The Metrological Electron Accelerator Facility (MELAF) for Research in Dosimetry for Radiotherapy

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Abstract

The Metrological Electron Accelerator Facility (MELAF) of the Physikalisch-Technische Bundesanstalt (PTB) offers access to well characterized high-energy (0.5–50 MeV) electron and photon radiation fields also for external researchers. This work outlines the capabilities of the facility to foster new collaborations. As example, the experimental determination of ionization chamber typical correction factors for Magnetic-Resonance guided Radiotherapy (MRgRT) is presented.

Keywords

High-energy electron radiation • High-energy photon radiation • Dosimetry • MRgRT • Magnetic field Ionization chamber • LINAC

1 Introduction

The PTB, Germany's national primary standard laboratory, operates the Metrological Electron Accelerator Facility (MELAF) for service and research in the field of dosimetry for external beam radiotherapy [1]. The PTB also offers access to its metrologically well characterized radiation fields for external researchers with other research projects beyond dosimetry.

The purpose of this work is to outline the capabilities and the properties of our facility in order to foster new collaborations. Our facility is equipped with two medical electron linear accelerators (LINAC) for the generation of high-energy photon and electron radiation, as well as a research LINAC, which operates on the same principle as medical LINACs, with adjustable energy up to 50 MeV. The properties of the research LINAC (e.g. spectral electron fluence, beam current, etc.) can be measured with small uncertainties. Therefore, radiation effects can be studied as a function of the fundamental physical quantities.

An electromagnet with magnetic flux density up to 1.4 T with sufficient space between the pole shoes to place a water phantom can be positioned in front of each accelerator for tests of dosimetry procedures for Magnetic-Resonance guided Radiotherapy (MRgRT) [2, 3].

In addition, a reference field of ^{60}Co γ radiation from a 130 TBq source, monoenergetic neutron fields up to 20 MeV and an ion microbeam are available on site. Furthermore, the PTB provides an S1 laboratory for cell culture and microbiological preparations with qualification for genetically modified cells.

Access to the facility is granted without fees on the basis of joint research collaborations or otherwise charged according to "Regulations Governing Charges for Services Supplied by PTB" (application anytime, decision by PTB).

2 Capabilities of the Facility

The MELAF is placed in a dedicated building with four irradiation rooms. All irradiation rooms are equipped with lasers to align the object under irradiation and air conditioning. Motorized precise XYZ positioning systems are available for the fixation and controlled movement of the object under irradiation as e.g. for the measurement of a depth dose distribution in a water phantom by means of an ionization chamber.

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2.1 Medical LINACs

There are two irradiation rooms equipped with Elekta Precise medical LINACs (Elekta Instrument AB, Stockholm, Sweden). Both can be operated independently. In total, 9 electron beam qualities (nominal energy 4, 6, 8, 10, 12, 15, 18, 20, or 22 MeV), and 6 photon beam qualities (nominal accelerating voltage 4, 6, 8, 10, 15, or 25 MV) can be generated. Both medical LINACs are equipped with a multileaf collimator for investigations in small and irregularly shaped fields, which allows field sizes of any shape up to 40 × 40 cm at 1 m distance to the source. Typical dose rates are 0.1–5 Gy/min.

2.2 Research LINAC

A photo of the research LINAC is shown in Fig. 1. It consists of two sections: A low-energy Sect. (0.5–10 MeV) and a high-energy Sect. (6–50 MeV). At both accelerator sections the electron beam can be deflected into the dedicated beam line in the respective separate irradiation hall. Both beam lines are equipped with devices for a precise characterization of the beam. Figure 2 shows a photo of the 6–50 MeV beam line. The research LINAC provides a pulsed beam with about 2.5 µs pulse duration at a variable pulse repetition rate from 1 to 100 Hz. The kinetic energy of the electrons can be varied continuously from 0.5 to 50 MeV. For the accurate determination of the energy a magnetic spectrometer is used [4]. The energy width of the beam is less than 1% of the mean energy and the relative measurement uncertainty of the mean energy amounts to 0.125%. The charge of each beam pulse, i.e. the number of radiated electrons, can be measured non-destructively with a measurement uncertainty of about 0.1% [5]. The pulse charge can be varied continuously (typical range: 0.1–200 nC). The drift of the mean pulse charge (after warming-up phase) is less than 0.1%/h. For the analysis of the beam profile and the beam divergence, several wire scanners and removable YAG:Ce screens are installed at the beamline. The profile of a typical optimized beam has a Gaussian shape with a FWHM of about 4 mm [5]. At the end of the beam line the electrons either pass through a beam exit window for electron irradiations or impinges on a bremsstrahlung target for the generation of high-energy photons with therapeutically relevant dose rates. The resulting photon field corresponds to a Flattening Filter Free (FFF) radiation field from a medical LINAC. Dose rates are up to several Gy/s.

