# Commissioning and periodic tests of the Esteya® electronic brachytherapy system

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## Abstract

A new electronic brachytherapy unit from Elekta, called Esteya®, has recently been introduced to the market. As a part of the standards in radiation oncology, an acceptance testing and commissioning must be performed prior to treatment of the first patient. In addition, a quality assurance program should be implemented.

A complete commissioning and periodic testing of the Esteya® device using the American Association of Physicists in Medicine (AAPM), Groupe Européen de Curiethérapie and the European Society for Radiotherapy & Oncology (GEC-ESTRO) guidelines for linacs and brachytherapy units as well as our personal experience is described in this paper. In addition to the methodology, recommendations on equipment required for each test are provided, taking into consideration their availability and traceability of the detectors. Finally, tolerance levels for all the tests are provided, and a specific frequency for each test is suggested.

## Purpose

A new Electronic Brachytherapy unit called Esteya® (Elekta Brachytherapy, Veenendaal, The Netherlands) has recently been introduced [1,2]. Before clinical use, as is the case with all radiation equipment, a complete commissioning of the system must be performed by the user after installation and acceptance.

According to the task group 40 (TG-40) report of the American Association of Physicists in Medicine (AAPM) [3], quality assurance (QA) of radiation therapy equipment is primarily an ongoing evaluation of functional performance characteristics. The QA program should be established on baseline values determined at the time of acceptance and commissioning. The procedures and conditions for acceptance tests should be reproducible and clearly described, so that every user is able to verify the manufacturer's specifications as well as establish baseline performance values for new equipment, or for equipment following major repair.

The AAPM TG-56 report [4] describes acceptance testing and commissioning of brachytherapy equipment as a process. Newly installed equipment is subjected to exhaustive performance testing to determine whether the vendor's technical specifications and the institution's clinical specifications are met. Physical and dosimetric data, which are required for clinical implementation of the system are also collected.

In light of these AAPM recommendations and the Groupe Européen de Curiethérapie (GEC) and the European Society for Radiotherapy & Oncology (ESTRO) practical guide for quality control of brachytherapy equipment [5], we have written this educational article, describing the tests needed for commissioning and periodic testing of the Esteya® electronic brachytherapy system. The proposed equipment, methodology, frequency, and tolerance levels are presented, based on our experience with the system, as well as on the information provided by the vendor. In addition to these tests, other specific institutional, state or federal guidelines related to this device/technology should be evaluated and implemented as required.

## Material and methods

### Radiation unit and equipment

The Esteya® electronic brachytherapy system is specifically designed for surface brachytherapy procedures

using a 69.5 kVp X-ray source. The description of this system and its dosimetric characteristics have already been published by García-Martínez *et al*. [1].

In this study, we have used the following equipment to perform the commissioning and QA tests: 1) Esteya® QA tool provided by Elekta; 2) solid phantom equivalent to liquid water for low energy photon beams (note, the water equivalence is very important; additional information regarding the validity of various solid phantom materials can be found in ref. [6]); 3) radiochromic films with adequate scanner and software for analysis [1]; 4) high resolution array of detectors can also be used for periodic tests instead of radiochromic films [7]; 5) solid-state detector or ionization chamber and high purity aluminum slabs for half-value layer (HVL) measurements; 6) equipment recommended for absolute dose rate measurements.

This equipment contains: 1) for in-air measurements, the Exradin A20 (0.074 cm$^3$) parallel plate ionization chamber (Standard Imaging, USA), calibrated in air by an accredited laboratory (e.g. Accredited Dosimetry Calibration Laboratory of University of Wisconsin) for the Esteya® beam quality can be used; for this chamber, a mount that holds the chamber in the measurement position is required; 2) for in-water measurements, the T34013 (0.0053 cm$^3$) parallel plate ionization chamber (PTW, Germany), calibrated in water by an accredited laboratory (e.g. PTW laboratory, traceable to national standards of the German National Laboratory, PTB) for the Esteya® beam quality can be used. A special slab of the solid phantom that accommodates the chamber is required.

