The Evaluation of Multiplane-Parallel Chamber Using Crystal Plate as Ionization Medium for Therapeutic Radiation Beams

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There has been necessity of an air free ionization chamber using the gold-crystal-aluminium plates, henceforth called the crystal chamber. The crystal chamber formed of parallel plates is very small in size and has more response for absorbed dose of therapeutic radiation beams. The gold plate on the crystal facing the photon and electron beam acts as an intensifier of signals and crystal plate as an ionization medium respectively. Both the copper guard ring and the aluminum collecting electrode are connected to an electrometer. Using high energy photon (6, 15 MV) and electron (9, 12, 15, 18 MeV) beams, the responses of the crystal chamber are evaluated against a PTW Farmer-type chamber at a field size of 10×10 cm^2 and 100 cm SSD. The responses of crystal chamber for therapeutic radiation electron and photon beams are greater in magnitude by several order than Farmer. The crystal chamber has good linearity without correction factor $C_{t,p}$ with respect to the signals, a reading reproduction with good accuracy and precision less than 0.5%, and has other useful functions in measuring radiation beams.

INTRODUCTION

The plane-parallel ionization chambers usually are suitable for dosimetry of high energy photon and electron beams in the buildup or the regions of steep dose gradients, e.g., at the surface of an irradiated object or at the interfaces within the object[1,2,3]. The properties of multi-parallel plate chamber using crystal plate as ionization medium are compared with a PTW Farmer chamber. Experimental results shown that, despite the extremely small volume in ionization medium of crystal chamber, the responses of absorbed dose for crystal chamber in the electron (9, 12, 15, 18 MeV) and photon (6, 15 MV) beams are approximately several hundreds times bigger than air cavity of the same volume.

Resultantly, in this study, the crystal chamber has number of advantages such as: a) air free ionization chamber, b) independence of temperature, pressure and humidity, c) independence of energy for photons and electrons beams, d) more accurate measurement of dose on the surface or in the buildup region, e) more sensitivity with respect to absorbed dose. Finally, crystal chamber is smaller in volume, but has enhanced stable responses for photons and electrons used in radiation therapy.

METHODS AND MATERIALS

A multi-parallel plate chamber having a sensitive volume of 0.014 cc and using the crystal plate (Quartz plate, Willouhby Quartz #643, General Electric Co.) as the sensitive medium instead of air was studied. The effective atomic number (11.75) of crystal plate is slightly smaller than bone (12.31)[4], and the gold plate with thickness of 140 μm on the crystal plate facing the photon and electron beams acts as an intensifier of signals. The gold plate, guard ring and the collecting electrode are connected to a electrometer(Victoreen 500). Both the guard ring and the collecting electrode are automatically held at the negative potential for all readings. In this configuration, the electric field strength are held at constant 300 volt/mm.

The signals of the crystal and PTW Farmer chamber as function of the monitor units are detected by electrometer at a field size of 10×10 cm^2 and 100 cm SSD with photon (6, 15 MV) and electron (9, 12, 15, 18 MeV) therapeutic radiation beams with Clinac 1800 Varian accelerator in Figure 1, (A) and (B).

