CCRI(I)/11-09

Progress Report on Radiation Dosimetry Standards at NMIJ/AIST

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1. Introduction

Ionizing Radiation Section in NMIJ/AIST provides the X-rays, γ-ray, and β-ray standards in Japan as a primary NMI. We provide air kerma rate of X-rays and γ-rays, and photon intensity of monochromatized synchrotron radiation and free electron laser in the soft X-ray region. We established air kerma standards for mammography low energy X-ray quality in 2009 and the absorbed dose to water for γ-rays from ^{60}Co in 2010. Clinical linac was installed in January of 2010. We performed the key comparison of absorbed dose to water (BIPM.RI(I)-K4) and mammography (BIPM.RI(I)-K7), and continue APMP.RI(I)-K2 as a pilot laboratory.

2. Developments of Standards

2-1. **Absorbed dose rate to water** in a Co-60 γ-ray field

A standard for absorbed dose rate to water in a Co-60 γ-ray field has been established using a graphite calorimeter (Figure 1) and a thick walled graphite cavity chamber. The graphite calorimeter determines the absorbed dose rate to graphite, and the measurements by the graphite cavity chamber in a calorimeter phantom and in a water phantom, determine the conversion factor of the absorbed dose rate from graphite to water. The reference distance from the source and the reference depth in water are 1 m and 5 g/cm^2, respectively. The field diameter on the reference plane is 11 cm. The radioactivity of the Co-60 source was 150 TBq on January 2009, and the heating power of the core in the calorimeter by this field was about 14 μW on June 2009. By correcting the measured results by some simulated factors using a Monte-Carlo code

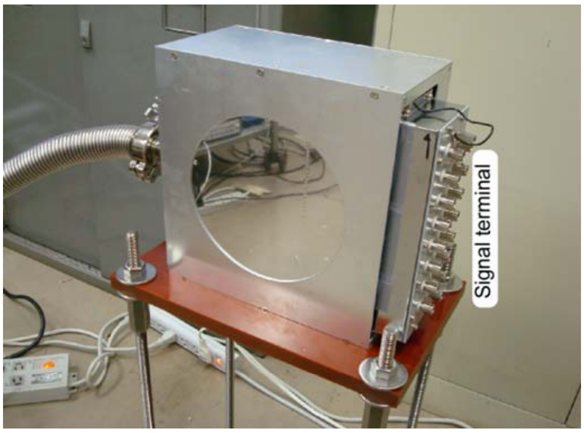

Figure 1: Graphite calorimeter

(EGS5), it was found that this power corresponds to 0.012 Gy/s in absorbed dose rate to water. Estimation of all the uncertainties in the measurements and the simulations, showed the total uncertainty of 0.38 % ($k = 1$).

We started the calibration service from August 2010, and participated in the international comparison by the APMP program and the bilateral comparison with the BIPM. The results will be soon reported elsewhere.

Testing the transfer chambers

Signal currents from some commercially available ionization chambers were measured both in air and in a water phantom by irradiating the Co-60 γ-rays [1]. The chambers were PTW 30013, Exradin A12 and Applied Engineering C-110. Build-up caps supplied by manufacturers were used in air. Build-up caps of 30013 and C-110 are made of PMMA, and that of A12 is made of C552 conductive plastic.

