Dosimetry in Afterloading Brachytherapy

1 Introduction

Brachy is the Greek word for "short". Brachytherapy means "short distance therapy". Different brachytherapy applications require specific measuring systems for quality assurance measurements. PTW-Freiburg offers specially designed measurement equipment for the following brachytherapy applications:

- Afterloading
- Permanent seed implantation
- Vascular brachytherapy
- Ophthalmic brachytherapy

In this application note only afterloading is considered. For other application fields of brachytherapy please ask PTW-Freiburg for specific application notes.

1.1 History of Afterloading

Brachytherapy with $^{226}$Radium needles was very successful in the beginning of the last century and was practiced until the seventies, but radiation protection for the staff was always a problem. With the invention of remote controlled afterloaders in the 1960s this problem was solved, as staff now could leave the room during treatment.

1.2 Afterloading today

Modern afterloaders work with stepping motors which enable the user to position a radioactive source precisely in an applicator inserted before in the target volume.

Afterloading is classified according to the applied dose rate into LDR (Low Dose Rate) and HDR (High Dose Rate) [1]:

- LDR: Dose rate 0.4 - 0.8 Gy/h
- HDR: Dose rate > 0.5 Gy/min

LDR afterloading brachytherapy with $^{137}$Cs sources with an initial activity of approx. 1480 MBq (40mCi) requires treatment times of about 8 hours. Due to the long session only few patients could be treated.

HDR afterloading brachytherapy with $^{192}$Ir sources (typical initial activity 370 GBq (10 Ci)) enable the operator to deliver the required dose in discrete fractions within a few minutes time to the outpatient setting.

PDR (Pulsed Dose Rate) afterloading brachytherapy is a recent development that combines single-stepping source remote afterloading with the radiobiological characteristics of conventional inpatient based low dose rate (LDR) brachytherapy. It simulates continuous LDR brachytherapy by administering a sequence of "mini" HDR fractions. [2]

A typical source for PDR afterloading is a $^{192}$Ir source with an initial source activity of 37 GBq (1 Ci).

Due to short treatment times HDR afterloading is the most popular form today.

Technically, the sources for HDR and PDR afterloading are realized by a core of pure $^{192}$Ir (approx. length 3.5 mm and 0.6 mm diameter) which is encapsulated in stainless steel at the end of a metal wire. The half life of $^{192}$Ir is approx. 74 days; sources are usually changed every 3 months.

Similar designs, containing e.g. $^{60}$Co or $^{169}$Yb, for HDR Brachytherapy are available as well.

1.3 Different applications for afterloading brachytherapy [1]

Intracavitary brachytherapy is the placement of radioactive sources in an applicator that has been positioned in a body cavity, i.e., the uterus, vagina etc.

Intraluminal brachytherapy is the temporary placement of a radioactive source inside a lumen. It is often used for tumors that obstruct the opening of a pulmonary bronchus, biliary duct, esophagus etc.

Interstitial brachytherapy is the temporary or permanent implantation of radioactive seeds or needles directly into a tumor volume. It is particularly suited for prostate, gynecologic, and locally recurrent cancers.

Figure 1: Well Type Chamber and UNIDOS E
2 Dosimetry and QA measurements

Dosimetry QA tasks are [3]:

- Measurement of the source strength
- Evaluation of attenuation factors for applicators
- Check of the dwell position of the source

2.1 Measurement of the source strength

AAPM TG-56 recommends that a qualified medical physicist shall calibrate each HDR/PDR source prior to clinical use in terms of air kerma strength and use this value as the basis for treatment planning and treatment prescription [1].

PTW-Freiburg offers two different systems to measure the source strength: the HDR well type chamber and the AL calibration phantom.

2.1.1 Measurement of the source strength with a well type chamber

The measurement of the source strength with a well type chamber is recommended by AAPM [1] and by DGM [3].

The PTW HDR chamber is a vented well type chamber with a measuring volume of 200 cm³.

Set up and measurement require only a few minutes; this makes the system suitable for routine checks.