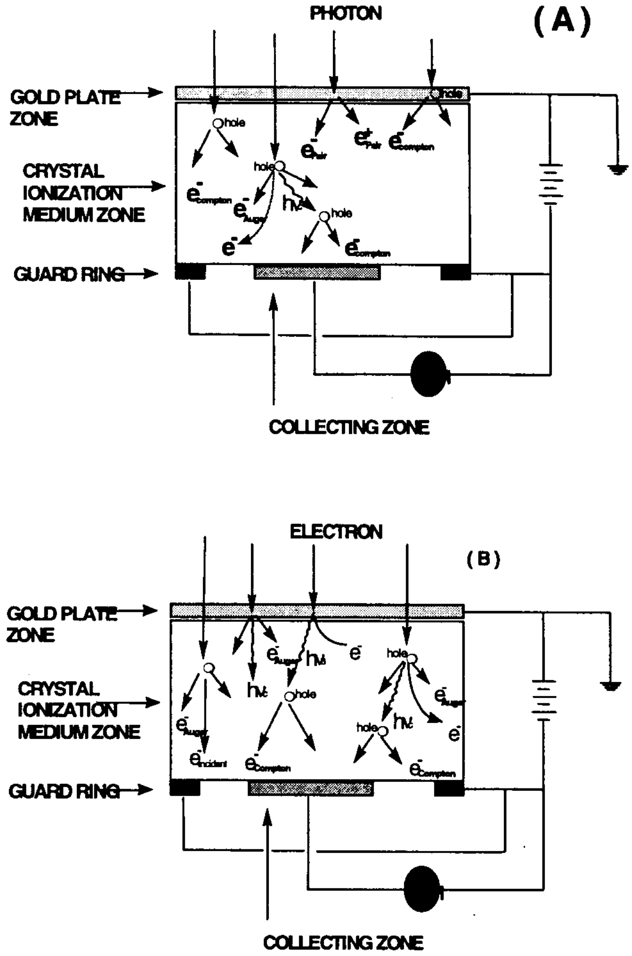

Fig. 1. (A) the schematic of crystal ion chamber for photon beams. The structure of crystal dosimeter is laminated form which consists of gold -crystal - aluminium and guard ring (copper). To maintain high electric field an internal bias supply voltage 300 is applied volts between gold and aluminium plate. Guard ring has the same potential with the aluminium plate, and it's separation is fixed electrode. (B) the schematic of crystal ion chamber for electron beams with the same structure of (A).

1. PHOTONS IN THE GOLD PLATE ZONE

When high energy photon (6, 15 MV) beams irradiate a material of high atomic number (Z) such as a gold plate, three types of interactions, Compton scattering, pair production and photoelectric effects exist. The first two types are the most dominant effects in this photon and gold plate interaction. Resultantly, there are number of Compton electrons, positrons and negatrons are produced in the gold plate with 140 μm thickness.

2. PHOTONS IN THE CRYSTAL IONIZATION MEDIUM ZONE

There are many types of interactions with crystal medium by incident photons, Compton electrons, positrons and negatrons which come from the gold plate. They are produced by Compton scattering, pair production process respectively and partly by few photoelectric effect. Whenever inner-shell electrons in the crystal medium are ejected from an atom by a hard collision of incident photons and/or positrons and negatrons, characteristic X-ray and/or Auger

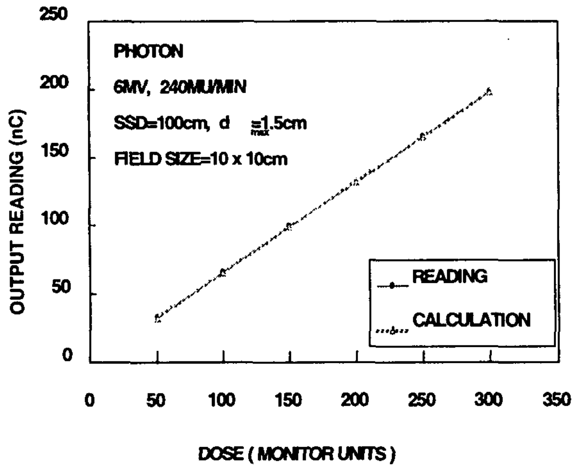

Figure 2. The linearity of output reading in nC units and the values of calculation of linearity as function of absorbed dose in monitor unit.

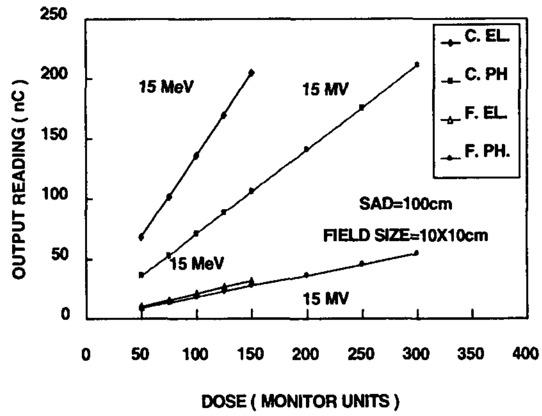

Figure 3. The linearities of output reading in nC units for electron (15 MeV) and photon (15 MV) beam measured by crystal and PTW Farmer chamber ; as function of absorbed dose in monitor units.

electrons will be emitted just as if the same electron had been removed by a photon interaction. As a results, the number of holes in the crystal medium are increased by creation of Auger electrons, Compton scattering[5]. If the Auger emitter is a part of a molecule, the positive electric charge (hole) accumulated on the emitter of crystal medium. The number of holes is related to the absorbed dose of photon beam and will be detected as signal by dosimetry electrometer.

