

CALIBRATION OF HIGH DOSE RATE COBALT-60 SOURCE USING A FARMER
TYPE CHAMBER IN A LOCALLY CONSTRUCTED HOLLOW PHANTOM

BY

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DECLARATION

Except for references to the other work which have been duly cited, this thesis is the result of research work undertaken by JEROME DAVID KAMBAUWA in the Medical Physics department, University of Ghana, under the supervision of Professor A.W.K. Kyere, Professor J.J. Fletcher and Mr Samuel N.A. Tagoe.

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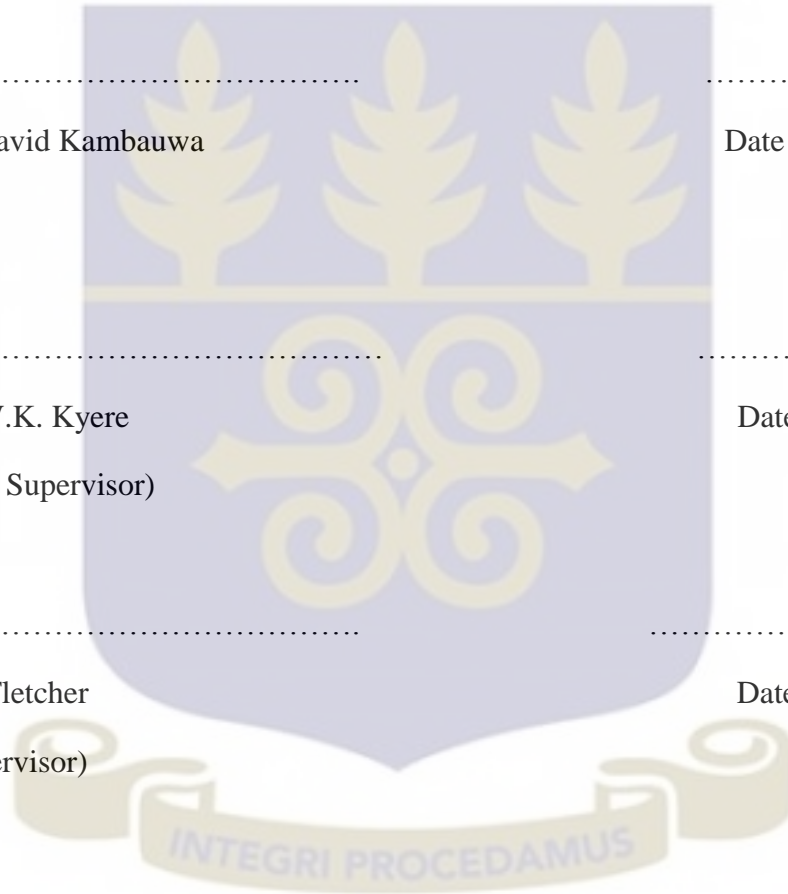
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DEDICATION

This work is for you the Almighty, You are always there for me. To my mother, Mirriam Nyamphande and father, David Cham'dzela Weluzani for always reminding me of the need to go to school and the importance of being “educated”.



ABSTRACT

An important aspect of general quality assurance program for brachytherapy dosimetry is source calibration. Vendors assign large uncertainties of up to $\pm 10\%$ for the stated source calibrated values. It is thus important to check the vendor stated calibration. There are three main methods of calibrating brachytherapy sources and they are the “Free-in-air” method, using a re-entrant (well) type chamber and using a thimble (Farmer) type ionization chamber in a phantom.

The main objective of this study was to compare values of source strength obtained by using the re-entrant chamber method and the thimble (Farmer) type ionization chamber in a phantom method. A cylindrical hollow phantom was constructed from Poly methyl methacrylate (PMMA) having four holes located at a distance of 8cm from the centre and the angle between each of the holes being 90° from the centrally located source holder. The experimental set up followed International Atomic Energy Agency (IAEA) Technical Document 1274 (IAEA-TECDOC-1274) for the re-entrant chamber method and DIN 68909-2 in combination with DGMP report 13 for the thimble ionization chamber in a phantom method.

Measurements carried out using the well type chamber deviated from the theoretical value of the source by -1.36% whereas those measured by the Farmer type ionization chamber in a locally constructed phantom deviated from the theoretical air kerma strength value by -2.1%. The difference in measured values from the two measuring methods was found to be 0.8%.

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To my parents and my siblings; Jack, Manga, Yami, Chiko, and Tina for the emotional and spiritual support.

Lastly, to my nephews and nieces for your sense of humour. No stopping, no settling !



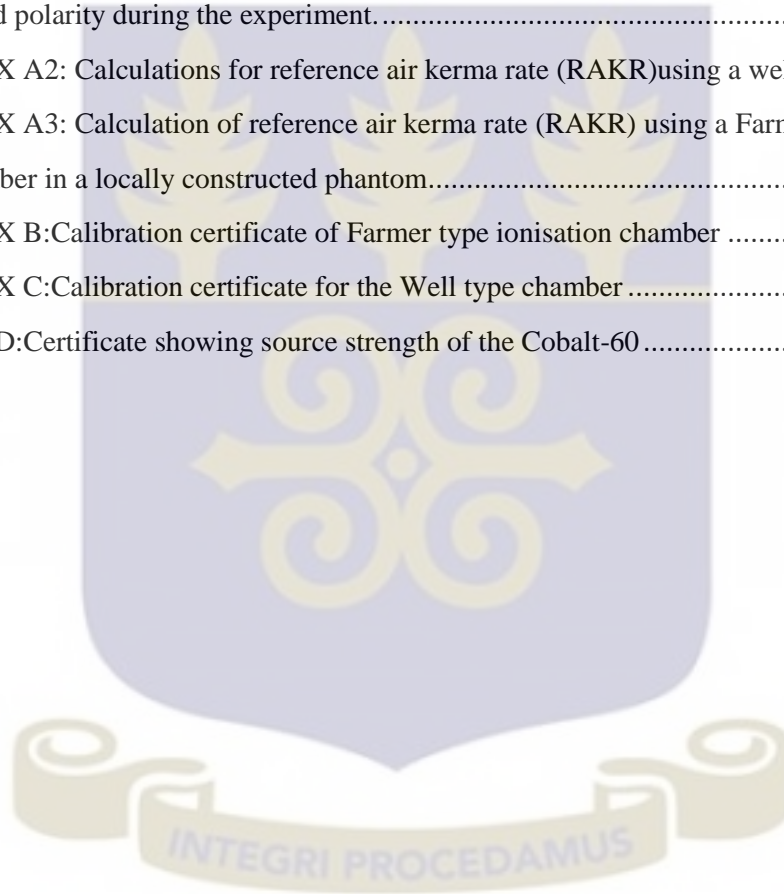
TABLE OF CONTENTS

DECLARATION	i
DEDICATION	iii
ABSTRACT	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF ABBREVIATIONS	xii
LIST OF PLATES	xiii
CHAPTER ONE: INTRODUCTION	1
1.0 Background.....	1
1.1 Statement of the problem.....	6
1.2 Relevance and justification.....	6
1.3 Objectives	8
1.4 Scope and limitation.....	8
CHAPTER TWO: LITERATURE REVIEW.....	9
2.0 Specification of source strength.....	9
2.0.1 Activity	9
2.0.2 Exposure rate at a specified distance	9
2.0.3 Equivalent mass of radium.....	10
2.0.5 Air kerma strength.....	10
$K = XW_{\mu\text{tr}}/\mu_{\text{enp}}$	11
2.0.6 Reference air kerma rate	11
2.1 Methods of calibration.....	12
2.1.1 Re-entrant (well-type) ionization chamber	12
2.1.2 Calibration point inside the well type chamber	16
2.1.3 Measurement techniques.....	17
2.1.4 Measurement corrections	17
2.1.5 Calculation of well type chamber calibration factor.....	18

2.1.6 Calibration of a hospital's well type chamber.....	18
2.2 The “ in-air “ method.....	19
2.2.1 Calibration of high energy photon source.....	20
2.2.2 Formalism of reference of air kerma rate.....	21
2.2.3. Correction factors for free in- air measurements.....	22
2.2.3.1 Measurement distances.....	22
2.2.3.2 The scatter factor.....	23
2.2.3.3 The non conformity factor.....	24
2.2.4 Corrections for the attenuation of primary photons in air.....	26
2.2.5 Corrections for transit effects, leakage current and recombination losse.....	27
2.3 Solid phantoms.....	28
2.4 Other calibrations.....	28
2.4.1 Calibration of low dose rate sources in the form of wires and ribbons.....	28
2.4.2 Calibration of low dose rate pre-loaded source trains.....	29
2.4.3 Calibration of multiple low dose rate sources of similar strength.....	30
2.4.4 Calibration of high dose rate cobalt -60 sources of similar source strengths.....	33
2.5 Properties of brachytherapy sources.....	34
2.5.1 Properties of cobalt -60.....	35
Table 2.3 Properties of Cobalt-60.....	35
2.6 Calculations of dose distributions.....	37
2.6.1 Calculation of air kerma rate.....	38
2.6.1.1 Unfiltered line source in sir.....	38
2.6.1.2 Filtered line source in air.....	38
2.6.1.3 Filtered line source in water.....	39
2.7 Calculation of dose using TG-43 protocol [41].....	40
2.8. Dosimetric verification of air kerma strength.....	41
2.8.1 Measurement of air kerma rate with a Farmer type ionisation chamber in a solid phantom following DIN 6809-2 in combination with DGMP report No 13.....	41
2.8.2 Measurement of reference air kerma rate with farmer type ionization chamber free in air following DIN6809-2 in combination with DGMP report 13.....	43
2.8.3 Measurement of reference air kerma rate with a Farmer type ionization chamber free in air following IAEA- TECDOC -1274.....	45

2.8.4 Measurement of reference air kerma rate with well type chamber following DIN6890-2 and IAEA-TECDOC-1274	45
2.8.5 Measurement of reference air kerma rate with Farmer type ionization chamber following AAPM Report 41	46
2.8.6 Measurement of reference air kerma rate with well type chamber according to AAPM Report 41	47
2.8.7 Air density correction factor	47
2.8.8 Polarity Correction factor.....	48
2.8.9 Saturation correction factor.....	48
2.8.10 Calculation of uncertainty in reference air kerma rate.....	49
CHAPTER THREE: MATERIALS AND METHODOLOGY.....	51
3.0 Introduction.....	51
3.1 Materials	51
3.1.1 The BEBIG MultiSource© HDR brachytherapy machine.....	52
3.1.2 Technical specifications for equipment used	53
3.1.3 Construction of the hollow phantom	54
3.2 Methodology.....	61
3.2.0 Quality Assurance of the HDR Afterloader	61
3.2.1 Measurement of reference air kerma rate.....	64
3.2.1.0 Measurement of reference air kerma rate using well type chamber.	65
3.2.1.0.0 Determination of calibration point.....	66
3.2.1.1 Measurement of reference air kerma rate using a Farmer type ionization chamber in a locally constructed phantom following the DIN 6809-2 in combination of DGMP report 13	67
3.2.1.2. Calibration point.....	70
3.2.1.3 Phantom calibration factor	70
3.1.3 Calculation of reference air kerma rate/air kerma strength.....	70
CHAPTER 4: RESULTS AND DISCUSSIONS	72
4.0 Results	72
4.1 Measurement of reference air kerma rate or air kerma strength using a well type ionization chamber	72
4.2 Measurement of reference air kerma rate /air kerma strength using a farmer type ionization chamber in a locally constructed phantom in accordance to DIN 6809-2 in conjunction with DGMP report 13	75

4.3 Discussions	81
4.4 Statement of uncertainties used in the experiment	82
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS	83
5.1 Conclusions.....	83
5.2 Recommendations	83
5.2.1 Brachytherapy centres.....	83
REFERENCES	84
APPENDIX A1: Tables of Electrometer readings, room temperature, pressure, change of bias voltage and polarity during the experiment.	90
APPENDIX A2: Calculations for reference air kerma rate (RAKR) using a well type chamber ..	98
APPENDIX A3: Calculation of reference air kerma rate (RAKR) using a Farmer	100
type chamber in a locally constructed phantom.....	100
APPENDIX B: Calibration certificate of Farmer type ionisation chamber	102
APPENDIX C: Calibration certificate for the Well type chamber	105
Appendix D: Certificate showing source strength of the Cobalt-60	106



LIST OF TABLES

Table1. 1: Brachytherapy treatments according to type of implant, duration of implant, method of source loading and dose rate[2]	1
Table1. 2 :Some characteristics of isotopes used in brachytherapy	3
Table1. 3 :Type and frequency of accidents reported in brachytherapy treatment[12]	7
Table 2. 1: Non uniformity factors correction factors for farmer type ionization chambers (internal radius 3.15mm, length 24.1mm)[12]	26
Table 2. 2: k_{air} correction factors of ^{60}Co at different distances between the source and the ionization chamber	27
Table 2. 3 Properties of Cobalt-60	35
Table3. 1: shows the technical specifications of the BEBIG MultiSource© HDR Brachytherapy machine, the well type chamber , the electrometers and the ionization chamber.	53
Table 4. 1 :Values used to calculate the reference air kerma rate/air kerma strength	74
Table 4. 2: Values for calculation of reference air kerma rate/source strength	81
Table 4. 3 Uncertainty in parameters	82



LIST OF FIGURES

Figure2. 1:A typical re-entrant chamber with Perspex holders 13

Figure2. 2: Relative response of chamber with respect to distance 14

Figure2. 3. Dimensions of Cobalt -60 Source 36

Figure2. 4: Decay scheme for ⁶⁰Co 36

Figure2. 5: γ -Spectrum for ⁶⁰Co..... 37

Figure2. 6:Geometry used in dose calculation for Linear source 38

Figure3. 1: The PMMA 9193 PTW Freiberg “Krieger phantom” 54

Figure3. 2: Dimensions of the phantom (mm)..... 57

Figure3. 3: Cross sectional view and dimensions of the ionization chamber holder(A) and
 plug(B)(mm)..... 58

Figure3. 4: cross sectional view and dimensions of ionization chamber insertion hole(C) and
 source holder(D) (mm)..... 59

Figure3. 5: Computer monitor window for selection of operational test tab..... 63

Figure3. 6 Computer monitor window for selection of treatment administration tab..... 63

Figure3. 7: Source position indicator (LLH03-03) 64

Figure3. 8: Image obtained during source position accuracy test..... 64

Figure 4. 1: Electrometer reading as a function of dwell position within well type chamber 73

Figure 4. 2: Average Electrometer reading as a function of dwell position for insertion hole A 75

Figure 4. 3: Average electrometer reading as a function of dwell position for insertion hole B 76

Figure 4. 4: Average electrometer reading as a function of dwell position for insertion hole C 77

Figure 4. 5: Average electrometer reading as a function of dwell position for insertion hole D 78

LIST OF ABBREVIATIONS

ISO	International Organisation of Standards
LDR	Low Dose Rate
MDR	Medium Dose Rate
HDR	High Dose Rate
AAPM	American Association of Physicists in Medicine
RAKR	Reference Air Kerma Rate
ICRU	International Commission on Radiation Units and Measurements
ACDL	Accredited Dosimetry Standards Laboratory
PSDL	Primary Standards Dosimetry Laboratory
SSDL	Secondary Standards Dosimetry Laboratory
IAEA	International Atomic Energy Agency
DGMP	German Society of Medical Physics
TEC DOC	Technical Document



LIST OF PLATES

Plate 3. 1: The constructed phantom..... 60

Plate 3. 2 : The bottom part of the phantom..... 61

Plate 3. 3: Positioning of plugs and guide tube in the phantom..... 69

Plate 3. 4:Set up of the afterloader, phantom and the ionization chamber 69



CHAPTER ONE: INTRODUCTION

1.0 Background

Brachytherapy is used to describe short distance treatment of cancer with radiation from sealed sources, where a sealed source is one in which the radioactive material is encapsulated so that the material cannot be lost under any foreseeable degree of physical or chemical stress. The sources are encapsulated in other metals whose function is to prevent the escape of radioactivity, providing source rigidity and absorbing unwanted beta particles. Brachytherapy sources must all conform to the International Organisation of Standards regulations(ISO 1990a).[1,2]

Brachytherapy treatment can be summarized according to type of implant, duration of implant, method of source loading and dose rate as shown in Table 1.1:

Table1. 1: Brachytherapy treatments according to type of implant, duration of implant, method of source loading and dose rate[2]

Type of Implant	Description
Intracavitary	Sources are placed inside body cavities close to the tumour volume surgically
Interstitial	Sources are implanted surgically within the tumour volume
Surface(mould)	Sources are placed over the tissue to be treated
Intraluminal	Sources are placed in a lumen surgically
Intraoperative	Sources are implanted into the target tissue during surgery
Intravascular	A single source is placed into small or large arteries surgically

Type of implant	Description
Temporary	Dose is delivered over a short period of time and the sources are removed after the prescribed dose has been reached
Permanent	Dose is delivered over the lifetime of the source until complete decay
Method of Loading	Description
Hot loading	The applicator is preloaded and contains radioactive sources at the time of placement into the patient
Afterloading	The applicator is placed first into the target position and radioactive sources are loaded later, either by hand(manual loading) or by a machine(remote after loading)
Dose rate	Numerical value of the dose rate at the dose specification point(s)
Low dose rate(LDR)	0.4-2 Gy/h
Medium Dose Rate(MDR)	2 – 12 Gy/h
High Dose rate(HDR)	>12 Gy/h

Currently there are many radioactive sources which are used in brachytherapy, some of which are shown in Table 1.2:

Table1. 2 :Some characteristics of isotopes used in brachytherapy

[2]

Isotope	Average ^a photon energy(MeV)	Half life	HVL Lead(mm)	in Γ_{AKR} (Air kerma rate constant) ^b $\left(\frac{\mu Gy m^2}{GBqh}\right)$	Λ (dose rate constant) ^b $\left(\frac{cGyh^{-1}}{cGy cm^2 h^{-1}}\right)$
C0-60	1.25	5.26 years	11	309	1.11
Cs-137	0.66	30 years	6.5	77.3	1.11
Au-198	0.41	2.7 days	2.5	56.2	1.13
Ir-192	0.38	73.8 days	3	108	1.12
I-125	0.028	60 days	0.02	-	-
Pd-103	0.021	17days	0.01	-	-

^a These are approximate values depending on source make and filtration

^b usage of generic values of the air kerma rate constant or dose rate for low energy photon source may lead to errors in dose calculations hence they are not given for I-125 and Pd-103

Brachytherapy can be achieved using manual after loading and remote after loading systems. In high dose rate(HDR) brachytherapy, the remote after loading system, where the applicator is placed first into the target position and radioactive sources are loaded later by a machine, is used. Nowadays HDR brachytherapy using after loaders is used in many facilities because it provides shorter treatment time thus patients are treated as

outpatients. Additionally there is optimization of dose distribution and also elimination of staff radiation exposure. However, HDR brachytherapy has disadvantages in that there is uncertainty in biological effectiveness. There is also the potential of accidental high exposures and probability of serious errors.[2]

Normally, after loading systems have the following components: a shielded safe made of tungsten or depleted uranium to house the radioactive source, a radioactive source, local or remote operating console, a source control and drive mechanism, source transfer guides, treatment applicators and a treatment planning computer[10].

An important aspect of general quality assurance program for brachytherapy dosimetry is source calibration. For some brachytherapy sources, vendors assign large uncertainties to their stated calibrated values, in some cases up to $\pm 10\%$. It is thus important not only to check the vendor's stated calibration but also to ensure traceability to internationally accepted standards. The report from the task Group TG-40 of the American Association of Physicists in Medicine(AAPM) states“Each institution planning to provide brachytherapy should have the ability to independently verify the source strength provided by the manufacturer”. [1,15]

Source strength is specified as the air kerma rate, in air, at a reference distance of 1m, corrected for attenuation and scatter in air. The unit to use for low dose rate brachytherapy is the μGyh^{-1} and μGys^{-1} for high dose rate applications. The specification quantity is called the reference air kerma rate(RAKR), which is the name used by the International Commission on Radiation Units and Measurements(ICRU)[5,16,17]. Commercial manufacturers of brachytherapy sources provide a measure of the source

strength within a broad range of activity, however it is improper to solely rely on this value for patient dose calibration. Departments providing brachytherapy services should have the ability to verify source strength independently and improve the overall precision of the measurement.

Radiation characteristics of sources are affected by the chemical composition of the radionuclide, inert filler material, the distribution within the source and details of the encapsulation. It is important to have the above information because attenuation in the source capsule may significantly affect the dose distribution around the source and affect the dose distribution in a variety of ways especially when measurements are made with re-entrant ionization chambers. It is possible for two sources of different construction to have the same source strength but significantly different radiation distributions close to the sources [5].