### Commissioning

Below is a list of the proposed tests for the commissioning of the Esteya® system. In addition to those listed in this section, the user is also referred to the acceptance document from Elekta [8] detailing the commissioning of light indicators, door interlock (if required), applicator interlock, radiation area monitor (if required), emergency buttons, and timer.

The proposed tests should be repeated after each X-ray source replacement or major service (hardware and software) that may introduce changes to the radiation beam or the system unit, which should not typically happen before 4000 treatment fractions. All tests included in the commissioning and periodic tests must be performed with the plastic cap of each applicator in place.

In addition to the proposals of this study, all recommendations (current and future) from the manufacturer and institution, as well as state or federal guidelines related to the use of this device/technology should be observed and implemented as required.

### Flatness, symmetry, and penumbra

Film dosimetry is the preferred option to measure the dose distribution in a plane perpendicular to the axis of the radiation beam, from which flatness (*F*), symmetry (*S*), and penumbra (*P*) can be evaluated. This study suggests that radiochromic films should be located at 3 mm depth (a typical clinical prescription depth) in a solid phantom equivalent to water. The applicator surface should be placed in contact with the phantom surface, avoiding air gaps.

A treatment plan is created on the console and irradiated, prescribing 7 Gy (or typical clinical dose) at 3 mm depth. This test should be repeated for all applicator sizes. The films are digitized and converted to a dose map using the appropriate procedure, either with the red channel or the triple channel calibration method. An example with a detailed protocol can be found in ref. [1].

Flatness, symmetry, and penumbra are then evaluated for the profiles AB and GT according to the IEC 60976 criteria [9]:

$$\text{Flatness} = \frac{D_{max} - D_{min}}{D_{max} + D_{min}},$$

where $D_{max}$ and $D_{min}$ are the maximum and minimum dose values measured in the flattened area of each profile. The flattened region is defined as 80% of the distance between the two points, where dose takes 50% of the central dose value.

$$\text{Symmetry} = \max\left[\frac{D(x)}{D(-x)}\right],$$

where $D(x)$ and $D(-x)$ is the dose at point $x$ and $-x$ within the flattened region, symmetrical with respect to the central axis. Symmetry is defined as the maximum ratio within the flattened region.

Penumbra regions are quantified for two orthogonal profiles as the distance between points with dose values corresponding to 80% and 20% of the dose at the centre of the profile.

### Half-value layer

Half-value layer (HVL) is used to characterize the spectrum of an X-ray beam and is required to calculate the absolute surface dose rate. Half-value layer should be measured in a scatter-free and narrow beam [10]. Thus, a detector with sufficient buildup thickness is required to remove the electronic contamination. Solid-state detectors for quality assurance of diagnostic X-ray units as well as ionization chambers can be used.

For these dose measurements, the detector should be placed at least 50 cm away from the attenuating material, which is at least 50 cm beyond the X-ray source. The detector should be placed in air or above a non-scattering and light material, such as styrofoam. It is important to keep the beam axis perpendicular to the entrance window of the detector. To minimize uncertainties, the 30 mm diameter applicator is recommended.

First, a reading is taken without aluminum slabs in place. Then, increasing thicknesses of aluminum are added until the reading is below 50% of the initial value recorded without the aluminum. For each added aluminum slab, a set of three irradiations should be recorded. Half-value layer can then be interpolated from a fitting curve of the readings vs. slab thickness, corresponding to the aluminum thickness, for which the reading is half of the initial value.

### Position of the virtual focus of the X-ray tube

In a clinical situation, the patient skin is placed in full contact with the applicator exit surface. To evaluate the distance between the position of the virtual focus and the applicator exit surface (i.e. source to surface distance, SSD), at least six measurements should be performed at several distances from the X-ray source. The inverse square law should be applied to extract the distance from the virtual focus to the applicator surface.

