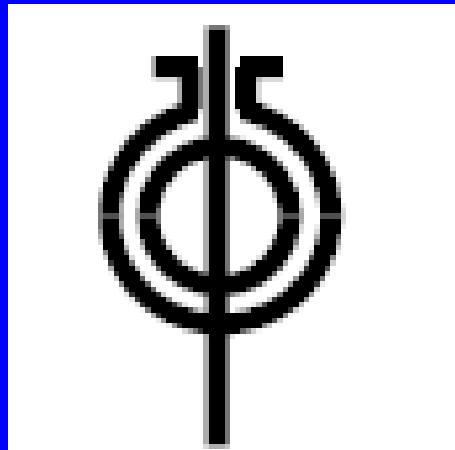


ACPSEM

Australasian College of Physical Scientists and Engineers in Medicine

TRAINING,
EDUCATION
&
ACCREDITATION
PROGRAM
PORTFOLIO



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The ACPSEM is to advance services and professional standards in medical physics and biomedical engineering for the benefit and protection of the community.

DECLARATION

The content in this portfolio was based on the progress of clinical training in the oncology department of Palmerston North hospital in New Zealand. The training and portfolio preparation followed the guidelines provided by ACPSEM and other organizations:

1. ACPSEM, Syllabus for the Radiation Oncology Medical Physics Training Program V2.7, 2005.
2. ACPSEM, Knowledge and Competencies Required By Radiation Oncology Medical Physicists V3.2, 2005.
3. IAEA, Clinical Training Guide Modules, 2007.
4. AAPM, Essentials and Guide lines for Hospital-Based Medical Physics Training Programs, AAPM Report No.36, 1990.
5. ESTRO/EFOMP, Guidelines for education and training of medical physicists in radiotherapy Recommendations from an Estro/EFOMP working group. Radiotherapy and Oncology 70, 125(2004).

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“The best way to learn something is by hands and brain.”
.....Aitang Xing.

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TRAINING SUMMARY

This executive summary of my TEAP training covers history of training, motivation of training, training methodology, development and coverage of portfolio.

Training history

I started TEAP training on 02/2005. 2009 is the fifth year of my training.

1. I finished studying of six medical physics courses in University of New Zealand from 02/2005 to 11/2005. On average, **A** was achieved. For the key courses such as Physics of radiotherapy and medical physics, I got **A⁺**. **A** for medical imaging and anatomy and physiology.
2. I start my clinical training in Palmerston North Hospital from 11/2005 till 2009. As stated in declaration, the training follows ACPSEM documents covered all modules.
3. I submitted my M.S.thesis on 08/2007 and was reviewed by two thesis examiner: Dr. Jergon, senior lecturer, University of Canterbury, New Zealand and Prof. Bhdatt Paliwal, Director of The Wisconsin Clinical cancer center of the University of Wisconsin, USA. **A⁻** was awarded to my thesis. I graduated in 02/2008 with first class honors and got my degree in clinical medical physics within one and half year.
4. I sat and passed Session1 and Session2 theoretical exams on 03/2008 and 09/2009, respectively.
5. In final year 2009, ACPSEM approved and will arrange my practical and oral exam.

Motivation

“ No matter where I am going to work after qualified, I need real knowledge, real experiences and real skills, not just passing the exams to get accredited.” I need a broad and in-depth knowledge covered in each training

modules to work independently as a medical physicist. I need the competitive practical skills and experiences covered in each module competence to work independently as a medical physicist.

This is the motivation of my clinical training.

Because I am highly motivated, I always want to learn more and do more in my clinical training. Because I am highly motivated, I work so hard during my training. I spend almost every weekend and 90% of nights working in radiotherapy department for my clinical training.

Methodology

“ Theoretical knowledge and indirect experience guide the clinical practice, the direct practices achieve the practical experiences and skills, and also deepens the understanding of knowledge.”

This is methodology of my clinical training.

Specifically, the in-depth and broad knowledge of each training module were achieved by extensively self-studying of reading list recommended by each training module, the teaching lectures given by medical physicist and other professions, numerous discussion with medical physicist, extensively and comprehensively reading of published papers related to subject of each training module and by the attending external training courses.

As an example, Fig.1 shows the published papers I read, which is related to the dosimeters and their applications for the module of radiation dosimetry. From studying these papers, not only the in-depth knowledge about dosimeter's characteristics and their calibration, but also the indirect experience is gained regarding the cautions and pitfalls of how to use them.

However having knowledge of a subject and a procedure from published papers, protocols, and guidelines is just to know what and how to do. The practical experiences and skills can only and were achieved by doing but not by reading or studying. For the competency covered in each training module, practical experience and skills were gained by doing routine works, by doing real clinical projects and by doing a series of projects designed for training.

For example, calibrating photon and electron beam is one of basic task and competency of medical physicist. The practical and skills were achieved by weekly reference dosimetry as a routine work. The procedure and cautions regarding how to cross calibrate the chamber are described in details in IAEA TRS398. However, the practical skills and experiences can only be gained by calibrating a chamber. On the other hand, the practical experiences deepens the understanding of concept and procedure of cross-calibration. This specific example illustrates general methodology used for my clinical training.

Portfolio development

For each module, a large number of projects were did to cover the competencies listed in competency document. Each project I did was recorded in my training logbook. The logbook recorded the detail of each project. The logbook recorded the date and time when the project was did, the purpose of project, the materials and procedures used for the project, more importantly, the results. The project is either a real clinical project aiming at solving the problems encountered in clinic, or a project designed for training, or a research project or a routine work.

The whole portfolio was developed based on the records of my logbooks. I used logbook as a working diary from the beginning of my clinical training. Until now I have 13 logbooks, as shown in Fig.2. Each logbook is labeled with the period and volume number. Because the limited space of portfolios, I picked up one or a few projects to write the reports for each training module.

Portfolio coverage

The clinical training was based on the ACPSEM syllabus V.2.7 and ACPSEM competency V.3.2 since the beginning of my clinical training. The IAEA guidelines for each module were also extensively referenced. Therefore the clinical training and portfolio covers the following 10 modules: clinical rotation, radiation dosimetry, radiotherapy equipment and QA, radiotherapy treatment planning, brachytherapy, radiation safety, clinical study, radiobiology, anatomy and biology, profession awareness and communication.

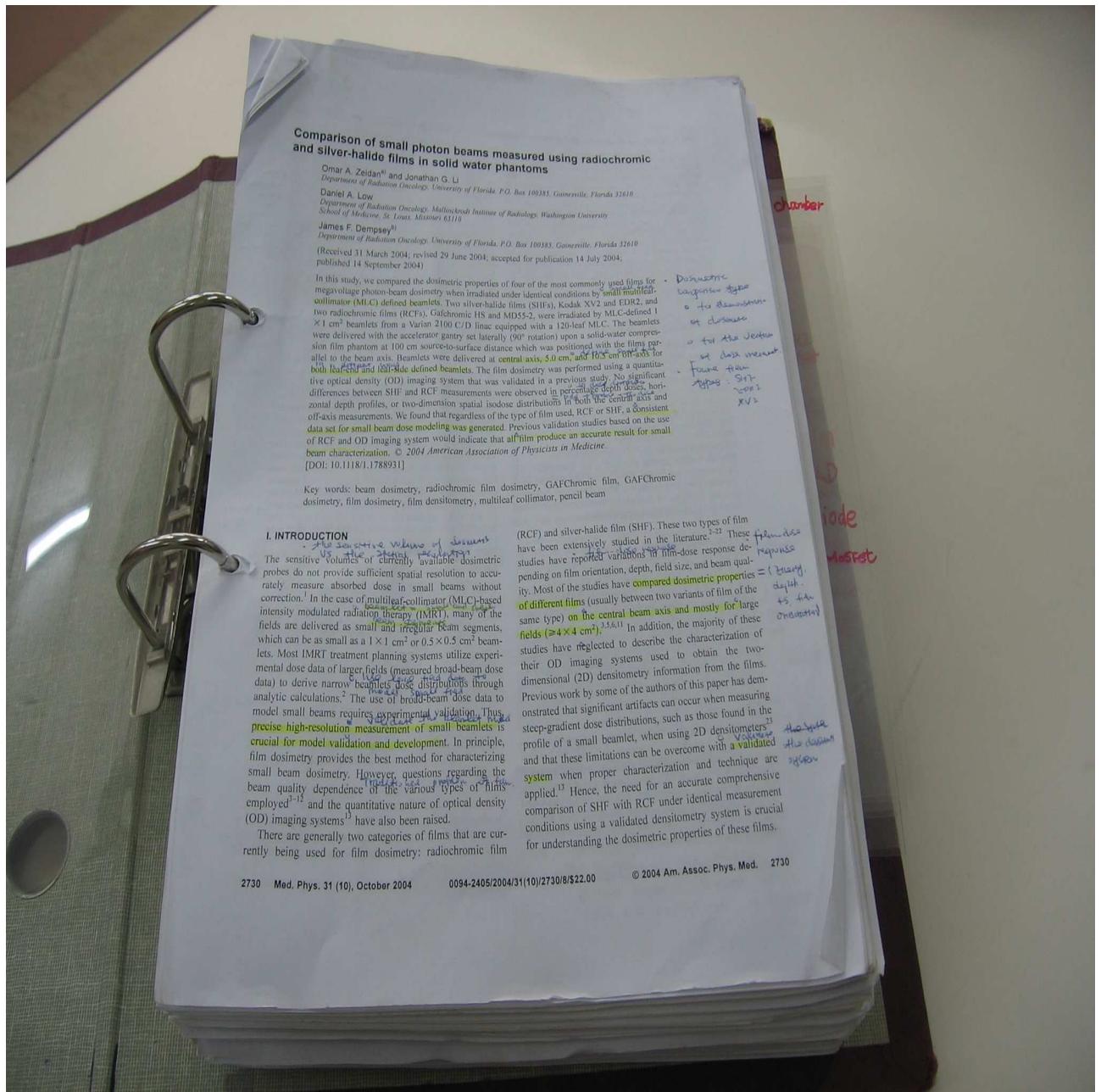


Figure 1: The published papers I read on the dosimeters and their application for the module “Radiation dosimetry”.



Figure 2: The portfolio was developed based on 13 logbooks.

ACADEMIC TRANSCRIPTS

COMPETENCY CONFIRMATION

COURSE, MEETING AND SEMINARS

External courses and Seminars

1. ESTRO Teaching course on “**Dose Calculation and verification for external beam therapy**”, Dublin,Ireland, 20/04/2008-24/04/2008.
2. ESTRO Teaching course on “**Physics for clinical radiotherapy**”, Limassol, Cyprus, 21/10/2007-25/10/2008.
3. NZ registrar workshop on “**HDR brachytherapy with Varian source**”, Wellington, New Zealand, 14/05/2007-17/05/2007.

National and international conferences

1. EPSM-ABEC 2008 conference, Christchurch, New Zealand, 16/11/2008-20/11/2008.
2. NZPEM conference, Wellington, New Zealand 6/11/2007-7/11/2007.
3. NZPEM conference, Hamilton, New Zealand, 9/11/2006-10/11/2006.

RESEARCH PROJECT SUMMARY

Dosimetric Investigation of Electron Arc Therapy Delivered Using Siemens Electron Arc Applicator with a Trapezoidal Aperture

Abstract

This study investigated the delivery of electron arc treatment with a trapezoidal aperture. The aim of the investigation is to reduce the nonuniformity of the dose

PUBLICATIONS

Published conference papers

1. Aitang Xing, Dili Banjade and Keith Croft. *Characterization of electron Beams for electron arc therapy.* Australas. Phys. Eng. Sci. Med. Vol.31(4): 519(2008).
2. Dili Banjade, Aitang Xing and Keith Croft. *Dose distribution of small field electron and SXR beams in radiotherapy.* Australas. Phys. Eng. Sci. Med. Vol.31(4): 495(2008).

Papers submitted and being reviewed

1. Aitang Xing, Keith Croft and Dili Banjade. *Determination of trapezoidal aperture of a dedicated short electron applicator for electron arc therapy.* Submitted to ACPSEM journal on 19/01/2009.

Papers in preparation

1. Aitang Xing, Dili Banjade and Keith Croft. *Comparison of a RK chamber, Mosfet detector and Cafchromic® film for point dose measurement in a rotation electron beam.* Being prepared and to be submitted to Journal of clinical medical physics.

Part I

Radiation Dosimetry

2 Cross calibration procedure and results

2.1 Equipments and setup

The RK chamber was calibrated using a Siemens Primus linear accelerator which was commissioned to deliver electron arc treatment with 6 MeV and 9 MeV beams. It was calibrated against the local reference dosimeter: a Farmer electrometer(type 2570/1 SN.1311) plus Wellhofer FC65-G chamber(type NE2570/1 SN. 457). The local standard was calibrated by National Radiation Laboratory(NRL) in New Zealand following IAEA TRS398 protocol.

The quality conversion factor $k_{Q,Q_{int}}$ for the RK chamber is not listed in Table 19 in IAEA TRS398 protocol [1], “**Calculated values for kQ, Q_{int} for various chamber types calibrated in electron beams as a function of beam quality R_{50}** ”. To determine RK chamber’s $k_{Q,Q_{int}}$, A PTW Roos chamber was used following the method propose by Karaj et al [2]. The methods was described in Section 2.3.

A little water phantom made according to the criteria by IAEA TRS398 was used for the measurement. This water tank is used to calibrate the linac beams on a weekly basis.

