UNIVERSITI SAINS MALAYSIA

UNIVERSITI SAINS MALAYSIA

STUDY OF OUTPUT FACTORS OF ELECTRON BEAM BASED ON THE SIMPLE MODEL.

Dissertation submitted in partial fulfillment for the Degree of Bachelor of Health Science in Medical Radiation.

NORHANNA BINTI SOHAIMI

School of Health Sciences
Universiti Sains Malaysia
Health Campus
16150 Kubang Kerian, Kelantan
Malaysia

2004

CERTIFICATE

This is to certify that the dissertation entitled

" Study of Output Factors of Electron Beam Based On The Simple Model "

is the bona fide record of research work done by

Ms. Norhanna Binti Sohaimi

During the period from September 2003 to February 2004

Under my/our supervision:

....

Signature of Supervisor

Associate Professor Dr Ahmad Zakaria

Universiti Sains Malaysia

Health Campus

16150 Kubang Kerian, Kelantan

ACKNOWLEDGEMENTS

The preparation of this dissertation has been aided by the significant contributions of many individuals, which are gratefully acknowledged.

First and foremost, I wish to express my sincere appreciation to my beloved supervisor, Associate Professor Dr Ahmad Zakaria for his guidance, advices, good-will and supports in giving the idea in my study.

Secondly, Special acknowledgements are owed to Department of Radiotherapy, Hospital Universiti Sains Malaysia especially their Radiographer, Mr. Rozaimey for his kindness in guides and teaching me to do my study and Mr. Mustapa who helping me preparing the field sizes made of Cerrobend.

My great gratitude also goes to my beloved parents, Mr. Hj. Sohaimi bin Hj. Murad and Mrs. Hjh. Rokiah binti Hj. Osman for their tolerance of my absences, physically and emotionally. I am blessed and strengthened by their support and love.

Finally yet importantly, I would like all my friends and staff in Radiotherapy Department who were involved in my study. Without helping and supports from all person who involved in this study, I might not finish and doing my study very well. This study also was taught me how to appreciate persons in my life.

CONTENTS

Title	Page
Abstract	1
Introduction	2
Objective of the Study	10
Materials and Methods	11
Results	22
Discussion	52
Conclusion	54
References	55

LIST OF TABLES, FIGURES AND ILLUSTRATIONS

TITLE	PAGE
Figure 1. Flow Chart of Research Project.	17
Figure 2. The diagram of experimental set up.	20
Figure 3. The real experimental set up.	21
Figure 4. The cutout of Cerrobend for 10 x 10 cm^2 applicator.	Appendix
Figure 5. The cutout of Cerrobend for 25 x 25 cm^2 applicator.	Appendix
Figure 6. The Markus Chamber with the Markus base plate.	Appendix
Figure 7. The Aneroid Barometer.	Appendix
Figure 8. The 25 x 25 cm^2 and 10 x 10 cm^2 applicator.	Appendix
Figure 9. The experimental set up.	Appendix
Figure 10. The experimental set up.	Appendix
Table 1.Output factors measured for 5 MeV electron beams using square field insertions of Cerrobend (reference: 10 x 10 cm^2 open cone).	25
Table2. Output factors measured for 5 MeV electron beams using rectangular field insertions of Cerrobend (reference: 10 x 10 cm^2 open applicator).	27
Table3.Output factors measured and calculated for 5 MeV electron beams using rectangular field insertions of Cerrobend (reference: 10 x 10 cm^2 open applicator).	29
Table4.Output factors measured for 10 MeV electron beams using square field insertions of Cerrobend (reference: 10 x 10 cm^2 open cone).	31
Table5.Output factors measured for 10 MeV electron beams using rectangular field insertions of Cerrobend (reference: 10 x 10 cm^2 open applicator).	33
Table6.Output factors measured and calculated for 10 MeV electron beams using rectangular field insertions of Cerrobend (reference: 10 x 10 cm^2 open applicator).	35

Table7.Output factors measured for 5 MeV electron beams using square and rectangular field insertions of Cerrobend (reference: 25 x 25 cm^2 open cone).	37
Table8.Output factors measured for 5 MeV electron beams using square and rectangular field insertions of Cerrobend (reference: 25 x 25 cm^2 open applicator).	39
Table9.Output factors measured and calculated for 5 MeV electron beams using rectangular field insertions of Cerrobend (reference: 25 x 25 cm^2 open applicator).	41
Table10.Output factors measured and calculated for 5 MeV electron beams using rectangular field insertion of Cerrobend (reference: 25 x 25 cm^2 open applicator).	43
Table11.Output factors measured for 10 MeV electron beams using square and rectangular field insertions of Cerrobend (reference: 25 x 25 cm^2 open cone).	45
Table12.Output factors measured for 10 MeV electron beams using square and rectangular field insertions of Cerrobend (reference: 25 x 25 cm^2 open applicator).	47
Table13.Output factors measured and calculated for 10 MeV electron beams using rectangular field insertions of Cerrobend (reference: 25 x 25 cm^2 open applicator).	49
Table14.Output factors measured and calculated for 10 MeV electron beams using rectangular field insertion of Cerrobend (reference: 25 x 25 cm^2 open applicator).	51