Let $x_d$ be the reading of the chamber when its top surface is placed at a distance $d$ from the collimator surface, and let $x_0$ be the reading of the chamber when it is in contact with the collimator surface (i.e., $d = 0$). The effective point of measurement of the chamber is found at a depth $d_c$ from its entrance surface. Then the next relationship (inverse square law) should be satisfied:

$$x_d = x_0 \times \left( \frac{SSD + d_c}{SSD + d_c + d} \right)^2 \rightarrow \frac{1}{\sqrt{x_d}} = \frac{1}{\sqrt{x_0}} + \frac{1}{(SSD + d_c)\sqrt{x_0}} \times d \quad (1)$$

Thus, from several readings taken at different distances $d$, the fitting coefficients of a linear curve can be used to obtain SSD. For the particular cases of the Exradin A20 and T34013 chambers, $d_c = 1.8$ mm (according to ref. [11]) and 0.25 mm (according to the chamber manufacturer and calibration certificate, as discussed in next section), respectively. These $d_c$ values are used in next sections.

### Absolute dose rate and output factors

The absolute surface dose rate in water for each applicator should be measured and compared with the internal values used by Esteya® to calculate the treatment time. This test can be done with either a chamber calibrated in air or a chamber calibrated in water. Independent of the method used to perform the measurements, the output factor (OF) for each applicator is calculated as the ratio between the surface dose rate for a specific applicator and the surface dose rate for the 30 mm applicator, such that the OF for the 30 mm applicator is 1.0.

### Measurement of surface dose rate with a chamber calibrated in air

The surface dose rate (at $z = 0$ mm depth, *i.e.*, at the exit surface of the applicator) can be determined with an ionization chamber calibrated in air using the recommendations of the AAPM Task Group 61 [10]. The detector surface should be placed in full contact and centered with the applicator exit surface, with no scattering material near the detector. The corrected absorbed dose rate in the surface of a water phantom is given by:

$$\dot{D}_w = \frac{M_Q N_{K,Q_0} k_{Q,Q_0} p_{stem,air}}{t} \left[ \left( \frac{\mu_{en}}{\rho} \right)^w_{air} \right]_{air} \left( \frac{SSD + d_c}{SSD} \right)^2 \quad (2)$$

where:
- $M_Q$ is the reading of the detector in air, corrected for pressure, temperature, and electrometer calibration. If the electrometer voltage and polarity used is the same as during the calibration, the polarity and ion recombination effects can be disregarded [12].

- $N_{K,Q_0}$ is the air-kerma calibration factor for the reference beam quality $Q_0$ used in the calibration, which is provided by the calibration laboratory.
- $k_{Q,Q_0}$ is a chamber-specific factor that corrects for differences between the beam quality Q used in the measurement, and the beam quality used during the chamber calibration $Q_0$.
- $B_w$ is the backscatter factor. Its value depends on source-to-surface distance ($SSD = 60$ mm), field size (collimator diameter), and HVL, and can be determined for each available collimator, from Table V given by TG-61 [10].
- $p_{stem,air}$ is the stem correction factor, which accounts for the change in photon scatter from the chamber stem between the calibration and measurement (mainly due to the change in field size). The estimation of $p_{stem,air}$ requires a comparison between the chamber used and a reference chamber, for which $p_{stem,air}$ is known.
- $\left[ \left( \frac{\mu_{en}}{\rho} \right)^w_{air} \right]_{air}$ is the mass energy-absorption coefficient ratio of water-to-air. It can be determined from Table IV given by TG-61 and depends on HVL.
- The reading of the chamber is corrected by the factor $((SSD + d_c)/SSD)^2$, bringing the reading to the exit surface of the applicator. SSD is the source-to-surface distance (60 mm), and $d_c$ is the distance between the entrance surface of the detector and its effective point of measurement.
- $t$ is the radiation time given by the console.