3. ELECTRONS IN THE GOLD PLATE ZONE

There are two types of interactions, Bremsstrahlung and characteristic X-ray by secondary radiations, between gold plate and high energy incident electron beams, 9, 12, 15, 18 MeV. Some electrons which do not interact with gold plate will be transmitted into the crystal medium directly.

4. ELECTRONS IN THE CRYSTAL IONIZATION MEDIUM ZONE

The *incident* electrons and secondary radiation from the gold plate interact with crystal medium n many ways. Incident electrons and secondary photons should increase the number of Auger electrons in the crystal ionization medium and eventually holes. The lower effective atomic number of crystal materials, the higher probability of Auger electron and creation of hole[6]. The Augers have a low energy, so they are easily shifted to outside of detecting zone by the strong electric field. As a result, the relative abundance of holes in the crystal plate should be rapidly increased and then should be rapidly detected as a signals of absorbed dose for electron beams by electrometer.

RESULTS AND DISCUSSIONS

Crystal chamber is irradiated by photons for a range of absorbed dose up to 300 monitor units. The output readings of crystal chamber was in nC unit for 6 MV photon at field size 10×10 cm^2, d_{max} = 1.5 cm, 100 cm SSD. The values of calculated linearity are plotted in Figure 2. The line of linearity coincides well with the calculated line with the differences less than 0.5%.

There is no supralinearity or infralinearity in large monitor units. The linearity of dosimetry is fundamental and important property in the therapeutic radiation beam detections. In this line, especially, if the line of linearity lengthens, then it approaches to the null point with zero signal intensity. It means that the crystal chamber, in spite of the wide irradiation range of monitor unit, has no noise effects, but has the stable signal for the radiation photon beam in Figure 2.

In Figure 3, the crystal and PTW Farmer chamber are irradiated by photons (15 MV) with Clinacs 1800 Varian accelerator for a range of absorbed dose from 50 up to 300 monitor unit. After reading, they were irradiated again by electrons (15 MeV) for a range from 50 to 150 monitor units. The output readings for photon and electron beam are obtained by dosimetry electrometer in nC units at field size 10×10 cm^2, D_{max} and 100 cm SSD. All the lines of linearity of measurements for electron and photon beams against crystal and PTW Farmer chamber agree with the values of calculation of linearity very well. There is only a small difference within ± 0.5% between output readings and calculations of linearity. When the lines of linearity extended, all of the lines approach to the null point. As mentioned before, in the wide range of energy of the incident photon and electron beams, the crystal chamber has not noise effects of itself, but has stable and enhanced signals for therapeutic radiation beams.

In case of the same radiation beam energy, since the incident particle (electron) beam has a larger total stopping power in the crystal medium than photon,

$$\left(\frac{S_{tot}}{\rho}\right)^{electron}_{crystal} > \left(\frac{S_{tot}}{\rho}\right)^{photon}_{crystal} \qquad (1)$$

The left side term means the stopping power of crystal for electron and right side is for photon. The incident electrons should transfer more amount of their incident energy to the crystal medium per unit path length than that of the photon beam.

$$(\overline{E}_{tr})_{electron} > (\overline{E}_{tr})_{photon} \qquad (2)$$

The left term means the average energy of electron transferred into the crystal and right side is for photon.

Vacancies in inner atomic shells can be produced not only by photons or electrons and positrons bombardment, but also in nuclear internal conversion and capture processes. The law of conservation of energy satisfied by the simultaneous creation of a photon or by the ejection of an electron carried away the extra energy in an outer shell to a state in the continuum. The latter process is called as Auger transition. The residual atom is highly excited by incident photons and electrons. De-excitation take place with the initiation of one or more atomic vacancy cascades leading to the emission of photons or Auger electrons and the consequent creation of holes[7].