2.3 Dosimetry

Numerous different kinds of ionization chambers, calibrated traceably to the PTB primary standards, are available for dose measurements at the highest accuracy level. For instant verication of the shape of the radiation field a 27 × 27 cm detector matrix (PTW OCTAVIUS Detector 1500) and a computed radiography system based on 24 × 30 cm storage plates (Kodak ACR-2000i) are available which can be used even for absolute dosimetry [6]. Different water and PMMA phantoms as well as an anthropomorphic Alderson phantom are available. Furthermore, it is possible to create IMRT fields by means of a Monaco radiotherapy treatment plan system and to measure the 3D dose distribution by means of a OCTAVIUS 4D dosimetry system.

2.4 Magnet for MRgRT Dosimetry

MRgRT is a new technique providing real-time Magnetic Resonance Imaging (MRI) and irradiation of the tumour volume simultaneously by means of a MRI scanner integrated with a LINAC [7] (MR-LINAC). Due to the strong magnetic field of the MRI scanner, the reading of the commonly used ionization chambers may deviate from the value at standard conditions, i.e. without a magnetic field, by up to several percent [2, 3]. For experiments regarding the development of a reference dosimetry protocol a transportable electromagnet (BRUKER ER073) is available at the MELAF.

Figure 3a shows the magnet in front of one of the medical LINACs, while the isocenter of the LINAC is between the pole shoes. The maximal magnetic flux density amounts to 1.4 T, which corresponds to the magnitude at the existing MR-LINACs [2, 7].

Figure 3b shows the magnetic flux density as measured by means of a Hall probe as a function of the position in the plane between the pole shoes at nominal 1.4 T. The uniform area with <0.5% drop is 110 mm in diameter. The space between the pole shoes is 100 mm (for up to 1.0 T) or 70 mm (for up to 1.4 T), respectively. For both configurations a dedicated water phantom with corresponding width is available. Figure 3c shows an ionization chamber in the water phantom between the pole shoes at the isocenter of the medical LINAC marked by laser lines. The ionization chamber is mounted at a precise four axis remote positioning system installed atop of the magnet (see Fig. 3a).