The parallel plate ionization chamber Exradin A20 is recommended for measurements in air. It should be used with a chamber mount designed for the Esteya® to keep it in a reproducible vertical position during measurements (Fig. 1). No further buildup material is required, $d_c = 1.8$ mm [11], and the stem effect is negligible (*i.e.* $p_{stem,air} = 1$).
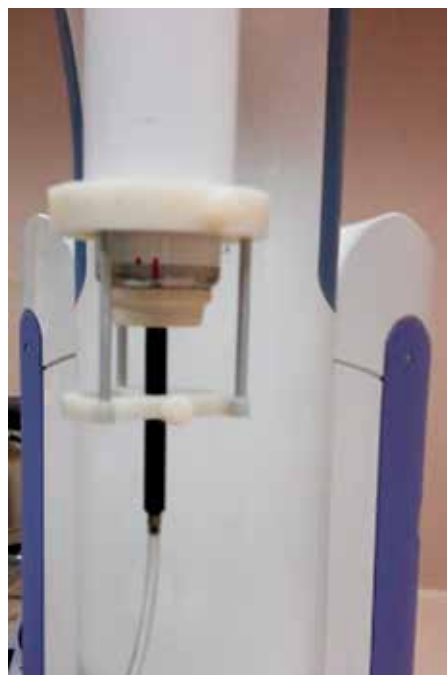


**Fig. 1.** Setup for measurements with the Exradin A20 ionization chamber

### Measurement of surface dose rate with a chamber calibrated in water

The surface dose rate (at $z = 0$ mm depth, *i.e.*, at the exit surface of the applicator) can be determined with an ionization chamber calibrated in water using the TRS-398 code of practice from the International Atomic Energy Agency (IAEA) for low-energy kilovoltage X-ray beams [12]. To determine the surface dose rate using the TRS-398 code of practice, the chamber is placed above a 10 cm slab of a solid phantom equivalent to water. On top, there is a slab of the same material with a specifically designed groove that allocates the chamber. The surface of the entrance window of the chamber should be placed in full contact with the applicator exit surface to perform the dose measurement at the surface. More details are given in ref. [1]. The corrected surface absorbed dose in water can be calculated using the following equation:

$$\dot{D}_w = \frac{M_Q N_{D_w,Q_0} k_{Q,Q_0} p_{stem}}{t} \left(\frac{SSD + d_c}{SSD}\right)^2 \qquad (3)$$

where:

- $M_Q$ is the reading of the detector at the depth of measurement, corrected for pressure, temperature, and electrometer calibration. If the polarity used in the dose measurements is the same as in the calibration, the polarity and ion recombination effects can be disregarded [12].
- $N_{D_w,Q_0}$ is the calibration factor in terms of absorbed dose to water for the reference quality $Q_0$.
- $k_{D_w,Q_0}$ is a chamber-specific factor that corrects for differences between the beam quality Q used in the measurement, and the beam quality used during the chamber calibration $Q_0$.
- $p_{stem}$ is the stem correction factor, which accounts for the change in photon scatter from the chamber stem between the calibration and measurement (mainly due to the change in field size). The estimation of $p_{stem}$ requires a comparison between the chamber used and a reference chamber for which $p_{stem}$ is known.
- The reading of the chamber is corrected by the factor $((SSD + d_c)/SSD)^2$, bringing the reading to the exit surface of the applicator. SSD is the source-to-surface distance (60 mm), and $d_c$ is the distance between the entrance surface of the detector and its effective point of measurement.
- $t$ is the radiation time.

The parallel plate ionization chamber T34013 is recommended for measurements in solid water. According to the manufacturer's data, it has a thin entrance foil of 0.03 mm. In addition, there is a groove of 0.22 mm depth in the plastic cover of the chamber, just above the entrance foil. This air groove provides protection to the entrance foil when the chamber is in full contact with applicator. The resulting effective point of measurement, $d_c$, is located at 0.25 mm. The chamber T34013 does not require further buildup because of the presence of the plastic cap mounted at the end of all Esteya® applicators. The plastic cap being in contact with the ionization chamber at the time of measurement provides adequate buildup for a 69.5 kVp X-ray beam. In addition, during calibration,

an air gap of at least 30 cm between the X-ray source and the chamber is used, which also adds enough equivalent buildup. Furthermore, the stem effect has been evaluated to be negligible for the different Esteya® applicator sizes [13]. However, prior to data collection, pre-irradiation is required prescribing 7 Gy at the chamber position until the readings are consistent (typically 2 to 4 irradiations are needed).