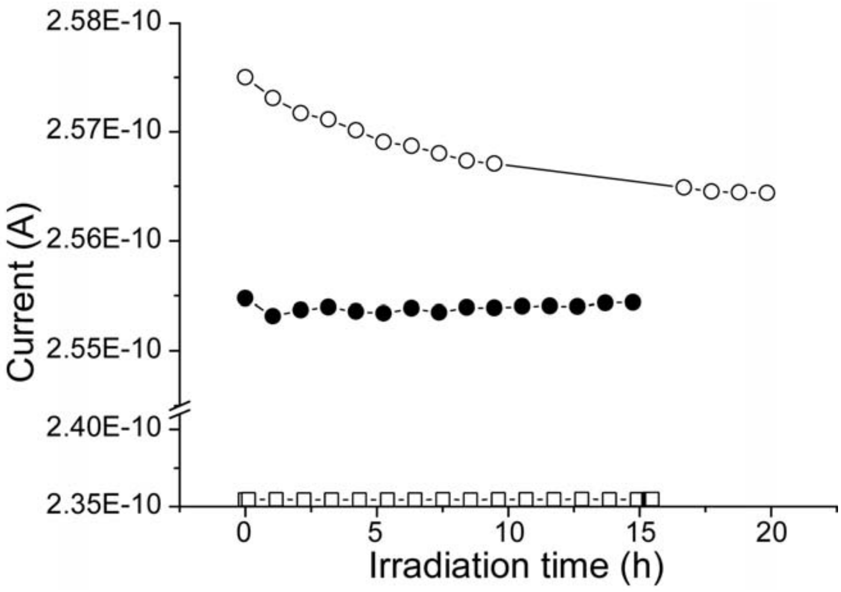

Figure 2: Currents measured with the 30013 chamber

Open and filled circles in Figure 2 show the currents from the 30013 as a function of the irradiation time when the chamber was irradiated in air and in the water phantom. The air kerma rate and the absorbed dose rate were about 40 Gy/h. The current measured in air decreases by about 0.4 % after 700 Gy irradiation, while the current was constant when the chamber was irradiated in the water phantom. Similar results were obtained for the C-110 chamber. On the other hand, the A12 chamber exhibited a constant signal current both in air and in the water phantom.

A reason of this current decrease in 30013 and C-110 is the positive charge accumulated near the surface of the PMMA build-up cap where the electron equilibrium is not fulfilled. The electric field induced by this positive charge decelerates the secondary electrons and prevents them from entering into the cavity of the chamber. To confirm this, the 30013 chamber with the build-up cap was wrapped with a thin Al foil and further wrapped with a PMMA tube. Although the positive charge is accumulated on the PMMA tube, the Al foil at the ground potential shields the electric field inside of the Al foil. The squares in Figure 2 show the current measured with this chamber, and the current is constant.

Development of compact-size control system for a graphite calorimeter

We have developed a compact-size control system for a graphite calorimeter. We use thermistors for measuring the temperature on a core, a jacket, and a shield in the calorimeter. Each thermistor is connected to a Wheatstone bridge which is driven by an AC oscillator, and the output from the bridge is measured with a lock-in amplifier. The temperatures on the core, the jacket, and the shield in the calorimeter are controlled by PID control technique. We need many electronics for this control as seen in Fig.3.

Figure 3 Present control system for the graphite calorimeter.

The new compact-size control system consists of three sets of the temperature measurements, power supplies, and control units. The size of the system is 430 mm(W) x 440mm(D) x 200mm(H) (Fig.4).

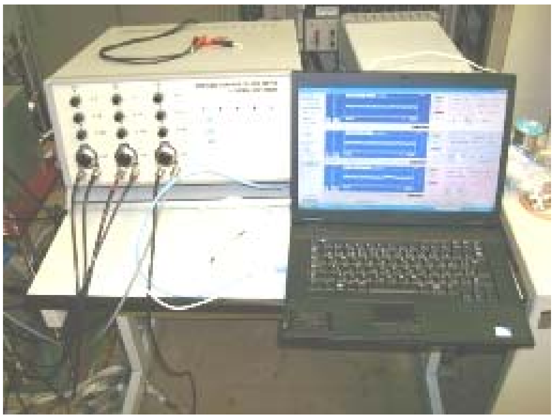

Figure 4 The new compact-size control system for the calorimeter.

This new control system can operate in both the constant temperature mode and the quasi-adiabatic mode. Figure 5 shows the temperature of the core for both modes. Table 1 shows the comparison of the absorbed gamma-ray power measured by both modes. The measured values are very close each other.