Method:
The HDR chamber must be placed in the treatment room and connected to an appropriate electrometer.

The applicator, connected to the afterloader, must be inserted into the acrylic adapter of the well type chamber.

Nucletron, the manufacturer of the microSelectron afterloader, recommends a measurement without an applicator. A specially designed adapter can be connected to the afterloader with the standard transfer tube. The source travels directly inside the adapter without an applicator.

For the measurement, the source must be placed inside the chamber at the point of maximum response (approx. 84 mm below chamber top). This point can easily be found by moving the source in small steps inside the applicator and observe the signal on the connected electrometer.

Although only air kerma strength should be used to quantify source strength, the obsolete quantities “apparent activity” and “exposure strength” are partially still customary. [1]

The calibration certificate for the PTW HDR chamber gives calibration factors for all three quantities. The source strength can be calculated with:

\[ S_i \approx M \times N_i \times P_{ion} \times k_{PT} \]

- \( S_i \) Source strength
- \( M \) Well type chamber reading
- \( N_i \) Calibration factor
- \( P_{ion} \) Reciprocal of ion collection efficiency factor \( A_{ion} \) (with a collection potential > 300 V Pion = 1)
- \( k_{PT} \) Correction for pressure and temperature

Due to the different calibration factors, \( S_i \) can be calculated in:

- Air kerma strength (mGy m² h⁻¹)
- Apparent activity (GBq or Ci)
- Exposure strength (R m² h⁻¹)

Electrometers:
The PTW HDR chamber works with all appropriate electrometers. The electrometer must have a reading in pA and a wide dynamic range. Measurement of collected charge and an adjustable interval time function is necessary for further tasks (e.g. measurement with the afterloading phantom).

The measuring range depends on the dynamic range of the electrometer.

- Measuring range with UNIDOS: 1.7 MBq (0.05mCi) ... 8.3 TBq (224 Ci) [1]
- Measuring range with MULTIDOS: 83 MBq (2.25mCi) ... 8.3 TBq (224 Ci) [1]

These recommended electrometers are well suitable for all measurements in HDR, PDR and LDR afterloading brachytherapy.

Calibration:
Every HDR chamber comes with a calibration for the following remote afterloader sources:

- Nucletron, microSelectron ™
- Varian, GammaMed ™
- Varian, VariSource ™
- Eckert & Ziegler BEBIG, MultiSource ™ (Ir-192 and Co-60)

The calibration of the HDR chamber is traceable to PTB[2] and NIST[3]. Re-calibration is recommended every two years.

Adapters:
To fit most of the available applicators PTW-Freiburg offers three different adapters:

- Universal adapter for probes 1.0 to 1.8 mm (e.g. Varian plastic tipped standard catheter 4.7 French). (Order No.: T33004.1.012)
- Universal adapter for probes 1.8 to 3.2 mm (e.g. Varian GammaMed stainless steel probe with outer diameter 3.05 mm, or Bebig LAA1400RU 3 mm). (Order No.: T33004.1.013)
- Adapter for Nucletron. (Nucletron recommends source calibration without an applicator. The specially designed insert can be connected to the afterloader with the standard transfer tube.) (Order No.: T33002.1.009)

Calibration and adapters for LDR \(^{137}\text{Cs}\) are available upon request.

---

[1] The upper limit of the measuring range at 400 V for saturation of 99.5% is 4 TBq
[2] PTB = Physikalisch-Technische Bundesanstalt, German National Standard Laboratory
2.1.2 Measurement of the source strength with the AL calibration phantom

The nominal source strength declaration for afterloading sources is the reference air kerma rate which is defined in 1 m lateral distance from the centre of the activity. In clinical practice, a direct measurement in 1 m distance is not practicable for routine measurement, because of low dose rates at one meter distance and backscattering effects.

DIN 6809-2 section 3 recommends the measurement in a solid phantom with the possibility of very accurate positioning of the source and the ionization chamber. The PTW AL calibration phantom T9193 is recommended by DGMP for source strength measurement and for calibration of in vivo measuring probes [3].