The phantom setup and chamber positioning strictly comply with the reference conditions recommended by IAEA TRS398. The specific reference conditions in this situation is listed in Table 1. For all measurements, the gantry and collimator were both set to be 270^0 .

2.2 Determination of Calibration factor

The RK chamber was cross calibrated together with Theradose dual channel electrometer. The bias voltages were -200 V for RK chamber and -250 V for the reference chamber. The calibration followed the standard procedure provided in TRS398. The first step is to get the chamber’s calibration factor using the highest electron energy beam(18 MeV).

Once the little water tank and linac were setup following the reference conditions. The local reference dosimeter and RK chamber were alternatively positioned at the reference depth under the same radiation conditions. The calibration factor of RK chamber is calculated as follows:

$$N_{D,W,Q_{cross}}^{RK} = \frac{M_{Q_{cross}}^{ref}}{M_{Q_{cross}}^{RK}} N_{D,W,Q_0}^{ref} k_{Q_{cross}, Q_0}^{ref} \quad (1)$$

In Eq. 1, $N_{D,W,Q_{cross}}^{RK}$ is the calibration factor of RK chamber in terms of beam

Table 1: Setup reference conditions for RK chamber cross calibration.

Nominal Energy $E(\text{MeV})$	6	9	18
Phantom	a little water tank		
Field size(cm \times cm)	10 \times 10 applicator		
SSD(cm)	100		
chamber reference point	on the inner surface of its window at its center for plane parallel chamber On the central axis at centre of the cavity volume for cylindrical chamber		
Beam quality $R_{50}(\text{cm})$	2.33 3.5 7.67		
$d_{ref}(\text{cm})$	1.3 2.0 4.5		
positioning of chamber	at d_{ref} for plane-parallel chambers 0.5 r_{cyl} deeper than d_{ref} for cylindrical chambers.		

quality $Q_{cross}(18 \text{ MeV})$. N_{D,W,Q_0}^{ref} is the calibration factors of local reference dosimeter, which was obtained in terms of ^{60}Co . $M_{Q_{cross}}^{RK}$ and $M_{Q_{cross}}^{ref}$ are the charges collected by the RK chamber and reference chamber, respectively. The readings from both chambers were corrected for pressure and temperature, polarization and ion recombination for both chambers. The quality conversion factor for reference chamber, k_{Q_{cross}, Q_0}^{ref} was interpolated from the data provided in IAEA TRS398.

The calibration results are presented in Table 2 along with the specific reference conditions for each beam

2.3 Determination of $k_{Q,Q_{cross}}$

Once the calibration factor was measured, the next step is to determine the quality conversion factor, $k_{Q,Q_{cross}}$. For the most commonly used plane-parallel chamber, this value can be found or interpolated from Table 19 in IAEA TRS398. RK chamber is not listed in the table. The method proposed by Karaj et al [2] was used here to determine RK chamber's quality conversion factor. The basic idea is that RK chamber's quality conversion factor was measured by equating the dose measured by RK chamber and another reference chamber whose calibration factor and quality conversion factor are known. The measurement

Table 2: Results of RK chamber cross calibration.

Chamber	Reference	Field
	NE2571 chamber	RK chamber
N_{D,W,Q_0}^{NE2571} (Gy/nom.Gy)	0.986	
Nominal energy(MeV)(Q_{cross})	18	18
R_{50} (g cm $^{-2}$)	7.67	7.67
SSD(cm)	100	100
field size(cm \times cm)	10 \times 10	10 \times 10
z_{ref} (cm)	4.5	4.5
$N_{D,W,Q_{cross}}^{RK}$ (Gy/nom.Gy)		0.050134252
$N_{D,W,Q_{cross}}^{RK}$ (Gy/nC)		0.0024538779

were performed under the reference conditions as listed in 1 for both chambers.

The reference chamber chosen here is the Roos chamber. The experimental values of $k_{Q,Q_{cross}}^{RK}$ for RK chamber were obtained by:

$$k_{Q,Q_{cross}}^{RK} = \frac{N_{D,W,Q_{cross}}^{Roos} M^{Roos} k_{Q,Q_{cross}}^{Roos}}{N_{D,W,Q_{cross}}^{RK} M^{RK}} \quad (2)$$

where $N_{D,W,Q_{cross}}^{Roos}$ and $N_{D,W,Q_{cross}}^{RK}$ are the cross calibration factors for RK and Roos chamber in 18 MeV electron beam, respectively. M^{Roos} and M^{RK} are Roos and RK chamber readings corrected for temperature and pressure, recombination and polarization.

The measured $k_{Q,Q_{cross}}^{RK}$ for 6 MeV and 9 MeV electron beams are shown in Table 3.

2.4 Verification

Once the calibration factor and quality conversion factor were obtained, the RK chamber can be used to calibrate the electron beams as we use the Roos chamber to calibrate electron beam every week. To verify the accuracy of the measured RK calibration factor and quality conversion factor, the RK chamber was used to calibrate the beam several times on different weeks.

The verification procedure and setup are exactly the same as the one used for checking the output of machine with the in-house made little water tank and Roos chamber. The 6

MeV and 9 MeV electron beams were calibrated to deliver 1 cGy/MU at the maximum-dose depths.

For the RK and Roos chambers, the dose is calculated as:

$$D_w = M^{RK} K_{total}^{RK} \quad (3)$$

where the total dosimetric factor is $K_{total} = N_{D,w,Q_{cross}}^{RK} k_{Q,Q_{cross}}^{RK}$ and M^{RK} is the chamber readings (nC) corrected for temperature and pressure.

The calibration and verification results are shown in Table 3. The results clearly show that the calibrated RK chamber gives 1 Gy/100MU within 1% under the reference conditions, which validated the calibration factors obtained for RK chamber.

Table 3: RK chamber verification results.

Chamber	RK chamber	
Nominal energy(MeV)	6	9
SSD(cm)	100	100
Field size(cm × cm)	10 × 10	10 × 10
z_{ref} (cm)	1.3	2
$k_{Q,Q_{cross}}$	1.04408	1.03363
K_{total} (Gy/nC)	0.002562	0.002536
MUs	100	100
Averaged Readings(nC)	390.056	395.291
Dose to water $D_w(z_{ref})$ (Gy)	0.9993	1.003

3 Summary

Following the IAEA TRS 398 protocol, the RK cylindrical chamber was cross calibrated against the local standard dosimeter for 6 MeV and 9 MeV electron beams. Due to its small physical dimension, it was used to measure the absolute dose in a dynamic electron beam.

Bibliography

- [1] International atomic energy(IAEA). An international code of practice for dosimetry based on standards of absorbed dose to water, Technical report Series No.398, Vienna, 2000.
- [2] E Karaj, S. Righi and F. D. Martino. Absolute dose measurements by means of a small cylindrical ionization chamber for very high dose per pulse energy electron beams. Med. Phys. 34, 952, 2007.

Commissioning two p-type silicon diodes for electron beam dosimetry

Abstract. Two p-type Scanditronix diodes designed for electron dosimetry, EDD2-1510 and EDD2-1520, were commissioned with the initial intention for being used in a rotating electron beam. The influence quantity correction factors, field factor ,SSD factor and angular factor, were investigated and compared with the manufacture's specifications. Two diodes were also calibrated and an excel sheets for calculating the diode dose were developed. However, due to their angular dependence, two diodes were finally not chosen as the dosimeters for electron arc project.

Period: 14/04/2007-17/04/2007

1 Motivation

Diode dosimeter plays a key role in clinical photon and electron dosimetry in many aspects, eg, commissioning and acceptance of new linac and TPS, in vivo dosimetry and daily and monthly QA. It has high spatial resolution due to its small physical size and very thin sensitive volume but with very higher sensitivity due to the high atomic number of silicon compared with the air-cavity based chamber. However, several influence quantities effect the measured signal from diode. Their effects on the diode signal are corrected using different correction factors.

Two Scantronix p-type diodes on the shelf have never been used before since they were

purchased. The intention of commissioning them is to measure the absolute dose in an electron arc beam.

2 Materials and methods

2.1 Commissioning parameters

For the diode used for absolute dose measurement, the following parameters are usually included in the commissioning process of the diode: sensitivity variation with dose per pulse(SSD), temperature and cumulative dose, field size dependence, directional dependence, energy dependence and the perturbation of radiation field behind detector.

In our clinical use, the diode is left on the phantom longer enough to reach the thermal equilibrium. The manufacturer's specified temperature dependence is $0.4\%\pm0.1\%$. The temperature effect is negligible. They were preirradiated to 8 kGy by manufacturer. The total dose the diodes may receive in the project investigation is no more than 10 Gy. The degrading of diode sensitivity due to the radiation damage is also not considered here. In addition, there is no detector used under the diode, the diode perturbation factor was not investigated.

2.2 Phantom and dosimeters

Two diodes(EDD2-1510 and EDD2-1520)were commissioned along with a Theradose dual channel electrometer, which is shown in Fig.1. Before every measurement, the leakage is checked and subtracted from the final readings in unit of nC. EDD2 diode is designed for electron beam in vivo dosimetry with the diameter of 1.5 mm and the effective thickness of measuring volume is $60\mu\text{m}$. The EDD2-1510 was commissioned for 9 MeV and EDD2-1520 for 6 MeV.

Field factor was measured using slabs of plastic water at 100cm SSD with the electron arc applicator. The applicator was shaped into different rectangular apertures. The readings for each rectangular aperture is normalized to the readings with normal electron applicator of 10cm-by-10cm size. For the measurement of SSD dependence, the same setting as those for field factor were used. The only changed parameter here is the distance between the surface and the end of electron arc cone. Similarly, the results were normalized to that at 100 cm SSD.



Figure 1: The Theradose dual channel electrometer along with the two p-type diodes (EDD2-1510 and EDD2-1520).

When angular dependence are measured, a cylindrical PMMA phantom was used. The phantom is aligned with gantry rotation axis. The diode is directly placed at the center of field and 100cm SSD. The radius of phantom is 16 cm. The measurement was performed in air without any buildup or bolus covered over the diode.

Once the correction factors were determined, two diode were calibrated against a Roos chamber. The Roos chamber is routinely used for calibrating the electron beams. The beam output at d_{max} was first checked with plastic water phantom under the conditions used for reference dosimetry.

Then the diode was calibrated at d_{max} under the reference conditions. The maximum dose depth was provided by covering the diode with bolus sheets. There were two reasons for this: the diode will be used under bolus in electron arc dosimetry. The diode has a non-flat surface, there is a considerable air gap between two plastic slabs holding the diode if the plastic water is used.

2.3 Results and discussion

2.3.1 Field size dependence

The variation of dose response with field size is shown in Fig. 2. The long side of rectangular field size is always kept to be 23.5cm and only field width is changed. The field size

dependence for electron is caused by variation of lateral scattering in the phantom. The manufacturer specified its field dependence is less than 2%. Our results for both fields and energies are within this specification.

2.3.2 SSD dependence

The instantaneous dose-rate dependence of the sensitivity is responsible for the SSD dependence. When the dose per pulse increases, the fraction of total minorities produced and collectable increases and the the fraction of total minorities that are recombined decreases. As a net result, the diode sensitivity varies with SSD. Fig.3 shows the SSD dependence. They are less than 0.7% and well within 1%, which is specified by manufacturer.

2.3.3 Directional dependence

The manufacturer's specification did not give the specification of diode 's angular factor. Within the range of angles interested, as indicated in Fig.4, the angular dependence is within 1%. The interesting observed here is that angular dependence curves are not

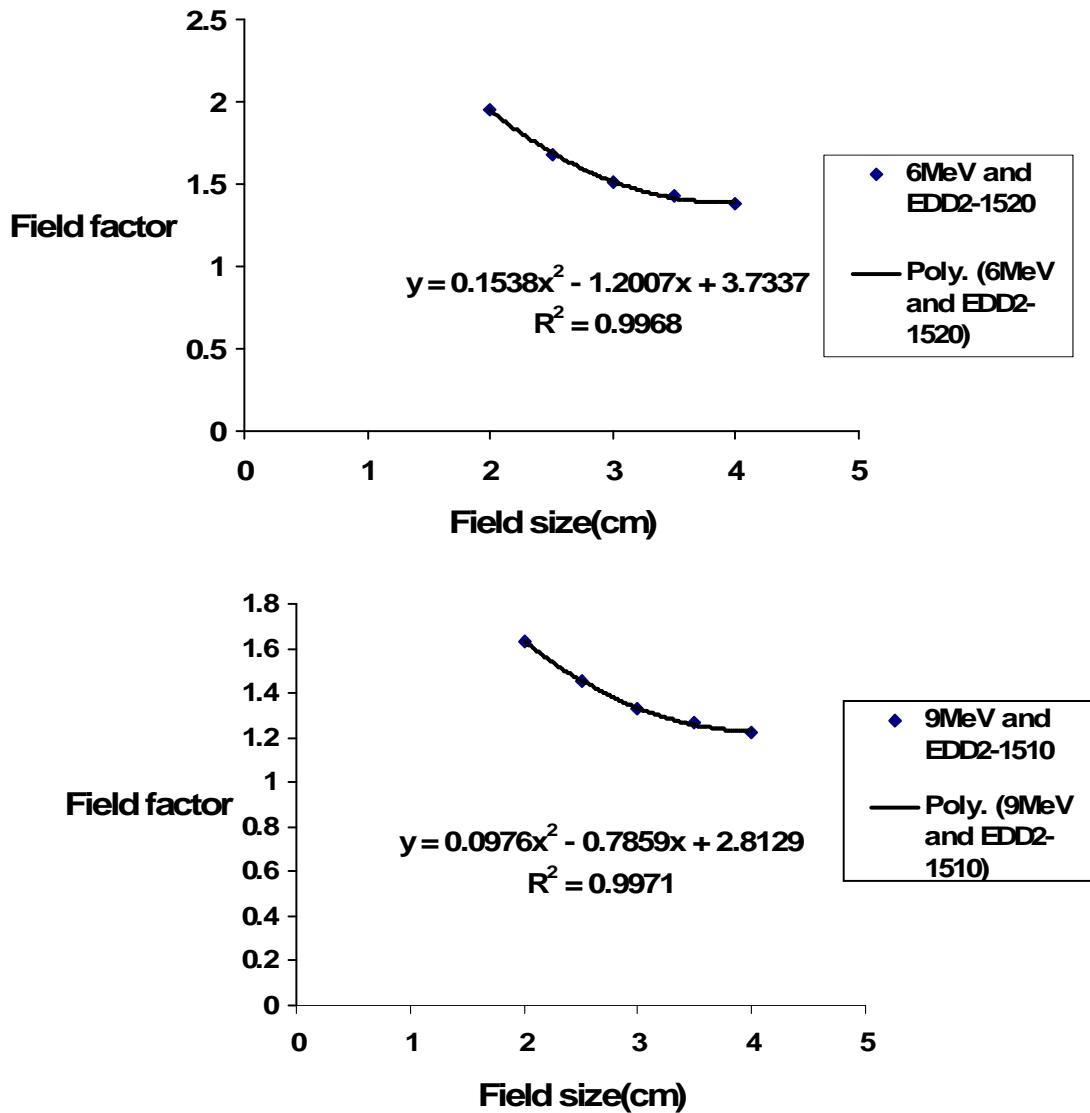


Figure 2: variation of sensitivity of the EDD2 silicon diode with the field size for 6 MeV and 9 MeV electron beams.

