Progress report on new facility for medium-energy x-rays

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1. Introduction

The BIPM free-air chamber primary standard FAC-M-01 for medium-energy x-rays was developed in the early 1970s. A new x-ray tube and high-voltage generator were installed in 2004 but at that time no change was made to the standard nor to the x-ray tube support or measurement bench, which are entirely mechanical with no automation of measurement procedures feasible. In recent years a primary standard of absorbed dose to water was developed, incorporating a water phantom into the arrangement whose positioning again does not allow automation (Burns *et al.* 2017).

In 2019 the high-voltage generator started to display an intermittent fault and, given the age of the various system components and its critical use as the international reference, a plan was developed to install a new generator, x-ray tube, automated measurement bench and free-air chamber in parallel with the existing arrangement. The new generator (GE Isovolt Titan E 320) and x-ray tube (Comet MXR-320/26) were purchased. As it happened, the existing generator failed in early 2020 and in June it was replaced by the new generator (which will now serve both the existing facility and the new facility).

The purpose of this report is to outline the present state of development of the various components of the new system.

2. The new x-ray tube support

The design of the new x-ray tube support is shown in Figure 1. The support incorporates a tungsten beam shutter and an automated filter wheel. A tungsten collimator is incorporated into the tube housing, to be accurately machined after measurement of the radiation beam profile so as to result in a circular field of diameter 100 mm at the reference distance of 1200 mm.

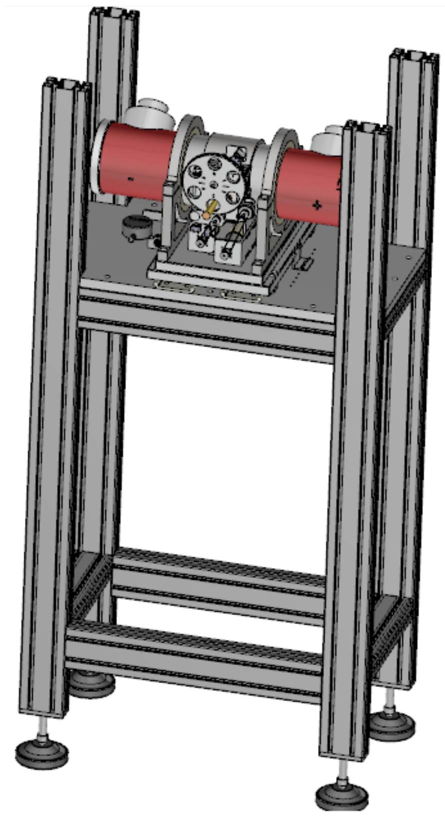

Figure 1. *Design of the new x-ray tube support showing the automated filter wheel.*

A critical component for highly-reproducible dosimetric measurements over the long term is the accurate determination and adjustment of the axial distance from the x-ray tube centre to the reference plane for devices under measurement. The new system incorporates both mechanical and optical devices for these measurements as well as a micrometer adjustment of the axial tube position. This will ensure that distance changes observed with the existing system, perhaps due to building movements and seasonal effects, can be accurately measured and corrected.

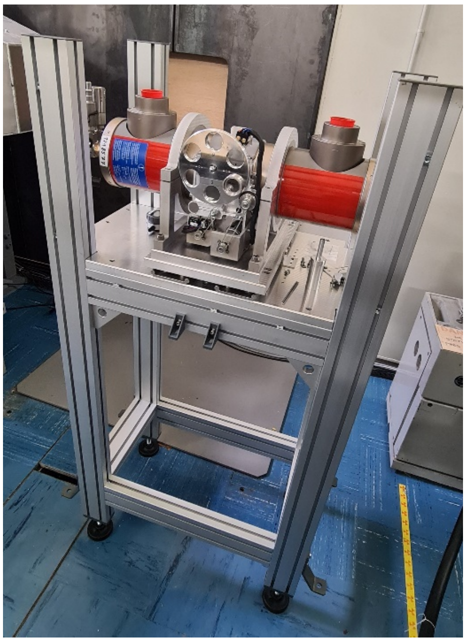

Figure 2. Photograph of the new x-ray tube support in its temporary location.

One of the difficulties when setting up a new x-ray facility, and for future changes when a tube eventually fails, is alignment such that the radiation beam axis is both horizontal and parallel to the axis of the free-air chamber. To facilitate this, translational and rotational adjustments have been incorporated into the design of the tube support and an on-axis laser will be used to visualize the beam axis after it has been determined ionometrically.

The new support was constructed at the BIPM workshop in late 2020. It is essentially complete and the x-ray tube provisionally installed. However, alignment cannot commence until the new measurement bench is constructed and in position and appropriate cavity ionization chambers can be mounted to determine the beam axis. A photograph of the new arrangement in its temporary location is shown in Figure 2.

3. The new measurement bench

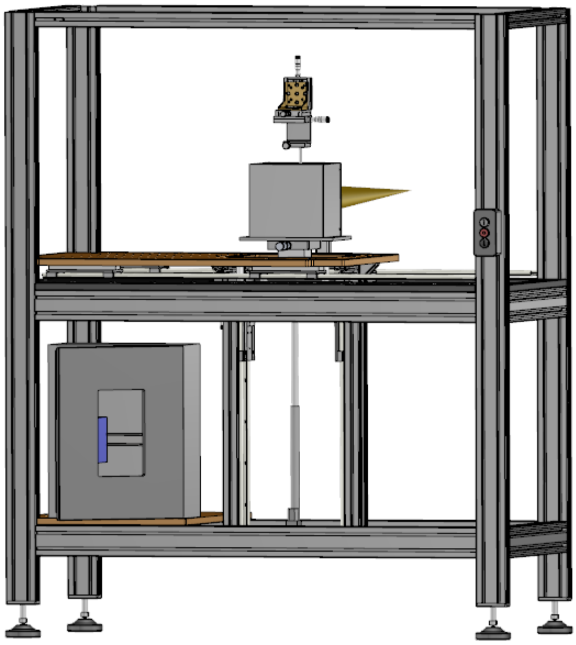

Figure 3. Design of the new measurement bench showing the water phantom in its raised position with the cavity chamber support above it.