ABSTRACT

The output factors for clinical electron beams have been shown to be dependant on beam energy, field size and collimator design. The purpose of this study was to investigate the application of the equation of the output factors for a rectangular field size, which developed from Gaussion scatter model for electron beams used in Radiotherapy Department, Universiti Sains Malaysia Hospital. The output factors were measured for 5 MeV and 10 MeV electron beams for various applicators and square or rectangular insert combinations used in clinical services. The field sizes ranged from 3 cm x 3 cm to 25 cm x 25 cm at source to surface distance of 100 cm. The parallel plate ionization chamber was used to collect the charge and was placed at d_{max} inside the solid water material for each electron beam energies. Calculated output factors for the fields studied agreed with the measured output factors within ±2%. This demonstrated that for this Linear Accelerator (MXE; LINAC MEVATRON), the output factors calculated in homogenous solid water phantom could be predicted accurately using theoretical formula.

INTRODUCTION

Besides photon-beam, linear accelerators also produce electron-beam for therapy. For that purpose, in the accelerator head, the target is removed and the beam of accelerated electrons is directly oriented towards the patient.

The penetration of electron beams in the tissues is much shallower than that of the x-ray beams. In addition, it can be adjusted by varying the energy of the incident electrons. Therefore, electron-beam therapy is used to treat superficial or semi-deep-seated tumors extending (close) to the skin surface. Beyond the depth of the maximum, the dose falls off rapidly. Treatment energies range from about 4 to 20-25 MeV, but some accelerators reach higher energies up to 35 MeV. The 50 MeV electron beam produced by the racetrack microtron opens new perspectives in electron beam therapy (ICRU Report 35).

Electron beams are used for most of the patients referred to the radiation therapy department, this proportion varying from country to country and from centre to centre depending on the local treatment policy. Electrons are often used in combination with photon beams (e.g., as a boost against the residual tumor). Two specific applications of the electron beams deserve to be mentioned.

A skin cancer, mycosis fungoides, is most often treated with total skin electron irradiation. The aim of the basic treatment is to irradiate the total skin envelope as homogeneously as possible. The depth of the lesions suitable for this type of treatment varies with the stage and type of disease and/or the body surface. This may lead to the use of different beam penetrations. When tumorous lesions are present, there may be a need for a special boost and/or shielding. The maximum depth of the target volume varies from approximately 5 to 15 mm in most of the lesions. For the most frequent indications, with localized and even generalized plaques, the target volume is located within the first 5 mm. Infiltrated plaques, ulcerations, and tumorous lesions justify an individual estimate of the thickness of the lesions whenever possible (J.E. Coggle, 1983).

A variety of techniques are available for measuring radiation output and for measuring relative dose rates at different locations within a treatment field and at different depths within an irradiated volume. Dose rate and integrated dose measurements are usually made using a calibrated ionization chamber and exposure meter. The ion chamber is usually located beyond the depth of maximum dose buildup below the surface of a plane phantom, solid water phantom or water equivalent phantom. The phantom material is near to tissue equivalence and is usually either water, which simplifies movement of measurements and for use at variety of beam angles. Note that checks must be made of susceptibility of this system to the pulsed nature of the radiation beam. These measurements can be used to calibrate the dosimetry system and to test its linearity and sensitivity to dose rate.

Field size is defined as the treatment beam irradiated area of a plane surface, perpendicular to the central beam axis at the nominal treatment distance for the medical LINAC. This distance is usually either 80 cm or 100 cm, corresponding to the distance between the source and axis of gantry rotation for isocentrically mounted LINAC. For electron field collimation, electron treatment must be maintained almost to the skin surface of the patient because electrons scatter readily in air. Not only the unscattered primary beam makes the treatment fields. It also made by primary electrons scattered from parts of the variable collimator, secondary electrons and x-rays emitted from the collimator. It is easier to control and reduce these other contributions to acceptable levels in a series of cones, which usually have less surface area of material directly facing the scattering foil than can be achieved in a variable collimator.

Phantom is the material and structure that models the radiation absorption and scattering properties of human tissue of interest. There are two kinds of phantom; geometrical phantom and anthropomorphic phantom. The geometrical phantom is mimic dosimetric properties of human tissues but in simple shapes like square or circular. Anthropomorphic phantom or human phantom is an ideal radiotherapy phantom not only matches attenuation and scattering properties of human tissues but also mimic external and internal contours of the patient.

In this experiment, we want to obtain the output factors for 5 MeV (low energy) and 10 MeV (high energy) electron beam using the LINAC MEVATRON in Radiotherapy Department, Universiti Sains Malaysia Hospital for various field sizes.

Output Factors

Output is the term that expressed the dose per monitor unit. Output is a function of field size. For machines with applicators, measurements of electron beam output are necessary for each applicator and each electron energy. Therefore, the total number of output measurements is usually quite substantial (Khan *et al.*, 1976; Goede *et al.*, 1977; Biggs *et al.*, 1979; Purdy *et al.*, 1982).

Regularly shaped electron fields are obtained by one or two methods. For most accelerators a set of applicators or cones are provided that are attached to the head of the machine. When an electron one is inserted on most medical accelerators, the x-ray collimators open automatically to a field size preset by the manufacturer. This setting may be a function of energy. The manufacturer will usually supply a number of cones and may also provide inserts for the cones that cover a range of field sizes and standard shapes like square, circular or rectangular.