Calibration of sources should be traceable to national or international standard laboratories at various levels. There are four ways of tracing brachytherapy sources. Firstly, where a source or calibrator has been calibrated at a national standards laboratory or an accredited dosimetry calibration laboratory (ACDL), direct traceability is achieved. Secondly, secondary traceability when a source of the same design and comparable strength which has direct traceability or when the source is calibrated using an instrument with direct traceability. Thirdly, there is secondary traceability with statistical inference, where multiple sources of the same activity from a suitable random sample have been calibrated with secondary traceability. Lastly, remote traceability occurs if the user relies upon the manufacturers calibration as the only standard, which may, or may not, be

traceable to national or international standards laboratory. Ideally all sources for brachytherapy should be traceable directly or secondary.

1.1 Statement of the problem

Korle Bu Teaching Hospital procured a high dose rate brachytherapy machine in the year 2013. The machine was successfully commissioned in 2014. The facility has a well type chamber for calibration of sources, which provides the user with the reference air kerma strength but does not have a redundancy standard. The goal of the redundancy standard is to check the source with an independent instrument that measures a quantity that is of interest in brachytherapy: the instrument measures a dose in a phantom while the well type chamber measures kerma in a gas.[11] The research aims to compare the ^{60}Co HDR source strength obtained using a well type chamber, to that obtained in a locally hollow constructed phantom using a Farmer type chamber.

1.2 Relevance and justification

As indicated earlier, calibration of sources has to be traceable to national standards laboratory or an accredited dosimetry calibration laboratory. Accurate knowledge of source strength will reduce the uncertainties in the calculated dose distribution by the brachytherapy treatment planning system. Table 1.3 shows reported number of accidents that have occurred over the years in brachytherapy. In developing countries, due to financial constraints not all institutions practicing brachytherapy may be able to afford the well type ionization chamber for the measurement of source strength. With reference

to this, it is imperative to look for alternative ways of calibrating brachytherapy sources which would be more cost effective.

Table1. 3 :Type and frequency of accidents reported in brachytherapy treatment

[12]

Accident cause by	Number of cases
Dose error calculation	6
Errors in quantities and units	2
Incorrect source strength	7
Equipment failure	4
Other	13
Total	32

The procuring of a recommended calibrator i.e. the well type (re-entrant) chamber is far more expensive than the Farmer type ionization chamber which is used in the locally constructed water phantom. Constructed local hollow phantom can be used as a redundancy standard at the brachytherapy department as well as for routine source calibration.

1.3 Objectives

The objectives of the study are as follows:

1. To calibrate high dose rate brachytherapy cobalt -60 source using a re-entrant(well-type chamber at Korle Bu Teaching Hospital
2. To measure the source strength of cobalt -60 source using a farmer type chamber in a locally constructed phantom.
3. To compare the values obtained from measurement of source strength of cobalt-60 HDR source using a re-entrant chamber with those obtained using the Farmer type chamber in a locally constructed phantom.
4. To propose and develop a protocol for the farmer type ionization chamber and the locally constructed phantom for the calibration of Cobalt-60 brachytherapy sources for clinical implementation.

1.4 Scope and limitation

The project will cover construction of the hollow phantom, calibration of HDR sources using the well type ionization chamber and testing of the sources using a farmer type ionization chamber and the constructed hollow phantom. Measures will be put in place to make sure that the dimensions and components of the locally constructed phantom are precise using the available machines on the market .The calibration procedures will follow the set up as recommended in IAEA-TECDOC-1274 and DIN6908-2

CHAPTER TWO: LITERATURE REVIEW

2.0 Specification of source strength

The strength of brachytherapy sources can be specified in terms of activity, exposure rate at a specified distance, equivalent mass of radium, apparent activity, air kerma strength and reference air kerma rate [6].

2.0.1 Activity

This is the number of disintegrations the radionuclide undergoes per second [2]. The unit for activity is the Becquerel (Bq).

2.0.2 Exposure rate at a specified distance

The National Council on Radiation Protection and Measurements [22] recommends that the strength of gamma emitters at a specified distance should be specified directly in terms of exposure in air[22]. The exposure rate at any particular point is proportional to the product of the activity and its exposure rate constant [6]

$$X = (A\Gamma_x)/d$$

Where X is the exposure rate, A is the source activity, Γ_x is the exposure rate constant in $R.m^2.Ci^{-1}.h^{-1}$ and d is the distance in metres[2]

2.0.3 Equivalent mass of radium

For historical reasons some users still specify brachytherapy sources in terms of equivalent mass of radium. The conversion to equivalent mass of radium is done by simply dividing the exposure rate of the source at 1m by exposure rate of radium (point source filtered by 0.5mm Pt(platinum)) at 1m[6]

2.0.4 Apparent activity

This is the activity of a hypothetical unfiltered point source of the same radionuclide that would give the same air kerma rate, in air, at reference distance along the perpendicular bisector of the source[2]. The apparent activity is the ratio of the measured exposure rate at 1m to the exposure rate constant of the unfiltered source at 1m[2]

2.0.5 Air kerma strength

Air kerma strength, S_k is defined as the air kerma rate, in vacuo and due to photons of energy greater than δ at a distance d , multiplied by the square of this distance.

$$S_k = K_\delta(d)d^2$$

kerma is the sum of only kinetic energies of electrons and positrons released by photons in a medium per unit mass. The unit of the kerma is the gray and kerma pertains only to photon beams. kerma (K) is related to exposure by the following equation:

$$K = X \left(\frac{W}{e} \right) \left(\frac{\mu_{tr}}{\rho} \right) / \left(\frac{\mu_{en}}{\rho} \right)$$

where X is the exposure , W/e is average energy absorbed per unit charge of ionization in air, μ_{tr}/ρ is the average value of mass transfer coefficient and μ_{en}/ρ is the average value of the mass absorption coefficient. It should be noted that

$$\frac{\mu_{en}}{\rho} = \frac{\mu_{tr}}{\rho(1 - g)}$$

where g is the average energy of an electron lost to bremsstrahlung. For the brachytherapy range and air medium it is approximated that the average value of mass energy absorption coefficient is the average value of the mass transfer coefficient

$$\frac{\mu_{en}}{\rho} = \frac{\mu_{tr}}{\rho}$$

therefore,

$$K = X \left(\frac{W}{e} \right)$$

And therefore

$$S_k = X_d \left(\frac{W}{e} \right) d^2 [6]$$

2.0.6 Reference air kerma rate

The reference air kerma rate (RAKR) is the air kerma rate at a distance of 1 m from the source in free space. RAKR is measureable apart from a small correction due to attenuation and scatter in air. Specification for RAKR is for a standard geometry. For line sources such as needle and for seeds, the air kerma rate (AKR) on a line bisecting the axis

of source and perpendicular to it is required. For a wire the strength is normally specified per millimeter of wire length[1].The SI unit for RAKR is the Gys^{-1} .

It should be noted that the air kerma strength and RAKR are equal at 1m.

2.1 Methods of calibration

There are three principal methods of calibrating brachytherapy sources. The first method is by using a calibrated re-entrant ionization chamber. The second method is by the use of an ionization chamber to measure the air kerma rate at a known distance from the source. The calibration of the re-entrant ionization chamber is actually achieved by use of the radiation source, the air kerma strength of which has been measured in air. The third method is the use of a solid phantom into which sources and ion chamber can be introduced in a convenient and reproducible way[5,9,31,32].

2.1.1 Re-entrant (well-type) ionization chamber

The re-entrant ionization chamber, also known as the well type chamber consists of a cylindrical well and an ion collection volume, which surrounds the source approximating at 4π geometry. The ionization chamber should respond linearly throughout its measuring range, its energy response must be known and care must be taken to ensure that when measuring high activities there is no drop in sensitivities. It should be noted that the response of the chamber will be dependent upon the geometric configuration of the source, its filtration and encapsulation. The chamber should have characteristics according to AAPM TG40 report[15]. It is recommended that the reproducibility of the

calibrator should be better than 2% and the signal to noise ratio should be greater than 100:1. Orientation of the source and its position in the well affects the response of the chamber so it is essential to devise a holder of the source that will reproduce the source positioning. The scale factor and the linearity of each scale used on the electrometer should be determined and monitored, this is highly recommended. The collection efficiency should be better than 99%. Sensitivity of the reentrant chamber depends on the energy of the photons, therefore calibrated sources of one radionuclide cannot be used to determine the source of another radionuclide. To verify and quantitate the extent of the change in sensitivity with source position, the relative orientation of the source is important thus the source should be moved through the active volume of the chamber because of dose anisotropy about the source. Figures 2.0 and 2.1 show a typical re-entrant chamber and variation of sensitivity with source location in the chamber well respectively:

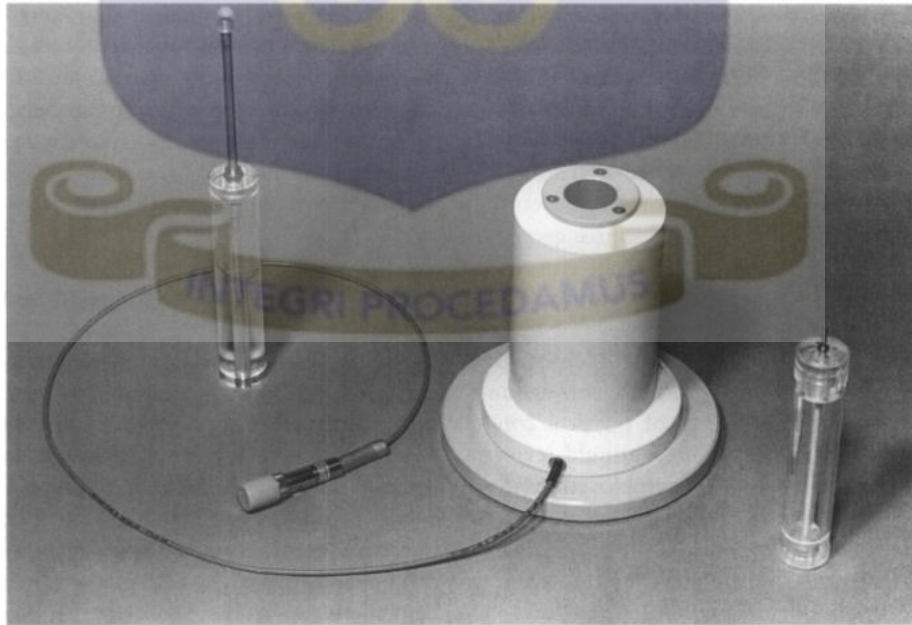


Figure2. 1:A typical re-entrant chamber with Perspex holders[5]

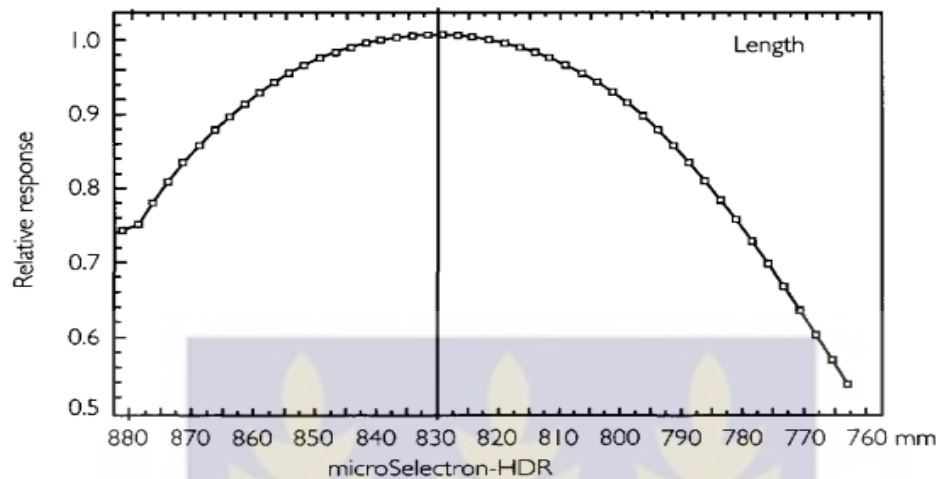


Figure2. 2: Relative response of chamber with respect to distance[5]

The re-entrant chamber should be used according the AAPM report 13[25] where for long lived sources the following should be done:

- For each radionuclide and encapsulation to be measured, one source should be identified as a standard source. The source should be marked or otherwise identified so that it can be recognized later
- The standard source should be sent to an appropriate calibration laboratory for calibration
- The standard may be used to calibrate all other similar sources by sequential placement of the standard sources and the sources to be calibrated in the same geometry within the chamber and comparing readings.

For short lived sources the following should be done:

- Identify a long lived source as the reference source
- Obtain a standard source of the appropriate short lived radioisotope and compare this with reference source. The inter comparison will be used to establish a baseline comparison of the relative sensitivity of the system to the two sources
- Submit the standard source to a suitable calibration laboratory for calibration
- There are two methods that can be used to transfer the calibration:
 1. The chamber is calibrated with short lived standard source, and the reference source used to check that the chamber is functioning properly.
 2. A correction factor defined as the ratio of two measurements chamber response using the standard source is calculated. The correction factor relates the response of the chamber to the short lived standard source in terms of the response to the reference source.
- For the two methods described above, the reference source is measured every time the chamber is used to calibrate the short lived sources.
- After decay of the standard source, the reference source is used for subsequent calibrations.

The construction of the source affects the mean energy of the emitted radiation and any calibration must be made with a calibrated source of the same design as the sources being investigated[5,33].

For brachytherapy source calibrations, the well type chamber should specifically be designated for radiotherapy applications and only those that are open to the atmosphere should be used. Pressurized well type chambers ionization chambers used in nuclear medicine should not be used in brachytherapy measurements for the following reasons:

- The chambers measure activity only
- Brachytherapy sources have no settings on these chambers
- Contamination from nuclear medicine procedures may occur
- Gas leakages from the pressurized volume may affect the response over time
- Because thick walls are required for pressurization, a significant part of the radiation to be measured may be absorbed by these walls.

The well type chamber and the electrometer may have independent calibrations thus the total calibration factor must be the product of the calibration factor of the well chamber and the calibration of the electrometer [12].

2.1.2 Calibration point inside the well type chamber

The point at which the centre of the source is positioned during calibration procedure is called the calibration point. The point differs from one source to another due to source length. There are chambers that have a fixed, non-removable spacer in the well and the source is placed on top of the spacer. Some chambers have a mechanism to move and fix the source holder to different heights and the source then placed at the bottom of the movable holder during calibration. The calibration point is stated on the chamber's certificate. For chambers that are identical to the IAEA standard, the calibration point is with the source at the position of maximum response. The position is dependent on the source type and must be determined prior to the calibration[12].

2.1.3 Measurement techniques

Measurements must be done in a minimum scatter environment thus the chamber should at least be 1m from any wall or floor. The chamber should minimally stay 30 minutes to reach equilibrium with its surroundings before calibration and the temperature to be measured must be for the chamber volume instead of the room temperature. Measured charge or current should have a minimum of 4 significant digits. Charge should be accumulated for a set time depending on activity. 5 measurements or more for each source insertion that are neither monotonically increasing or decreasing should be obtained and minimum of two source insertions should be made. For HDR sources the measurements should be within 0.3% of the average reading and the average of two sets of readings should within 0.5% [12]

2.1.4 Measurement corrections

Recombination correction factor, k_{recom} , may be determined by using the two voltage technique. If the ratio of the voltage used in this technique is exactly 2, then the recombination correction can be determined from:

$$\frac{1}{k_{\text{recom}}} = \frac{4}{3} - \left(\frac{Q_1}{3Q_2} \right),$$

where Q_1 is the charge collected at the higher voltage and Q_2 is the charge collected at the lower voltage. Good quality chambers exhibit negligible recombination effects for brachytherapy sources [40].

Air density corrections are calculated using the following equation:

$$K_{TP} = \frac{273.15 + T}{273.15 + T_0} \times \frac{101.3}{p}$$

Where T is the temperature in Celsius and P is the pressure in kPa and T_0 is the reference temperature at calibration usually it is 20°C . For electrometers calibrated separately, the calibration factor of the electrometer, N_{elec} , must be applied[12].

2.1.5 Calculation of well type chamber calibration factor

For separately calibrated electrometer, the reference air kerma calibration factor of the well type chamber is determined from the following equation:

$$N_{\text{kr}} = \frac{K_{\text{r}}}{M_{\text{u}} \times K_{\text{TP}} \times K_{\text{recom}} \times N_{\text{elec}}}$$

Where K_{R} is the air kerma rate of the source and M_{u} is the scale unit reading, k_{TP} , k_{recom} and N_{elec} are corrections for temperature and pressure, recombination losses and the electrometer calibration factor, respectively. If the chamber and electrometer are calibrated as a system, then N_{elec} is considered to be 1[12]

2.1.6 Calibration of a hospital's well type chamber

Calibration of the well chamber to be used at any hospital offering brachytherapy is done using the secondary standards dosimetry laboratory (SSDL) source at the SSDL. At first the response curve for the hospital's chamber is determined. Then a source is inserted into the hospital's chamber using the appropriate spacer and insert. Corrections for ion

recombination must be determined and accounted for if necessary, further if it is open to the atmosphere then the reading must also be corrected for temperature and pressure[12].

2.2 The “in-air” method

The “in-air” measurement technique is the primary method of determining the strength of brachytherapy sources and is a convenient method for checking the relative strength of individual sources by comparing the signal strength of the unknown source against that for a reference source of known air kerma strength. This method is less dependent upon the effects of differences in encapsulation than for the re-entrant chamber measurements.

Unfortunately it has several inherent problems thus, its use is mainly confined to specially equipped laboratories and HDR after loading systems. For a low strength source, the air kerma rate at a large distance from the source will be low and difficult to measure, scattering from the surroundings is also a problem for which allowance must be made. Measurements can be made closer to the source but as the measurement distance is decreased, the significance of the physical dimensions of both the source and the ion chamber increases.

Positioning uncertainty also becomes a problem for shorter distances as it requires large volume chambers to achieve signal to noise ratio greater than 100:1. In this method a jig is used to provide mechanical rigidity without contributing scatter to chamber. Corrections for room scattered radiation can be made by making measurements at various distances.

Room scatter can be determined from examination of data, assuming that it is constant over the distance measured and also that the dose data set after correction for room scattering should comply with the inverse square law. The ion chamber and electrometer used for calibration purposes should have a traceable calibration for the same energy that is being investigated and preferably be relatively insensitive to changes in photon energy over a wide range[5].

In the “in –air” method, the chamber is positioned at one or several well determined distances from the source, and the reading is recalculated to the reference distance with inverse square law. A scatter free rigid jig is used to keep the chamber usually 5 to 20 cm from the source[18]

2.2.1 Calibration of high energy photon source

The method is used for all high energy photons but should not be used for low energy sources such as ^{125}I and ^{103}Pd . The reasons for not using this method for low energy photon sources are:

- There is large uncertainty in the air calibration factor for the air cavity chamber which is unacceptably high
- Generally, low energy photons do not have sufficient high reference air kerma rate for measurements done in air. Further, there is also possibility of high leakage currents making the measurement largely uncertain.
- Air humidity affects attenuation of the low energy photons[12].

2.2.2 Formalism of reference of air kerma rate

The reference air kerma rate, K_R , may be determined from free in air measurements from the equation:

$$K_R = N_k \times \frac{M_u}{t} \times K_{air} \times K_{scatt} \times K_n \times \left(\left(\frac{d}{d_{ref}} \right)^2 \right)$$

Where:

N_k : Is the air kerma calibration factor of the ionization chamber for that particular photon energy

M_u : Measured charge, corrected for ambient temperature and pressure, recombination losses and transit effects during source transfer in case of afterloading systems, collected during a time t

k_{air} : Correction factor for attenuation of the primary photons due to air between the source and chamber

k_{scatt} : Correction factor for scattered radiation from external influences such as the walls, floor, measurement set-up, air, etc

k_n : Non uniformity correction factor, for the non-uniform electron fluence within the air cavity

d : Measurement distance, being the distance between the source centre and the ionization chamber centre

d_{ref} : Reference distance of 1m

This equation provides the reference air kerma rate on that particular day. For measurements on any other day, corrections should be made for the source decay. For

HDR sources, it is recommended that ionization chambers with volumes greater than 0.5cm^3 be used.