### Linearity of dose with timer for each intensity range

The current of the Esteya® beam changes with prescribed dose in order to keep the irradiation time relatively constant [1]. There are three possible current values: 0.5 mA, 1.0 mA, and 1.6 mA, which are selected automatically by the system based on the prescription dose. For each current value used in clinical practice, the linearity of output with time should be evaluated. Different doses are prescribed, and the reading of the chamber is represented as a function of the irradiation time. A linear fitting to the data is then applied.

### Percentage depth dose curves

The percentage depth dose curves (PDD) for each applicator size should be measured and compared with the internal values used by Esteya® to calculate the treatment time. The procedure is the same as in the absolute measurements with plastic water. However, in this case, slabs of 1 mm or 2 mm thickness are inserted between the detector and the applicator exit surface to calculate the absorbed dose as a function of depth in the phantom. For a given applicator size, 7 Gy is prescribed at 3 mm depth (typical written directives [2]). The same plan is irradiated for different slab thicknesses. Finally, the dose reading at each depth is normalized by the dose reading taken at the surface, i.e., with no slab between the detector and the applicator. This is repeated for the different applicators and different depths between 0 and 5 mm.

### Other considerations

Although not directly part of commissioning of the Esteya® unit, adequate training should be provided and documented for the brachytherapy team (current and new members). A shielding survey should be performed and documented prior to clinical use and available for inspection. A continuing quality management program should be in place.

### Periodic testing

According to the current recommendation of the ESTRO [5] and AAPM [3,4], each high dose rate unit needs a QA program that guarantees the proper and safe delivery of the selected radiation dose. This section describes the tests that the manufacturer considers appropriate for the Esteya® system (to be performed by the user), together with the recommended methodology and frequency. Tolerance levels are given in the corresponding results section.

### Self-test and diode QA tool

As required by the manufacturer [14], the user has to run a self-test whenever the unit is turned on. Once this test is completed without any issues, another test using the so called "*Diode QA tool*" is required. This tool is mounted on the unit in a similar way to the applicators (Fig. 2). It is composed of 26 diodes, placed in two parallel planes at different off-axis distances [14], which are used to evaluate the output, flatness, and percentage dose depth curve at the same time.

### Independent calculation

Once a plan is created for a given applicator diameter (Ø), prescription dose (*D*), and prescription depth (*z*), the authorized user must review and approve this plan, including the input parameters. When proceeding to treatment delivery, the Esteya® calculated treatment time *T* is displayed. An independent calculation of this treatment time should be done based on the measured surface dose rate $\dot{D}_w$ (depends of Ø and beam current *I*) and PDD (depends of Ø and *z*). This can be calculated according to:

$$T(D,I,\phi,z) = \frac{D}{\dot{D}_w(\phi,I) \times PDD(\phi,z)} \qquad (4)$$

### Chart QA

The accuracy of the number of fractions, plan revision, and accumulated dose for each patient should be checked periodically.

### Flatness and symmetry of the 30 mm applicator

The flatness and symmetry should be evaluated for the 30 mm applicator by placing the radiochromic film at 3 mm depth in a solid phantom equivalent to liquid water. As a measure of constancy, this test could also be performed using a high spatial resolution array of detectors [7].

### Periodic output and PDD verification

Independent output and PDD constancy can be maintained on a monthly basis by evaluating the values at depths of 0 mm and 3 mm for the 30 mm applicator. Output and PDD constancy should be verified for all other applicators but can be done less frequently.

## Results and Discussion

### Commissioning

#### Flatness, symmetry and penumbra

According to the acceptance document, the commissioning experience [14], and the estimated uncertainties, for all applicators but the smallest one, the proposed tolerances are presented in Table 1. For the 10 mm applicator, flatness should be below 7.5%, symmetry should be between 93% and 107%, and penumbra below 1.5 mm.