The design of the new measurement bench is shown in Figure 3. The bench must incorporate measurements for both air kerma and absorbed dose to water. The arrangement for air kerma is relatively straightforward, involving a lateral translation table to enable alternate measurements between the free-air chamber and the cavity chamber under measurement. A removable micrometer support can be positioned at the front of the bench for accurate measurement of the axial position of the device under measurement (free-air chamber or cavity chamber). The distance of this support from the x-ray tube is measured by the mechanical and optical devices incorporated into the tube support. A second translation table is incorporated into the free-air chamber support to accurately set the reference distance of 1200 mm, while micrometer movement in all three planes is included in the cavity chamber support. The removable micrometer support can also be used to place on the beam axis, for each chamber type normally measured, a machined adaptor with a hollow precisely matching the chamber outline; this facilitates rapid positioning of the chamber reference point on the beam axis at the 0.1 mm level.

As described in Burns *et al.* (2017), the novelty of the BIPM set-up for absorbed dose to water is that the cavity chamber is first positioned free-in-air at the reference distance, as described above, and then the water phantom is raised from below such that the chamber is then very close to the reference depth in water. To enable fine tuning of the depth to 2 g cm^{-2}, the water phantom is supported on a translation table and there is a 'minimal-contact' mechanical system (as well as a laser system under test) for accurately measuring the distance from the removable micrometer support to the outer surface of the phantom window, this window being only 1.7 mm thick and very easily disturbed. Lateral translation of this 'raised' phantom is still necessary to alternate between the free-air chamber and the water phantom. While this complicates the bench design somewhat, the gain is that the (waterproof) cavity chamber is easily and accurately positioned at the reference depth; this depth is critical, the dose gradient at 100 kV being 1.5 % per mm.

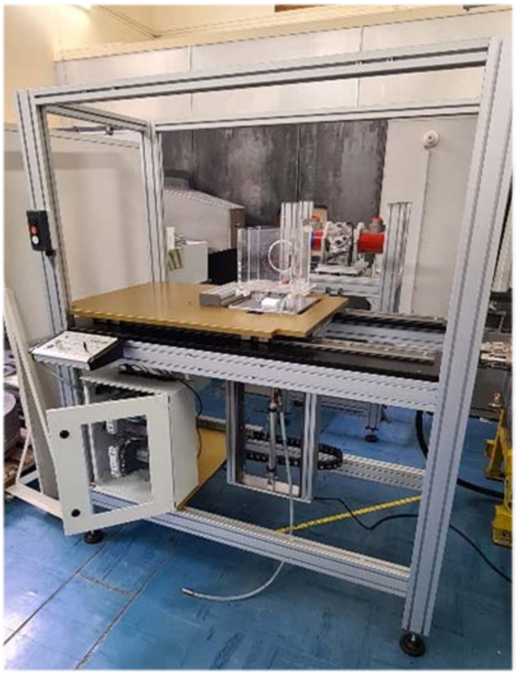

Figure 4. *The new measurement bench in the final stages of development.*

The new bench was constructed largely in the BIPM workshop in early 2021 (three components were too large for the BIPM workshop and were contracted out). Its mechanical construction is essentially complete and work continues on the electronics, following which new software will be developed to control the bench movements. A photograph of the new arrangement in its temporary location is shown in Figure 4.

4. The new free-air chamber

Because of its status as the international reference, the decision was taken to keep the basic design parameters for the new free-air chamber (plate separation, attenuation length, collecting length) to be the same as those for the existing chamber FAC-M-01, including the use of the same entrance diaphragm (which is easily removable). This will ensure that almost all of the correction factors remain unchanged.

It is notable that the single largest uncertainty component for the existing standard (apart from the value for the physical constant W/e) is that arising from the possibility of electric-field distortion (Kessler *et al.* 2018). The plan is to incorporate into the new free-air chamber two changes that will allow information on field distortion to be obtained. The first is to have a guard arrangement for which the potential can be offset (from the collecting electrode at virtual ground) by a small and variable amount, thus introducing a potential difference between the guard and the collecting electrode; this deliberate introduction of field distortion should help both to minimize field distortion and to better quantify the uncertainty. The second change will be to arrange the entrance diaphragm so that it is either at ground potential, the arrangement for the existing standard, or at half the polarizing potential of the chamber (which will be operated at 4000 V). It is known from finite-element electric-field simulations that having the diaphragm at ground potential disturbs the electric field in the collecting region, but these calculations have not been able to quantify the effect. Measurements of this type will resolve this potential source of error and should reduce the uncertainty. Work on the detailed design and construction of the chamber will begin in late 2021 or early 2022 (depending on the priorities of other elements of the dosimetry programme).

References

Burns D T, Kessler C, Roger P 2017 New BIPM absorbed-dose standard for medium-energy x-rays *CCRI(I)*/2017-06

Kessler C, Burns D T 2018 Measuring conditions and uncertainties for the comparison and calibration of national dosimetric standards at the BIPM *Rapport BIPM*-2018/06