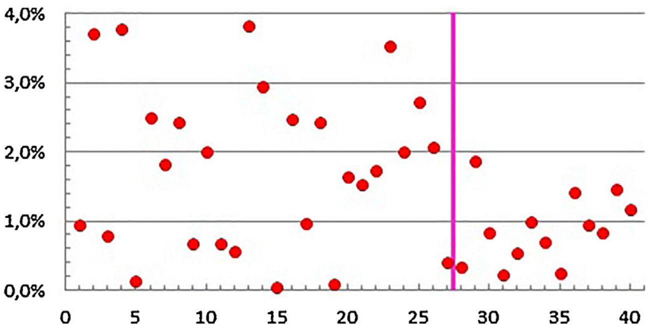

Fig. 2 – Percentage deviation of the mean output for the Novac11™ accelerator nominal energy 6 MeV. Vertical line represents introduction of the STV tuning procedure.

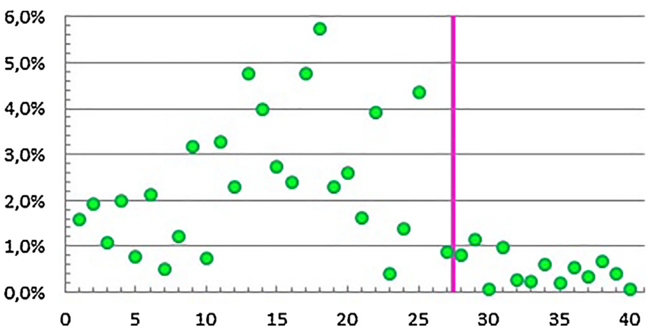

Fig. 3 – Percentage deviation of the mean output for the Novac11™ accelerator nominal energy 8 MeV. Vertical line represents introduction of the STV tuning procedure.

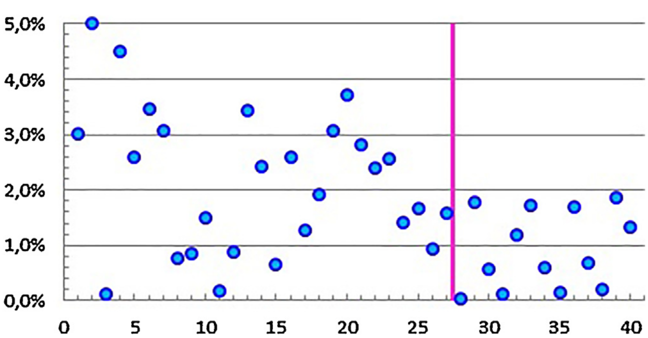

Fig. 4 – Percentage deviation of the mean output for the Novac11™ accelerator nominal energy 10 MeV. Vertical line represents introduction of the STV tuning procedure.

ing the initial period, 27 output measurements were carried out and during the later period, 14 measurements.

In Figs. 2, 3 and 4, the absolute values of percentage deviation from the mean output in consecutive measurement sessions for clinically used beam qualities are presented.

4. Discussion

The collected results of output measurements of the Novac11™ accelerator indicated that the long-term stability does not fulfill the requirements of the manufacturer. The standard deviation established during the period before October 2015 (27 measurements) exceeded 2.0%, 2.5% and 2.5% for beam nominal energies of 6, 8 and 10 MeV, respectively. According to the manufacturer, they should not exceed 2% [2]. The manufacturer, when informed of this fact, recommended a tuning of the Start Tune Value (STV) parameter before each measurement session. After the introduction of the STV parameter tuning procedure in October 2015, the stability of the output increased considerably. The standard deviations for 14 measurements since October 2015 were 1.01%, 0.63% and 1.22% for beam energies 6, 8 and 10 MeV, respectively.

It should be pointed out that we did not observe any problems with stability of any other beam parameters caused by problems with magnetron, nor the influence of frequency of use of Novac11 on short- or long-term stability either.

It should be noted that the limiting values of the long-term stability accepted in this study are lower than the values given in the Report of the TG72 of the AAPM [9]; recommendations of the Italian Instituto de Sanita [10] and the Polish norm for the stationary clinical electron accelerator 2% [11,12] (so far, there are no Polish norms for intraoperative accelerators).

Acceptance test of Novac11 covers the long-term radiation beam stability, and it met the presented criteria. There were no suspicions about malfunctioning of magnetron tuning. From the current perspective, we highly recommend paying particular attention to the matter of long-term stability of Novac11 accelerators.

It is worth mentioning that even during the initial period of clinical use of the Novac11™ accelerator, when its long-term stability was below the manufacturer's requirements, it was not necessary to discontinue the clinical irradiations, because of the very good short-term stability of below 1% for all beam energies.

5. Conclusion

After the introduction of the STV parameter tuning procedure, the long-term stability of the Novac11™ output increased considerably and is within the values declared by the manufacturer.

Conflict of interest

None declared.

Financial disclosure

None declared.

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