From a given inner vacancy, a great number of different Auger transitions may result and create a lots of holes. For absorption of radiation in the K-shell electrons of very low atomic numbers (as in Quartz, living cell, ...), emission of Auger electrons is dominant (only a few % K-X-rays). The Auger process is governed by electrostatic forces produced by the interaction of a hole in an incomplete shell with its surrounding electron clouds, and is not strictly depending on selection rules. If the Auger emitter is a part of a molecule, the high positive electric charge (hole) accumulated on the emitter.

In case of electron beam, there are much more energy in the excited atom of crystal medium than photon beam. When the electron comes into the crystal, the probabilities of Auger chain reaction and the resulting holes are increased than the photon case.

$$(P_{Auger.Hole})_{electron} > (P_{Auger.Hole})_{photon} \qquad (3)$$

The $P_{Auger,Hole}$ means probabilities of Auger chain reaction and the resulting creation of holes in crystal medium for electron and photon beams.

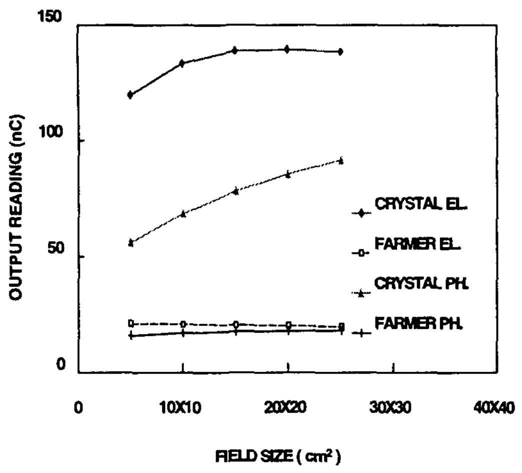

Figure 4. The responses of crystal chamber that is dependent of field size are evaluated against a PTW Farmer chamber which is not dependent. The curves of crystal and Farmer chamber as fuction of the field size for electron (EL ; 15 MeV) and photon (PH ; 15 MV) beams at 100 cm SSD with 100 monitor units of 240 MU/min dose rate and Dmax position.

Table 1. The output reading of crystal and PTW Farmer chamber with pressure, temperature and correction factor $C_{T,P}$ for 6MV photon beam with 100 minitor units.

6MV, SAD=100cm, F. S.=10x10cm2, BUILDUP=1.5cm, 100MU

P (mmHg)	T (°C)	Farmer (nC)	$C_{T,P}$	Dose (nC)	Crystal (nC)
742.3	27.0	17.78	1.041	18.51	67.8
746.0	27.5	17.84	1.038	18.51	67.7
746.6	30.5	17.73	1.047	18.56	68.0