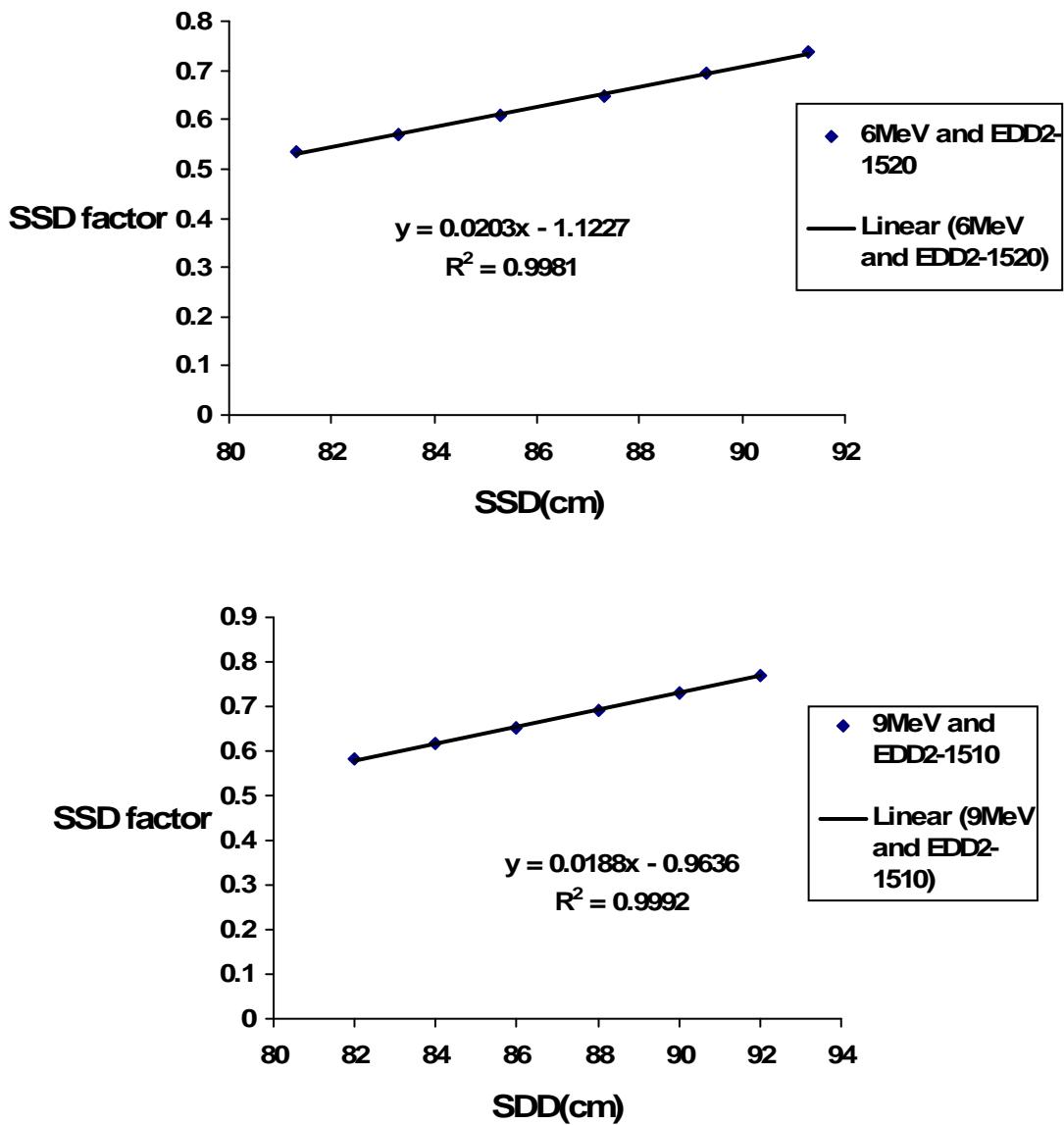


Figure 3: Sensitivity variation with SSD for the EDD2 silicon electron diode, measured in 6 MeV and 9 MeV.

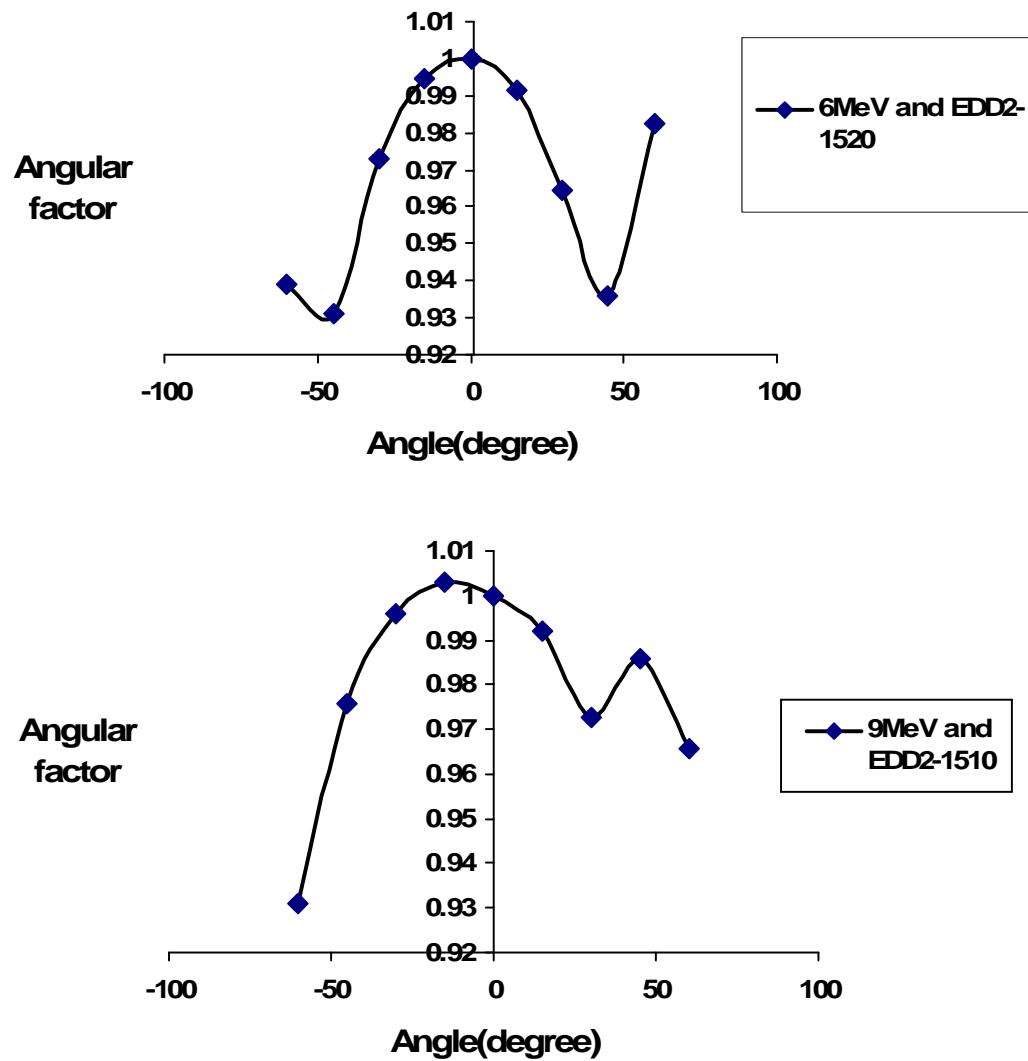


Figure 4: The direction dependence of the EDD2 silicon diode as a function of electron energy and angle for the electron arc applicator with open aperture.

3 Conclusion

With the initial intention of commissioning the diodes for the absolute dose measurement in a rotating beam, however, the diodes were finally not chosen for the project due to large uncertainties because of the angular factors.

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6 MeV EDD2-1520 DIODE DOSE CALCULATOR

1.Radiation conditions

SSD(cm):	
Field size(cm):	

2.Electrometer readings

Measurements	Background (nC)	Raw readings(nC)	Corr. Readings(nC)
1			
2			
3			
Average(nC):	#DIV/0!		

3.Dose Calculator

Field facotor:	3.7337
SSD factor:	-1.1227
Dose(Gy):	#DIV/0!

Note: The angular factor is applied separately after the dose is calculated. For electron arc beam, the average of angular factors for a series of angles across the arc is used as effective angular factor.

9 MeV EDD2-1510 DOSE CALCULATOR

1.Radiation conditions

SSD(cm):	
Field size(cm):	

2.Electronmeter readings

Measurements	Background(nC)	Raw readings(nC)	Corr. Readings(nC)
1			
2			
3			
Average:	#DIV/0!		

3.Dose Calculator

Field facotor:	2.8129
SSD factor:	-0.9636
Dose(Gy):	#DIV/0!

Note: The angular factor is applied separately after the dose is calculated. For electron arc beam, the average of angular factors for a series of angles across the arc is used as effective angular factor.

Figure 5: The diode dose calculator excel sheet developed for EDD2 diodes for 6 MeV and 9 MeV electron beams.

Calibration of GAFCHROMIC EBT[®] and Kodak radiographic films with a VIDAR film scanner, a HP flatbed document scanner and a point densitometer

Abstract. To find a suitable dosimeter for the point dose and 2D dose measurement in electron arc project, GAFCHROMIC EBT[®] film, Kodak EDR2 and XOMAT-V film were calibrated using a HP flatbed document scanner, a VIDAR film scanner and a point densitometer with and without a red filter. It was found that the calibration curves strongly depend on the type of scanner or the reader of optical density(OD). The GAFCHROMIC EBT[®] film and the point densitometer was chosen for measuring the point dose, whereas the Kodak EDR2 and Vidar film scanner was used for 2D dose distribution delivered by electron arc beam.

Period: 15/12/2006-20/12/2006

1 Motivation

Film dosimeters play an important role in clinical dosimetry and have becomes an integrated part of routine quality assurance, for example for checking the coincidence between light field and radiation field, star shot for the rotation axis of gantry, collimator and

couch. It also offers a convenient and quick way of obtaining 2D dose distribution and has been using widely for complex treatment verification, such as IMRT and electron arc treatment verification.

Two AAPM protocols provided excellent guidelines for theoretical and practical aspects of film dosimetry for both radiographic and radiochromic films [1, 2]. The pitfalls, advantages and disadvantages for film dosimeters are discussed in details in these two protocols and other numerous published papers.

The purpose of investigation is **to investigate the calibration of three types of films using different film scanners for absolute dosimetry in electron arc project.**

2 Materials and methods

2.1 Scanners and densitometer

A film dosimeter comprises film, film processor, film scanner and imaging process tool(or a point densitometer). For the features of three types of film, the reader refers to two AAPM protocols. Calibration of the film is essentially to calibrate the film dosimeter as a whole. The quantity of interest in film dosimetry is optical density(OD), or equivalent pixel for the digitized film image. The film calibration curve of depends on the each component of the dosimeter, especially the the film scanner and densitometer. A point densitometer, a flat document scanner and a VIDAR film scanner were used to calibrate Kodak X-OMAT V film, Kodak EDR2 film and GAFchromic EBT film. The film images were analyzed using an in-house software, IMRTchecker.

2.1.1 HP scanjet automatic document feeder

HP scanjet C7710A is a type of flatbed document scanner designed for high quality photographic scanning. It is used along with its scanner software, HP PrecisionScan Pro.3.0. Before scanning, the lamp is warmed up for half an hour and several film scanned. The optical resolutions are 2400 pixels per inch(ppi) with unlimited enhanced resolution. The film is digitized as greyscale Black and white image. The scan speed is less than 25 seconds to scan a film image.

The scanner operates transmission mode. It employs a fluorescent light source with a

broadband emission spectrum and a linear charge coupled device CCD array detector.