Figure 2: AL calibration phantom T9193 with rigid stem chamber (left) and AL applicator

The phantom consists of a PMMA (acrylic) cylinder with a diameter of 20 cm and a height of 12 cm. In the centre there is a hole for acrylic adapters for different afterloading applicators.

On a circle with a radius of 8 cm there are 4 holes situated 2 cm from the rim of the phantom for detector adapters at 0°, 90°, 180° and 270°.

Set up and measurement:

To avoid backscattering, the phantom has to be placed on a tripod, with minimum distance of 60 cm to walls and floor.

Source strength measurement should be performed at 4 points surrounding the applicator. If the electrometer provides an interval measurement function (like UNIDOS webline, UNIDOS, UNIDOS E and MULTIDOS), source traveling time has not to be considered, as the measurement can be started and terminated while the source is placed in the phantom. At each position a 60 sec. charge measurement is recommended. This makes the measurement rather fast.

For source strength measurement, PTW-Freiburg recommends a 0.3 cm³ rigid stem chamber (model 23332). Using a well type chamber and the AL calibration phantom, the responsible physicist has two independent systems for source strength measurement.

2.2 Evaluation of attenuation factors for applicators

If an applicator other than the standard applicator is used, the different attenuation should be corrected by means of an attenuation correction factor. DGMP recommends the PTW AL calibration phantom for this task [3].

Method:

The air kerma strength of the source should be measured with the standard applicator in the AL calibration phantom. Then the measurement should be performed with the new applicator and a corresponding adapter for the phantom.

The comparison of the two measurements gives the correction factor.

Adapters for all common afterloading applicators are available. For special applicators custom designed adapters can be ordered (T9193/2xx).

2.3 Check of the dwell position of the source

The source position in the applicator should be determined once, and routinely checked to verify consistence between the position displayed on the afterloader control unit and the actual source position. This is usually made with a phantom and X-ray films.

PTW-Freiburg recommends the POSICHECK test object for this task. POSICHECK is made of acrylic glass. The applicator of the afterloading unit is inserted into one of the grooves (with different width for different applicators). The position of the source and the measuring lines made of lead are exposed on an X-ray film. The exposure of line and source allows easy determination of the position of the source within the applicator.

Figure 3: POSICHECK test object T43006
3 In-vivo measurement

3.1 MULTIDOS, multi channel dosemeter

The MULTIDOS is a multi channel dosemeter system for in-vivo patient dosimetry during gynecological radiation therapy by remote controlled afterloading systems. It complies with the safety standard IEC 60601-2-9. MULTIDOS allows direct monitoring of doses in rectum and bladder with semiconductor probes. The single probe for bladder measurements has a diameter of only 3 mm and is to be used in a catheter. The flexible five fold rectum probe for dose distribution measurements in the rectum has five detectors spaced 15 mm apart from each other enhancing the chance to measure at the point of maximum dose. Both probes can be calibrated in the AL calibration phantom using appropriate detector adapters.

![MULTIDOS with bladder and rectum probe, detector connection box, and AL calibration phantom](image)

3.2 MultiSoft

The MultiSoft software package enables the user to control the MULTIDOS and to store patient data and associated dose values in a data base. Printouts for each session make it possible to document the treatment in accordance with the European Council Directive. [4]

4 Conclusions

QA of afterloading brachytherapy requires accurate measuring equipment.

PTW-Freiburg recommends as:

**Basic equipment:**
- Well type chamber 33004
- Dosemeter UNIDOS E

**Advanced Equipment:**
- Well type chamber 33004
- Dosemeter UNIDOS E
- Afterloading Phantom T9193 with accessories
- PosiCheck T43006

**Expert Equipment:**
- Well type chamber T33004
- Afterloading Phantom T9193 with accessories
- PosiCheck T43006
- Dosemeter MULTIDOS AL
- Software MultiSoft
- Semiconductor single probe T9111 or T9113 for bladder
- Five fold semiconductor probe T9112 for rectum