2.2.3. Correction factors for free in- air measurements

2.2.3.1 Measurement distances

For measurements using an ionization chamber, there are four effects that contribute to the uncertainties in brachytherapy sources. These effects expressed as a function of source to chamber distance are as follows:

- Uncertainty due to the effects of chamber size. The uncertainty in the non-uniformity correction factor inversely proportional to source to chamber distance(SCD)
- Scatter which as a percentage of the total signal is directly proportional to increasing SCD
- Inverse square law applies to the positional uncertainty and thus decreases with increasing SCD
- An increase in SCD leads to an increase to leakage current relative to the ionization reading.

It is recommended that measurements should be made at set different distances and the RAKR should be determined from measurements made at each distance[12,20].

2.2.3.2 The scatter factor

Placement of the source and chamber should be in the centre of the room and at least above the floor to reduce the effects of scattered radiation. The shadow shield and the multiple distances are the methods which are employed to determine scatter correction.

A) Shadow shield method

To prevent primary photons from reaching the chamber, a cone of material made of high atomic number, Z , is placed between the source and the chamber. The scatter correction is found by dividing the measured charge with and without the shield. Sufficient attenuation should be provided by the height of the cone and should not be placed close to the chamber due to the possible scattering effects of the cone [12,35,37].

B) Multiple distance method

Readings are made at a several distances with carefully measured intervals. The readings taken at different distances reflect the inverse square law differences between them and an assumed constant amount of scatter. Correction, c that that yields the true centre to centre source to chamber distances d' , is derived from making changes in distance precise and accurate. The distance for a reading is then given as:

$$d' = d + c \dots (a)$$

where, d' is the centre to centre distance of the source and chamber accounting for the offset c in the distance, d is the apparent centre to centre distance of the source and chamber and c is the offset in the set up distance. Scatter radiation contribution to the air kerma rate, K_s , is included in the measured air kerma rate, $K(d')$. Therefore the air kerma value due to primary photons only, $K_p(d')$, is given by:

$$K_p(d') = (K(d') - K_s) \times \frac{(d+c)^2}{d'} \quad (b)$$

Combining equation a and b gives:

$$K_p(d') = \frac{(K(d') - K_s)(d+c)^2}{d'} (c)$$

for any distance. The scatter correction factor can be determined to be :

$$K_{\text{scatt}} = 1 - \frac{K_s}{K(d')} = 1 = \frac{K_s}{N_k \times M_u \times K_n}$$

where M_u has been corrected for ambient conditions. The determined values of c should be within $\pm 1\text{mm}$. [12,36]

2.2.3.3 The non conformity factor

For measurements of brachytherapy sources, the non-collimated geometry, which has high divergence of incident photons, differs from geometry of the collimated beams such as those external beams used for calibrating the chamber, therefore there is variation in the photon fluence over the different parts of the chamber. Application of a non uniformity correction factor to convert the measured charge or current into air kerma rate at the measurement distance is therefore necessary. The non uniformity factor k_n is dependent upon the following factors:

- Shape and dimensions of the ionization chamber
- Measurement distance and source geometry
- Material used in production of the inner wall of the chamber
- Energy of the photons emitted from the source

Kondo and Randolph [12,23] have produced non uniformity factors which assumes that the fluence of electrons in the air cavity of the ionization chamber is isotropic. Bielajew [12, 34], later extended Kondo and Randolph's [23] theory to include the angular distribution of fluence of electron in the air cavity of the chamber. Bielajew's

anisotropic theory predicts the dependence of the energy and wall material in the non uniformity correction factor. The relation between the two theories is given by:

$$A_{pn}(d) = A_{pn}^{KR}(d) + \omega A_{pn}(d)$$

Where $1/A_{pn}^{KR}(d)$ gives the non uniformity correction factor using the isotropic theory by Kondo and Randolph[23] and $1/A_{pn}(d)$ is the non uniformity correction factor from the anisotropic theory by Bielajew[34]. $A_{pn}'(d)$ takes into account the anisotropic electron fluence within the air cavity and the degree of anisotropy is given by the energy and material dependent factor ω . Bielajew[34] theory predicts dependence of the energy and wall material in the non uniformity correction factor. The factor $A_{pn}(d)$ is recommended to be used for determination of k_n . This gives

$$k_n = 1/A_{pn}(d)$$

For cylindrical ionization chambers, it has been shown that the non uniformity correction factor obtained with the anisotropic theory is insensitive to the energy and material dependent factor values[38]. Tables 2.0 and 2.1 show material and photon energy dependent factors, ω , and non uniformity factors correction factors for farmer type ionization chambers(internal radius 3.15mm, length 24.1mm) respectively.

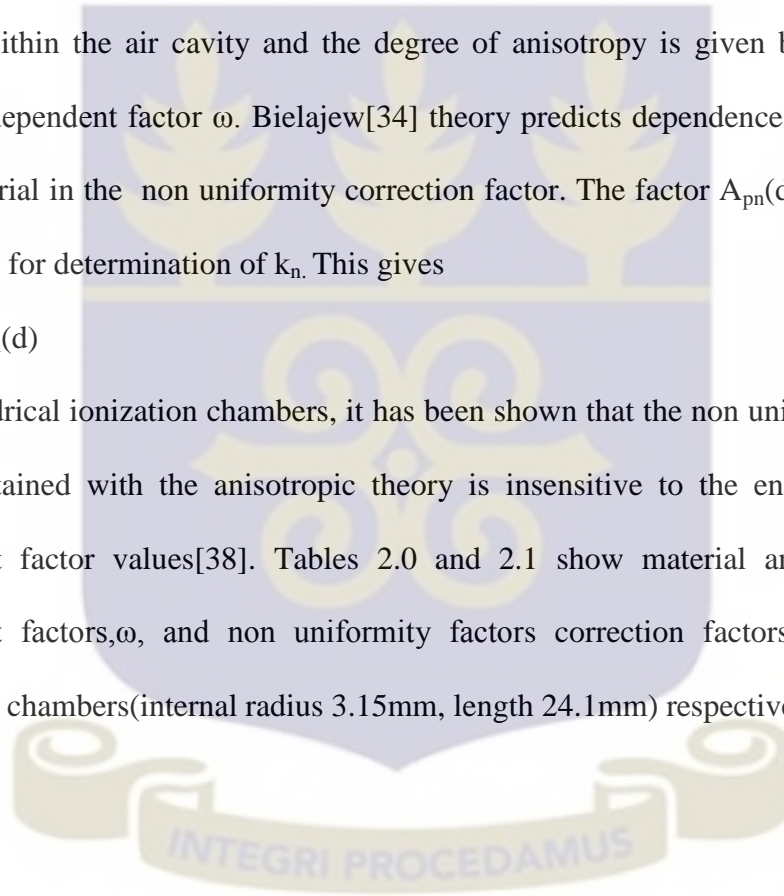


Table2. 1: Material and photon energy dependent factors, ω [12]

Inner wall material	Ω
A-150	1.066
PMMA	1.014
Graphite	0.992

Table 2.1: Non uniformity factors correction factors for farmer type ionization chambers(internal radius 3.15mm, length 24.1mm)[12]

Distance(cm)	k_n
10	1.009
15	1.005
20	1.004
25	1.003
30	1.002
40	1.002
50	1.001

2.2.4 Corrections for the attenuation of primary photons in air

Attenuation of primary photons between the source and chamber should be corrected.

Table 2.2 below gives the k_{air} correction factors of ^{60}Co at different distances between the source and the ionization chamber

Distance(cm)	^{60}Co
10	1.000
20	1.000
30	1.000
40	1.000
50	1.000
60	1.000
70	1.000
80	1.000
90	1.000
100	1.000

Table 2.2: k_{air} correction factors of ^{60}Co at different distances between the source and the ionization chamber[12]

2.2.5 Corrections for transit effects, leakage current and recombination losses

Source movement into and away from the measurement position produces a signal which is detectable and it is referred to as the transit signal. The magnitude of the transit signal is dependent on the source to chamber distance and is important at the distances used in calibration. There are several methods to completely remove the transit component of the signal:

- an externally triggered electrometer is used to collect charge during an interval after the source has stopped moving

- Subtraction of the two readings taken for differing intervals to eliminate the transit charge common to both
- Using a current reading after the source has stopped moving for a signal is that is large enough

For electrical leakage current greater than 0.1% of the signal, a correction should be taken into account. Further corrections should be made for recombination losses and ambient temperature and pressure[12].

2.3 Solid phantoms

This method employs a solid phantom which contains a centrally placed ionization chamber with two or more cavities for source catheters positioned radially around the chamber. Source measurements in solid phantoms are more reproducible and straight forward than in the other methods. At the point of measurement, it is necessary to take into account the replacement of the phantom material by the ionization chamber. Some phantoms are designed to be filled with water: this simplifies attenuation corrections, but the need for scatter and chamber displacement factors still applies.

2.4 Other calibrations

2.4.1 Calibration of low dose rate sources in the form of wires and ribbons

Remote afterloaders that are designed to treat interstitially with wire sources or catheters loaded with radioactive ribbons are equipped with up to 20 or more channels. In case of seeds, a re-entrant chamber can be used to measure the individual activity. For wire

sources, it is necessary to measure the source strength per unit length of the wire and this requires special scanning devices such as collimated detectors that can be used to scan the length of the wire up to 135mm. The wire to be used in the re-entrant chamber must have been measured at a P

primary standard dosimetry laboratory (PSDL). The measurement of this wire provides the baseline, which can be compared against a source with a longer half-life. This reference source can be used to monitor the chamber response over the long time periods in between the definitive calibrations. Appropriate source holders are particularly important when using long wire sources so that the source is held centrally in the chamber well. As part of the calibration process, a reference curve should be constructed that shows the dependence of the chamber output upon the length of the wire. Calibrations should be made on all sources after the wires have been cut to length and sealed in catheters[5].

2.4.2 Calibration of low dose rate pre-loaded source trains

Pre-loaded source trains consist mainly of one or more source capsules separated by inactive spacers, all of which are contained in a flexible, stainless steel spring. Before using in a clinic, the location of individual sources should be established by autoradiography and densitometric scanning of the autoradiograph to locate the centre of each source. It is very difficult to calibrate source capsules that are very close, therefore users of source trains should get a guarantee from the manufacturer that the strength of each source loaded in the train does not differ by more than 5% from that stated. The location and relative

strengths of individual sources in the source train can also be recorded by a device having a highly collimated detector[5].

2.4.3 Calibration of multiple low dose rate sources of similar strength

Meertens[40] has described a method to calibrate multiple low dose rate sources of similar strength. The method is based on the use of a phantom consisting of three parallel perspex catheters with a wall thickness of 0.11cm fixed together in a cylindrical geometry at 120° angles. A perspex support for a 0.6cm³ graphite walled farmer type NE2505/3A ionization chamber was mounted between the three catheters parallel to their axes, the distance between each of the catheters and the chamber was 5cm. The catheters and the ionization chamber were placed in 36 x 32 x20 cm full scatter water phantom. The procedure was designed to measure the mean source strength of a set of sources as follows:

- The air kerma rate in water at a point about 5.5 cm distance from a number of sources is measured
- The air kerma rate in water at the same point for the same set of sources is calculated for a reference kerma rate of 100μGyh⁻¹ in free air for each source
- From the ratio of the measured and calculated air kerma rates in water, the mean actual reference air kerma rates of the set of sources can be determined.

Meertens[40] determined that the kerma rate, k_m in water can be found by using the following equation:

$$K_m = M \times N_k \times \pi K_i \times \pi \frac{P_i}{t}$$

where M is the corrected instrument reading and

$$M = M_{\text{uncor}} \times P_t \times P_p \times P_{\text{hum}} \times P_{\text{ion}} \times P_{\text{pol}}$$

M_{uncor} :	Uncorrected instrument reading
P_t :	Temperature correction factor
P_p :	Pressure correction factor
P_{hum} :	Humidity correction factor
P_{ion} :	Ion recombination correction factor
P_{pol} :	Correction for polarity effects

$$\pi K_i = K_{\text{att}} \times K_m \times K_{\text{st}} \times K_{\text{ce}}$$

where

k_{att} :	Correction for attenuation in the wall and build up cap of the ionization chamber
k_m :	Correction for the difference in composition between the wall plus build up cap and air
k_{st} :	Correction for the stem effect for the employed field size
k_{ce} :	Correction for the effect of the central

electrode on the response of the chamber during calibration

$$\pi P_i = P_{wall} \times P_d \times P_{ce}$$

where

P_{wall} :

Corrects for the difference in composition between the ionization chamber wall and the water

P_d :

Displacement direction factor that corrects for the effective centre of the ionization chamber and is a function of the photon energy, the source to chamber distance, and the size of the ionization chamber

P_{ce} :

Corrects for the effects of the central electrode on the response of the chamber during measurements in the water phantom

t :

Integration time

The contribution of one point source with a given reference air kerma rate, k_{ref} in μGyh^{-1} at 1 m free air to the calculated air kerma rate k_c in cGyh^{-1} in water at a distance d, in cm from the point source was calculated as from the equation:

$$K_c = \left(\frac{K_{ref}}{d^2} \right) \times S(d) \frac{\text{cGy}}{h}$$

where

$$S(d) = A_0 + B_0 d C_0 + d^2 + D_0 d^3$$

where

S(d)	Absorption and scatter correction factor according to Meisberger[5,29]
A ₀	=1.0091
B ₀	= -9.015 x 10 ⁻³ cm ⁻¹
C ₀	= - 3.459 x 10 ⁻⁴ cm ⁻²
D ₀	= -2.817 x10 ⁻⁵ cm ⁻³
k _{ref}	= 100 μGh ⁻¹

2.4.4 Calibration of high dose rate cobalt -60 sources of similar source strengths

Chenery *et al*[27] and Messina *et al*[28] have described a method of measuring the air kerma rate with a Farmer type chamber at a distance of 500mm with all sources in a straight applicator. The chamber used should be traceable to PSDL and should be used with a build up cup. For reproducible results, some form of fixation device should be used to ensure that the applicator and ion chamber are in parallel and held so that the applicator is not displaced by the transfer of the sources. The principal error is likely to be associated with the position of the sources in the applicator: they are not constrained to lie perfectly on the axis of the applicator. The positional errors, including those associated with the measurement of the applicator-chamber separation, produce

uncertainty in the measured dose rate of less than 1%. Chamber leakage should be measured for which appropriate corrections are effected.

2.5 Properties of brachytherapy sources

For γ -emitting sources that must be used in brachytherapy, they must have the following features:

- Charged particles or soft particles radiation emitted from the radionuclide must be either absent or easily absorbable by the thin layer of the encapsulation material
- No toxic gases must be produced by the radionuclide decay
- The radionuclide must have high specific activity so that reasonably small sources can be produced with adequate dose rate
- Other physical properties such as emitted energies and half life should fit the purpose of the application
- The radionuclide must be capable of fabrication in a radioactive material that is not highly soluble and toxic in biological tissue in order to minimize the risk presented in case of unintentional leakage of radioactivity into patient or in handling by medical personnel.
- The radionuclide must be capable of fabrication as radioactive material that maintains physical integrity in the event of damage to the source , for example it should not become fine powder or dust and should not sublime or vaporize.

- The radionuclide should allow fabrication of encapsulated sources of different sizes and shapes
- The radionuclide in the fabricated radioactive source should not be susceptible to damage at during at least one of the common methods of sterilization in the surgical room[20]

2.5.1 Properties of cobalt -60

Cobalt-60 is produced through thermal neutron capture reaction $^{59}\text{Co}(n,\gamma)^{60}\text{Co}$ in a nuclear reactor. Table 2.3 shows some of its properties:

Table 2.3 Properties of Cobalt-60

Half life(years)	5.27
Type of Disintegration	β^- , γ
Mean γ - energy (KeV)	1252.0
Mean X-ray(KeV)	0.51
Mean β^- ray(KeV)	96.5
Air kerma rate constant ($\times 10^{-18}$ Gym ²	85
Nominal Specific Activity $\times 10^5$ TBq/Kg	0.41

Half value layer

12mm Lead

Sources have a cylindrical core of 3.5mm in length and 0.5 mm in diameter. The capsule is 5 mm in length and 1 mm in diameter. The sources are laser welded to the end of a flexible steel wire[21].

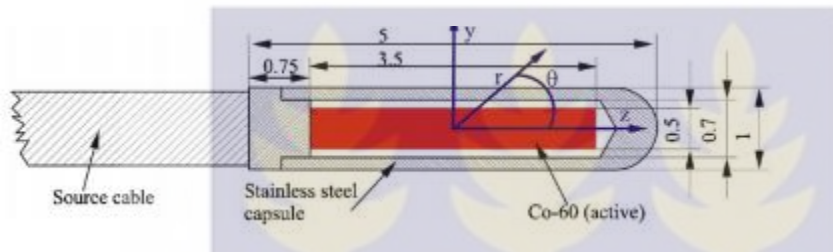


Figure2. 3. Dimensions of Cobalt -60 Source[8]

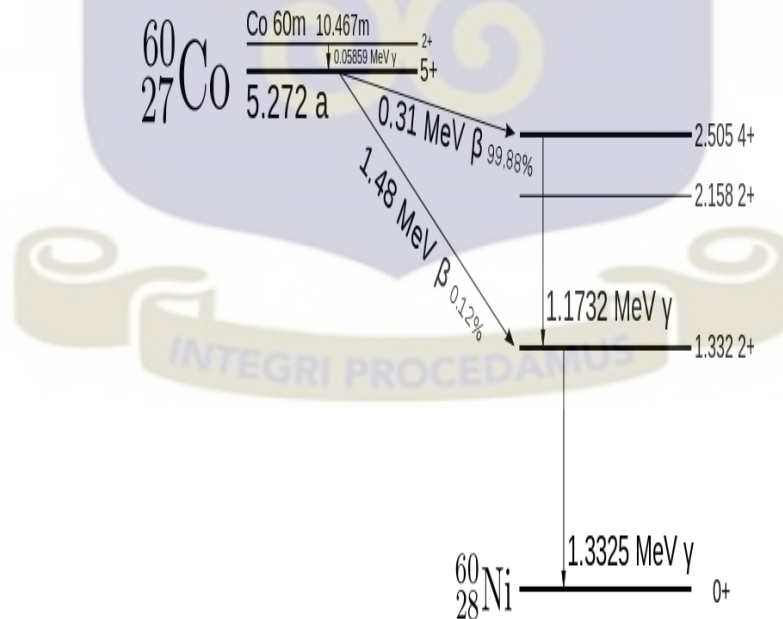


Figure2. 4: Decay scheme for ⁶⁰Co[26]

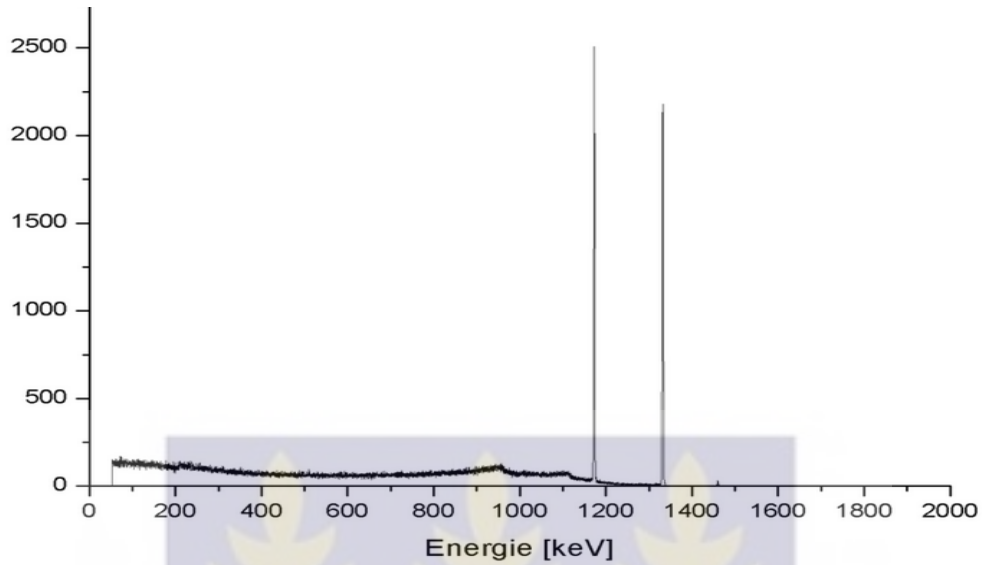


Figure2. 5: γ -Spectrum for ⁶⁰Co[26]

2.6 Calculations of dose distributions

For dosimetry, the quantity of interest is the absorbed dose rate at a distance of approximately 1cm in a tissue equivalent medium[1]. Ideally for a given material to be water or tissue equivalent, it must have the same effective atomic number, electrons per gram and mass density. However, considerations are made to materials whose electron density is similar. The electron density is given by

$$\rho_e = \rho_m \times N_A \times \frac{Z}{A}$$

where ρ_m is the mass density, N_A is the Avogadro number, Z is the atomic number and A is the molar mass[6]. The AKR can then be given by

$$AKR = \frac{A_E \Gamma}{d^2}$$

where A_E is the equivalent activity i.e. the activity of bare source strength with no self absorption of gamma radiation and Γ is the AKR constant.