The output factor OF (F) is defined as the ratio of dose per monitor unit U at d_{max} for a given field size F to that for the reference field size at its own $d_{max,0}$.

$$\boxed{OF\ (F) = \frac{D/U\ (F, d_{max})}{D/U\ (F_0,\ d_{max,0})}} \qquad (1)$$

where the F_0 is the reference field size (Khan *et al.*, 1991).

In this experiment, the dose per monitor unit is replaced by charge at d_{max}. The charge deposited d_{max} are depends upon electrons that travel by a number of paths. First, some of the electrons come directly from the source which undergoing only scattering in the intervening air and phantom. Second, some others electrons are scattered from the x-ray jaws. And finally, the electrons are scattered from the cones or trimmers.

According to A. Kapur *et al.*, the reference configuration for the calculation of the output factors was the 15 cm x 15 cm open applicator field with the water phantom at a nominal SSD of 100 cm. In this experiment, the reference configurations for the calculation of the output factors were 10 cm x 10 cm and 25 cm x 25 cm open applicator for each applicator field that we were used with the solid water phantom at a nominal SSD of 100 cm. The output factor for a given field was calculated by taking the ratio of the maximum calculated dose in that configuration to the maximum calculated dose in the reference configuration (AAPM 1991).

Cone or applicator systems

In the electron therapy mode the x-ray collimator jaws are usually opened to their maximum extent and the appropriate cone is attached to an adaptor fastened to the lower face of the treatment head. Interlocks are provided to prevent electron therapy unless the cone and adaptor are correctly positioned. The adaptor may incorporate a thin wall ion chamber or other device used for electron beam monitoring.

Electron therapy cones are usually constructed of lightweight materials such as transparent lexan and aluminium, for ease of handling, enhanced visibility of the electron field and to minimize bremsstrahlung x-ray production. However, some recent prototype designs incorporate a thick dense diaphragm near to patient skin which is sufficient to stop the electrons and adequately attenuated the x-ray produced.

The output measurements can be made for all standard cone, insert and jaw setting combinations as recommended by A. Kapur *et al.,* 1991. The measurements must be made over the range of inserts to be used clinically in order to if the cones accept additional inserts. It is possible to obtain output factors for other clinical field sizes of regular shape with sufficient data. The output factor depends on the cone or applicator size (C_s) and the insert size (I_s). Based upon the previous discussion the output factor in equation (1) may be written as

$$\boxed{OF(F) = \frac{D/U\,(C_s, I_s)}{D/U\,(C_0, I_0)}} \qquad (2)$$

which is equivalent to

$$OF(F) = \frac{D/U\,(C_s, I_0)}{D/U\,(C_0, I_0)} \times \frac{D/U\,(C_s, I_s)}{D/U\,(C_s, I_0)} \qquad (3)$$

where the first term of equation (3) is the dose per monitor unit ratio between a cone size C_S and the reference cone C_0; this term is sometimes called the open cone ratio. The second term is the dose per monitor unit ratio between a cone with an insert and the same cone with its reference insert (open cone). Often the cone insert ratio, equation (2) is measured directly from the experimental.

The output data for each energy can be presented in a number of ways including

i) A table of dose per monitor unit at dmax for each cone and insert combination

ii) A table or graph of output factors as a function of the cone and insert combinations and the dose per monitor unit for the reference field

iii) A table of monitor units necessary to deliver a given dose at a particular isodose level for each cone and insert combination

For all of these methods it would be particularly useful if output factors could be represented as a function of an equivalent square field size. But in this experiment, we only used a table of charge at dmax for each cone and insert combination. According to the table, a table of output factors was creates as a function of the cone and insert combinations. Biggs (1979) has shown this to be sufficiently accurate for clinical use for a particular accelerator. Biggs also showed that it was possible to obtain the cone ratio to within 2% using equivalent areas. He also stated that this would not be true for rectangular fields with high aspect ratios.

In this experiment, the rectangular field sizes were used in order to prove either calculated and the measured output factor are same or not. The Gaussian scatter model for pencil beams has been used to develop a formula for determination of the output factor for any rectangular field from a small set of measured data for the Therac-20 (Mills, 1985). The output factor for a rectangular field produced by scanning beams can be represented by one of the following equations:

$$OF\,(X,Y) = [\,OF\,(X,X) \times OF\,(Y,Y)\,]^{1/2} \tag{4}$$

(square root method)

$$OF\,(X,Y) = [\,OF\,(X,Y_0) \times OF\,(X_0,Y)\,] + CF\,(X,Y) \tag{5}$$

(one-dimensional method)

where X_0 and Y_0 are reference field dimensions and CF is a correction factor that accounts for differences primarily due to scatter off the x-ray jaws. In this experiment, we considered the equation (4), which called the square root method that predicts rectangular output factors. This equation is accurate within approximately 3% (Khan *et al.*, 1991). This method is least accurate for large fields with large aspect ratios, e.g., 30 cm x 10 cm.

OBJECTIVE OF THE STUDY

The main objective for this study is to compare the output factors of measurement and the predicted by the equation of the square root method due to several field sizes and energy of electron beam.