2.1.2 VIDAR film scanner

The Vidar scanner operates only in transmission mode. Vidar scanners have a long diffuse fluorescent white light source with spectral distribution between 250 and 750 nm, coupled to a linear CCD digitizing system. The scanner is used routinely for IMRT QA and routine work with Kodak EDR2 or X-OMAT V film. The film images were analyzed using in-house software, IMRTchecker.

2.1.3 Pehamed point densitometer

As shown in Fig.1, the Pehamed Denso-Dent (SN:0156) is a small portable densitometer. Its measurement arm length is 10 cm. The measurement point is 7 mm^2 and measurement range: $0 \leq OD \leq 4.5$. The measurement repeatability is $\delta D \leq \pm 0.02$. The uncertainty of measurement is $\delta D < \pm 0.02$.



Figure 1: Photo of Pehamed point densitometer and the red filter used for film calibration.

2.1.4 IMRTchecker

An in-house program named “IMRT Checker” was designed and developed by Keith Croft, the chief physicist of department. Fig 2. shows its graphic user interface. The programs main window is arranged as a series of Tabs. The program was developed for IMRT

patient QA. It also used routinely as a film image analysis tool. Once the film images are imported into the program, it provide a variety of tools for analyzing the film, such as obtaining the pixel value of interest region, dose profile, isodose curves and the map of gamma index when two dose distributions from two films or from film and TPS calculated planar dose. The detailed description of IMRTChecker can be found in its user manual.

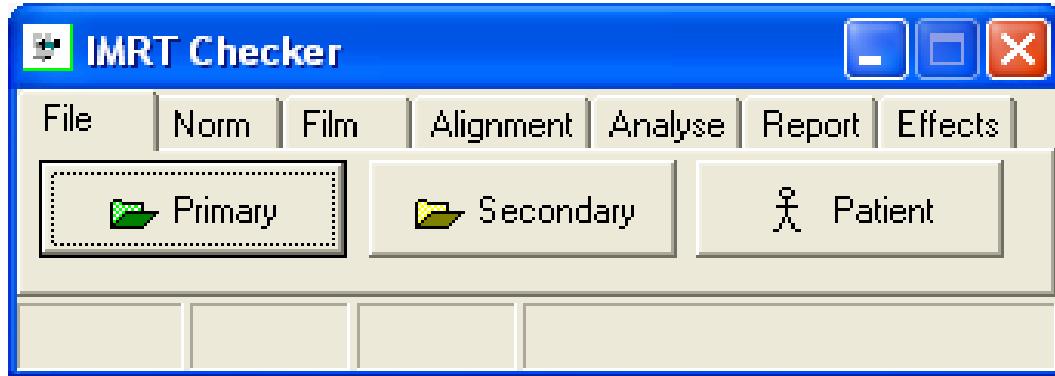


Figure 2: The functions provided by Analyze Tab for film dosimetry.

2.2 Calibration procedure

2.2.1 Experimental setup

Three types of films were calibrated using a Plastic Water® with a Siemens Onco linear accelerator. The calibration was done using perpendicular calibration geometry, namely, the gantry and collimator at their zero positions. The film was placed at d_{max} for 6 MeV and 9 MeV beams with SSD of 100 cm. The thickness of 10 cm plastic water to provide enough back scattering. The field size is $10cm \times 10cm$. Before the calibration, the beam output was checked by reference dosimetry.

Depending on the film type, the number of dose values and their spacing of the calibration points were chosen very carefully because they are critical to accurate film dosimetry. All the films were taken from same batch and one unexposed film separated from the rest was used to provide the zero dose (base plus fog) value. For radiographic films, one film is used for each calibration dose point. For GAFchromic EBT® film, one film was carefully cut into the pieces of $4cm \times 4cm$ square. Each piece was used for one dose point.

Before and after exposure, the films were handled with the cautions recommended by AAPM protocols. For radiographic films, the film was punctured at one corner to allow

any trapped air to escape. When the films were placed between slabs of phantom, the good compression was made sure to reduce or eliminating the any air effect. Two hours after exposure, all films were developed in one session. Before developing the film, the film processor was warmed up at least half hour and stabilized by feeding several wasted films.

For radiochromic films, the film piece was inspected visually ensuring no scratch or dirt on it. The films were read and handled in normal incandescent light as they are very sensitive to the sunlight and fluorescent light. Six hours after the exposure, the films were read using two scanner and the densitometer. The films was placed on the scanner or densitometer in the same orientation and alignment to minimize the polarization effect and the non-uniformity of scanner light source illumination. The exposed and unexposed films were stored in a dark and dry.

2.2.2 Image processing and OD reading

When the film was scanned using HP scanner, it was digitized as greyscale Black and white image and save as a BMP image. The film was carefully placed on the flatbed in same position for all film. For the Vidar scanner, the scanner was warmed up and calibrated several times before scanning the film. The resolution of scanning was 75 dpi while the pixel depth 8 bits. For HP scanner, the 12bit bitmap image format was used under the setting of automatic exposure after the scan area selection.

To read the OD with the point densitometer, it was first zeroed. The OD was read several time for same film pieces at different location. The averaged OD value was used. For GAFchromic film, a red filter was also used to increase the OD values.

Once the film images were imported into IMRTChecker, there were two methods used for sampling the pixel value. The first method is to get the pixel values at different location near the center of exposure. Then the averaged pixel value was adopted. The second one is to get inplane and cross plane pixel profile going through the center of field. The final pixel value was taken as the averaged value of the pixel of profile around the profile center.

3 Results and discussion

3.1 GAFCHROMIC EBT[®] calibration curves

The GAFCHROMIC film pieces were calibrated with two scanners and densitometer. For the point densitometer, the film was calibrated with and without a red filter.

The calibration curves are shown in Fig.3-7. The following conclusions can be drawn from the observation:

1. The calibration curve strongly depends on the type of scanner or densitometer as expected.
2. The calibration curve can be well fitted by a second order or third order polynomial.
3. The calibration curve can be divided into three segments: low-dose non-linear region, the linear region between 80 cGy and 200 cGy and the non-linear region beyond 2Gy. Two nonlinear regions are slightly different for different scanner and densitometer, which caused by different noise-to-signal ratio of OD readers and different sensitivity of film. The linear region is best area which is used to do the absolute dose measurement as seen in Fig.3(b) and Fig.4(b).
4. For the point dose measurement, it was found that the calibration curve with or without filter is quite convenient to use.

3.2 Kodak EDR2 and XOMAT-V calibration curves

For Kodak EDR2 and XOMAT-V films, the calibration curves were established only for Vidar scanner. For XOMAT film, the film response is nonlinear, but there is a roughly linear region up to 50 cGy. The EDR2 is quite linear up to 400cGy. These observations are in agreement with the the results in published papers and common knowledge.

4 Summary

Following two practical guidelines recommended by AAPM, the commonly used GAFCHROMIC film, Kodak EDR2 and XOMAT-V film were calibrated using a Vidar film scanner, a HP flatbed document scanner and a point densitometer. The calibration curves were obtained for 6 MeV and 9 MeV beams and compared.

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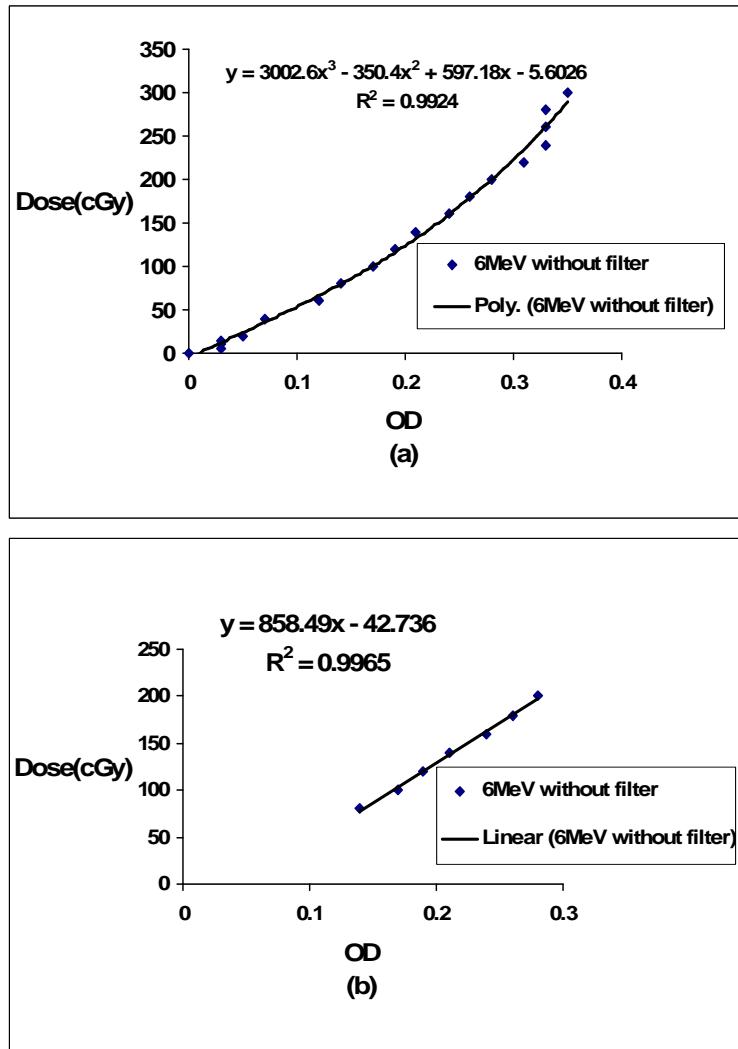


Figure 3: GAFCHROMIC EBT[®] film calibration curves obtained with the densitometer without filter for 6MEV(a) and its linear portion(b).

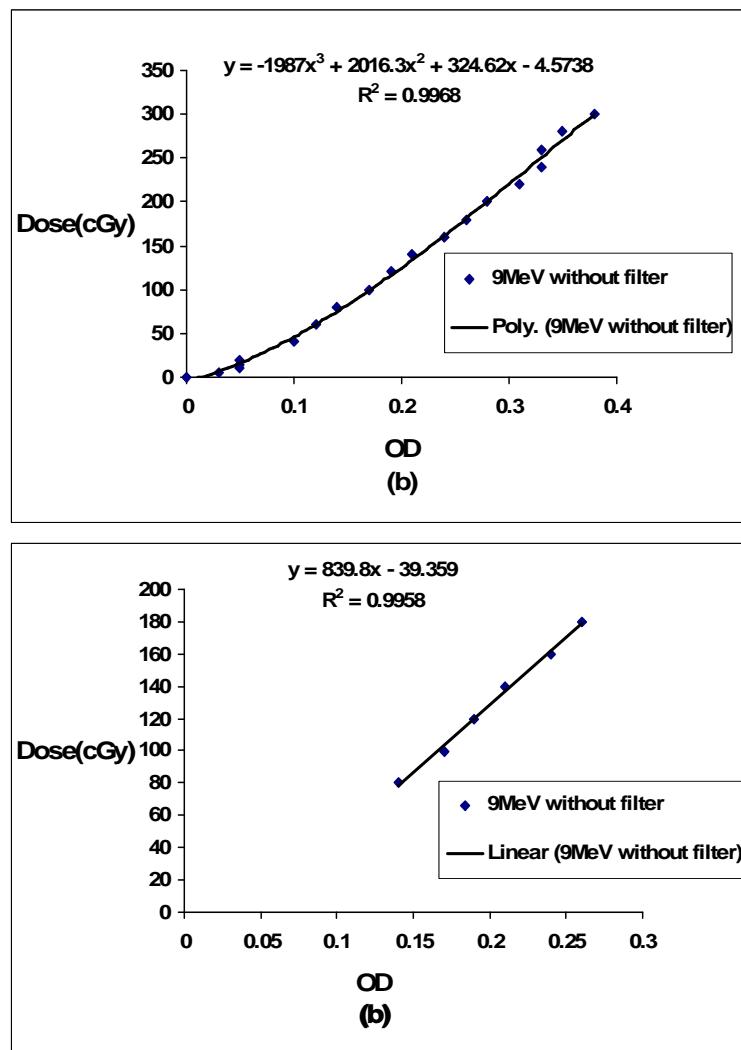


Figure 4: GAFCHROMIC EBT[®] film calibration curves obtained with the densitometer without filter for 9MEV(a) and its linear portion(b).