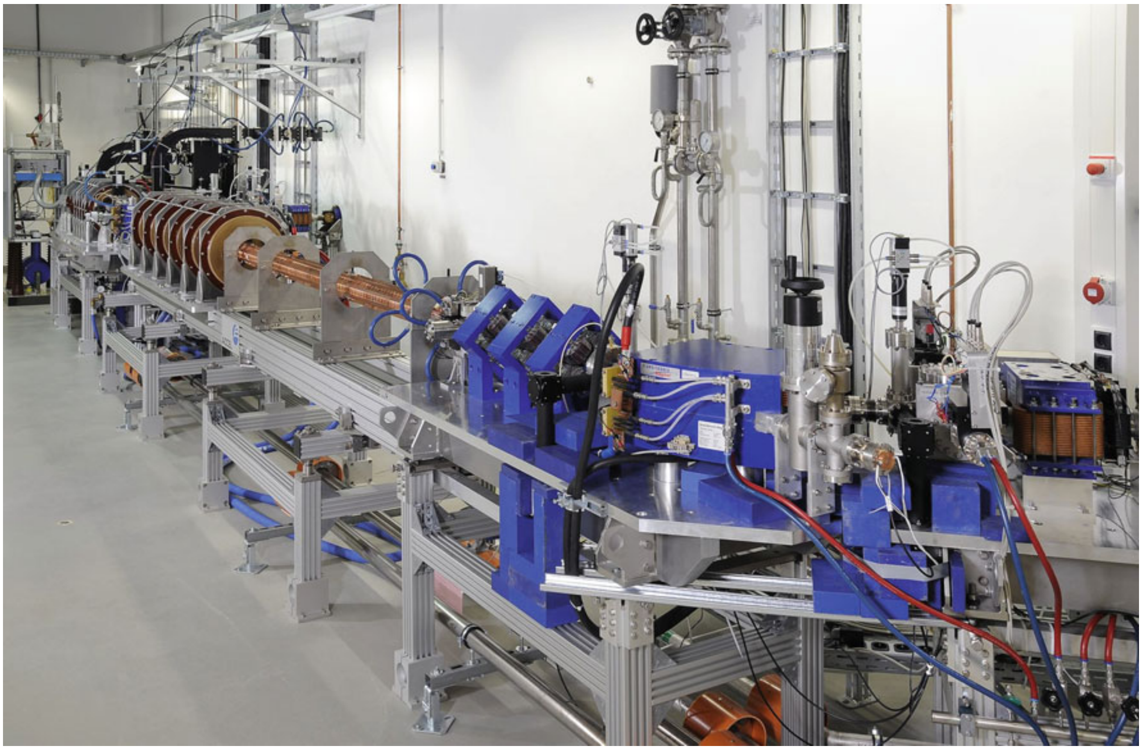

Fig. 1 Photo of the research LINAC

Fig. 2 Photo of the 6–50 MeV beam line of the research LINAC (beam enters from right)

An example for an application is the experimental verification of a MC calculation of the response of an ionization chamber in a magnetic field as shown in Fig. 4 for a farmer type ionization chamber (PTW 30013, Freiburg, Germany) irradiated by photons at 6 MV accelerating voltage. For simulation and measurement, the magnetic field vector, the LINAC beam direction and the chamber rotational axis were each pairwise perpendicular. The ionization chamber was placed at 10 cm depth inside the water phantom. Simulations were done using EGSnrc with the recently published algorithm for enhanced electron transport in electromagnetic fields [8].