MATERIALS ANDS METHODS

Materials

Linear accelerator (LINAC) Mevatron

LINAC Mevatron was used in this study to produce the electron beam. The serial or machine number is 3347 and the accelerator type is 8067. The accelerator serial number is 771009C. In this study, the energy that we used are 5 MeV and 10 MeV. The value of monitor unit is 100.

For electron beam, we need to put the applicator. The applicators that we used inthis study are 10 cm x 10 cm and 25 cm x 25 cm. This applicators is product by SIEMENS Medical Laboratories INC, Concord, CA, USA. For the applicator 10 cm x 10 cm, the part number is 8505067 and the code is EA110. The size of the applicator is 100 cm and the jaw opening is A= 19cm, B= 19cm. For the applicator 25 cm x 25 cm, the part number is 8505091 and the code is EA125. The size of the applicator is 100 cm and the jaw opening is A = 32 cm, B = 32 cm.

The source to surface distance (SSD) was used in this experiment. The SSD is 100 cm. There was not air gap between the applicator and the surface of solid water phantom. Refer to experimental set up; figure 2 and figure 3.

Solid Water Phantom

Serial number : 2139-L (10 mm)

Model : 74-604

Size : 2.0 x 30 x 30 cm

Product : NUCLEAR ASSOCIATES (USA)

Markus Type 23343 base plate

RMI-74-608-3290

In this experiment, we used solid water phantom. Ideal solid water phantom should be water equivalent requires that it have same linear collision, stopping power and linear angular scattering power as water. So, the material must have same electron density and effective atomic number, Z_{eff} as water. Solid water material is based on epoxy resin material. It is water like because it composed of low Z material with Z_{eff} close to soft tissue. The advantages of this material are strong, robust and inert. This material also has no charge storage effect with electron beam because solid water is conductive. Solid water phantom also do not require depth or fluencies correction to convert measurement to water.

Cerrobend

Although a number of systems have been used for field shaping (Powers *et al.*, Earl *et al.*, Maruyama *et al.*, Edland *et al.*, Jones D, Parfitt H, Karzmark *et al.* and Kuisk H), the one introduced by Powers *et al.*, is most commonly used in radiotherapy. As we know, the extensive field shaping is sometimes needed in electron beam therapy. This system uses a low melting point alloy, Lipowitz metal (brand or trade names: Cerrobend, Ostalloy and Lometoy) that has a density of 9.4 g/cm^3 at 20^{0}C (~83% of lead density). This material consists of Bismuth (50.0%); lead (26.7%), tin (13.3%), and cadmium (10.0%) alloy (Powers *et al.*). The main advantage of Cerrobend over lead is that it melts at about 70^{0}C compared to 327^{0}C for lead and therefore can be easily cast into any shape. At room temperature, it is harder than lead.

Ionization chamber parallel plate

Type : Markus chamber

Certificate number : 98 0992

Failla designed an ionization chamber for measuring surface dose in irradiated phantom in 1937 (Faiz M. Khan, 1984). Parallel plate chamber are similar to the extrapolation chambers except for the variable electrode spacing. In the extrapolation chambers, micrometer screws can vary the electrode spacing accurately. But the electrode spacing of the parallel plate chambers is small (~2 mm) but fixed. A thin wall or window (e.g. foils of 0.01 to 0.03 mm thick Mylar, polystyrene, or mica) allows measurements practically at the surface of a phantom without significant wall attenuation. By adding layers of phantom material on top of the chamber window, one can study the variation in dose as a function of depth, at shallow depths where cylindrical chambers are unsuitable because of their larger volume (Faiz M. Khan, 1984).

The small electrode spacing in a parallel plate chamber minimizes cavity perturbations in the radiation field. This feature is especially important in the dosimetry of electron beams where the cylindrical chambers may produce significant perturbations in the electron field.

Electrometer

Type : Precision Electrometer/Dosemeter

Model number : 525

Serial number : 186

Product : VICTOREEN, USA

The electrometers are used as exposure measuring devices. The electrometers are available in which the chamber remains connected to the electrometer during exposure. The cable is long enough so that the electrometer is placed outside the treatment room at the control console of the linear accelerator.

There are many dosimetry systems (chambers and electrometers) with thimble chamber connected to electrometers via long shielded cables. The instrument can operate either in the integrate mode or the rate mode. In the integrate mode, the central electrode of the chamber is connected to one plate of condenser and the chamber wall is connected through a battery to the other plate of the condenser. The voltage supplied by the battery should be high enough to provide better than 99% ion collection efficiency.

As the chamber is radiated, the charge due to ionization begins to accumulate in the condenser. At the end of the radiation, a charge Q is accumulated and the voltage V generated across the condenser is given by Q/C, where C is the condenser capacity. Measurement of this voltage is essentially the measurement of ionization charge and hence the exposure. Since the magnitude of the charge liberated is very small, complex electronics circuitry is used to measure it accurately.

In the rate mode, the condenser is replaced by a resistance R. irradiation of the chamber causes an ionization current I to flow through the circuit, generating the voltage $V = IR$ across the resistance. The measurement of this voltage reflects the magnitude of the current or the charge liberated per unit time or the radiation exposure rate. Again, due to the smallness of the ionization current, its measurement is difficult. Special electrometer circuits have been designed to accurately measure ionization currents, even as low as 10-15 A (John HE *et al.*, 1969).