2.6.1 Calculation of air kerma rate

2.6.1.1 Unfiltered line source in air

For unfiltered source as shown Fig 2.5 below:

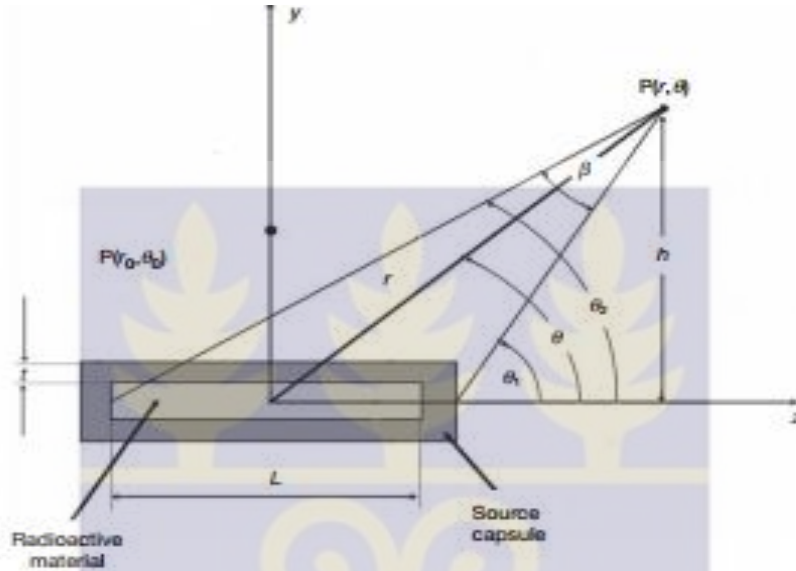


Figure 2. 6: Geometry used in dose calculation for linear source[2]

By changing to polar coordinates

$$(\dot{K}_{air})_{air} = \left(A\Gamma_{AKR}/Lh \right) \times (\theta_2 - \theta_1)$$

2.6.1.2 Filtered line source in air

Using Figure 2.5. The air kerma rate in air for a filtered line source in air is given by:

$$(\dot{K}_{air})_{air} = \left(A\Gamma_{AKR}/Lh \right) \left(\int_0^{\theta_2} e^{-\mu t/\cos\theta} d\theta - \int_0^{\theta_1} e^{-\mu t/\cos\theta} d\theta \right)$$

where

$$\int_0^{\theta} e^{-\mu t/\cos\theta} d\theta$$

is the Sievert integral accounting for photon attenuations, t is the thickness and μ is the attenuation of photons in the capsule material. For $\theta < 0.35$ radians (20°) the equation reduces to

$$\int_0^\theta e^{-\mu t / \cos \theta} d\theta = \theta \times e^{-\mu t}$$

Sievert integrals are available in tabulated forms, but they may also be solved using numerical methods. The Sievert integral does not account for multiple scattering of photons in the source or its capsule. In the Sievert integral approach, photons emitted from every infinitesimal source element are assumed to be subject to narrow beam geometry.

2.6.1.3 Filtered line source in water

The air kerma rate for a filtered line source in water is given by:

$$D_w(d, \theta) = \left(A \Gamma_{AKR} / Lh \right) \left(\int_0^{\theta_2} e^{-\mu t / \cos \theta} M(d, \theta) d\theta - \int_0^{\theta_1} e^{-\mu t / \cos \theta} M(d, \theta) d\theta \right) \times \left(\mu_{tr} / \rho \right)_{tr}^w \times (1 - g)$$

Where $M(d, \theta)$, is the absorption and scatter correction over the source length and d is the distance between point P and source segment, [2]. The last factor

$$\left(\mu_{tr} / \rho \right)_{tr}^w \times (1 - g)$$

is generally ignored because it is very small [1]

2.7 Calculation of dose using TG-43 protocol [41]

The dose rate, $\dot{D}(r, \theta)$, at a point with polar coordinates (r, θ) in a medium from the centre of air kerma strength S_k is given by:

$$\dot{D}(r, \theta) = \Lambda S_k \frac{G(r, \theta)}{G(1, \pi/2)} F(r, \theta) g(r)$$

Where r is the distance from the origin to the point of interest P , θ is the angle between direction r and the long axis of the source, S_k is the air kerma strength and Λ is the dose rate constant, the dose rate per unit air kerma strength along the transverse axis of the seed and has units of $\text{cGyh}^{-1}\text{U}^{-1}$.

$$\Lambda = \dot{D}(r, \frac{\pi}{2}) \div S_k$$

The dose rate constant depends on the type of source, its construction and its encapsulation[6]. The geometry factor $G(r, \theta)$ accounts for variation of relative dose within the source due to the spatial distribution of activity within the source. $G(r, \theta)$ reduces to $\frac{1}{2}$ for point source approximation and to $\beta/Lr\sin\theta$ for line source approximation with β and L as defined in figure 6. The radial dose function $g(r)$ equals to

$$g(r) = \frac{\dot{D}(r, \frac{\pi}{2}) G(r, \frac{\pi}{2})}{\dot{D}(1, \frac{\pi}{2}) G(1, \frac{\pi}{2})}$$

It accounts for the absorption and scatter effects in water along the transverse axis of the source $(\theta, \pi/2)$. Filtration of photons by the encapsulation and source material may also influence the factor. The anisotropy factor $F(r, \theta)$ equals to

$$F(r, \theta) = \frac{\dot{D}(r, \theta) G(r, \frac{\pi}{2})}{\dot{D}(r, \frac{\pi}{2}) G(r, \theta)}$$

It accounts for the anisotropy of dose distribution around the source inclusive of the absorption and scatter in water effects[2,6]

2.8. Dosimetric verification of air kerma strength

Recommended dosimetric verification of air kerma strength for after loading sources are provided for in the following documents: IAEA –TECDOC 1274, AAPM report 41 and in Germany the DIN 6809-2 in combination with DGMP report 13[4].

2.8.1 Measurement of air kerma rate with a Farmer type ionisation chamber in a solid phantom following DIN 6809-2 in combination with DGMP report No 13

The reference air kerma rate is determined using the following equation:

$$K_R \left[\frac{\text{mGy}}{\text{h}} \right] = \frac{1}{1 - g_w} \times \frac{1}{t_{w \rightarrow a}^{en}} \times K_{wp} \times K_{zp} \times K_r \times K_T \times K_A \times K_p \times K_s \times K_r \times K_Q$$

$$\times N_w \left(\frac{\text{mGy}}{\text{nC}} \right)$$

$$\times M(\text{nC}) \dots \dots \dots \text{Eqn (2.8.1)}$$

Where:

g_w : The fraction of the energy of the electrons from the source decay liberated by photons in water that is lost to radiative processes(mostly bremsstrahlung)

$t_{en w/a}$: Ratio water/air of the average mass energy absorption coefficients = 0.900 for Co-60

k_{wp} : Correction factor for the differences in

scatter and distortion of the radiation
between water and PMMA = 1.000

k_{zp} :

Correction factor accounting for differences
in scattering and absorption in the PMMA
phantom surrounding the measuring probe
in comparison to free in air conditions. This
is also referred to as the phantom calibration
factor

k_r :

$=(r_M/r_0)^2$, the correction for measuring
distance r_M between the source and probe in
relation to the reference distance r_0 for
 $r_0=100\text{cm}$

k_A :

Correction for attenuation and scatter by the
applicator

k_p :

Correction factor for the polarization effect
of the ionization chamber

k_s :

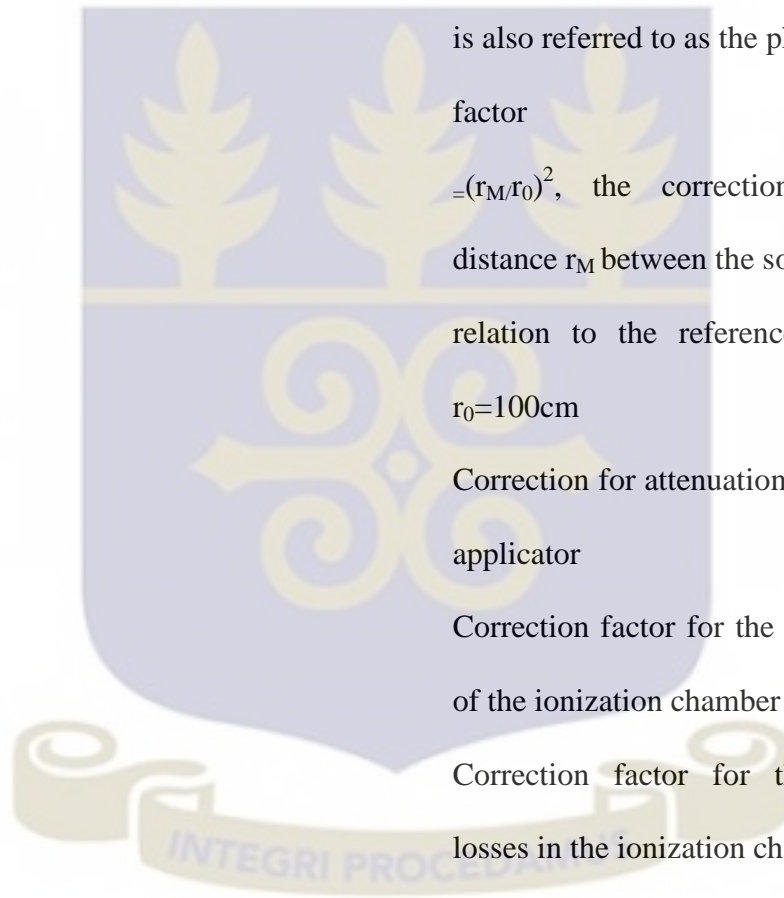
Correction factor for the recombination
losses in the ionization chamber

k_T :

Air density correction factor for differing
temperature and air pressure from standard
room temperature and pressure conditions

k_Q :

Correction factor for the different response
of the ionization chamber at the measured



radiation quality in comparison to the calibration quality of Co-60 beam

N_w : Ionization chamber calibration factor in terms of absorbed dose to water

M : Electrometer reading in nanocoulomb

k_T : $60/(T/\text{min})$ with T = duration in min

2.8.2 Measurement of reference air kerma rate with farmer type ionization chamber free in air following DIN6809-2 in combination with DGMP report 13

The reference air kerma rate is obtained using the following equation:

$$K_R[\text{mGy/h}] = K_{\text{air}} \times K_{w \rightarrow a} \times \frac{1}{(1-g_a)} \times \frac{1}{t_{w \rightarrow a}^{\text{en}}} \times K_{AK} \times K_r \times K_T \times K_A \times K_V \times K_p \times K_s \times K_Q \times K_{\text{scatt}} \times N_w[\text{mGy/nC}] \times M[\text{nC}] \dots \dots \dots \text{Eqn 2.8.2}$$

where:

k_{air} : Correction factor for losses of primary radiation due to attenuation and scattering effects in the air between source and ionization chamber ($k_{\text{air}} = \exp[\mu * r_M]$ with $\mu = 0.00011/\text{cm}$ for Co-60)

k_{w-a} : Correction factor for the differences in scatter and radiation field distortion in air surrounding the measuring probe in comparison to water ($K_{w-a} = 1.000$ for Co-60)

g_a : Fraction of the energy of the electrons from

the source decay liberated by photons in air that is lost is lost to radiative processes (mostly bremsstrahlung)

k_{AK} : Correction factor for attenuation and scatter effects from a build up cap ($k_{AK} = 1.005$ for Co-60)

k_V : Correction for the exact volume of the measuring probe (recommended by Kondo and Randolph. The 1cm^3 thimble ionization chamber has $k_V = 1.0010$ for the source to chamber distances between 15 and 25 cm and k_V for source chamber distances ≥ 30 cm)

k_{scatt} : Correction factor for scatter from surrounding objects (floor, water, set up, etc)

k_{scatt} : $= (M - M_{scatt}) / M$ with M = electrometer reading without scatter absorber, M_{scatt} electrometer reading with absorber

N_w : Ionization chamber calibration factor in terms of absorbed dose to water

M : Reading on electrometer in nano coulomb

And the rest of the quantities are defined as in eqn 2.8.1.

2.8.3 Measurement of reference air kerma rate with a Farmer type ionization chamber free in air following IAEA- TECDOC -1274

The reference air kerma rate is determined from the following equation:

$$K_R[\text{mGy/h}] = K_{AK} \times K_r \times K_T \times K_A \times K_{\text{air}} \times K_v \times K_s \times K_P \times K_{\text{scatt}} \times N_k[\text{mGy/nC}] \times M[\text{nC}] \dots \text{Eqn (2.8.3)}$$

where:

- k_v : Correction for the exact volume of the measuring probe (referred to as non uniformity correction factor in IAEA-TECDOC -1274)
- N_k : ionization chamber calibration factor in terms of air kerma
- M : Electrometer reading in nano coulomb

2.8.4 Measurement of reference air kerma rate with well type chamber following DIN6890-2 and IAEA-TECDOC-1274

Measurements are performed with the electrometer set to the current mode after achieving a constant current. The reference air kerma rate is given by the following equation:

$$K_r[\text{mGy/h}] = K_p \times K_s \times K_r \times N_k \left[\frac{\text{mGy}}{\text{h}} \frac{1}{\text{nA}} \right] \times M[\text{nA}] \dots \text{Eqn (2.8.4)}$$

Where

- k_s : $1/A_{ion}$: correction for recombination losses in the well type
- N_k : Calibration factor of well chamber in terms of absorbed dose to water
- M : Electrometer reading in nano amperes

2.8.5 Measurement of reference air kerma rate with Farmer type ionization chamber following AAPM Report 41

The reference air kerma rate is determined by the following equation:

$$K_R[\text{mGy/h}] = \frac{1}{(1-g_a)} \times K_{AK} \times \left(\frac{W}{e}\right)_{air} \times K_{air} \times K_r \times K_T \times K_A \times K_V \times K_s \times K_{scatt} \times N_x[\text{mGy/nC}] \times M[\text{nC}] \dots \dots \dots \text{Eqn(2.8.5)}$$

where:

$(W/e)_{air}$: $=33.7\text{J/C}=8.76\text{mGy/R}$ is the ionization energy of dry air

k_s : ionization chamber correction factor for recombination losses(also named “correction for collection efficiency at calibration A_{ion} ” or “ correction for the collection efficiency at the time of the study P_{ion} ” in AAPM report 41

k_{scatt} : Correction for room scatter(“ room scatter correction P_{RS} ” in AAPM report 41)

N_x : Ionization chamber calibration factor in terms of exposure

M: Reading on electrometer in nano coulomb

2.8.6 Measurement of reference air kerma rate with well type chamber according to AAPM Report 41

AAPM report 41 requires that measurements should be taken with a well chamber which is calibrated in terms of exposure. The reference air kerma rate is given by the following equation:

$$K_R \text{ [mGy/h]} = \left(\frac{W}{e}\right)_{\text{air}} \times K_p \times K_s \times K_r \times N_x \left[\frac{R}{h}/\text{nA}\right] \times M[\text{nA}] \dots \dots \dots \text{Eqn 2.8.6}$$

where:

N_x : Calibration factor of well type chamber in terms of exposure

M: Reading on electrometer in nano Amperes

2.8.7 Air density correction factor

This is a factor to correct for the air temperature and pressure under which the study is performed, if different from reference conditions during calibration of the chamber .

Note that the temperature was measured inside the chamber. The following equation was used to calculate the air density correction factor:

$$K_{TP} = \frac{(273.15+T_{\text{measured}})}{273.15+T_{\text{ref}}} \times \frac{1013.15}{P_{\text{measured}}} \dots \dots \dots \text{Eqn(2.8.7)}$$

Where K_{TP}	air density correction factor
T_{measured}	measured temperature
T_{ref}	reference temperature
P_{measured}	measured room pressure

2.8.8 Polarity Correction factor

This correction factor is for the polarity effect of the bias voltage for the photon energy of the radionuclide. This factor is found by using the following equation:

$$K_{\text{pol}} = \left(\frac{[M_+] + [M_-]}{2M_+} \right) \dots\dots\dots \text{Eqn (2.8.8)}$$

Where

K_{pol}	polarity correction factor
M_+	electrometer reading at positive bias voltage
M_-	electrometer reading at negative bias voltage

2.8.9 Saturation correction factor

This factor takes into account that not all released charges are collected due to the recombination of charge carriers in the ionization chamber. These readings were made at the calibration point. The following equation was used to find the saturation correction factor:

$$K_{\text{sat}} = \frac{\left(\frac{V_1}{V_2}\right)^2 - 1}{\left(\frac{V_1}{V_2}\right)^2 - \left(\frac{M_1}{M_2}\right)} \dots\dots\dots \text{Eqn (2.8.9)}$$

Where

K_{sat}	Saturation correction factor
V_1	Positive bias voltage
V_2	Half positive bias voltage
M_1	Positive electrometer reading at bias voltage
M_2	Positive electrometer reading at half bias voltage

2.8.10 Calculation of uncertainty in reference air kerma rate

The overall uncertainty of the reference air kerma rate results is the sum of the partial variances of all contributing parameters. This is given by the equation below:

$$\left(\frac{\delta K_{\text{ref}}}{K_{\text{ref}}}\right)^2 = \left(\frac{\delta N_w^{\text{SSDL}}}{N_w^{\text{SSDL}}}\right)^2 + \left(\frac{\delta P}{P}\right)^2 + \left(\frac{\delta T}{T}\right)^2 + \left(\frac{\delta K_s}{K_s}\right)^2 + \left(\frac{\delta K_{\text{pol}}}{K_{\text{pol}}}\right)^2 + \left(\frac{\delta Q}{Q}\right)^2 \quad (2.8.10)$$

Where the following are:

δK_{ref}	Error in reference air kerma rate
K_{ref}	Reference air kerma rate
δN_w^{SSDL}	Error in ionization chamber calibration factor

N_w^{SSDL}	Ionization chamber calibration factor
Δt	Error in temperature
δP	Error in pressure
δK_S	Error in saturation correction factor
δK_{pol}	Error in polarity correction factor
δQ	Error in measured average charge
P	Measured pressure
T	Measured temperature
K_S	Saturation correction factor
K_{pol}	Polarity correction factor
Q	Measured average charge

In case of recalculation from time of measurement t_m to a different reference date t_o the radionuclide decay has to be corrected by using the following equation:

$$K_{ref}(t_o) = K_{ref}(t_m) \times \exp \left[-\ln(2) \times \frac{t_o - t_m}{T_{1/2}} \right] \dots \dots \dots \text{Eqn 2.8.11}$$

where

K_{ref}	Reference air kerma rate
t_o	Reference date
t_m	Date of measurement
$T_{1/2}$	Half life of radionuclide

CHAPTER THREE: MATERIALS AND METHODOLOGY

3.0 Introduction

This chapter provides the details of the materials, equipment and methodology used in the study. The methodology provides details on the construction of the locally constructed hollow phantom, the experimental set up of the two methods which were employed to measure the reference air kerma rate and description of the parameters that were measured and calculated to find the reference air kerma rate.

3.1 Materials

The following equipment and materials were used:

- BEBIG MultiSource© high dose rate brachytherapy machine
- HDR plus well chamber
- UNIDOS E electrometer
- Max 4000 electrometer
- 0.6 cc Farmer type ionization chamber
- Barometer
- Thermometer
- Locally constructed hollow phantom

3.1.1 The BEBIG MultiSource© HDR brachytherapy machine

The BEBIG MultiSource© HDR Brachytherapy machine consists of a treatment unit, MultiSource© and a separate treatment planning system, HDR plus®, which uses TG-43 formalism based dosimetry. The treatment unit operates by automatically stepping a single source to discrete dwell positions for specified times based on dose optimization plan generated by the operator with HDR plus treatment planning system. The source travels through either a single or series of transfer tubes (catheters) from the HDR machine into specialized applicators inserted or implanted in the patient to be treated. The number of catheters to use is dependent on applicator choice and the dose distribution one wants to achieve. A catheter is connected to a specific channel on the HDR machine defined by the treatment plan generated for a particular patient. The source is welded to one end of a steel cable which is driven in and out of the source storage container within the HDR machine, using a stepper motor and position scale convention which has a zero distance at the end of the applicator connected via a catheter. This corresponds to the furthest distal point, and increasing position values are obtained as the source moves back towards the HDR machine. The position values represent dwell positions defined by the treatment plan. The HDR machine also contains a dummy source which is configured and designed just like the real source used for treatment. Prior to the movement of the source, the dummy source is sent out first to reach the distal point to check for obstructions. Once there are no obstructions, the real source is sent out. The unit consists of 20 applicator channels and uses linear movement of an indexing plate to align both source and dummy source with the required channel during treatment.[10]

3.1.2 Technical specifications for equipment used

Table3. 1: shows the technical specifications of the BEBIG MultiSource© HDR brachytherapy machine, the well type chamber , the electrometers and the ionization chamber.