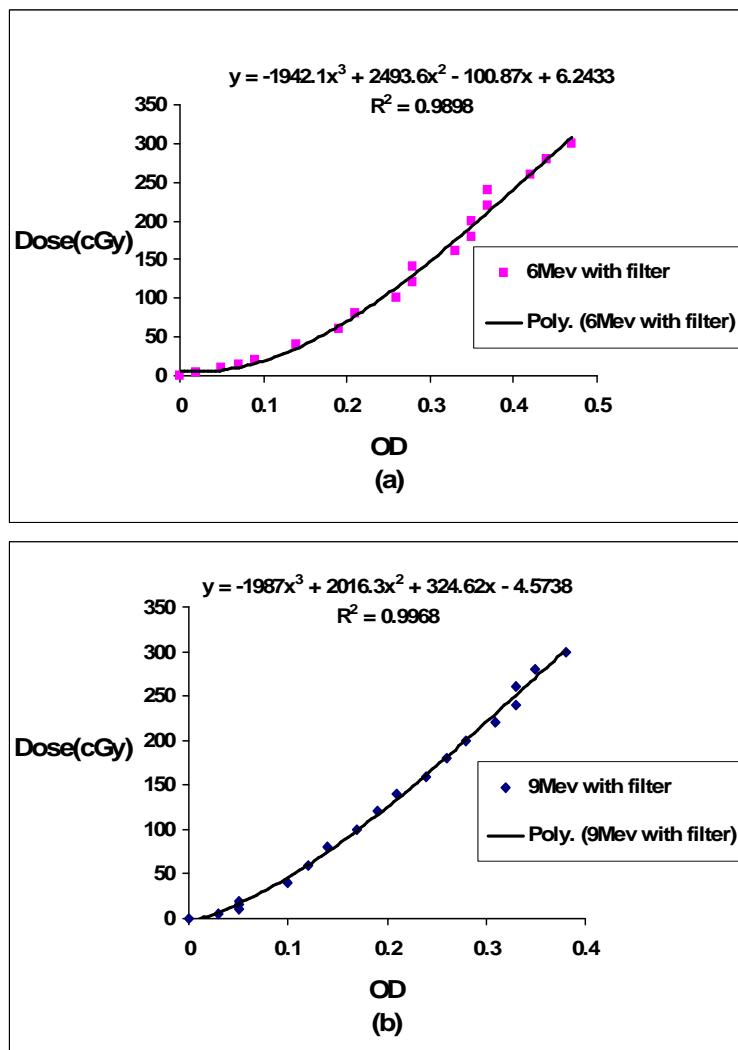


Figure 5: GAFCHROMIC EBT® film calibration curves obtained with the densitometer with filter for 6MEV(a) and 9MeV(b).

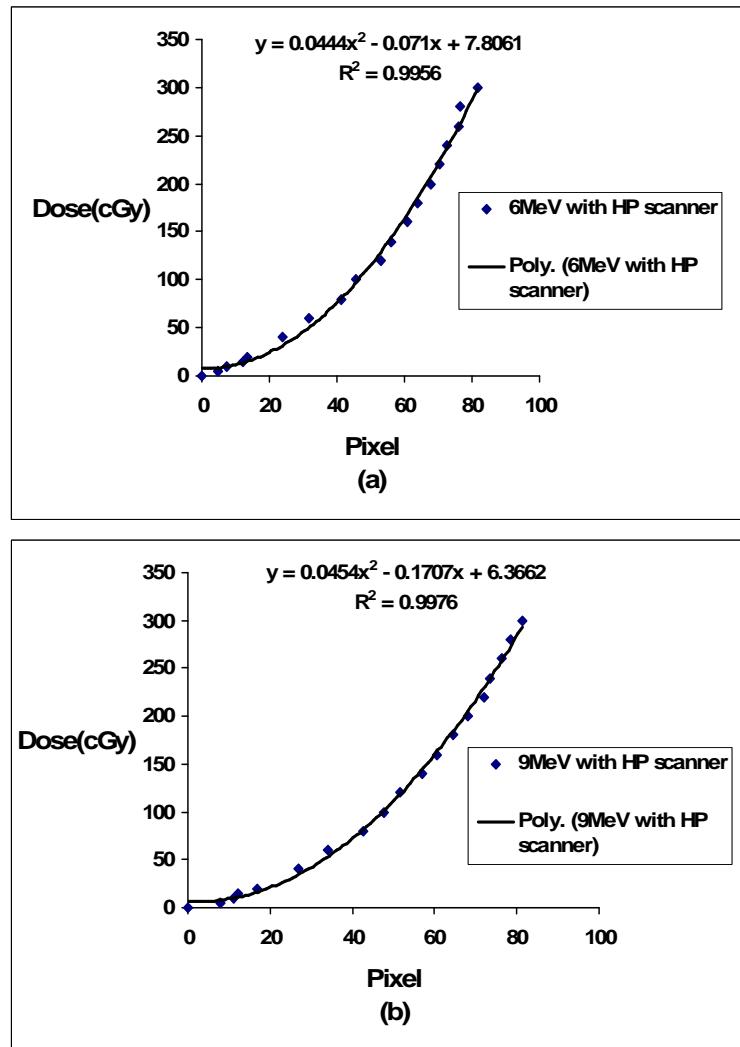


Figure 6: GAFCHROMIC EBT film calibration curves obtained with the HP scanner for 6MEV(a) and its linear portion(b).

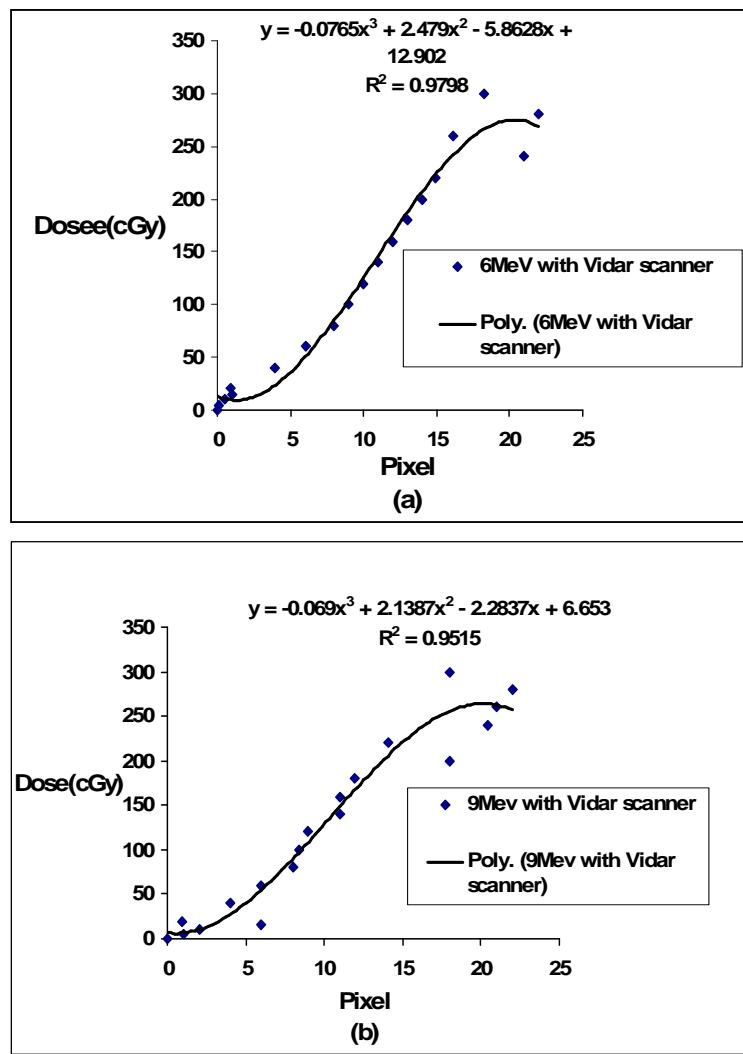


Figure 7: GAFCHROMIC EBT film calibration curves obtained with the Vidar scanner for 6MEV(a) and its linear portion(b).

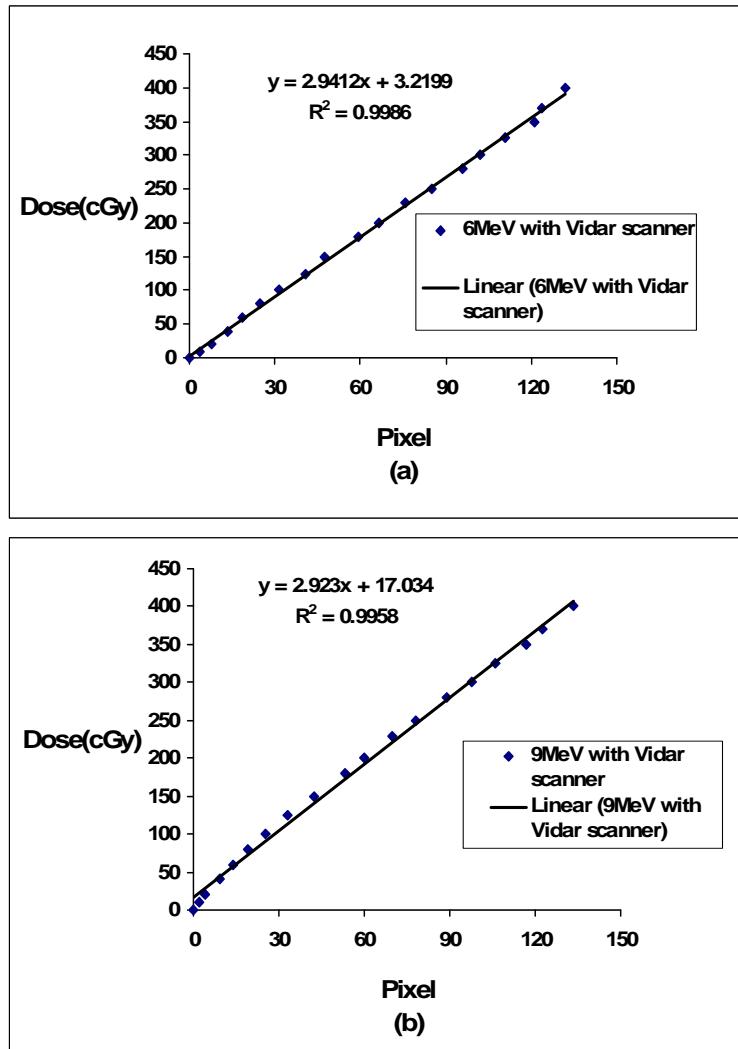


Figure 8: Kodak EDR2 film calibration curves obtained with the Vidar scanner for 6MEV(a) and 9MeV (b).

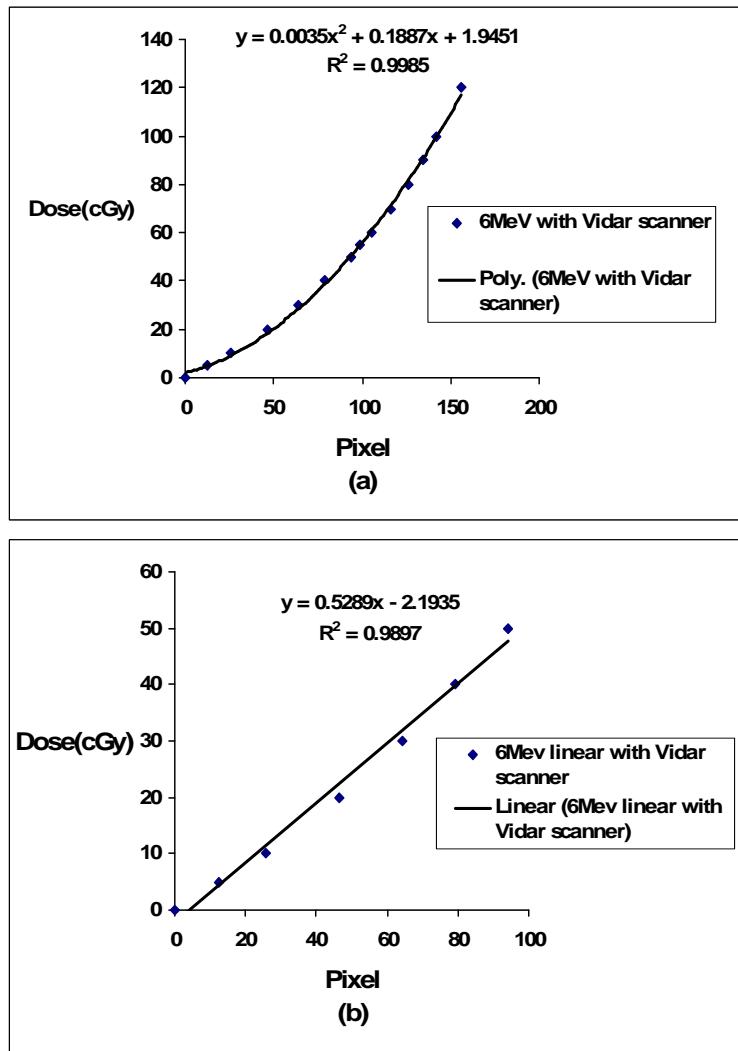


Figure 9: Kodak XOMAT-V film calibration curves obtained with the Vidar scanner for 6MEV (a) and its linear portion (b).

Methodological comparison of patient IMRT QA based on EPID dosimetry and chamber-film dosimetry

Abstract. As a medical physicist working in Palmerston North Hospital, patient specific IMRT QA is part of my routine work. I have done a number of patients using either EPID dosimetry or chamber-film based dosimetry. In this report, two verification techniques are compared methodologically from the point of view of how to implement an IMRT QA program. It covers the aspects of implementation: how to chose and calibrate dosimeter, how to design a suitable phantom and how to write up a good procedure-based protocol. The basic procedure and methodology described here can be applied to create a QA program for radiotherapy procedure and treatment planning system.

Period: 01/11/2005-1/11/2009

1 Motivation

In our centre, intensity-modulated radiotherapy (IMRT) has been used as a standard treatment technique for head and neck tumor since 2004. Its complexity requires physicist to establish an IMRT QA program and perform extensively QA for each patient before treatment.

Similar to other centers, an IMRT QA program was established based on the chamber

dosimetry and film dosimetry. The advantage of using this method is a standard techniques adopted widely around the world and well established. However, it is time-consuming. From planning to setting up phantom and measurement to analyzing the results and writing report, typically it takes about 4 hours. Especially, with increasing number of IMRT patients, the burden on clinical physicist dramatically increases.

Every effort has been made to find a more efficient way to do IMRT QA. Recently more attention has been focusing on using EPID to verify IMRT treatment [1, 2]. A numerous papers on this subject has been published in “Medical physics” and “Physics in biology and medicine” and other medical physics related journals. An IMRT QA program was implemented using EPID dosimetry in June, 2008.