Aneroid Barometer

Model number : 03316-72

Brand : OAKTON

Distributed by : Cole-Parmer Chicago, IL 60648

Aneroid barometer is used to measure the temperature and pressure of the room before the experiment was started.

Latex Examination Gloves

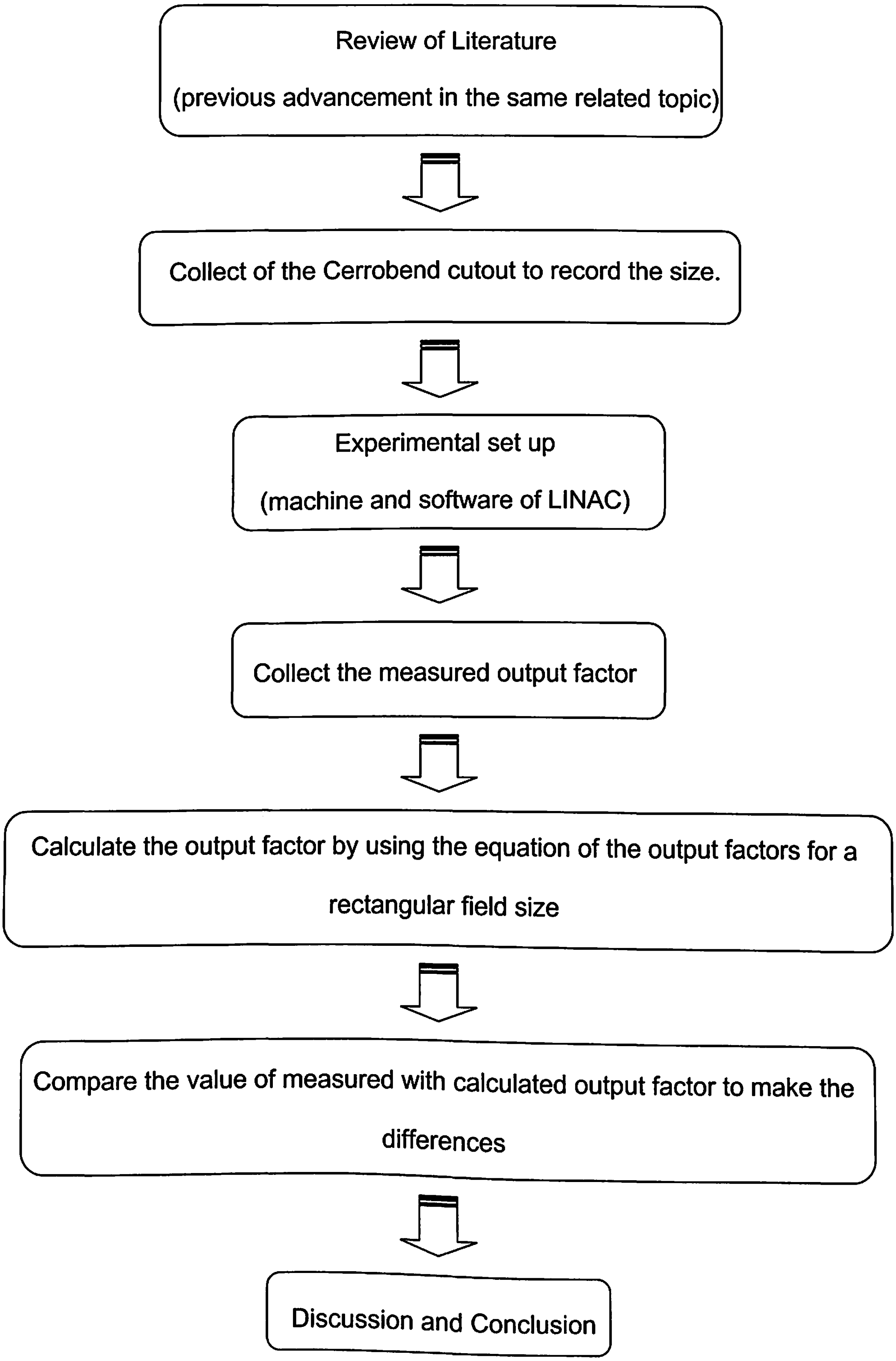
Brand : AMBIDEXTROUS

Made of : Natural Rubber Latex

Size : Medium

Latex examination gloves are used as protection. The gloves are used to protect our hand during handling the Cerrobend. This gloves is lightly powdered and non sterile. As we know, the Cerrobend is made of Bismuth (50.0%); lead (26.7%), tin (13.3%), and cadmium (10.0%) alloy (Powers *et al.*). So, it might be toxic when we handling them.