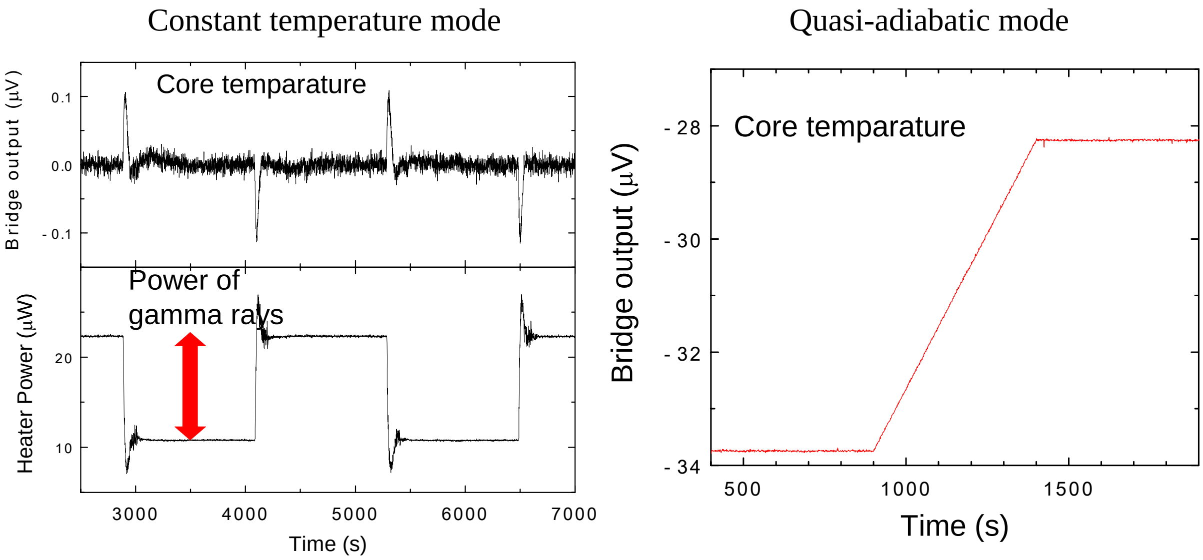

Figure 5 The temperature of the core for the constant temperature mode (left) and quasi-adiabatic mode (right).

Table 1 The absorbed gamma-ray power measured by the constant temperature mode and the quasi-adiabatic mode.

	Power (μW)	Standard deviation (%)
Constant temperature mode	11.489	0.08
Quasi-adiabatic mode	11.491	0.12

2-2. Mammography radiation quality

We have developed air kerma standards for mammography radiation with Mo X-ray tube and Mo filters (thickness: 30μm and 32 μm) and with Mo X-ray tube and Rh filter, 25 μm in thickness. Figure 6 shows the low-energy X-ray calibration facility.

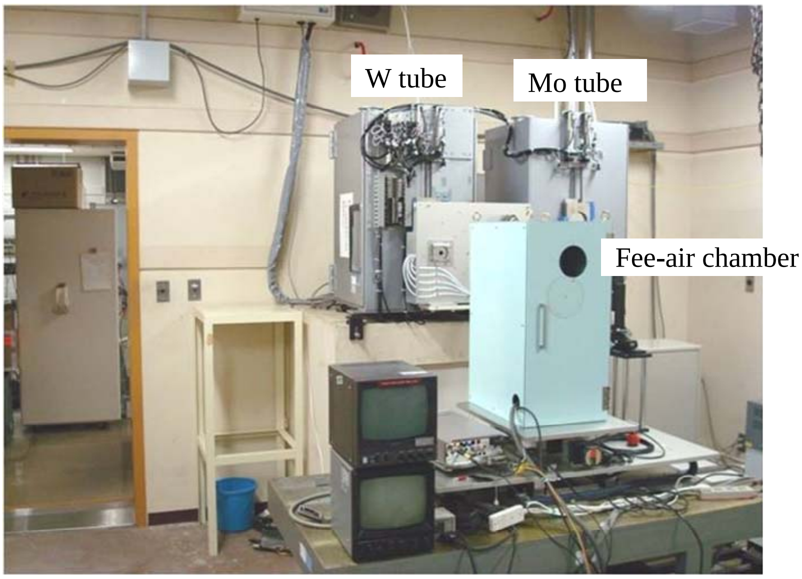

Figure 6　Photograph of the low-energy X-ray calibration facility.