**Fig. 2.** Setup of the diode QA tool

**Table 1.** Tolerances for flatness, symmetry, and penumbra proposed in this study for Esteya

| Flatness | ≤ 5% |
|---|---|
| Symmetry | ≥ 95% and ≤ 105% |
| Penumbra | ≤ 1.5 mm |

#### Half-value layers

The proposed tolerance of HVL should be within the range 1.7 to 1.9 mm. In the case that HVL cannot be measured by the user, the nominal value of 1.8 mm Al should be used. According to our clinical experience with this system and the ionization chambers previously described, differences of ± 10% in the HVL have been shown to influence the dose rate in air by ± 0.6% and ± 0.4% in water.

#### Position of the virtual focus of the X-ray tube

The proposed tolerance of *SSD* should differ by less than 1 mm from the nominal value of 60 mm. In the case that SSD cannot be measured by the user, the nominal value of 60 mm should be used, given the small uncertainty introduced by small variations of this parameter.

#### Absolute dose rate and output factors

The difference between the measured and nominal dose rate used by Esteya® should be within the uncertainties of the dose measurement. Assuming an uncertainty in the dose measurement of about 3% and an uncertain-

**Table 2.** Output factors (OF) included in treatment console

| Applicator diameter (mm) | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|
| Nominal OF | 0.933 | 0.954 | 0.975 | 0.988 | 1.000 |

ty of the nominal dose rate of 3%, the maximum difference should be below 4.5%. The difference between the measured and nominal (used by Esteya®, see Table 2) OF should be less than 3%.

*Linearity of dose with timer for each intensity range*

Any of the dose measurements should not differ from the best linear fitting curve by more than 3%.

*Percentage depth dose curves*

Differences between depth dose curves (PDD) values measured during the commissioning and internal PDD values used by Esteya® should be ≤ 3% for any applicator and depth, except for the 10 mm applicator, for which the tolerance is higher (< 5%) because of a larger uncertainty. Table 3 presents the internal PDD values used by Esteya®.

### *Periodic test*

*Diode QA tool*

With respect to the QA tool, the maximum differences between the measurement and the reference/baseline values must be as specified in the user manual [14]:
- surface dose rate: < 3%,
- PDD at 5 mm depth: < 3%,
- all 9 flatness: < 3%,
- irradiation time: < 1%.
- if this test does not meet the above criteria, the system will not allow patient treatments. The periodicity is daily (*i.e.* at the start of each treatment day).

### *Independent calculation*

The difference between the treatment time calculated by the user and the treatment time generated by Esteya® should be less than 5% if using the surface dose rate and PDD measured during the commissioning, and 0% if using the internal values of Esteya® to do the independent calculation. This test should be done prior to first fraction of each treatment plan (or revised one).

*Flatness and symmetry of the 30 mm applicator*

Differences with respect to reference values taken during commissioning should be less than 3%. The proposed periodicity is monthly, as recommended for medical accelerators [3].

### *Periodic output and PDD verification*

The surface dose rate and PDD at 3 mm should differ by less than 2% when compared with the reference values measured during commissioning. The proposed periodicity is monthly for the 30 mm applicator, and semi-annual to annual for the others. The constancy of the PDD implies the constancy of HVL.

## Conclusions

The content and methodology of the commissioning and periodic tests have been proposed for the electronic brachytherapy system Esteya®. In addition to the methodology, recommendations on equipment are also provided, taking into consideration their availability and the traceability of the detectors. Finally, a frequency and tolerance level for each test is proposed.

## Acknowledgments

## Disclosure

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**Table 3.** Internal PDD values included in treatment console

| Applicator diameter (mm) | | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|
| Depth (mm) | 0 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| | 1 | 0.930 | 0.932 | 0.933 | 0.934 | 0.935 |
| | 2 | 0.865 | 0.868 | 0.872 | 0.873 | 0.874 |
| | 3 | 0.803 | 0.808 | 0.812 | 0.814 | 0.816 |
| | 4 | 0.746 | 0.752 | 0.757 | 0.760 | 0.763 |
| | 5 | 0.693 | 0.700 | 0.706 | 0.710 | 0.713 |

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