Figure 1 : Flow Chart of Research Project



Methods

The medical linear accelerator chosen for this study was the LINAC MEVATRON in Radiotherapy Department, Universiti Sains Malaysia Hospital. Five electron energies (5, 6, 7, 9 and 10 MeV) were available. Cerrobend inserts were placed in the lowermost scraper. The beams studied were those of 5 and 10 MeV nominal energy collimated by the 10 cm x 10 cm and 25 cm x 25 cm applicators. The square field sizes ranged from 3 cm x 3 cm to 9 cm x 9 cm for 10 x 10 applicators at a nominal SSD of 100 cm. The square field sizes for 25 cm x 25 cm applicators were 16 cm x 16 cm and 20 cm x 20 cm. There are a lot of rectangular field sizes for both applicators (refer to tables of the results). The beams were perpendicular to the phantoms within the accuracy of machine set-up.

First and foremost, the room temperature and pressure are recorded. The LINAC and the electrometer were warmed up before use it to measure the charge. The polarizing voltage was set at +200 V. The solid water phantom must be set-up by placing the Markus base plate in the bottom of set-up. The ionization chamber parallel plate, Markus chamber was placed carefully into the Markus base plate. The output factors were obtained with the Markus Chamber by placing the effective measurement point at the predetermined measured position of R100 for the given and reference fields respectively.

Then, solid water phantom was placed due to the thicknesses of maximum depth for each energy slowly. For example, 1.0 cm thickness for 5 MeV electron beams and 2.0 cm for 10 MeV electron beams. The 10 cm x 10 cm applicator was placed at the head of the LINAC. After that, the ionization chamber was connected to the electrometer outside the treatment room. The square field size of Cerrobend was inserted at the last scraper of the applicator. The set up of this study was shown in figure 2.

Then, we set up the software of the LINAC MEVATRON by inserted the data; the 10 cm x 10 cm field size, the energy (5 MeV) and the dose value (100 MU) by using the SSD set up. After finishing the set up, the radiation was turn on to get the charge. The charge was collected three times and the average was taken. The reference field for output factor measurements was that obtained with the open 10 cm x 10 cm applicator. The reference field for output factor measurements due to 25 cm x 25 cm applicator was obtained with the open 25 cm x 25 cm applicator.

The procedure was repeated for all the field size determined made by Cerrobend inserts, for 10 MeV electron beams and also for the applicator 25 cm x 25 cm. The output factor for a given field was calculated by taking the ratio of the charge for any field to the maximum charge in the reference configuration. The measurement condition for both applicators was set to receive the same monitor unit setting for determination of output factors. This is a valid approach when the changes in the dose in the transmission monitor chamber between the reference field and the field being investigated due to backscatter are negligible (A Kapur *et al.*).