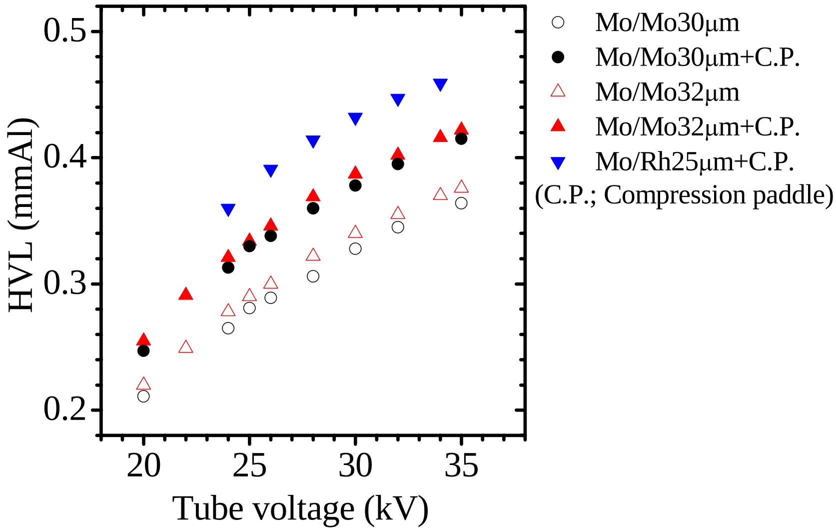

Figure 7　The Al HVL for mammography radiation qualities with Mo/Rh compared with Mo/Mo radiation qualities.

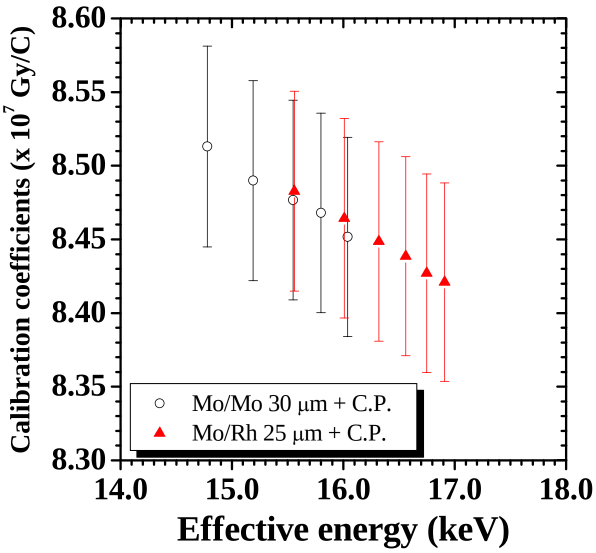

Figure 8 Examples of calibration coefficients for Mo/Rh radiation qualities compared with Mo/Mo.

Figure 7 shows the Al HVL for the Mo/Rh radiation qualities in addition to Mo/Mo radiation qualities. Figure 8 shows the calibration coefficients of PTW ionization chambers for Mo/Mo and Mo/Rh radiation qualities. The calibration coefficients of the PTW chamber look like fitting on the universal curve within the expanded uncertainty of 0.8 %.

A key comparison has been made between the air-kerma standards of the NMIJ and the BIPM in mammography x-ray beams (BIPM. RI(I)-K7). Good agreement (within 0.4 %) was obtained for the mammography radiation qualities.