Item	Manufacturer	Model	Serial number
Brachytherapy machine	Eckert and Ziegler	Multisource	479
Well type ionization chamber	Standard Imaging,inc USA	HDR 1000 plus	A083262
Electrometer	PTW Freiburg Germany	UNIDOS E	081102
Electrometer	Standard Imaging,inc USA	Max 4000	F083103
0.6 cc Farmer type Ionization chamber	PTW Germany	Freiburg TM 30010-1	000820
Barometer	Prazions		98889
Thermometer	EXTECH		39240

3.1.3 Construction of the hollow phantom

A cylindrical phantom was locally constructed to represent the commercially available Krieger phantom (PMMA 9193; PTW Freiburg, Germany). Krieger phantom is used for the measurement of reference air kerma rate of HDR brachytherapy sources with a Farmer type ionization chamber based on protocols of the DIN 6809-2 and DGMP report13 [4].

Figure 3.1 below shows the Krieger phantom.



Figure3. 1: The PMMA 9193 PTW Freiberg “Krieger phantom”[42]

The following materials were used to construct the phantom; 4 and 15 mm sheets and 40 mm rod Perspex or Polymethylmethacrylate) (PMMA). The choice of using Perspex was because it is a tissue equivalent material (it is able to absorb and scatter radiation in a similar way as tissue or water) and also it easy to machine into any shape. Two circular pieces each of diameter 20 cm were cut from the 15 mm Perspex with a jig saw to form the top and bottom of the locally constructed phantom. Four equidistant holes having

diameters of 20.4 mm were drilled in one of the sawn circular pieces to form the top of the phantom, such that from the center of each of these holes to the center of the circular piece was 8 cm. Another hole of diameter 10.5 mm was also drilled at the center of the circular pieces, such that the center of this hole was concentric to the centers of the four 20.5 mm diameter holes as shown in Figure 3.2. Four Perspex tubes each with dimensions; 120 mm in length and 20 mm in diameter were fabricated from the 40 mm Perspex rod, such that the wall of a tube was 5 mm. From the top of the tubes to about 10 mm downward was made broader (40 mm in diameter) to enhance gluing of the tubes to the top circular piece with holes.

A cross sectional view of one the fabricated tubes is shown in Figure 3.3A. A rod of dimensions; 130 mm in length and 10 mm in diameter was also fabricated from a piece of the 40 mm rod, but the top end with a thickness of 10 mm was made broader with diameter of 30 mm to ensure effective gluing of this rod to the circular piece forming the top of the phantom. A hole of diameter 3 mm was drilled central to this rod and the hole was 120 mm in length as shown in figure 3.4D. The 20 mm tubes and the 10 mm rod with the 3 mm hole were inserted into the 20.5 mm holes and 10.5 mm hole respectively in the circular piece forming the top of the phantom. The pieces were then glued in place with chloroform (Trichloromethane), which is found to dissolve Perspex.

A hole 25 mm in diameter with a cover was made central to the other circular piece forming the bottom of the phantom. Two rings of diameter 120 mm and thickness of 20 mm were fabricated from the 15 mm Perspex sheet. The two rings were glued together with chloroform to form a single ring. The ring formed was glued to the bottom circular piece of the phantom such that it was concentric with the hole of the cover. This was used

as a stand for the phantom and also to facilitate the filling of the completed phantom with water. The top of the bottom circular piece so formed was glued to the bottoms of the tubes in the top circular piece. In the gluing process with the chloroform, it was ensured that the circular pieces were in line with each other. The glued pieces were allowed a period of 24 hours for the glued parts to settle and harden before any further work could be carried out. To form the outer side of the phantom, a sheet of dimensions 13 cm in width and 70cm in length was cut from the 4 mm Perspex sheet. The sawn piece was heated in an oven to a temperature a little bit below the melting point of 160 °C for Perspex. This made the Perspex sheet to become malleable once removed from the oven. The malleable Perspex was wrapped around a metal tube having diameter similar to one of the circular piece forming the bottom or top of the phantom. The cast Perspex was held in place around the metal tube with two cords at each end until the Perspex sheet cooled down to room temperature. The cast Perspex sheet was removed and extra length cut out such that the ends met each other. The cast Perspex sheet was put around the bottom and top circular pieces assembly and the part glued in place with the chloroform. The phantom created was filled with water from the opening created at the bottom of the phantom to check for leakage and places leaking sealed.

Four rods each of dimensions; 120 mm in length and 20 mm in diameter were made from the 40 mm rod. A cross sectional view of one of the rods is shown in figure 3.3B. One of the rods was used to make a holder for 0.6 cc cylindrical Farmer type ionization chamber. A sectional view of this rod is shown in figure 3A. The remaining rods were used as plugs (or inserts) to seal the 20.5 mm holes in the phantom when the holes were

not in use for measurements when the phantom was filled with water. These holes were labeled: "A", "B", "C" and "D" for easy identification.

An applicator holder was also fabricated from Perspex and mounted on top of the phantom with a plastic screw. This was used to hold the applicator(catheter) going to the centre of the phantom in place.

Figures 3.2, 3.3A,3.3B, 3.4A and 3.4B show the dimensions of the phantom, dimensions and cross sectional area of the ionization chamber insert hole, plug, source holder and ionization chamber holder respectively:

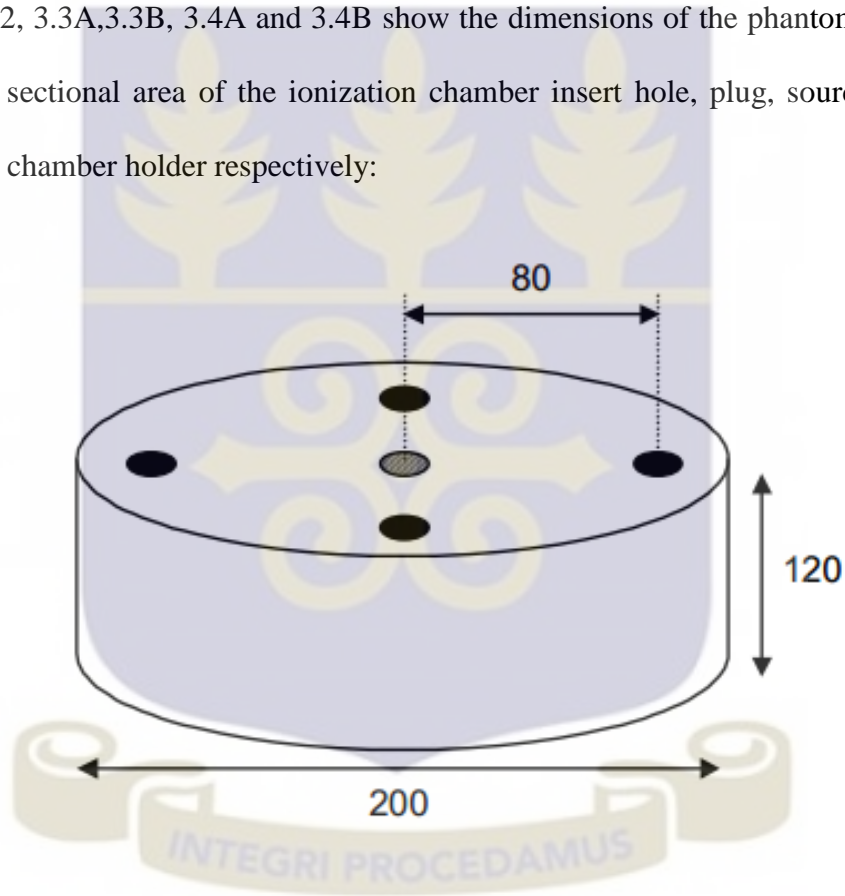


Figure3. 2: Dimensions of the phantom (mm)[11]

with the following components:

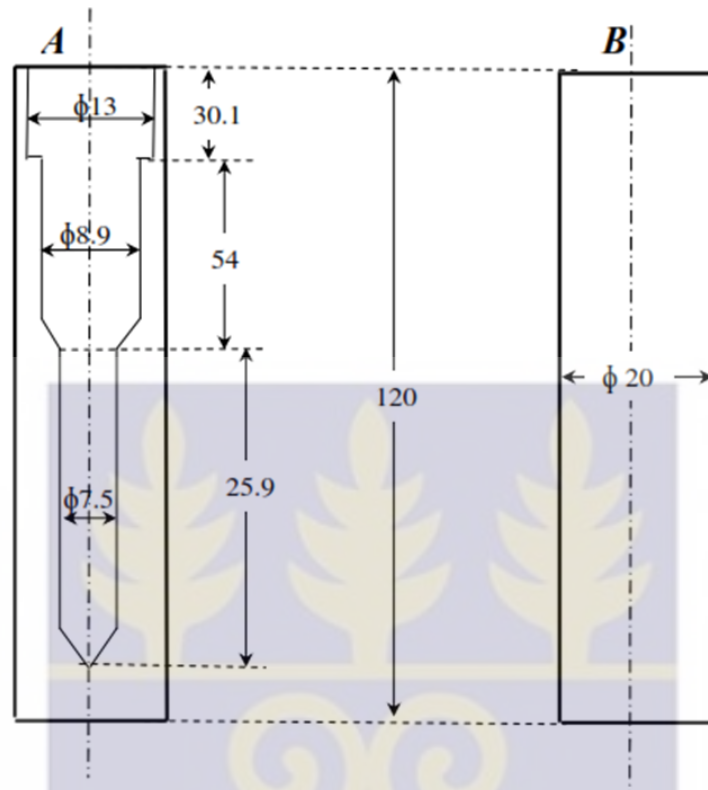


Figure3. 3:Cross sectional view and dimensions of the ionization chamber holder(A) and plug(B)(mm)



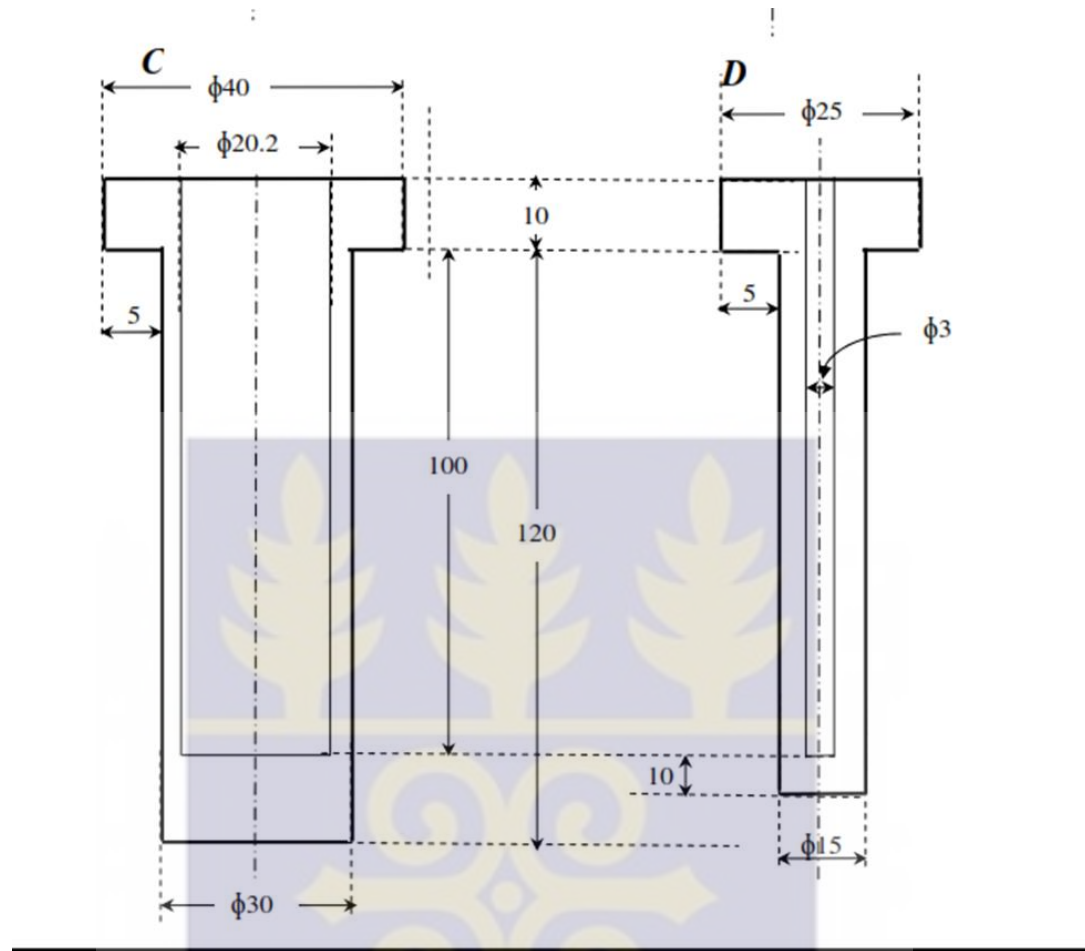


Figure3. 4: crosssectional view and dimensions of ionization chamber insertion hole(C) and source holder (D) (mm)

The individual components were made at a commercial machine shop with the dimensions as specified. It should be noted that the plug and ionization chamber holder dimensions are such that they fit the insertion chamber hole tightly. The ionization chamber holder was made after taking the dimensions of the ionization chamber used.

The components were glued together to produce a phantom as indicated in plate 3.1:



Applicator
holder

Plate 3.1: The locally constructed phantom

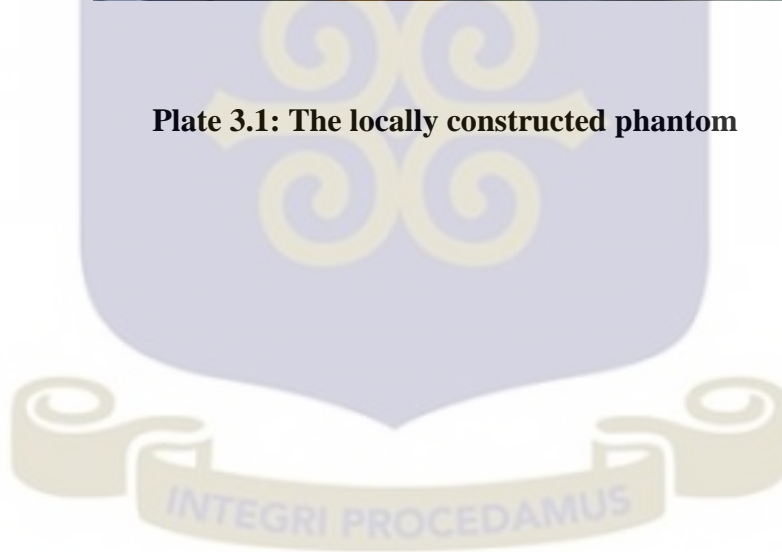




Plate 3.2 : The bottom part of the phantom

3.2 Methodology

3.2.0 Quality Assurance of the HDR Afterloader

Prior to the measurements, quality assurance (QA) tests mandated by the manufacturer of the afterloader machine were performed to check accuracy of source dwell positions as well as the functionalities of source indicator switches and interlocks, and performance of the stepper motors that drive the source and the dummy source. This also calibrates the drive systems. For the QA tests, the afterloader unit comprising its computer was switched on. A guide tube (LAZ20-02) was connected to the drive check connector close

to the channel panel on the HDR afterloader machine and the other end connected to channel 1 (or the channel multiplier). A catheter (or guide tube LAF1000) was connected to channel 2 and the other end connected to the source position indicator (LLH03-03) shown in figure 3.8, which was provided by the manufacturer of the Afterloader machine. The source position indicator was then connected to a monitor at the console area via internet interface such that images captured by the camera attached to the source position indicator were displaced on the monitor. An image obtained through this processes is shown in figure 3.8. On the treatment console of the HDR Afterloader machine computer, operational test option was selected and screen prompts followed to automatically calibrate the dummy source and source drives as well as checking the positioning precision of the source. The source had to approach three dwell points within a tolerance of $\pm 1\text{mm}$.

To initiate treatment, the treatment administration option was selected and treatment plans generated with the HDR plus treatment planning system (from the same manufacturer as afterloader machine) were exported to a shared folder on the afterloader machine computer, which had been linked to the HDR plus treatment planning system by Ethernet connection. The required plan was selected among files within the shared folder and imported into the treatment window for execution of the treatment plan. Fig 3.5 and 3.6 below show the window for the selection of the operational test and treatment administration options.



Figure3. 5: Computer monitor window for selection of operational test tab[43]

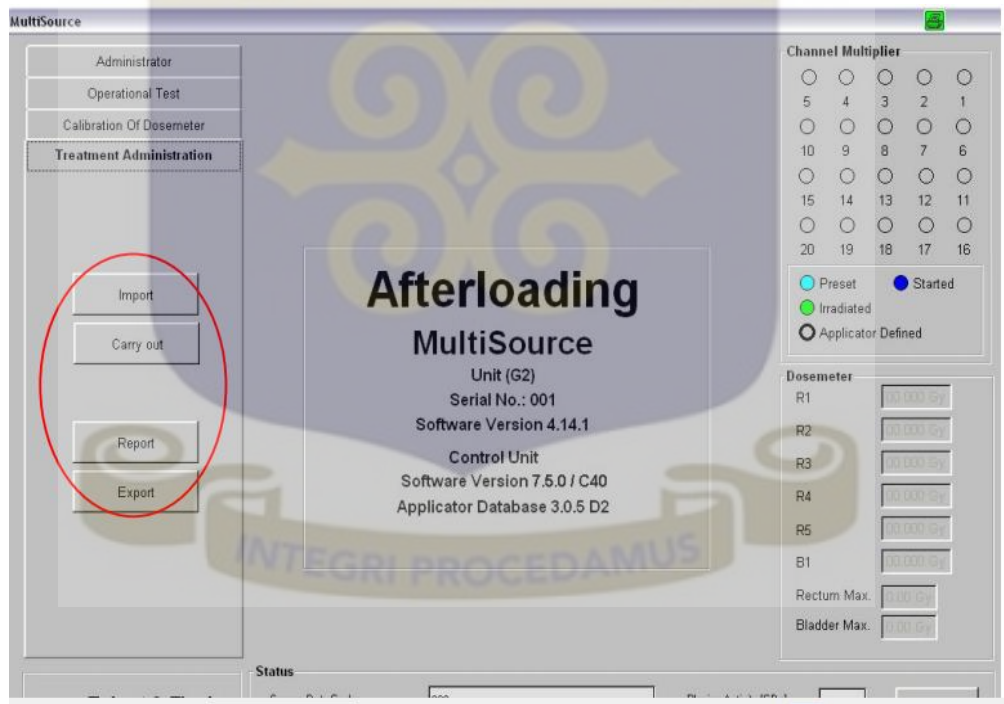


Figure3. 6 Computer monitor window for selection of treatment administration tab[43]

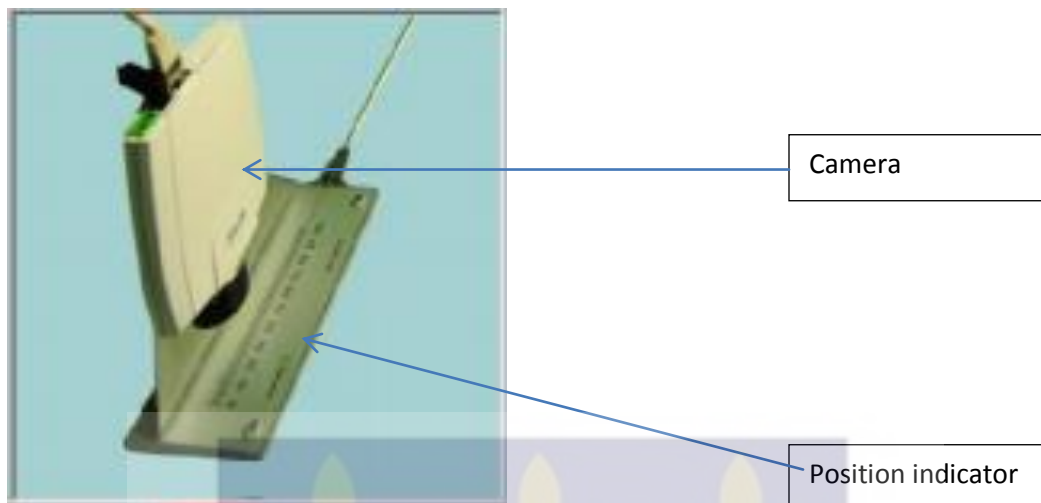


Figure3. 7: Source position indicator (LLH03-03)[43]

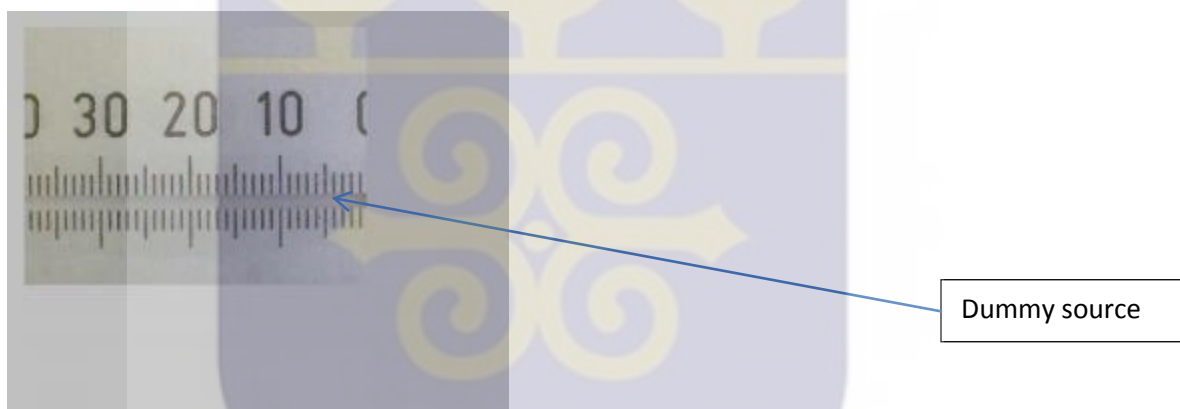


Figure3. 8:Image obtained during source position accuracy test[43].