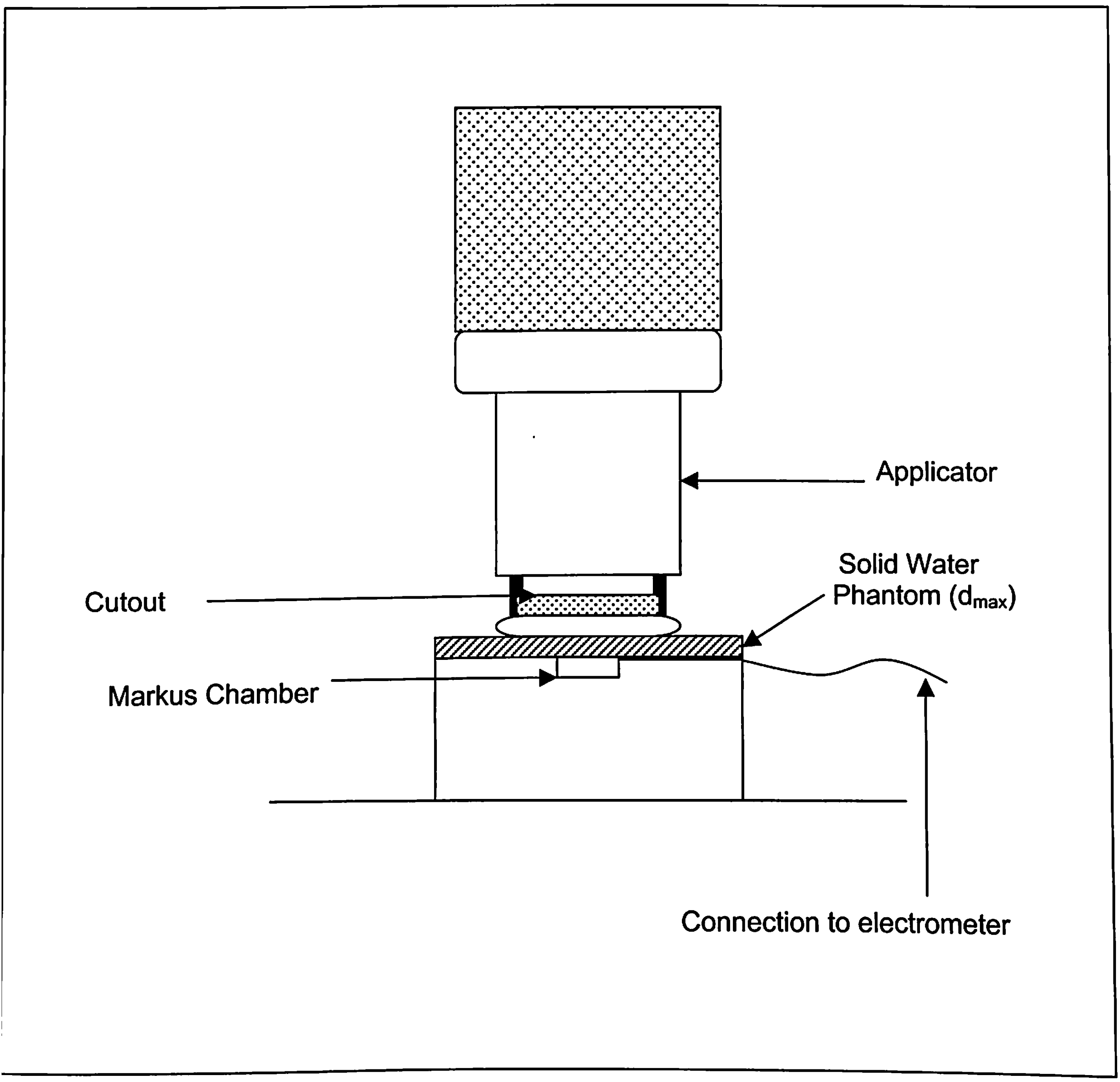


Figure 2 : The diagram of experimental set up.

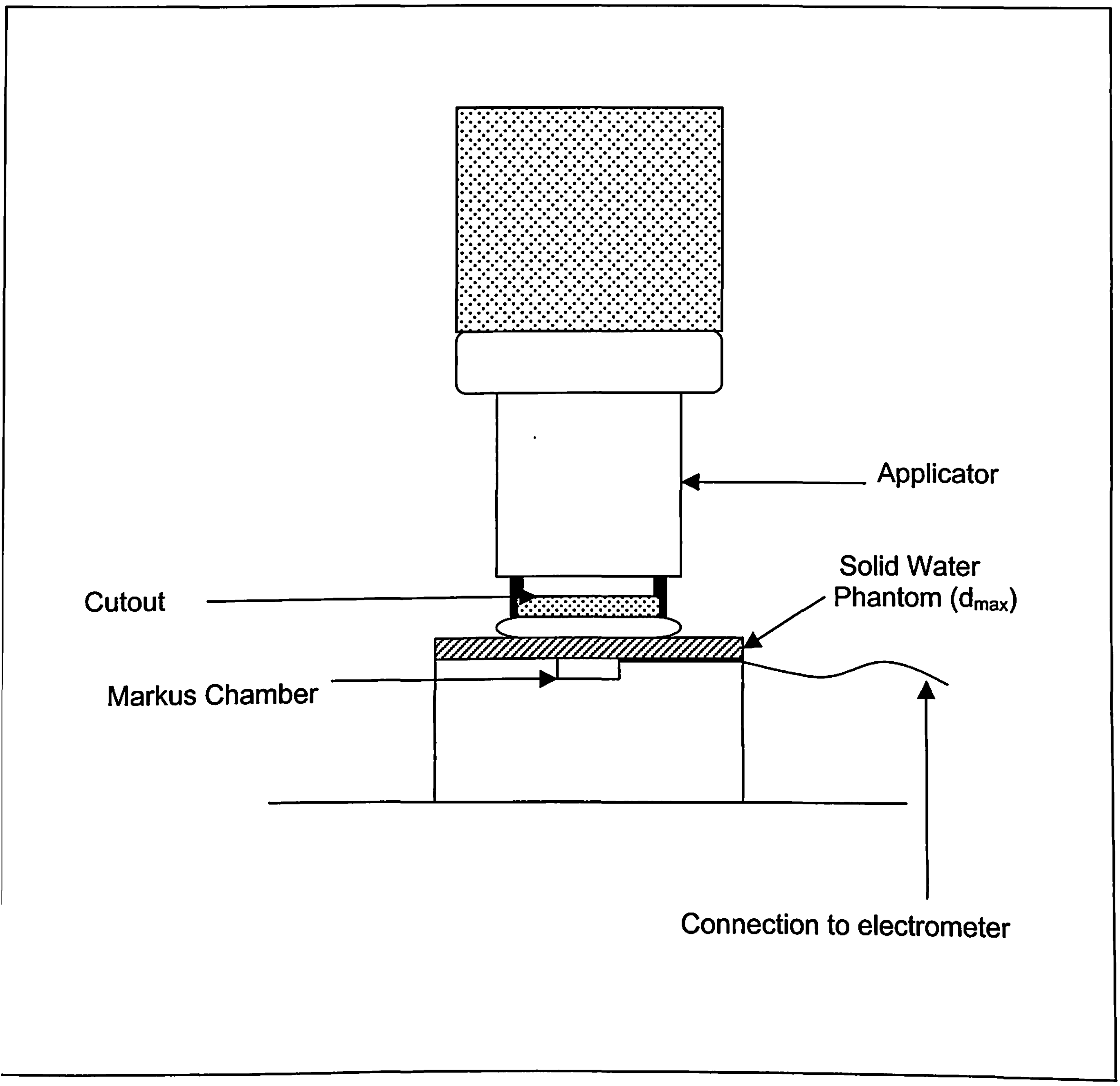


Figure 2 : The diagram of experimental set up.