As a physics registrar working in the department, IMRT QA with EPID and chamber/film is part of my routine job. I have done a number of patients either with old and new method. **The goal of this report is to methodologically compare these two IMRT verification techniques from the point view of implementation.**

2 General consideration and procedure for implementing an IMRT QA program

No matter what types of dosimeter are to be chosen for IMRT verification, general consideration are essentially same. They are following the same procedure:

- Firstly you need to chose the proper dosimeters and design a water-equivalent water phantom. A exactly same digital phantom is also to be created in treatment planning system via CT scanning the phantom or manually contouring.
- Then the chosen dosimeter need to be calibrated properly and carefully in order to measure the dose delivered in the phantom.
- Finally a procedure-based protocol should be written up as a guideline and a standard department document.

Although the general procedure looks pretty standard, each center usually modifies it to suit for their own situation. The following comparison is based on the specific implementation of IMRT QA program in radiotherapy department in Palmerston North Hospital.

3 Side-by-side comparison

3.1 Choice of dosimeters

3.1.1 Feature of ideal detector

Choosing the right detector for IMRT verification requires having the deep knowledge of physical and dosimetric characteristics of a variety of widely used dosimeter and clinical experience of using them in different situations. It is also a balance of between high accuracy, convenience of use and efficiency. Because of small segments of IMRT field and high local gradient existing in dose distribution. Based on these considerations, the idea detectors for IMRT verification are:

1. A minimum number of influence quantities and these quantities are accurately determined.
2. A minimum perturbation to beam, which can be accurately quantified.
3. A high resolution for point dose and 2D dose measurement.
4. Easy and convenient to use.

Fig.1 shows a list of detectors which can be chosen for IMRT verification.

3.1.2 Chamber and film

For chamber-film based IMRT verification, the CC13 thimble chamber was finally chosen instead of using a smaller pinpoint chamber. Although the pinpoint chamber has a high resolution, but its sensitivity is very low and the background signal and electronic noise are relatively large, which influences the accuracy of measurement. Kodak radiographic EDR2 was used as 2D dosimeter as other centers.

3.1.3 EPID

The EPID we are using is OPTIVUE EPID AG9 detector , which was manufactured by Siemens as an integrated part of Onco linear accelerator. Although EPID is originally designed for port imaging and widely used for geometric verification in radiotherapy, it was also a good 2D dosimeter with a very high resolution with the pixel size of typically of less 1 mm. It was widely used for Linac QA, in-vivo dosimetry and IMRT verification.

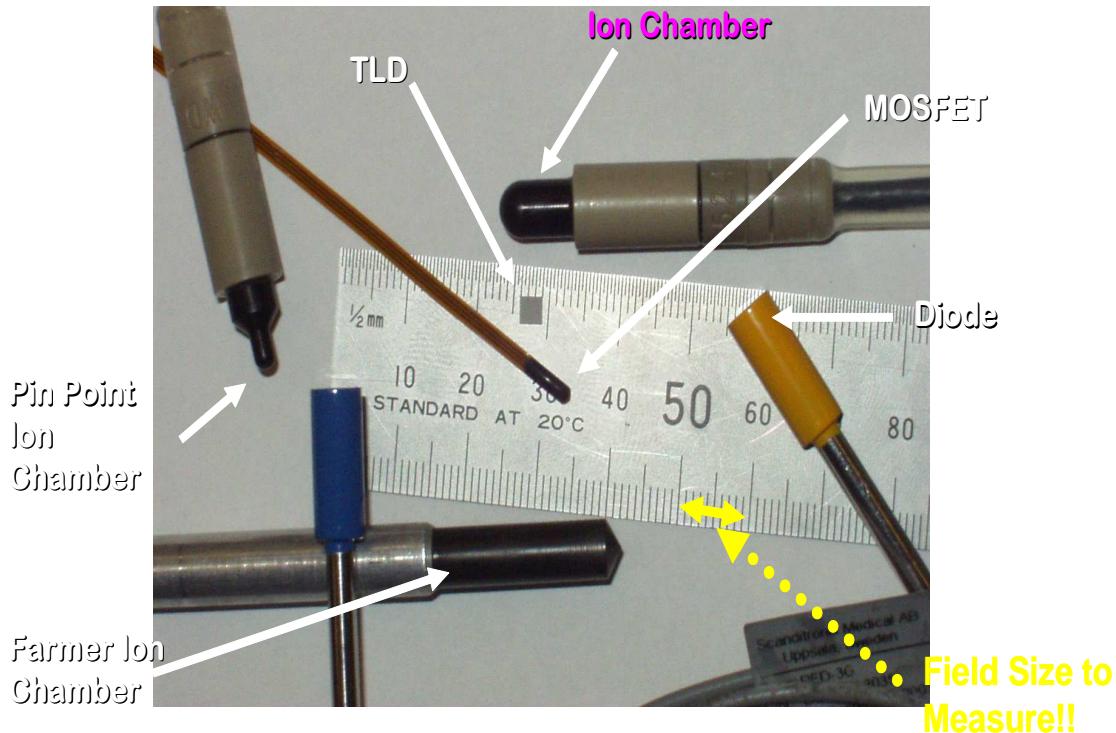


Figure 1: List of detectors available for IMRT verification.

Once it is calibrated, it not only gives the 2D absolute dose distribution but also the solute point dose.

The dosimeters mentioned above were chosen not only because of their accuracy but also the practical convenience. Other detectors such as large 6cc thimble chamber, Kodak XV radiographic film, radiochromic film, TLD and MOSFET were also investigated. They were discarded either because of inaccuracy or not easy to use. The final choice of CC13 chamber is a good balance between resolution, signal and stem effect.

3.2 Characterization and calibration of dosimeters

3.2.1 chamber and film

Performing clinical dosimetry with any detector is essentially to convert the reading corrected by influence-quantity factor into the dose absorbed to water via a calibration factor or a calibration curve. Before using the detector, it needs to be characterized and calibrated. Characterization of a detector is to identify and quantify the influence quantities and perturbation factor. The former removes the the influence quantities from detector's response quantity. For example, film processor and scanner conditions are the influence

quantities to optical density, the response quantity of film. The calibration of a detector is to determine the calibration factor, which converts response quantity of detector to the dose in water.

Although the perspex phantom is used, the dose calculated and measured is the dose to water. The chamber is calibrated following the IAEA TRS-398 protocol along with electrometer. There are two methods can be used to get the calibration factor with the difference less than 1%:

1. The calibration factor of chamber is measured in water phantom under the reference conditions by alternatively placing the local reference chamber and CC13 chamber. The chamber readings were corrected by polarization factor, temperature and pressure factor and recombination. To convert the reading of chamber positioned in perspex phantom at any point, the influence-conversion factor was measured and defined as the ratio of the reading of CC13 chamber positioned at reference depth in water to the reading of CC13 chamber positioned at reference depth under the reference conditions.
2. The calibration factor can also be obtained by alternatively positioned the local reference and CC13 chamber at water-equivalent reference depth but in perspex phantom. Chamber readings are also corrected by polarization, recombination and temperature and press correction factors.

For the film calibration, a quick calibration method using the step wedge formed by MLC and collimator. With this quick film calibration method, one film sheet from the same batch as one used for 2D dose measurement is calibrated after the verification measurement to create a calibration curve for each patient verification.

3.2.2 EPID

Calibration of EPID for clinical dosimetry is a little bit complicated because it is primarily designed for localization imaging. The problems to be addressed are: First, the response of the EPID with field size is not water-equivalent, which poses a problem for direct dose conversion; Second, a major problem arises from the automatic accounting of differential from the detector. The raw images is corrected by a dark and flood field before display, which make the profile and output information lost; Third, backscatter from the components of the EPID support are downstream to the detector can influence signal.

Various calibration methods for EPID calibration were proposed and published in numerous papers. They can be categorized into either empirical based on a serious of measurement, convolution/superpostion based on EPID scatter kernel or direct monte carlo simulation of EPID response.

Because of its simplicity, a empirical method was proposed by our center to calibrate our EPID. The basic procedure is briefly described here but not in details:

1. The EPID response is defined as the product of the pixel value of unfiltered image which is corrected by background and off-axis correction matrix and the number of frame to get the images.
2. The central axis calibration curve was obtained in term of pixel value versus dose. This was done by checking the EPID response against the dose measured with chamber in water.
3. The off-axis correction matrix was obtained the ratio of TPS calculated plane dose at 9 cm depth in water phantom under the maximum field size to the EPID response under the same field size.
4. The field-size dependence of EPID response is defined the ratio of EPID total scatter factor without any build up material to the total scatter factor calculated in CMS digital water phantom by TPS under the range of field size from the smallest size 2 cm × 2 cm to medium size 20 cm×20 cm.
5. The field-size dependent response of EPID was modeled and minimized to be within 2% by choosing the the proper depth in CMS and inhomogeneity embedded in this phantom as described in detail. Therefore an universal field-independent factor can be found. The digital phantom design is described in details in Sect.3.3.3.

For each IMRT field, after the raw image is corrected by dark-field and off-axis correction matrix, the EPID images is converted into the dose with the universal correction factor as follows:

$$EPIDDose = \frac{\sum_{i=1}^{N_{seg}} PV_i \times FN_{seg}}{FN_{fld} \times 47500} \quad (1)$$

where N_{seg} is the number of segments per field and FN_{seg} the number of frames per segment. FN_{fld} is the number of frames per field. 47500 is the averaged calibration factor of EPID converting the dose to pixel.

3.3 Creation of physical and digital phantom

3.3.1 Desirable features of phantom

Choosing a right phantom is another important part of implementing an IMRT QA program. The physical phantom can be designed and made in house or bought from a variety of available commercial IMRT phantoms. The desirable features of phantom are:

- Being water equivalent and CT scannable. The phantom shape either cubic or representing human torso.
- The phantom could be homogenous or with embedded inhomogeneity of certified electron density.
- The phantom should provided with the chamber holder or with the slab design for film dosimetry.
- The phantom should have be easily to set up with aid of markers similar to CT markers on the real patient.

3.3.2 Customized phantom for chamber-film based IMRT

As shown in Fig.2, an in-house phantom was designed and made for chamber-film based IMRT verification. The phantom was 8 perspex slabs of 48 cm × 30 cm. There are another two slab prepared for film dosimetry. Two slabs with two red cross lines was used to aid phantom setup.

The specially designed holder for CC13 chamber was fabricated, which was accommodated by two chamber holder slabs. For film dosimetry, the two chamber holder slabs are replaced with two other slabs. The film can be sandwiched between any two of 8 slab.

For EPID-based verification, no physical phantom is placed in the beam and the couch was also excluded. The reasons for this is the EPID dosimeter was calibrated to measure the dose in water phantom under the same conditions. This is also easy to setup and speeds up IMRT verification.

3.3.3 Digital phantom created in TPS for planning

As a software, TPS requires the patient or phantom data as its basic input. From the mathematics point of view, the patient or phantom is represented internally as a 3D matrix of pixel value or electron density and externally as CT images or DICOM-RT objects(eg.

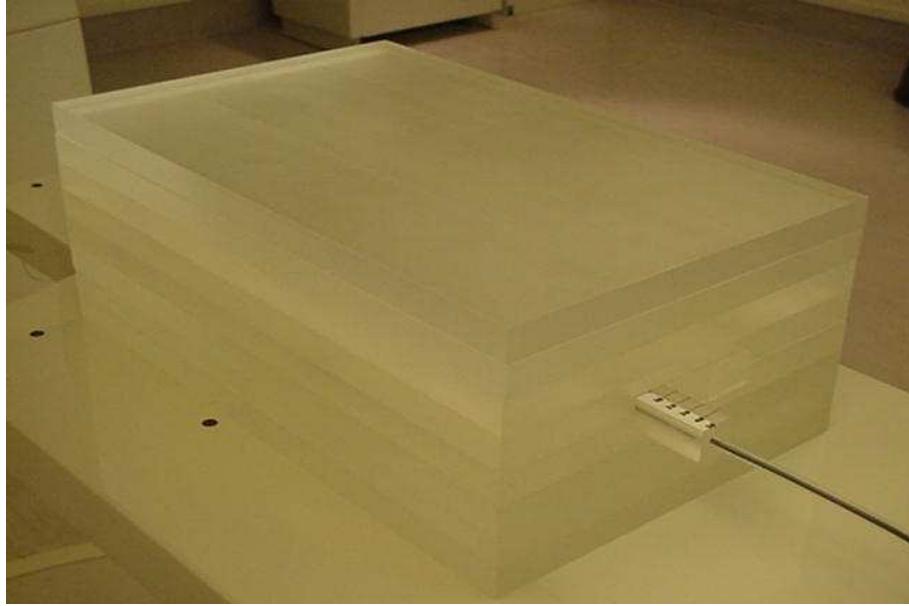


Figure 2: In-house made phantom for chamber-based IMRT QA. Slab designs allow the chamber holder or film up and down shift, while three spacers lets the chamber holder move left or right. The chamber can also be moved along longitudinal direction of couch.

contour, volume, points. The digital patient or phantom can be created by CT simulator or manually created with contouring function provided with TPS. For the purpose of IMRT verification, the detector possible position and its volume should be also created.

For both verification techniques, two digital phantom was created in CMS Xio treatment planing system, as seen in Fig.3. It is worth to be emphasized here that the purpose of function of these two phantoms are slightly different. The shared commons between them is that they both act as a virtual phantom into which the real patient IMRT plan is imported.