3.2.1 Measurement of reference air kerma rate

In this study, two methods were employed to measure the reference air kerma rate. The methods are (i) measurement of reference air kerma rate using well type chamber according to IAEA –TECDOC 1274 and DIN6809-2 document, and (ii) measurement of

reference air kerma rate using a Farmer type ionization chamber according to DIN6809-2 in combination with DGMP report 13. The methods are discussed in full below.

3.2.1.0 Measurement of reference air kerma rate using well type chamber.

The well chamber was placed in the treatment room at a height of 1 m above the floor and 1 m away from the nearest walls to minimize scattering effects. An applicator / guide tube was connected to channel 1 of the Afterloader machine and the other end connects to a 3 mm source holder provided by the manufacturer of the Afterloader machine. The source holder was inserted into the well of the HDR 1000 plus well type ionization chamber, which was connected to the MAX 4000 electrometer. It was also ensured that there were no excessive bends in the guide tube to create inaccuracies in the dwell positions. The electrometer was switched on and was allowed to initialize as well as correct for background radiation. While the electrometer was initializing, the well type ionization chamber was left in the room for about one hour before commencement of measurements to allow the chamber to acclimatize to the room condition.

Treatment plan was generated for a treatment length of 10 cm with dwell positions interval of 0.5 cm and dwell time of 20 seconds per dwell position. The applicator used was that used for source strength calibration. The treatment plan was done with HDR plus treatment planning system, and the plan exported to the HDR Afterloader machine's computer for treatment to start. The initial temperature and pressure within the treatment room were measured with a digital thermometer and aneroid barometer respectively prior to the commencement of treatment. The electrometer was set to measure current with a chamber bias voltage of + 300 V, and treatment allowed to start. The maximum

current reading was recorded for each dwell position, and the readings correlated against their respective dwell positions. The dwell position with the highest maximum current reading was found and the reading repeated three times for this dwell position. The measurements were also repeated for chamber bias of voltages of + 150 and - 300 V. The final temperature and pressure within the treatment room were measured at the end of the measurements.

The mean electrometer readings were calculated for each bias voltage. The mean maximum current reading obtained for the chamber bias voltage of +300 V was corrected for air density variations as the chamber used was vented to the environment (refer to section 2.8.7). The corrected reading was used to determine the source strength (refer to section 2.8.4). The mean readings for bias voltages of +150 and -300 were used to determine polarity and saturation effects associated with the chamber (refer to section 2.8.8 and 2.8.9).

Detailed procedure for the calculation of the source strength in terms reference air kerma rate is shown in appendix A2

3.2.1.0.0 Determination of calibration point

Selection of the calibration point as per the IAEA TECDOC 1274 requires that the source be moved vertically from the distal point in the chamber towards the afterloading unit with dwell positions equally spaced to find the position where there is maximum detection. The treatment plan used moved the source from dwell position 0.5cm through 7.0cm at 0.5 cm intervals and at each position the current was recorded. The position where the highest reading was recorded was taken as the calibration point.

3.2.1.1 Measurement of reference air kerma rate using a Farmer type ionization chamber in a locally constructed phantom following the DIN 6809-2 in combination of DGMP report 13

The UNIDOS E electrometer was set to measure charges at 30 seconds intervals with a chamber bias voltage of +400 V. The 0.6 cc Farmer type ionization chamber, which had been inserted into its fabricated adapter was connected to the electrometer. The chamber within its adapter was inserted one after the other into the holes within the locally constructed phantom marked or labeled A, B, C and D during these measurements. These holes were 2 cm from the rim of the phantom, such that the holes; A, B, C and D were at 0° , 90° , 180° and 270° of the top surface of the phantom respectively. The treatment plan generated for the measurements in section 3.2.1 of this chapter was used for these measurements, but the dwell time for each dwell position was change from 20 seconds to 70 seconds. The phantom without being filled with water and plugs removed from the other holes, was set up in the treatment room such that it was both 1 m from the floor and the closest wall. The source applicator or guide tube which was used in the source strength measurements in section 3.2.1.0 of this chapter was connected to channel 1 on the Afterloader machine and the other end inserted into the hole provided for it in the center of the phantom. The applicator holder mounted on the top of the phantom was used to secure the applicator/ guide tube in place. It was once again ensured that there were no excessive bends in the guide tube to create inaccuracies in the dwell positions. The set up was allowed one hour to acclimatize to the room condition, and the initial temperature and pressure readings of the room measured with the digital thermometer and the aneroid barometer respectively. With the chamber in hole "A" of the phantom, treatment was started. For the source at each dwell position, two successive readings

were taken with the electrometer for the set intervals. This was repeated until all dwell positions up to the 10 cm were covered. The chamber was then moved to each of the remaining holes; B, C and D, and measurements repeated. The final temperature and pressure of the room were measured. The average electrometer readings for the various dwell positions per a hole were determined and correlated against the equivalent dwell position. For each hole, the highest averaged electrometer reading was found, and the mean of these values determined for all the holes. By taking measurements for the four holes, possible equatorial anisotropy effects of the source and/or their positioning is nearly averaged. The mean reading was therefore corrected for variation in air density.

The measurements above were repeated with plugs in the remaining holes which did not have ionization chamber inserted in them. The measurements were also repeated with the phantom fully filled with water and the remaining holes which were not in use having plugs in them. In filling the phantom, it was ensured that there were no air bubbles within the phantom. When the phantom was filled with water, six hours were allowed to elapse before measurements were done to allow the phantom to acclimatize to the room temperature.

To determine polarity and saturation effects associated with the ionization chamber, the measurements were repeated for one of the hole at the dwell position that gave the highest reading for that particular hole for the set up with water in the phantom. Readings were obtained each with chamber bias voltage of +400 V, -400 V and 200 V.

Plate 3.3 and 3.4 below show positioning of the plugs and guide tube in the phantom and part of the experimental set up with the phantom, ionization chamber and HDR afterloader respectively:



Plate 3.3: Positioning of plugs and guide tube in the phantom

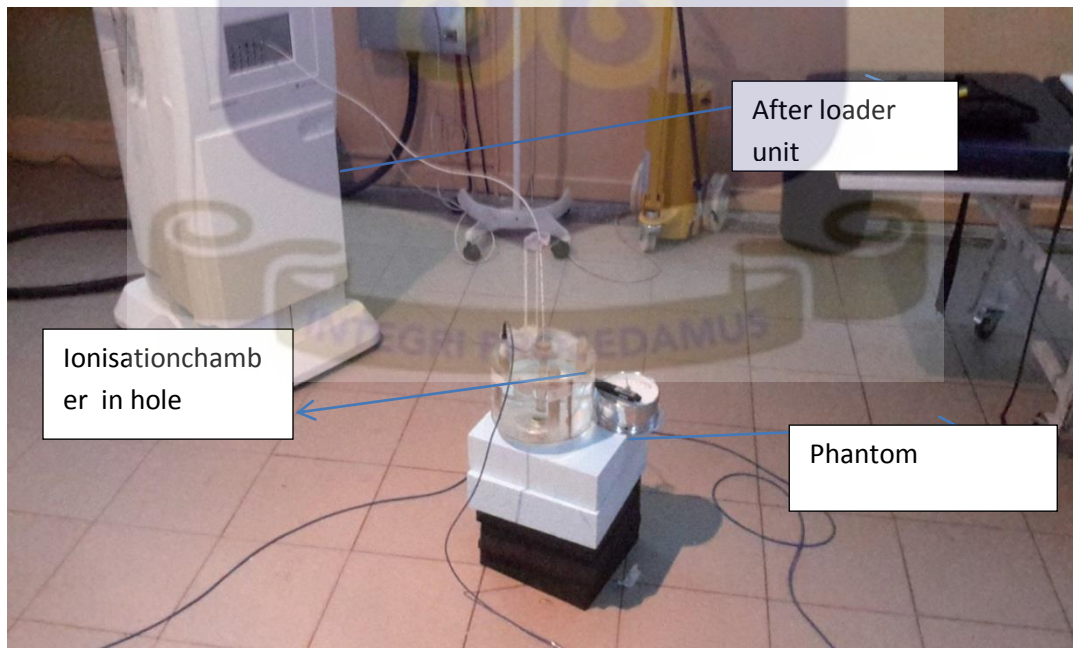


Plate 3.4: Set up of the afterloader, phantom and the ionization chamber

The following were the values which were determined: the air density correction factor, the calibration point and the phantom calibration factor.

3.2.1.2. Calibration point

Selection of the calibration point according to DIN 6809-2 requires that the source moves vertically from the distal point in the source holder towards the afterloading unit with dwell positions equally spaced and where the charge is maximum is to be the designated calibration point. This was done in all the four holes. The calibration point was determined to be the dwell position which provided the highest reading in charge in each hole. The overall calibration point charge was determined by getting the average charge of highest reading in each of the four holes.

3.2.1.3 Phantom calibration factor

This correction factor accounts for the differences in scatter and absorption in the PMMA phantom surrounding the measuring probe in comparison with the free in air conditions. This was determined by the ratio of the average charge at the calibration point with ionization chamber in one hole and the rest of the inserts covered by the plugs and the phantom filled with water to the average charge at the calibration point with ionization chamber in one hole and the rest of the holes covered by the plugs.

3.1.3 Calculation of reference air kerma rate/air kerma strength

Calculation for reference air kerma rate /air kerma strength using the Farmer type ionization chamber in the locally constructed phantom and using the well type ionization

chamber was done using equations 2.8.1 and 2.8.4 respectively. The rest of the values are taken from certificates in appendices B, C and D as well as from literature [4]. Calculation of the uncertainty was using equation 2.8.10. Equation 2.8.11 was used to make for corrections due to radionuclide decay



CHAPTER 4: RESULTS AND DISCUSSIONS

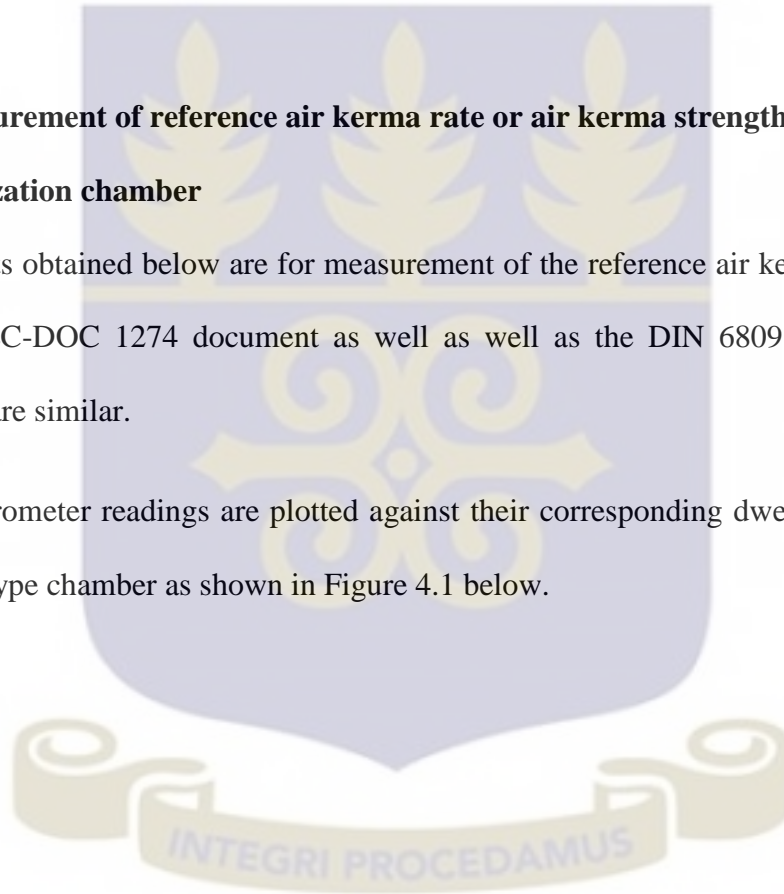
4.0 Results

This chapter contains results of the measured reference air kerma rate/source strength as measured by the farmer type ionization chamber in locally constructed hollow phantom and well type ionization chamber methods.

4.1 Measurement of reference air kerma rate or air kerma strength using a well type ionization chamber

The results obtained below are for measurement of the reference air kerma rate using the IAEA TEC-DOC 1274 document as well as well as the DIN 6809-2 document. The methods are similar.

The electrometer readings are plotted against their corresponding dwell positions within the well-type chamber as shown in Figure 4.1 below.



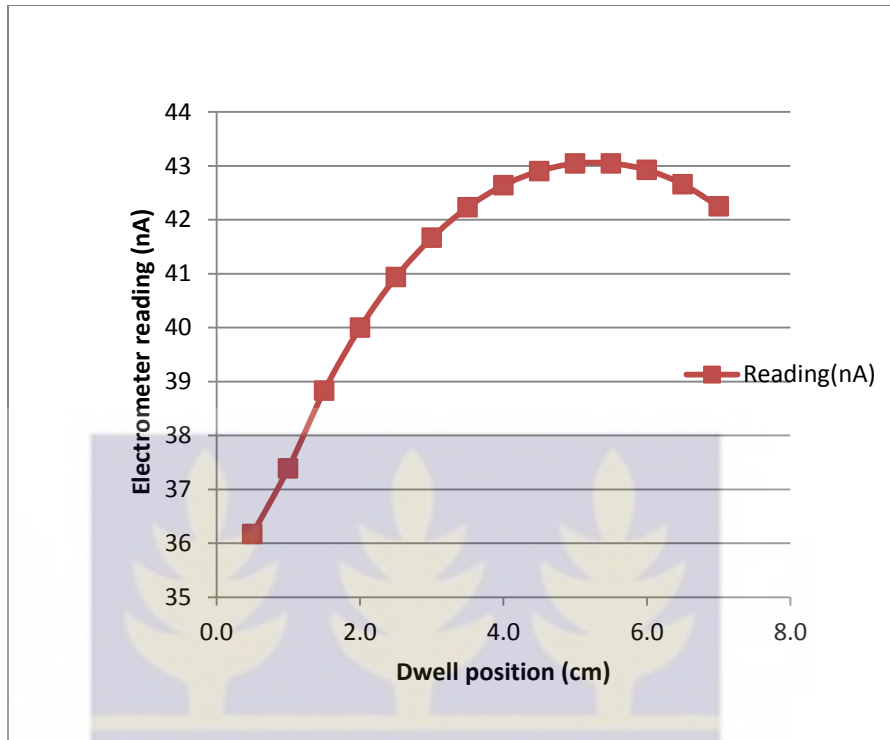


Figure 4.1: Electrometer reading as a function of dwell position within well type chamber

The Table 4.1 below shows values used to calculate the reference air kerma rate using the well type chamber method. The afterloader information was collected from appendix D, conditions during the time of experiment were obtained from Table A.1.0 from appendix A1. The chamber calibration factor is taken from appendix C. The correction factors were calculated using equations 2.8.7, 2.8.8 and 2.8.9. Calculation of the reference air kerma rate was obtained using equation 2.8.4. Appendix A2 shows all the calculations.

Afterloader source data			
	Half life	1925.2	Days
	Reference RAKR	23.21	mGy/h
	Reference date /time	18/07/2014	12:00
Conditions			
	Date of measurement	10/02/2015	10:00
	Air temp	28.4	°C
	Air pressure	1011.5	hPa
	Air Temperature	301.55	K
	Reference Air Temp	295.15	K
	Reference Air pressure	1013.25	hPa
Correction Data	Air Density	1.024	
	Polarity	0.9991	
	Saturation	1.0005	
Reading Electrometer	43.046		nA
Evaluation			
	Calculated RAKR	21.26	mGy/h
	Manufacturer certified RAKR	21.55	mGy/h
Deviation to source certificate		-1.36%	
	Calculated RAKR on 19 th May,2015	20.52	mGy/h

Table 4.1 :Values used to calculate the reference air kerma rate/air kerma strength

4.2 Measurement of reference air kerma rate /air kerma strength using a farmer type ionization chamber in a locally constructed phantom in accordance to DIN 6809-2 in conjunction with DGMP report 13

Plotting graphs of average electrometer meter reading as a function of dwell position was done for all the holes in the locally constructed hollow phantom. Figures 4.2, 4.3, 4.4 and 4.5 below show graphs of the plot of electrometer readings as a function of dwell positions, on the same axes, for each hole in three different set ups, where, (i), the plugs are not fitted into the phantom,(ii),where the plugs are fitted into the phantom and (iii), where the plugs are fitted into the phantom as well as water added to the phantom

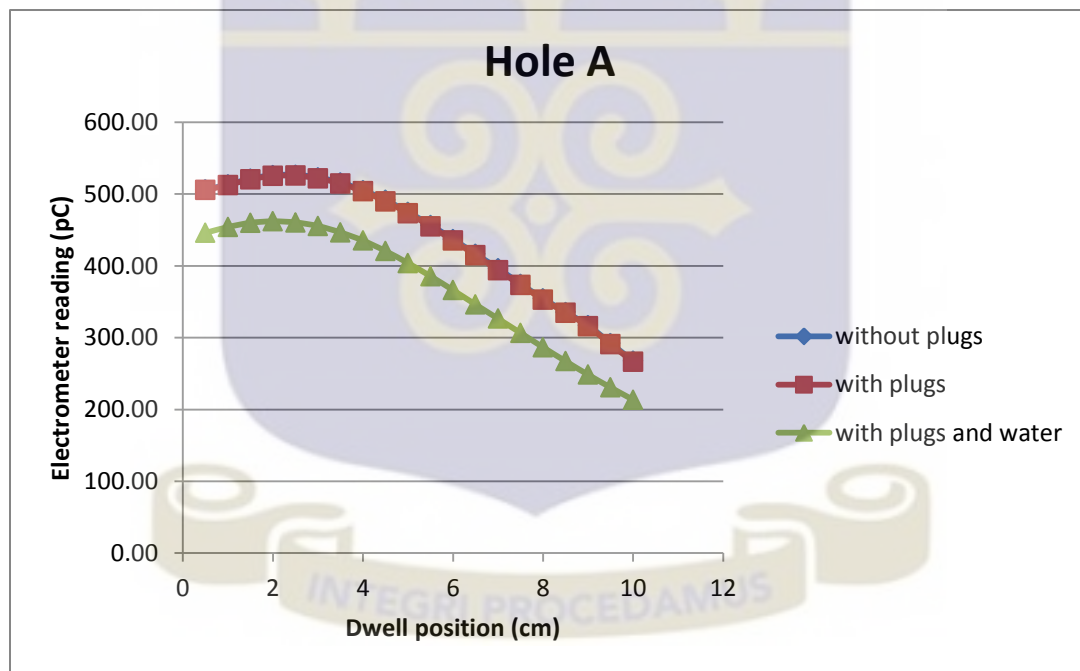


Figure 4.2: Average Electrometer reading as a function of dwell position for insertion hole A