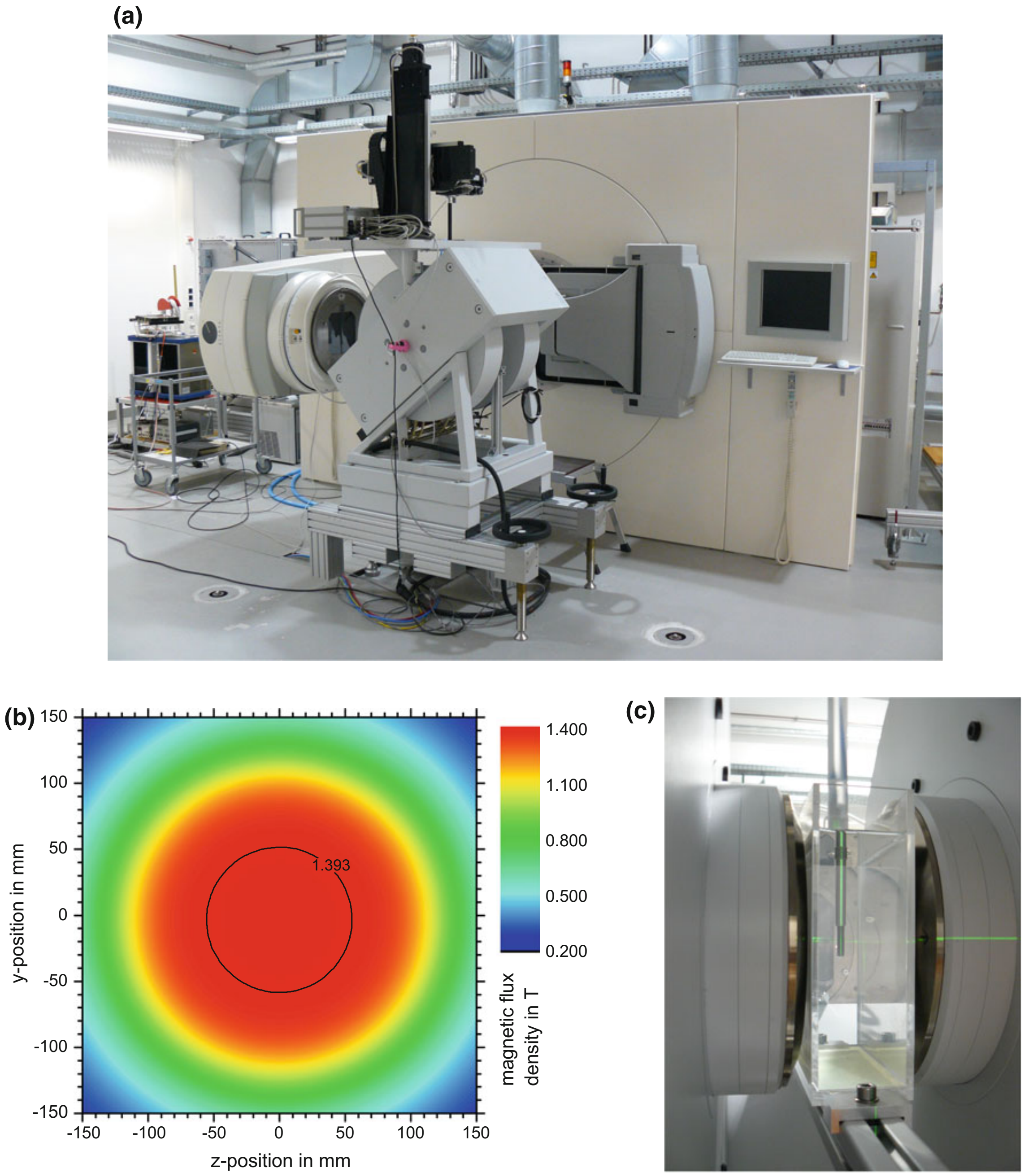

Fig. 3 **a** Electromagnet in front of a medical LINAC. **b** Measured magnetic flux density as a function of the position in the plane in the middle between the pole shoes at nominal 1.4 T. **c** An ionization chamber in a water phantom between the pole shoes of the electromagnet at the isocenter of the medical LINAC (marked by laser lines)

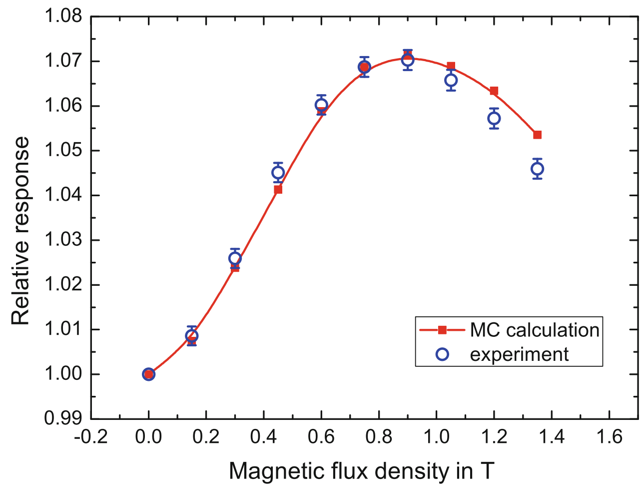

Fig. 4 Relative response of the ionization chamber with respect to the response without magnetic field as a function of the magnetic flux density for a PTW 30013 chamber at 10 cm water depth irradiated by photons of 6 MV accelerating voltage

3 Conclusion

The PTB offers access to its metrologically well characterized radiation fields and radiation dosimetry equipment for external researchers in order to exploit the potential of the existing infrastructure. MELAF provides capabilities way beyond standard conditions of medical LINACs as e.g. in energy range, in electron fluxes (dose rates) and in the traceable measurement of those parameters. Furthermore, experiments can be carried out for calibration of dosimetry equipment for MR-LINACs as well as for investigation of magnetic field effects on dose deposition and detectors in general.

Author's Statement The authors declare that they have no conflict of interest.

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