However, the intention of creating the digital phantom for chamber-film based IMRT verification is to exactly simulate the physics phantom in term of physical dimension, electron density, atomic composition and effective atomic number. The 16 possible measurement points with CC13 chamber were created and simulated by contouring a small volume same size as the effective volume of CC13 chamber. Because of its slab design, the coronal dose plan chosen for the film measurement can be any one between two of 8 slabs.

The digital phantom for EPID-based IMRT QA is not intend to simulate the neither the EPID itself or EPID setup. For the IMRT verification, the EPID positioned at 115 cm

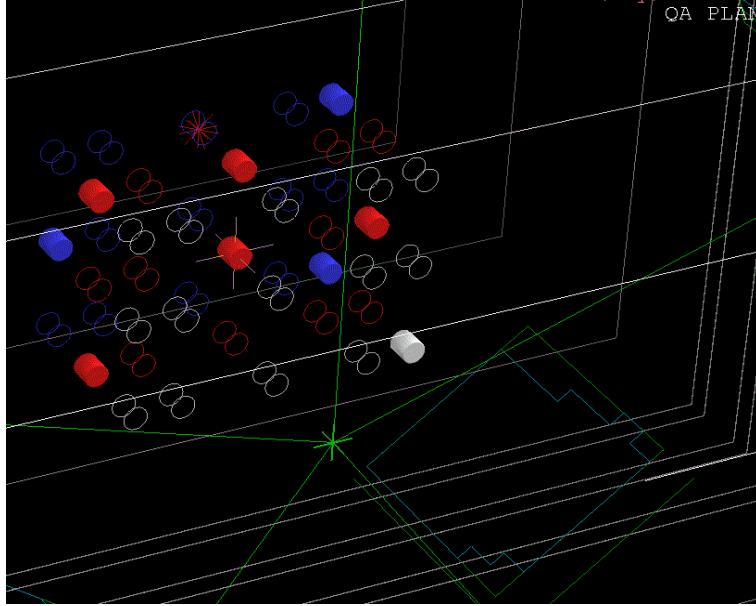


Figure 3: Physical phantom for chamber-based verification was contoured with chamber volumes indicating the possible point dose measurement. Choosing CC13 chamber is a good compromise between resolution, signal and small stem effect.

SID without any any absorber including the couch in the beam. The digital phantom is required because firstly the patient IMRT plan needs to be applied to a phantom for dose calculation. Therefore, the EPID has to be calibrated and characterized to measure the dose at a given depth in water phantom following the procedure described in Sect.3.2.2. This is the key point for understanding the special method used for the EPID IMRT verification in our department.

Secondly, as shown in Fig.4, the choice of depth of 11 cm in digital water phantom and the shape, volume and electron density of embedded inhomogeneity are determined by minimizing the field-size dependence of EPID response to be within 2% for typical IMRT segment size ranging from 2 cm to 20 cm equivalent square. This was achieved by maximizing the agreement between calculated beam profile using the EPID phantom and the profile measured with EPID under the same conditions. In other word, this digital phantom is used to model the EPID response instead of duplicating the physical phantom like the one used for chamber-film base IMRT verification.

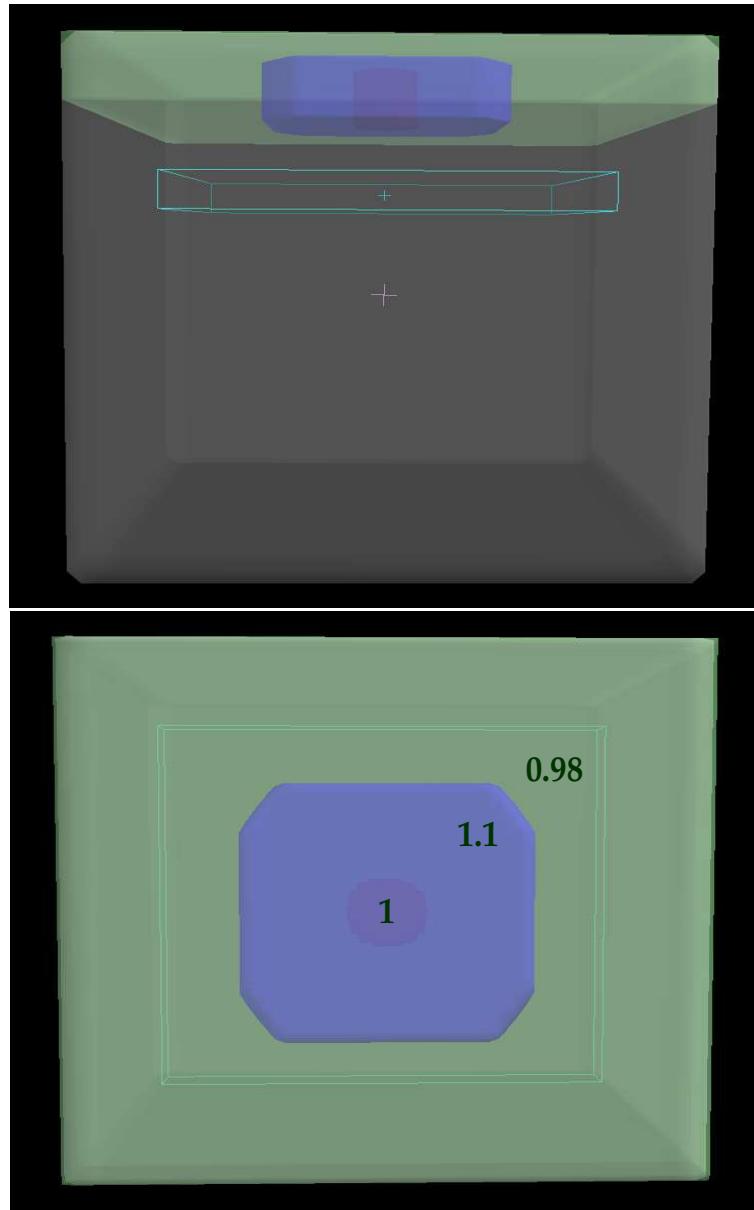


Figure 4: Upper: the digital phantom for EPID-based verification was contoured with three inhomogeneities embedded in phantom to model the field-size dependence of EPID response. Lower: the coronal view of EPID QA phantom's inhomogeneities with relative electron density. The EPID was calibrated to measure the coronal plane dose at 11 cm depth. This is because the profile measured with EPID for maximum profile is quite flat and the linac was also calibrated to give a reasonably flat profile at same depth. The difference between the calculated and measured profiles was further reduced by embedding the inhomogeneity at different region of profile.

3.4 Development of procedure-based protocol

Once the IMRT QA program is established and tested, then procedure-based protocol should be developed as a part of QA document control and a guideline for the physicist, registrar and technician to perform the IMRT QA task.

The protocol should satisfy the following criteria:

- The protocol should be written in a concise and illustrative way so that other people can follow it to the job.
- The protocol should describe the whole procedure step by step, including how to transfer patient plan to IMRT QA phantom, how to choose the measurement point or dose plane, how to setup the phantom and dosimeter in treatment room, how to deliver the patient plan to phantom and how to analyze the result with a proper software tool. In our center, comparison and processing were done with an in-house program called “IMRT checker”, which is mentioned in several other reports.
- A template for IMRT report should be designed carefully so that it should be professional, concise and leave the blank area for physicist, RTs and oncologists to write down their opinions and recommendations.

According to these requirements, two types of IMRT QA reports were designed to reflect the difference between two methods. As an example, Figure 4 shows a EPID IMRT QA report for a real patient. For both types of reports, the first page is the patient demographic information, the conclusions and suggestion drawn by the physicist and signature for the second physicist and oncologist who takes responsibility for the patient. Following the first page are the analyzed results, including point dose measurement for chamber-film based verification, the Gamma map, overlaid calculated and measured isodose distribution and profiles.

4 Summary

Developing a QA program for existing treatment technique or equipment is one of basic clinical skills and clinical experience for a clinical medical physicist or registrar. Two IMRT QA verification techniques used in our center are compared in terms of how they were implemented.

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- [2] J. Chang and C. C. Ling. Using the frame averaging of aS500 EPID for IMRT verification. Journal of Applied medical physics. 4(4):287, 2003.

Appendix

An EPID IMRT verification report

<u>PATIENT</u>	XXXXXX xx	<u>PHANTOM</u>	EPID QA
ID	EVS0207	ID	EQ1122
PLAN ID	FINALPLAN	PLAN ID	FINALPLAN
Date	31 Dec 08		

- EPID measurement

The results show good agreement between XiO calculated and EPIID measured dose distribution for the combined and individual fields.

- Conclusion

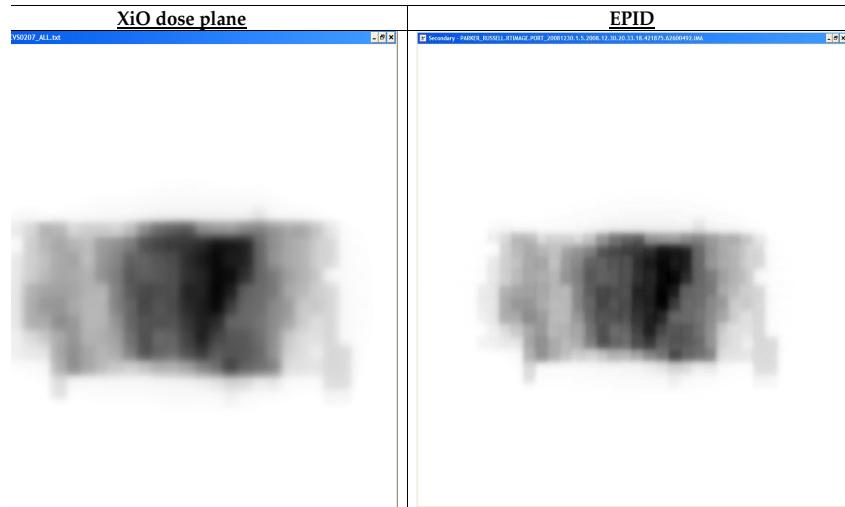
The treatment can proceed if the results are clinically acceptable.

Physicists:

Aitang Xing _____ Keith Croft _____

Radiation Oncologist: _____

Figure 5: The first page of an EPIID IMRT QA report-patient information and conclusion and suggestions made by the physicist. The patient name was omitted for confidentiality.



Gamma-function of the composite image.

The areas outside 3%/3mm limits are outlined on the film image.

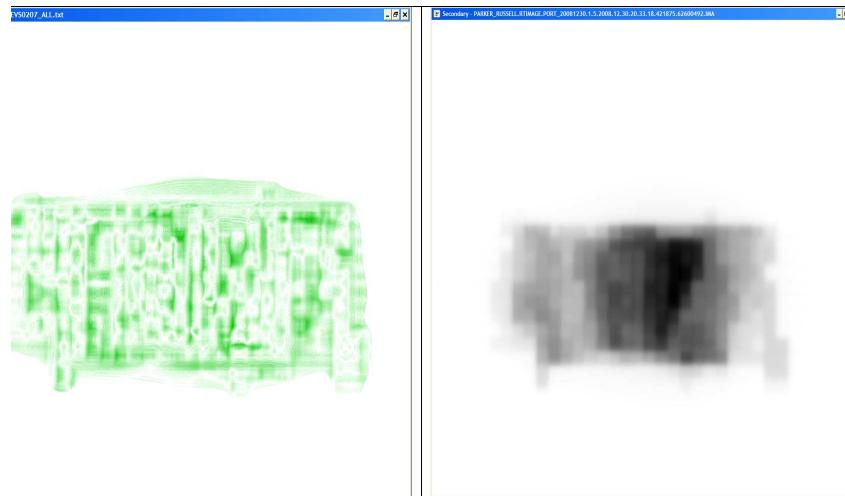


Figure 6: The second page of an EPID IMRT QA report- γ map, calculated and measured dose images.