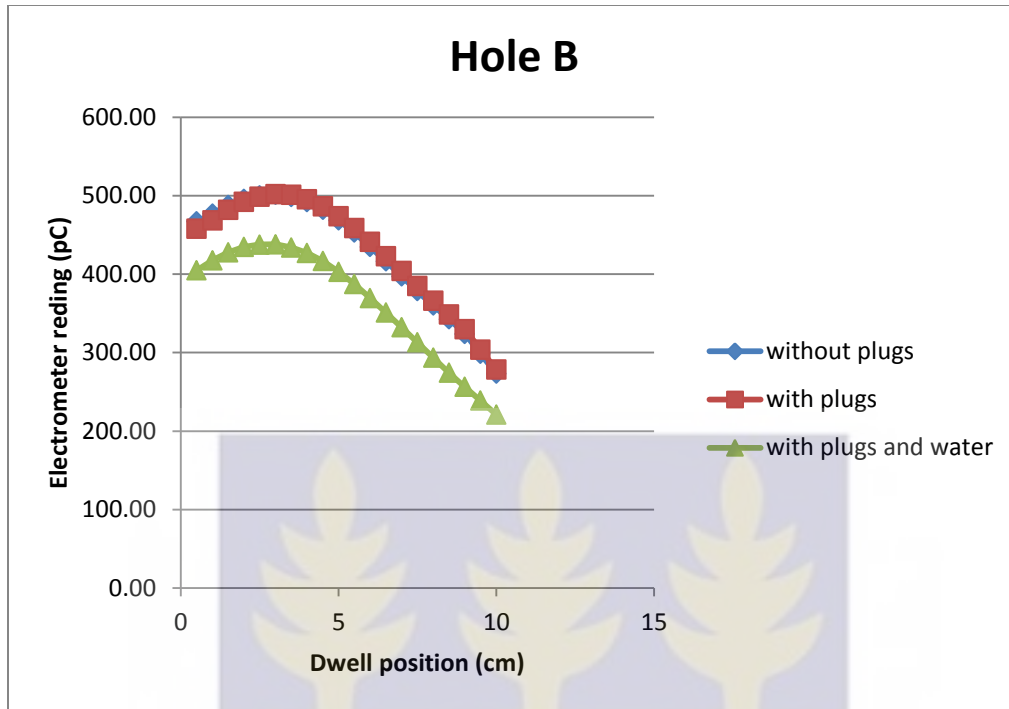


Figure 4.3: Average electrometer reading as a function of dwell position for insertion hole B



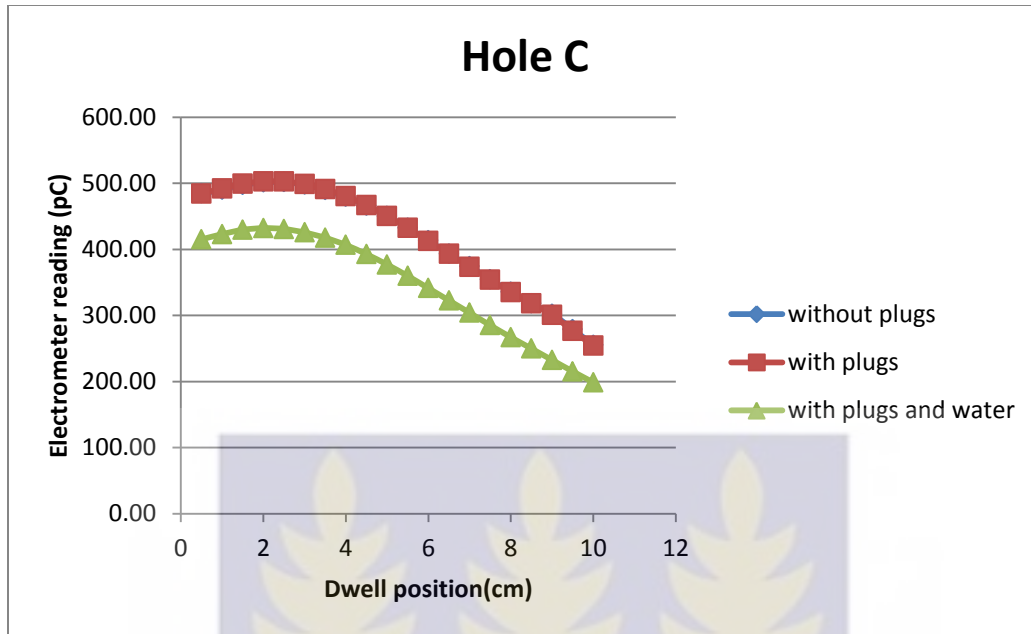


Figure 4.4: Average electrometer reading as a function of dwell position for insertion hole C



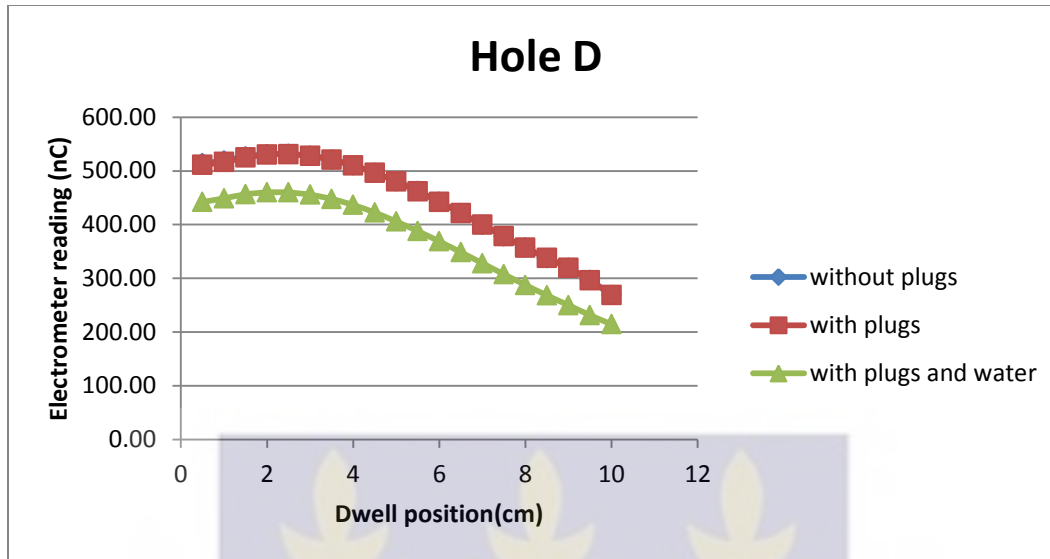


Figure 4.5: Average electrometer reading as a function of dwell position for insertion hole D

Table 4.2 below shows the values to calculate the reference air kerma rate /air kerma strength. The afterloader data is taken from appendix D, conditions during the time of the experiment are taken from Tables A.1.2 and A.1.4 in appendix A1, correction data was taken from Appendix B, using equation 2.8.7 and from literature[4].The reference air kerma rate was calculated using equation 2.8.1.Comparison of the certified source air strength to the calculated source strength was done by using equations 2.8.9 and 2.8.11 . Calculations are in Appendix A3.

Afterloader source data				Remarks
	Half life	1925.2	days	From appendix D
	Reference RAKR	23.21	mGy/h	From appendix D
Conditions	Reference date	18/07/2014	12:00	From appendix D
	/time			
	Date of	19/05//2015		
	measurement			
	Air temp	27.5	°C	
	Air pressure	1011.5	hPa	
	Air Temperature	301.55	K	
	Reference Air Temp	293.15	K	
	Reference Air pressure	1013.25	hPa	
	Measuring time	0.5	min	
Calibration factor	5.402×10^7	Gy/C	From appendix B	
Correction Data	Air Density	1.0256		Using eqn 2.8.7

	Polarity	1.0198		Using eqn 2.8.8
	Saturation	1.015		Using eqn 2.8.9
	Phantom calibration factor	0.869		
	K_Q	1.000		From appendix B
	K_r	0.0064	m^2	$\left(\frac{8}{100}\right)^2$
	g_w	0.0028		From[4]
	K_A	1.027		From[4]
	$t_{w/a}^{en}$	0.9		From[4]
Reading Electrometer Evaluation	0.448		nC	
	Calculated RAKR	20.35	mGy/h	Using Eqn 2.8.1
	Manufacturer certified source RAKR	20.80	mGy/h	Using decay equation 2.8.11
Deviation	to	-2.1%		

source certificate

Percentage 0.8%

difference

between the two

readings

Table 4.2: Values for calculation of reference air kerma rate/source strength

4.3 Discussions

Measurement for reference air kerma rate using the well type chamber was conducted on 10th February, 2015. The calculated reference air kerma rate was found to be 21.26 mGy/h whereas the manufacturer's value of the reference air kerma rate was found to be 21.55mGy/h. The manufacturer's value was found by using the decay equation with the reference date being 18th July, 2014 when the HDR machine was commissioned. The calculated reference air kerma rate measured using the well type deviated from the theoretical value by -1.36%.

Measurement of the reference air kerma rate using a Farmer type ionization chamber in a locally constructed cylindrical hollow phantom was conducted on 19th May, 2015. The calculated value of reference air kerma rate was found to be 20.35mGy/h whereas the theoretical value was found to be 20.80 mGy/h. The calculated air reference air kerma rate using the Farmer ionization chamber in a locally constructed phantom deviated by -

2.1% from the manufacturer's given value. The manufacturer's certified value taking into account the radionuclide decay from the reference date.

The calculated reference air kerma rate measured on 10th February, 2015 was then extrapolated to 19th May, 2015 using the decay equation and it was found to be 20.52mGy/h

Comparison of the air kerma strength as of 19th May, 2015, after using the decay equation for the result found on 10th February, 2015, gives a difference of 0.8% between the results.

4.4 Statement of uncertainties used in the experiment

The measurement set up had some uncertainties in some parameters. Table 4.3 shows the uncertainty as a percentage

Quantity	Relative standard uncertainty in %
Chamber calibration factor	1.25
Pressure	0.2
Saturation factor	0.1
Polarity factor	0.5
Temperature	0.2
Combined uncertainty	±1.38

Table 4.3 Uncertainty in parameters [42]

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The reference air kerma rate found using the well type chamber deviates from the manufacturer's certified value by -1.36% and thus falls within the range of less than 5% of the manufacturer's value. The reference air kerma rate obtained using a Farmer type ionization chamber in a locally constructed hollow phantom deviates from the manufacturer's certified value by -2.1%, thus within less than 5% of the quoted reference air kerma rate[18]. Both methods show that they are capable of giving the reference air kerma rate within reasonable error margins. The locally constructed phantom can be used for calibration of HDR brachytherapy sources and routine quality assurance tests in a clinical set up. The methodology employed in the study can be developed into a step by step guide to be used in brachytherapy centres for calibration of high dose rate cobalt -60 brachytherapy sources

5.2 Recommendations

5.2.1 Brachytherapy centres

The methodology employed in measurement of the reference air kerma rate and locally constructed phantom can be used in facilities that are financially constrained to calibrate sources of high dose rate cobalt-60.

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APPENDIX A1: Tables of Electrometer readings, room temperature, pressure, change of bias voltage and polarity during the experiment.

Table A.1.0 shows the values of the electrometer readings, room temperature and pressure, change of bias voltage and polarity during the experiment using the well type chamber.

Date	10/2/2015				
Temp (°C)±0.1	28.4				
Pressure (hPa)±0.5	1011.5 hPa				
	Voltage	300	-300	300	150
Position(cm)		Reading(nA)			
0.5		36.168			
1.0		37.389			
1.5		38.828			
2.0		39.996			
2.5		40.935			
3.0		41.664			
3.5		42.231			
4.0		42.64			
4.5		42.903			
5.0		43.045			
5.5		43.046	42.971	43.037	42.985
6.0		42.924			
6.5		42.658			
7.0		42.248			

Tables A.1.1, A.1.2 and A.1.3 shows the values of electrometer readings recorded for each hole with temperature and pressure in three different set ups, namely, (i) without the plugs, (ii) with plugs and, (iii) with water and plugs in the phantom respectively

Date: 19/05/2015

Hole

initial

Temperature($^{\circ}\text{C}$) ± 0.1

Initial Pressure(hPa)

± 0.5

Without plugs

	A		B		C		D	
Distance(cm)	1st (pC)	2nd	1st (pC)	2nd	1st (pC)	2nd	1st (pC)	2nd
0.5	506.5	506.6	466.9	467.1	484.7	484.7	514.2	514.5
1	513.0	513.1	477.1	476.9	490.0	490.1	519.2	519.2
1.5	521.1	521.6	487.8	488.1	497.5	497.6	526.9	526.9
2	526.4	526.0	495.8	495.8	501.1	501.5	530.9	531.2
2.5	526.6	526.7	500.2	500.3	501.9	501.6	531.4	531.3
3	523.1	523.2	501.2	501.1	497.7	497.7	527.9	527.9
3.5	515.9	515.7	498.1	498.0	490.1	489.6	520.6	520.6
4	505.3	505.3	491.5	491.6	479.6	479.8	510.0	510.0
4.5	491.7	491.6	481.4	481.8	466.2	465.9	496.6	496.7
5	474.8	474.9	468.2	468.3	450.6	450.2	480.3	480.6
5.5	456.7	456.7	452.7	452.8	432.7	432.6	462.6	462.7
6	437.1	437.1	434.4	434.4	413.5	413.4	442.2	442.1
6.5	416.6	416.6	416.3	416.1	393.5	393.6	421.0	421.2
7	396.9	395.8	397.0	397.3	374.5	374.6	399.1	399.3
7.5	374.8	374.9	378.2	378.2	354.7	354.8	377.8	377.6
8	354.5	354.5	359.9	359.9	335.8	335.7	356.7	356.8
8.5	335.5	335.8	342.5	342.5	318.4	318.4	337.4	337.8
9	317.1	317.1	323.7	323.6	302.3	302.4	319.4	319.4

9.5	292.3	292.3	298.5	298.3	279.2	279.3	296.7	296.5
10	267.5	267.6	272.9	272.9	255.3	255.1	268.6	268.7

Final Temp(°C)±0.1

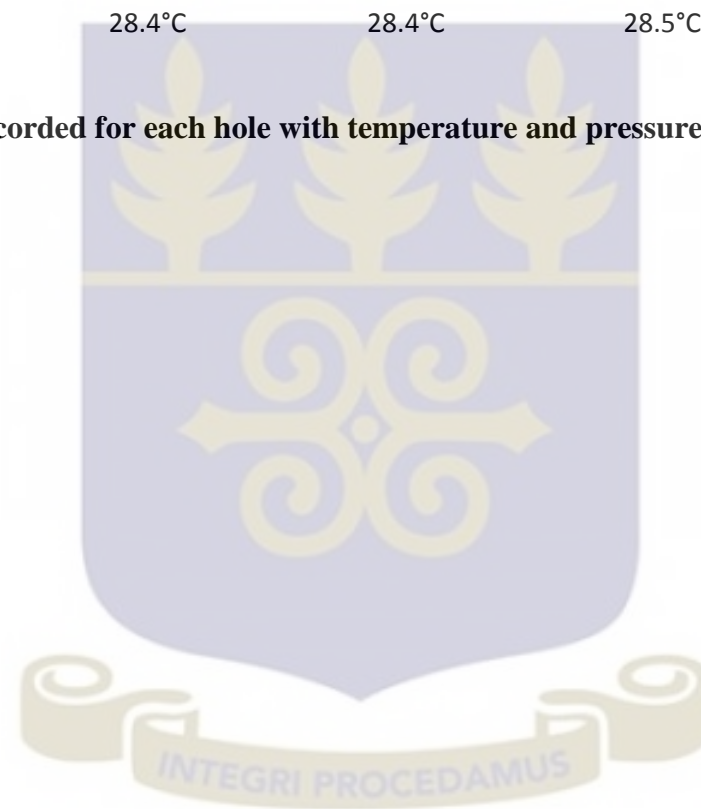
28.4°C

28.4°C

28.5°C

28.2°C

Table A.1.1 Electrometer reading recorded for each hole with temperature and pressure without the plugs



Date: 19/05/2015

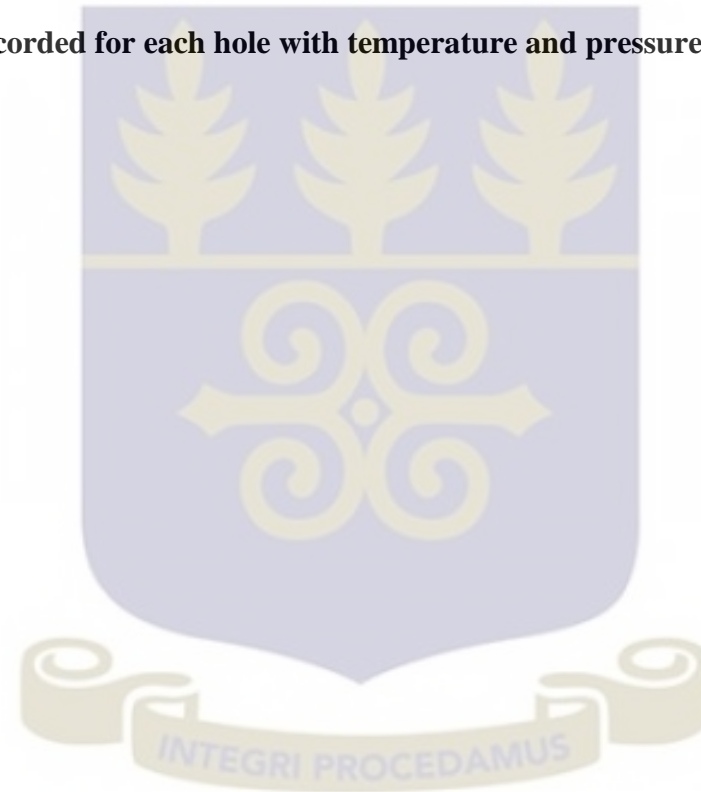
Hole
With plugs

initial
Temperature($^{\circ}\text{C}$) ± 0.1
Initial Pressure(hPa)
 ± 0.5

	A	B	C	D				
initial Temperature($^{\circ}\text{C}$) ± 0.1	28.2 $^{\circ}$	28.2 $^{\circ}\text{C}$	28.2C	28.2 $^{\circ}\text{C}$				
Initial Pressure(hPa) ± 0.5	1011.5	1011.5	1011.5	1011.5hPa				
Distance(cm)								
0.5	505.5	505.7	457.9	457.9	484.3	484.8	511.6	511.6
1	512.6	512.3	468.5	468.6	492.1	492.1	516.5	516.4
1.5	520.5	520.5	481.8	481.6	499.5	499.4	525.3	525.2
2	525.3	525.1	492.1	492.0	502.7	502.9	530.2	530.1
2.5	525.3	525.6	498.6	498.6	502.7	502.7	531.0	531.4
3	521.8	521.8	502.0	501.8	498.6	498.7	528.0	528.2
3.5	514.6	514.6	500.8	500.8	491.3	491.0	521.3	521.0
4	503.8	503.8	495.2	495.0	480.5	480.5	510.1	510.2
4.5	489.6	489.7	486.0	486.4	466.9	466.9	496.6	496.6
5	473.1	473.1	473.5	473.5	450.3	450.3	480.2	480.1
5.5	454.9	454.8	458.6	458.6	432.4	432.4	462.2	462.0
6	435.3	435.2	440.9	440.8	412.9	412.6	442.2	442.4
6.5	414.8	414.7	423.0	422.7	393.1	393.2	421.3	421.3
7	394.0	393.8	403.8	403.7	373.5	373.5	400.0	399.8
7.5	373.3	373.1	384.9	385.0	354.0	353.8	378.6	378.5
8	353.0	352.9	366.1	366.1	335.2	335.2	357.3	357.2
8.5	334.6	334.6	348.5	348.3	318.4	318.4	338.0	338.1

9	315.9	316.2	329.6	329.5	301.2	301.0	319.6	319.6
9.5	290.8	290.6	303.7	303.7	276.6	276.7	296.5	296.4
10	266.5	266.5	278.3	278.3	254.5	254.5	268.7	268.8