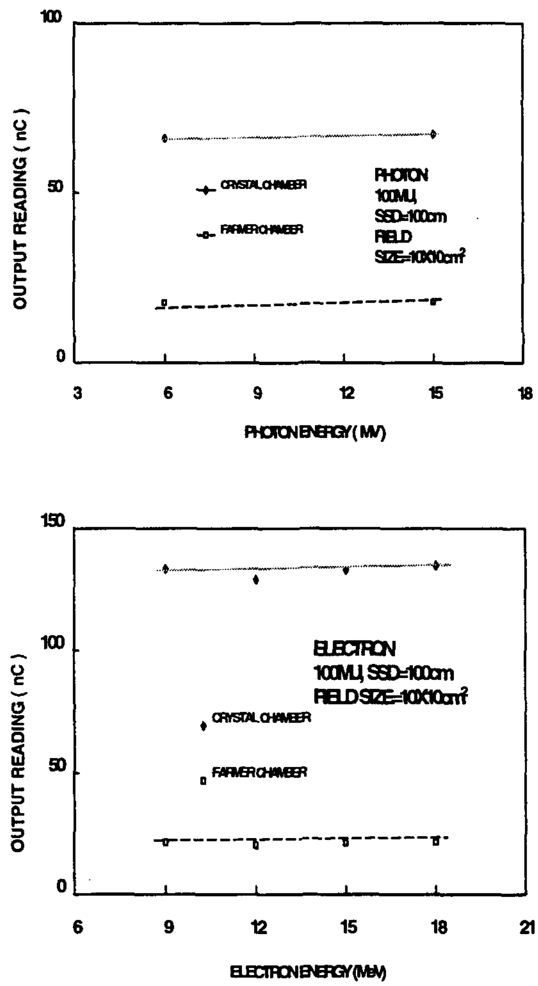

Figure 5. Irrespective of high or low energies of the incident photon and electron beams, the output readings of crystal chamber has higher constant responses than PTW Farmer chamber. (Upper) : output reading for photon (6, 15 MV) beams and (Lower) : for electron beams (9, 12, 15, 18 MeV)

Equation (3) means that the intensity of the signal from crystal chamber for electron beam is always much higher than that of the photon. The crystal medium chamber has a larger electron density per unit volume than the air medium chamber (PTW Farmer). Therefore, the probability of Auger chain reaction for crystal is higher than the air.

$$(I)^{electron}_{crystal} > (I)^{photon}_{crystal} > (I)^{electron}_{air} > (I)^{photon}_{air} \quad (4)$$

The term-(I) means the signal intensities of crystal and Farmer chamber for electron and

Table 2. The relative output responses of crystal chamber against the normalized signals of Farmer chamber for photon (15MV) and electron (15MeV) beam at the field size 10X10cm2 with 100 monitor units, 100cm SSD and Dmax position.

	sensitive vol. (cc)	dose response (nC/cGy)		signal sensitive vol.		reproducibility	linearity
		photon	electron	photon	electron		
Farmer	0.6	1	1	1	1	<~0.5%	1 : 1
Crystal	0.014	3.75	6.25	160	270	<~0.5%	1 : 1

photon beams respectively. As a result, the responses of crystal chamber for electron and photon are always much larger than that of air medium chamber.

In Figure 4, the reason why crystal chamber is dependent on the field sizes is that the sensitive crystal volume can detect up to the scattering photons and contaminant electrons from the gantry head, collimator jaws, and blocking tray. The larger field size, the more amounts of scattering photons and contaminant electrons coming from the accelerator machine could affect the signal intensity[8]. In fact, it should be the real total sum of absorbed dose from the accelerator at the D_{max} position or buildup region.

In Figure 5, independent on energy of the incident photon (6, 15 MV) and electron(9, 12, 15, 18 MeV) beam at the d_{max} level, the response of dosimetry has the same level of signals. And this is one of the basic properties of radiation dosimeter. The output readings of crystal chamber has not only higher constant response with respect to energies but also has smaller relative errors compare to the PTW Farmer chamber.

In Table I, the data of third column are the output readings in nC units of PTW Farmer chamber and fourth are the correction factors as function of pressures and temperatures. The fifth column is the absorbed doses corrected by $C_{T,P}$ and then has increment of 0.5% between first row and third row. The sixth column is the direct output reading of crystal chamber which doesn't need correction factor of atmosphere conditions and is under the same conditions above PTW Farmer chamber. The data of sixth column have also increment of 0.5% between first row and third. The increment between the data of crystal and Farmer chamber are approximately same values. The output readings of crystal chamber are easy to obtain in real time.

The relative output responses of crystal chamber with respect to normalized signals of Farmer chamber are greater than Farmer-type ionization chamber beyond comparison. The summary of results are in Table Ⅱ.

CONCLUSION

Making and handling crystal chamber is very simple and can be smaller in size than any other air ionization chamber. This process can be applied to all kinds of crystal plates or semiconductor chips. Crystal chamber has not only an excellent linearity but also has a reproduction with accuracy and precision good within ±0.5%. Experimently, the accuracy and precision of crystal chamber had a higher reproduction than that of PTW Farmer chamber and the signal intensity of crystal chamber is increased more for the electron than the photon beam.

In view of the results so far achieved, crystal chamber has a useful role to perform in the measurement of entrance, surface dose or dose in solid water phantom in the therapeutic electron and photon beams. It was for preparatory study of a development of small detectors can be used in stereotactic radiosurgery.

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