Using our mammography reference field, we have evaluated the glass dosemeter (Fig.9) used for quality control of mammography in many hospitals. The glass dosemeters are calibrated to the PTW ionization chambers with a compression plate. It was confirmed that the glass dosemeters can measure air kerma, tube voltage and HVL within their uncertainty of a few percent.

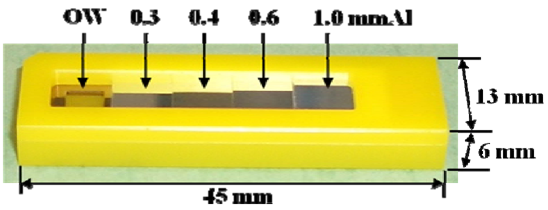

Figure 9 Picture of a glass dosemeter specially designed for measuring mammography radiation

2-3. Clinical linac

We have installed clinical linac (Elekta Precise) in the begging of 2010. The energies of X-ray are 6, 10 and 15 MV. The electron beam energies are between 6, 9, 12, 15, 18 and 22 MeV. We have also installed a water phantom to measure $TPR_{20,\ 10}$ for x-rays and depth dose curves for electron beams, as shown in figure 6.

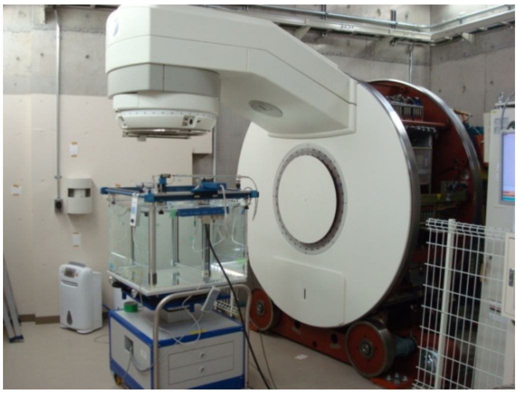

Figure 10 Completed installation of the Elekta Precise linac in the NMIJ/AIST.

We will develop the standards of the absorbed dose to water for high energy X-ray and electron beams using this linac.

2-4. ^{60}Co and ^{137}Cs gamma rays

Air kerma standards for ^{60}Co and ^{137}Cs gamma rays at NMIJ were peer-reviewed in October 2008 and ISO17025 quality system was established in 2004. Our largest ^{60}Co gamma ray source, ^{148}TBq, was replaced by a new one last January .The range of air kerma rate and calibration and measurement capability (*k*=2) are listed in Table 2.

Table 2 Range of air kerma rate and calibration and measurement capability (*k*=2)

Source	Range of air kerma rate (Gy/s)	Calibration and measurement capability (*k*=2)
^{60}Co γ-rays	1.6×10^{-9} ~ 1.5×10^{-1}	1.0 % at 1.3×10^{-2} Gy/s
^{137}Cs γ-rays	5.8×10^{-10} ~ 4.4×10^{-4}	0.8 % at 6.6×10^{-4} Gy/s

2-5. Medium-energy X-rays (50 kV – 300 kV)

Air kerma standards for medium-energy X-rays at NMIJ were peer-reviewed in October 2008, and ISO17025 quality system was established in June 2005. The range of air kerma rate and calibration and measurement capability (*k*=2) are listed in Table 3.

Table 3 Range of air kerma rate and calibration and measurement capability (*k*=2)

X-ray quality	Range of air kerma rate (Gy/s)	Calibration and measurement capability (*k*=2)
BIPM quality (ISO 4037-1) Narrow spectrum Low kerma rate High kerma rate Wide spectrum Japanese QI series	9.0×10^{-9} ~ 2.0×10^{-3}	1.2 % at 2.7×10^{-4} Gy/s

The qualities of X-rays provided are BIPM quality, 4 qualities in ISO4037 and Japanese QI (quality index, E_{eff}/E_{max}), where E_{eff} is the effective X-ray energy and E_{max} the maximum X-ray energy.