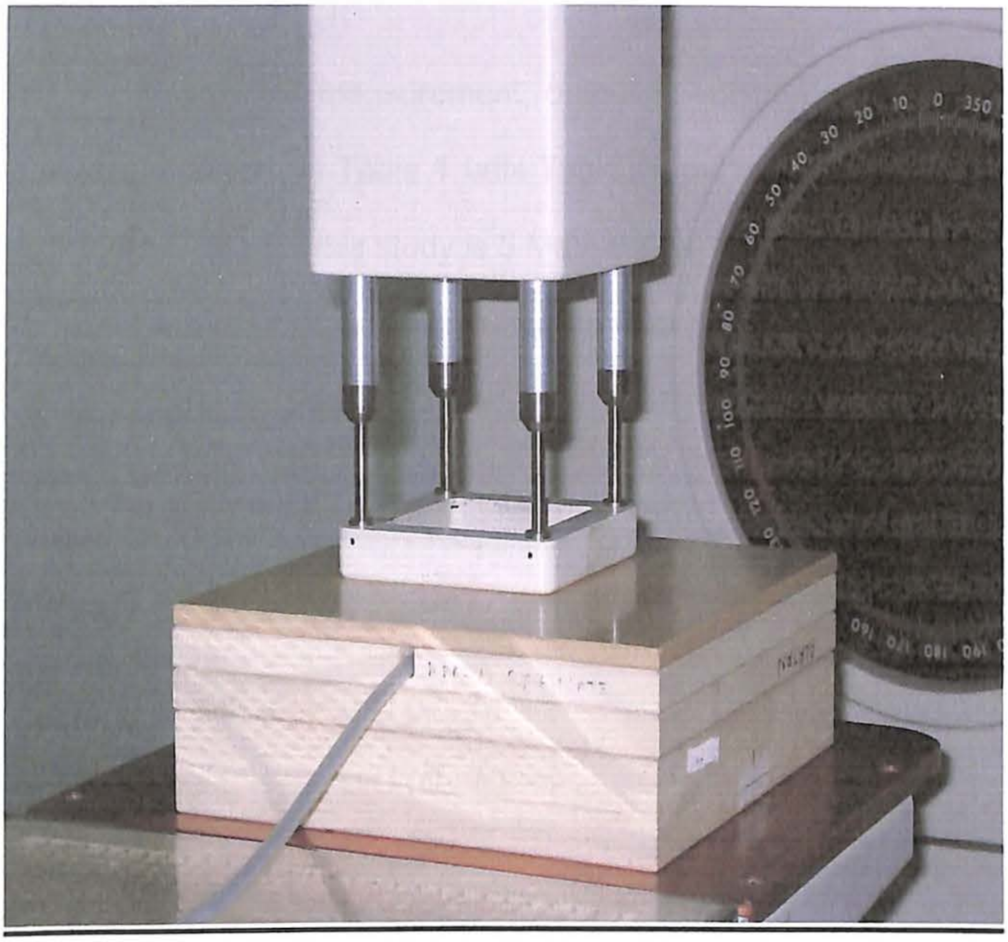


Figure 3 : The real experimental set up of the study.

RESULTS

The value of output measurement, output calculation and the differences between them are shown in Table 1 until Table 14 under certain circumstances. The energy that we used in this study is 5 MeV and 10 MeV.

For the measured output, there are several step calculation must do to convert from charge to measured output. The example of the calculation was shown below :

$$\boxed{OF\,(F) = \frac{D/U\,(C_S,\, I_S)}{D/U\,(C_0,\, I_0)}} \qquad (2)$$

or

$$\text{Output factors measured} = \frac{\text{Charge for any field size}}{\text{Charge for reference field size}} \qquad (6)$$

Example:

$$\text{Output factors measured for field size 3 cm x 3 cm, 5 MeV} = \frac{1.7660}{1.7621} = \underline{\underline{1.0022}}$$

For the calculated output, the step that involve in this calculations are shown below :

Equation of Output Factors

$$\text{Output factors calculated } (x, y) = \left[\text{Output factor } (x, x) \times \text{ Output factor } (y, y)\right]^{1/2}$$

Example: Field size 3 cm x 4 cm (5 MeV)

$$\text{Output factors calculated } (3, 4) = \left[\text{Output factor } (3, 3) \times \text{Output factor } (4, 4)\right]^{1/2}$$

$$= (1.0022 \times 1.0204)^{1/2}$$

$$= \underline{\underline{1.0113}}$$

The differences between the measured output and calculated output is made by using below equation :

$$\text{Difference } (\%) = \frac{(\text{Output factor calculated}_{x,y} - \text{Output factor measured}_{x,y})}{\text{Output factor calculated}} \times 100\%$$

Example for field size (3 x 4) cm^2 :

Output factor calculated for field size (3 x 4) cm^2 = 1.0113

Output factor measured for field size (3 x 4) cm^2 = 0.9995

$$\text{Difference } (\%) = \frac{(1.0113 - 0.9995)}{1.0113} \times 100\%$$

$$= \underline{\underline{1.17\%}}$$

The parameters of output factors measured for 5 MeV electron beams using square field insertions of Cerrobend (reference: 10 x 10 cm^2 open cone).

Energy : 5 MeV

Monitor Unit : 100 MU

Applicator : 10 cm x 10 cm

d_{max} : 1.0 cm

Temperature : 21.0 ^0C

Pressure : 759 mmHg