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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™ (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™ is developed from the Novac7™ model [2].

In August 2016, there were about 15 Novac11™ 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™ 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