2-6. Low-energy X-rays (10 kV – 50 kV)

Air kerma standards for low-energy X-rays at NMIJ were peer-reviewed in October 2008, and ISO17025 quality system was established in June 2005. The range of air kerma rate and calibration and measurement capability (*k*=2) are listed in Table 4.

Table 4 Range of air kerma rate and calibration and measurement capability (*k*=2)

X-ray quality	Range of air kerma rate (Gy/s)	Calibration and measurement capability (*k*=2)
BIPM quality (ISO 4037-1) Narrow spectrum Japanese QI series	2.5×10^{-6} ~ 1.0×10^{-2}	0.8 % at 4.4×10^{-5} Gy/s

2-7. Absorbed dose standards for beta-particle radiation

Standards of absorbed dose to tissue at a depth of 0.07 mm for beta particles emitted from Sr-90/Y-90, Kr-85 and Pm-147 were established and a calibration service for the area and personal dosemeters in these radiation fields have been offered in 2006. We have joined in EUROMET project No. 739, and our results have agreed among those of participated laboratories. The standards were peer-reviewed in October 2008, and ISO17025 quality system was established in March 2009. Beta Secondary Standard 2 (BSS2) is used for producing Series 1 reference beta particle radiation fields described in ISO 6980-1:2006 (Fig. 11). The absolute values of the absorbed dose rate determined by an extrapolation chamber and calibration and measurement capability (*k*=2) are listed in Table 5. We have contributed to establishment of a Japan Industrial Standard titled “JIS Z 4514 Calibration of absorbed dose to tissue meters and dose equivalent meters and the determination of their response as a function of beta radiation energy and angle of incidence”. We will perform APMP comparison of the standards as a pilot laboratory.

Table 5 The absorbed dose rate to tissue and calibration and measurement capability.

	Reference absorbed dose rate (Gy/s)	Uncertainty (*k*=2)
^{90}Sr/^{90}Y with a beam flattening filter at the distance of 30 cm	1.1×10^{-5}	2.8 %
^{85}Kr with a beam flattening filter at the distance of 30 cm	3.8×10^{-5}	2.8 %
^{147}Pm with a beam flattening filter at the distance of 20 cm	2.0×10^{-6}	4.8 %

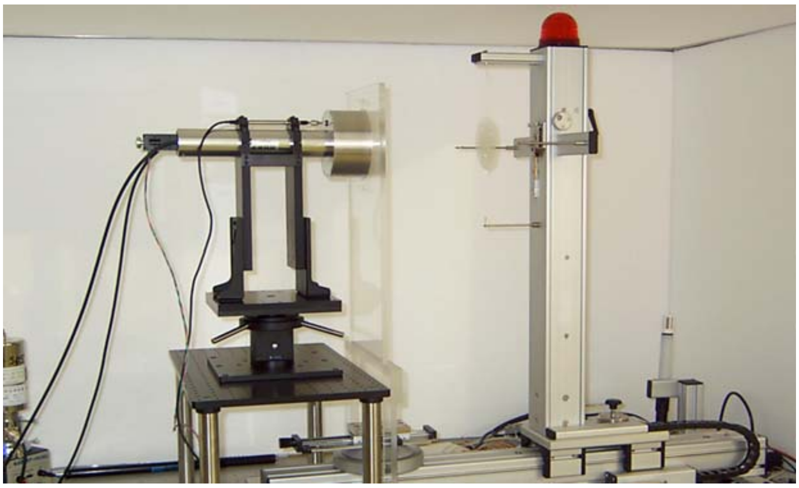

Figure 11 An extrapolation chamber and a beta-ray irradiation system.

References

[1] N. Takata and Y. Morishita, “Effect of radiation-induced charge accumulation on build-up cap on the signal current from an ionization chamber”, to be published in Radiat. Prot. Dosim.(already available in the web)