Table A.1.2 Electrometer reading recorded for each hole with temperature and pressure for set up with plugs in inserts



Date: 19/05/2015

Hole
With plugs and water

Initial
Temperature($^{\circ}\text{C}$) ± 0.1
Initial pressure(hPa)
 ± 0.5

	A	B	C	D				
Initial Temperature($^{\circ}\text{C}$) ± 0.1	27.5	27	27.5	27.5				
Initial pressure(hPa) ± 0.5	1011	1010.5	1010.5	1011				
Distance								
0.5	445.8	446.0	404.5	404.6	415.1	415.3	442.1	442.3
1	454.0	454.0	417.5	417.4	423.0	423.2	448.9	449.0
1.5	460.0	459.8	427.6	427.4	429.8	429.5	456.5	456.3
2	461.9	462.0	434.3	434.5	432.1	432.2	460.0	460.0
2.5	460.4	460.4	437.6	437.5	430.9	430.8	459.8	459.8
3	455.5	455.3	437.7	437.7	425.6	425.5	455.6	455.8
3.5	446.5	446.5	434.0	433.6	417.7	417.4	447.7	447.9
4	434.9	435.3	426.8	426.7	406.8	406.6	436.5	436.7
4.5	420.6	420.6	416.4	416.4	392.8	392.6	422.5	422.6
5	403.8	403.7	402.7	402.9	377.0	377.1	405.5	405.9
5.5	385.5	385.6	387.1	387.0	359.9	359.7	387.8	388.0
6	366.3	365.9	369.4	369.3	341.3	341.3	368.7	368.8
6.5	346.0	346.1	350.8	350.7	322.9	322.5	348.5	348.8
7	326.5	326.3	332.1	332.0	304.1	304.1	328.1	328.1
7.5	306.7	306.5	312.8	312.8	285.2	285.1	307.6	307.6
8	286.5	286.6	293.5	293.6	267.2	267.0	287.6	287.6
8.5	267.2	267.2	274.3	274.1	249.9	249.9	268.3	268.2

9	248.4	248.4	256.2	256.2	232.6	232.6	250.1	250.0
9.5	230.6	230.7	239.3	238.0	215.4	215.4	231.4	231.5
10	213.5	213.5	220.9	220.8	198.8	198.7	215.5	213.3

Final
Temperature(°C)±0.1

27.0

27.5

27.5

27.5

Final pressure(hPa)

1010.5

1010.5

1011.0

1011.0

Table A.1.3 Electrometer reading recorded for each hole with temperature and pressure for set up with plugs and water in phantom

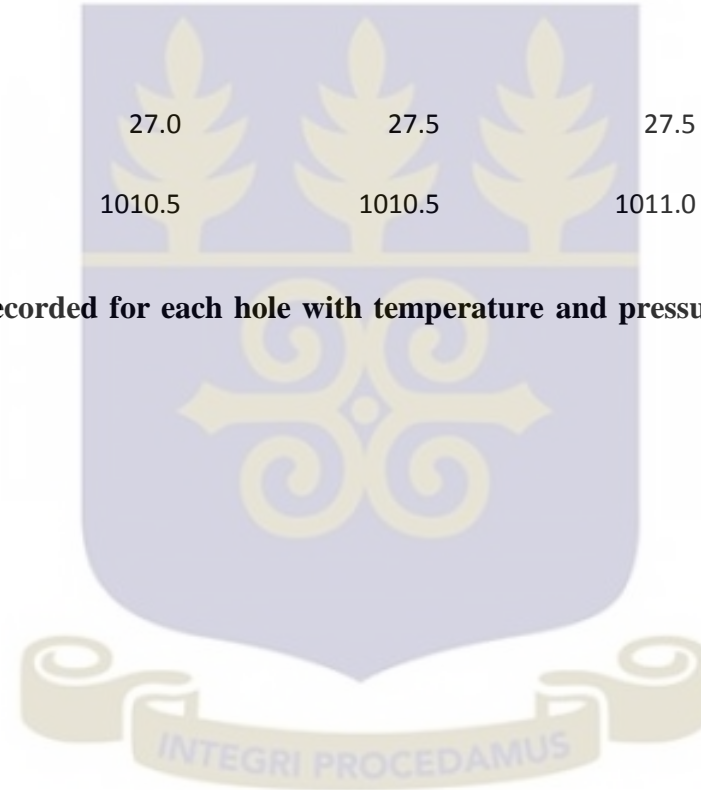


Table A.1.4 below shows the average electrometer reading per dwell position for each hole

Date: 19/05/2015

Hole	A	B	C	D
Initial Temperature(°C)±0.1				
Distance				
0.5	445.90	404.55	415.20	442.2
1	454.00	417.45	423.10	448.95
1.5	459.90	427.50	429.65	456.4
2	461.95	434.40	432.15	460.0
2.5	460.40	437.55	430.85	459.8
3	455.40	437.70	425.55	455.7
3.5	446.50	433.80	417.55	447.8
4	435.10	426.75	406.70	436.6
4.5	420.60	416.40	392.70	422.55
5	403.75	402.80	377.05	405.7
5.5	385.55	387.05	359.80	387.9
6	366.10	369.35	341.30	368.75
6.5	346.05	350.75	322.70	348.65
7	326.40	332.05	304.10	328.1
7.5	306.60	312.80	285.15	307.6
8	286.55	293.55	267.10	287.6
8.5	267.20	274.20	249.90	268.25
9	248.40	256.20	232.60	250.05
9.5	230.65	238.65	215.40	231.45
10	213.50	220.85	198.75	214.4

Table A.1.4 Average electrometer reading as a function of dwell position for each hole

APPENDIX A2: Calculations for reference air kerma rate (RAKR) using a well type chamber

$$K_{pol} = \left(\frac{[M_+] + [M_-]}{2M_+} \right) \dots\dots\dots \text{Eqn 2.8.8}$$

$$= \frac{43.046 + 42.971}{2 \times 43.046}$$

$$= 0.9991$$

$$K_{sat} = \frac{\left(\left(\frac{V_1}{V_2} \right)^2 \right)^{-1}}{\left(\left(\frac{V_1}{V_2} \right)^2 \right) - \left(\frac{M_1}{M_2} \right)} \dots\dots\dots \text{Eqn 2.8.9}$$

$$= \frac{\left(\left(\frac{300V}{150V} \right)^2 - 1 \right)}{\left(\left(\frac{300V}{150V} \right)^2 - \frac{43.096}{42.985} \right)}$$

$$= 1.005$$

$$K_{TP} = \frac{(273.15 + T_{measured})}{273.15 + T_{ref}} \times \frac{1013.15}{P_{measured}} \dots\dots\dots \text{Eqn 2.8.7}$$

$$= \frac{(273.15 + 28.4)}{273.15 + 22} \times \frac{1013.15}{1011.5}$$

$$= 1.024$$

RAKR = $K_{TP} \times K_{pol} \times k_{sat} \times \text{calibration factor} \times \text{Average Electrometer reading}$..Eqn 2.8.1

$$= 1.024 \times 0.9991 \times 1.005 \times 4.824 \times 10^5 \text{ Gy/hA} \times 43.046 \text{ nA}$$

$$= 21.26 \text{ mGy/h}$$

Calculation of manufacturer's RAKR

$$\begin{aligned}K_{\text{ref}}(t_o) &= K_{\text{ref}}(t_m) \times \exp\left[-\ln(2) \times \frac{t_o - t_m}{T_{1/2}}\right] \dots\dots \text{Eqn 2.8.11} \\&= 23.21\text{mGyh} \times \exp\left(-\ln 2 \times \frac{207}{1925.2}\right) \\&= 21.55\text{mGy/h}\end{aligned}$$



APPENDIX A3: Calculation of reference air kerma rate (RAKR) using a Farmer type chamber in a locally constructed phantom

$$K_{TP} = \frac{(273.15 + T_{\text{measured}})}{273.15 + T_{\text{ref}}} \times \frac{1013.15}{P_{\text{measured}}} \dots\dots\dots \text{Eqn 2.8.7}$$

$$= \frac{273.15 + 27.5}{273.15 + 20} \times \frac{1013.15}{1011}$$

$$= 1.0256$$

Average Electrometer reading from Table A.1.4

$$\text{Electrometer reading}_{Av} = \frac{\text{Highest reading}_A + \text{highest reading}_B + \text{highest reading}_C + \text{highest reading}_D}{4}$$

$$= (461.95 + 437.7 + 432.15 + 460)/4$$

$$= 448\text{nC}$$

$$K_{\text{pol}} = \frac{448\text{nC} + 465.74\text{nC}}{2 \times 448\text{nC}}$$

$$= 1.0198$$

$$K_{\text{sat}} = \frac{\left(\frac{400}{200}\right)^2 - 1}{\left(\left(\frac{400}{200}\right)^2\right) - \frac{448}{471.87}}$$

$$= 1.015$$

Reference air kerma rate calculation

$$K_R[\text{mGy/h}] = \frac{1}{(1-g_w)} \times \frac{1}{t_{w/a}^{en}} \times k_{wp} \times k_{zp} \times k_r \times k_T \times k_A \times k_p \times k_S \times k_r \times k_Q \times N_w \left[\frac{\text{mGy}}{\text{nC}} \right] \times M[\text{nC}], \dots\dots\dots \text{Eqn 2.8.1}$$

$$\begin{aligned}
 &= \frac{1}{(1 - 0.0028)} \times \frac{1}{0.9} \times 1.0 \times 0.869 \times 0.0064 \times 1.027 \times 1.0256 \times 120 \times 1 \times 1.015 \\
 &\quad \times 1.0198 \times 5.402 \times \frac{10^7 \text{ Gy}}{c} \times 448\text{pC} \times \frac{28.5}{27.5} \times \frac{1012.5}{1011.5} \\
 &= 20.35\text{mGy/h}
 \end{aligned}$$

Calculation of manufacturer's RAKR

$$\begin{aligned}
 K_{\text{ref}}(t_o) &= K_{\text{ref}}(t_m) \times \exp\left[-\ln(2) \times \frac{t_o - t_m}{T_{1/2}}\right] \dots\dots \text{Eqn 2.8.11} \\
 &= 23.21 \times \exp\left[-\ln 2 \times \frac{305}{1925.2}\right] \\
 &= 20.80\text{mGy/h}
 \end{aligned}$$

Calculation of RAKR on 19th May, 2015, using the RAKR calculated on 10th February using the well type chamber

$$\begin{aligned}
 K_{\text{ref}}(t_o) &= K_{\text{ref}}(t_m) \times \exp\left[-\ln(2) \times \frac{t_o - t_m}{T_{1/2}}\right] \\
 &= 21.26\text{mGy} \times \exp\left[-\ln 2 \times \frac{98}{1925.2}\right] \\
 &= 20.52\text{mGy/h}
 \end{aligned}$$



APPENDIX B: Calibration certificate of Farmer type ionisation chamber

CALIBRATION CERTIFICATE  **PTW**

No. 1401849

PTW-Freiburg, Lörracher Str. 7, 79115 Freiburg, Germany ☎ +49-(0)761- 49055-0 FAX +49-(0)761- 49055-70 E-Mail info@ptw.de

Calibration Object

Radiation Detector

Detector [REF] TM30010-1 [SN] 000820
 Detector Type Ionization Chamber

Manufacturer PTW-Freiburg
 Customer  Sweden Ghana Medical Centre Ltd
 GH- Cantonments, Accra

Order No. : R141284
 Order Date : 2014-04-30

Calibration Results

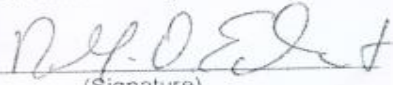
Measuring Quantity Absorbed Dose to Water (D_w)

Detector Calibration Factor $N_{D,w} = 5.402 \cdot 10^7 \text{ Gy} / \text{C}$

Beam Quality Correction	Beam Quality	Correction Factor k_Q	Uncertainty
	^{60}Co	1.000	1.1 %



Reference Conditions	Beam Quality: Temperature: Air Pressure: Relative Humidity: Chamber Voltage/Polarity: Ion Collection Efficiency:	⁶⁰ Co 293.2 K (20°C) 1013.25 hPa 50% + 400 V 100 %
Calibration Date	2014-04-30	
Recalibration Interval	2 years (recommended).	

Freiburg, 2014-04-30	PTW-Freiburg Physikalisch-Technische Werkstätten Dr. Pychlau GmbH
	 (Signature)

Page 1 / 2

PTW Page 2 / 2 of Calibration Certificate No. 1401849

Calibration Conditions and Set-up

Climatic Conditions	Temperature Range:	(294.2 ± 3) K / (21 ± 3) °C
	Air Pressure Range:	(1000 ± 50) hPa
	Rel. Humidity Range:	(40 ± 20) %

Beam Quality and Geometry	Quality	Filter [mm]	HVL [mm]	SDD [cm]	Size [cm]
	⁶⁰ Co	-	-	100	10 x 10

Quality: Beam qualities according to DIN 6809-5 / DIN 6809-4
 Filter: Total filtration (inherent and additional filters)
 HVL: Half value layer at the point of measurement
 SDD: Distance between radiation source and reference point
 Size: Field size at reference point, diam. = Field Diameter
 Reference depth: 5 g cm⁻² H₂O

Detector Arrangement	Chamber axis perpendicular to radiation beam axis Line on chamber stem faced towards the radiation source Reference point position at stated measuring depth / distance to the radiation source (For further information see manual and data sheet of detector.)
Dose and Dose Rate	Absorbed Dose To Water : min.: 5.0 · 10 ⁻² Gy / max.: 5.0 Gy Absorbed Dose To Water rate : min.: 50 mGy/min / max.: 300 mGy/min
Polarity Effect	≤ 0.2 % (not accounted for in the detector calibration factor)
Saturation Correction Factor	k _s = 1.000
Leakage	Negligible during calibration

Remarks

1. The uncertainty stated corresponds to the double standard deviation ($k=2$). The standard deviation was calculated according to ISO GUM from the partial uncertainties arising from the standard used, the calibration procedure, the environmental conditions and short time effects of the object of measurement. The uncertainties stated are composed of the uncertainties of the calibration procedure and those of the specimen during calibration. A share for the long-term instability of the object under calibration is not included.
2. The calibration is traceable to national standards of the German National Laboratory, PTB, Braunschweig. This calibration certificate may not be reproduced other than in full except with the permission of the issuing laboratory. This certificate is valid only with the ionization chamber showing the intact sticker with the certificate number. Calibration factors of chambers having been opened for repair are not comparable to previous calibrations. Calibration certificates without signature are not valid.
3. The components of the calibration object fully comply with the respective specifications given in the data sheet and user manual.
4. The calibration factor presented in this certificate can be equally used for Absorbed-Dose-To-Water determination with dosimetry protocols IAEA TRS 398, AAPM TG-51 und DIN 6800-2. However, it must be guaranteed that the reference temperature given in this certificate is in agreement with the reference temperature of the chosen dosimetry protocol. In the case of disagreement of reference temperatures an appropriate correction of the presented calibration factor with respect to the dosimetry protocols reference temperature must be applied.



APPENDIX C: Calibration certificate for the Well type chamber



Certificate of Factory Calibration and Quality
HDR 1000 Plus Well Chamber

Well Chamber Information

Well Chamber Model : HDR 1000 Plus
REF : 90008
Serial Number : A083262

Manufacturer : Standard Imaging, Inc.
3120 Deming Way
Middleton, WI 53562 USA

Calibration Information

Calibration Date : November 25, 2006
Uncertainty (k=2) : ± 3.0%

Calibration Coefficient : Air Kerma Strength (Gym²/h/A)
4.824E+05
Source Type : ⁶⁰Co High Dose Rate Brachytherapy Afterloading source
manufactured by Eckert & Ziegler Bebig GmbH

This certifies that the product(s), identified:

1. Was calibrated at Standard Imaging, with the calibration traceable to the United States National Institute of Standards and Technology (NIST).
2. Was designed, manufactured and distributed within a quality management system certified to ISO 9001:2008 and ISO 13485:2003, by Intertek-SEMKO.
3. Was listed with the FDA, and designed, manufactured and distributed within a FDA registered quality management system deemed compliant with 21CFR820 (cGMP/QSR).
4. Conforms with EU CE-MDD Annex II, as certified by Intertek-SEMKO.
5. Has been calibrated to the correlated conditions of the ⁶⁰Co High Dose Rate Brachytherapy Afterloading source manufactured by Eckert & Ziegler Bebig GmbH, with temperature and pressure corrected to 22 C° and 760 mm Hg, which resulted in the stated parameters.




Reviewed By _____ Title _____ Date _____

Doc. No. 4766-02 , 07/17/2014
Page 1 of 1

STANDARD IMAGING, INC. 3120 Deming Way, Middleton, WI 53562-1181 800-361-4466 608-831-0275 fax 608-831-2102 www.standardimaging.com

ADVANCING RADIATION QA™

Appendix D: Certificate showing source strength of the Cobalt-60

Zertifikat für umschlossene radioaktive Stoffe (Afterloader-Quellen) Certificate for sealed radioactive sources (afterloading sources)					Eckert & Ziegler
Allgemeine Angaben general information					
Zertifikat-Nr. certificate no. 62414	Kunde customer Teaching Hospital Accra, Ghana			Auftragsnummer order no. BBD-SO-13-00476	
Produkt-Code product code Co0.A86	Quellennummer (Bezeichnung als Hochradioaktive Quelle) source no. (high-activity-sealed-source no. - HASS) BB-AC 547			zertifiziert als radioakt. Stoff in besonderer Form special form certificate RUS/5900/S-96	
Nuklid nuclide Co-60	Nominalaktivität nominal activity [GBq] 74	Betriebsbeschränkung [Zyklen] limitation of use [transfers] 100 000	empfohlene Nutzungsdauer ^a recommended working life ^a 5 years	ISO-Klassifikation ISO- classification C65444	
Mess- und Prüfbericht weitere Informationen siehe Rückseite test report see over leaf for more information.					
Referenz Luftkerma Leistung ^b Reference air kerma rate ^b	scheinbare Aktivität ^c apparent activity ^c		Referenzdatum reference date ^d		
[mGy/h]	[GBq]	[Ci]			
23.21	75.85	2.05	2014-07-18		
Sichtprüfung visual test	Dichtheitsprüfung leakage test		Kontaminationstest contamination test		
Datum date passed	Datum date passed		Datum date passed		
2014-06-26	2014-06-26		2014-06-26		
Bemerkungen, Anlagen notes, annexes					
Datumsformat: jjjj-mm-tt Date format: yyyy-mm-dd					
INTEGRI PROCEDAMUS					
Dieses Zertifikat entspricht den Anforderungen nach ISO 2919 This certificate complies with the requirements of ISO 2919					
Ausstellungsdatum date of issue	2014-07-18	Unterschrift signature		Name name	Jannett Dullin
Eckert&Ziegler BEBIG GmbH•Robert-Rössle-Str.10•13125 Berlin•Germany•Tel.+49-30-941084-0•Fax +49-30-941084-112•e-mail: info@bebig.eu					
P09F011 / Rev. 07					

Absolute Dosimetry using Well type chamber

Customer	Accra / Ghana		
Afterloader	Bebig MultiSource		
Source Data	Source Type	Cobalt60	
	Product Code	Co0.A86	
	Serial Number	BB-AC 547	
	Half-life	1925.2	days
	AKR-constant (in certificate)	0,306	mGy / (h * Gbq)
	Source strength	23,21	mGym ² /h
	Reference date/ time	18.07.14	12:00
	Apparent Activity	75.85	Gbq
Detector Data	Type of Probe	WellChamber	200cm ³
	Serial no. of Probe	A083262	
	Calibration Factor Nw	4,824E+05	Gym ² /h*A
	Multimeter Type	SI	
Conditions	Date of Measurement	06.10.14	11:00
	Air-Temperature t	28,20	°C
	Air-Pressure p	101000	Pa
	Air-Temperature T	301,35	K
	Ref. Air-Temp T0	295,15	K
	Ref. Air-Pressure P0	101325	Pa
Correction Data	Air-Density Correction K(pT)	1,024	
Reading Electrometer	45,148	nA	
	Mean Current at Maximum point		nA
Evaluation	Calculated Source strength	22,31	mGy*m ² /h
	Certified Source Strength	22,55	mGy*m ² /h (at date of measurement)
		-0,243	mGy*m ² /h (at date of measurement)
Deviation to Source Certificate:		<u>-1,08%</u>	

Acceptance Test Passed

INTEGRI PROCEDAMUS

 Eckert & Ziegler

Date & Signature:

06.10.14