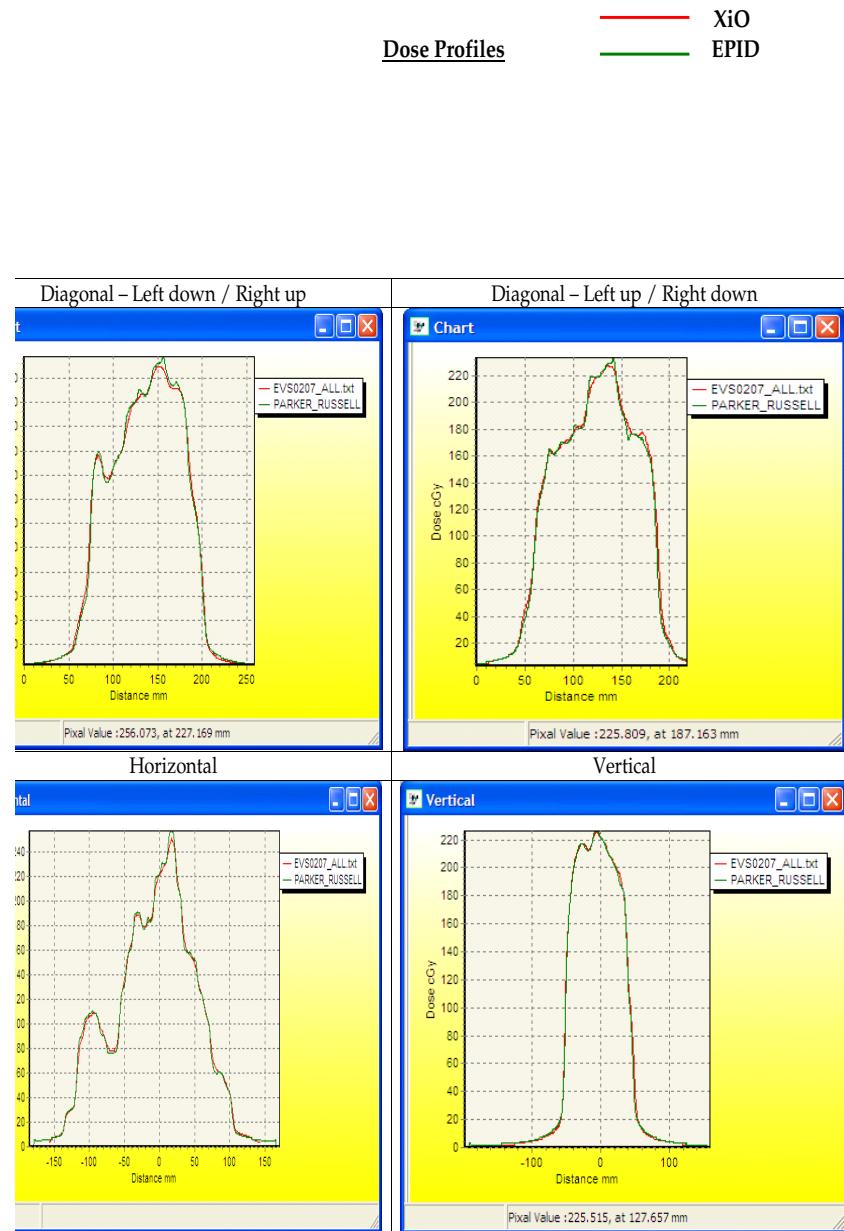


Figure 7: The third page of an EPID IMRT QA report-overlapping of measured and calculated profiles.

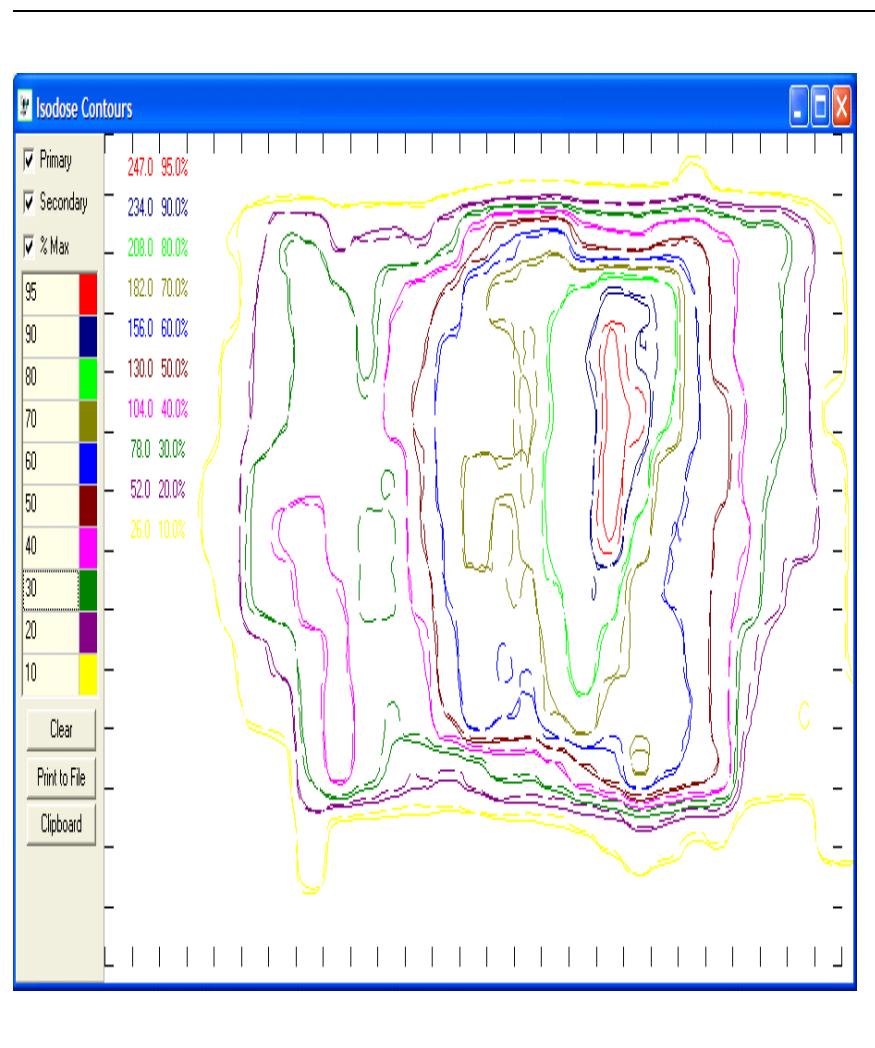
Dose Distribution

Figure 8: The fourth page of an EPID IMRT QA report-overlapping of measured and calculated isodose distribution.

Part II

Radiation Safety and Protection

Chapter 1

MODULE SUMMARY

The following clinical experiences were gained for this module:

1. **Application of radiation protection management in routine work** via housekeeper and periodic check of cesium source storage room, NZ registrar workshop on HDR brachytherapy etc.
2. **Local organization of radiation safety and protection** via collecting and monitoring staff film badge, linac room design of LA4 etc.
3. **Adoption of radiation safety and protection procedure in routine work** via annual wipe test of cesium sources, source calibration etc.
4. **Safety of radiation source** via involving management of source inventory, routinely handling checking source for chamber stability check etc.
5. **Radiation safety in brachytherapy** via source calibration, HDR brachytherapy workshop ect.
6. **Radiation protection design of brachytherapy room** via radiation survey and design of new Siemens Artiste bunker etc.

Note that module reports can not cover all these experiences and only a few representative experiences are presented as reports here.

Chapter 2

MODULE REPORTS

Radiation survey report for new Siemens Artiste bunker

Abstract. A preliminary and a full survey was performed before and after the installation of new Siemens Artiste linear accelerator. The survey meter, survey procedure and results are described in this report. The survey results show that the design and shielding of new linac bunker are adequate and satisfies the international and national regulations of radiation protection for public and radiation works.

Period: 20/10/2008-24/10/2008

1 Facility layout for Siemens Artiste linear accelerator

Radiotherapy department in Palmerston North decided to buy a new Siemens Artiste linear accelerator to replace the Varian 600C linear accelerator in 2007. The Siemens Artiste linac arrived at department in 09/2008 and installed in 10/2008.

Two Siemens linacs, Oncol labeled as LA1 and Primus labeled as LA3 that have been running for several years, were installed on the first floor. These two Siemens facilities are adjacent to each other. Under the bunkers of these two linacs, there are two basements that are locked by a door and interlocked with LA3 maize entrance door. Due to the limited space and taking into economical, social factor, the department decided to modify the LA3 basement to accommodate the new machine labeled as LA4.

Fig.1 shows the facility plan of LA4 bunker. The locations chosen for radiation survey are also marked on the plan. LA4 bunker is directly constructed below the LA3 facility.

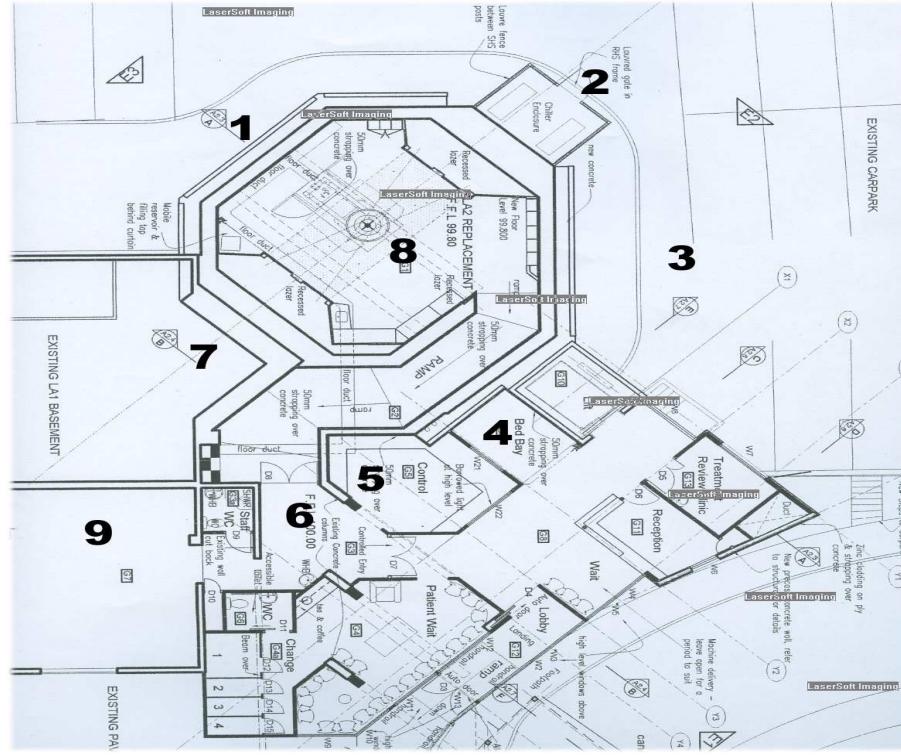


Figure 1: The facility layout for the new Siemens Artiste linear accelerator. The survey locations indicated by number are also marked on the plan.

The steel plate of 80cm thickness was added to the roof as they are both the primary barrier for LA4 and LA3. The basement ground was lowered down by 2 m and refilled with sand and concrete to increase the height of room. The thickness of basement wall was increased by pouring high density concrete to meet the design limits of shielding design. The whole facility was finished within about 10 months.

2 Radiation survey meters

As shown in Fig.2, the following survey meters were used for radiation survey:

- A photon dose survey meter: Victoreen 450P-DE-SI(SN:1243)
- A neutron dose survey meter: Neutron Monitor model 2222 (WENDHOLM MEDICAL)
- A Geiger counter: Victoreen model 491.

The photon survey meter used was calibrated by NRL on the 19th of August, 2005. It gives the readings in term of $\mu\text{Sv}/\text{h}$. It can operate either in dose rate mode or in inte-



Figure 2: The meters used for radiation survey (from left to right):Victoreen 450P-DE-SI(SN:1243), Neutron Monitor model 2222 (WENDHOLM MEDICAL) and Victoreen model 491.

grating mode. During the survey it was used for measuring the photon dose in controlled area or uncontrolled area.

The neutron survey meter was borrowed from New Zealand National Laboratory(NRL). It is a calibrated portable neutron meter for measuring neutron dose rate in mSv/h with approximately correct rem dose response within thermal neutron energy range up to 17 MeV. The neutron dose rate can be measured over a broad range from 0.001 mSv/h to 999.9 mSV/h. The instrument can also measure the accumulated dose displayed in μ Sv or mSv [1].

The Geiger counter is has three response speed: slow, medium and fast. It was used to scanning the linear accelerator facility to detect voids and crack. Before radiation survey, it was also used to locate the location with maximum leakage. The the photon survey meter was used to do the survey at same spot. All three survey meters are warmed up at least half a hour to stabilize it before they are used for survey.

3 Radiation survey procedure

3.1 Preliminary surveys

3.1.1 Preliminary survey during the bunker construction

During day time, the LA3 is operating for treating patient. Therefore, at the beginning of bunker construction, the contractor only works at night in LA3 basement. After the steel plate was added to the roof. A survey was performed to ensure the safety of the builders.

To do the survey, the LA3 is turned on with 15 MV and maximum field size of 40cm by 40cm. The maximum dose rate is 500 MU/min. The gantry directly is directed toward the floor of LA3(the roof of LA4), junction between LA3 floor and primary barrier walls.

The Geiger counter was first used to detect if there are some cracks or voids in room and the junction between the LA4 roof and wall. It is also used to locate the maximum leakage. The photon and neutron survey meters were used.

3.1.2 Preliminary survey during installation

There were two preliminary surveys during installations. The first preliminary survey was after the Siemens Artiste linac delivered its first beam. The purpose of survey is to ensure it is safe for the Siemens engineers and physicist working. The main survey area is the control room, maize entrance and the treatment room when LA3 is running above the roof. The survey was performed with photon dosimeters and neutron survey meters.

The second survey is during the installation. During the installation and machine acceptance test, the Siemens engineers need to align the beam by taking the flattening filter away and adjusting the bending magnet. The gantry angle is at 180 degree and directly toward the roof(the floor of LA3). It only took three days. However, without flattening filter, the intensity of photon beam will increase largely. To ensure the dose rate in LA3 treatment room is within radiation work limit, the photon dose and neutron dose were surveyed near the floor in LA3 treatment room.

3.2 Full radiation survey

After acceptance tests of Siemens Artiste linear accelerator, a full radiation survey was performed with Geiger counter, photon and neutron survey meters.

3.2.1 Choice of Survey locations

As shown in Fig.1, nine locations were chosen for the radiation survey. Location 2 and 7 are just behind the primary barriers of beam. Location 3 and 1 are the secondary barrier. Outside the location 1, 2 and 3 is a big public car park for patient, public and hospital staff. Location 4 is patient bed parking area and there is lifter on its right. Location 5 is the control room. Location 6 is the maize entrance.

Location 9 is a basement under the control room of LA1. There is lockable door between 6 and 9, and between 9 and 7. Location 7 is the basement of LA1 bunker. The doors were always locked during the operation of LA1. The location 9 is only surveyed when LA1 is turned on.

Location 8 is either in LA3 treatment room or LA4 treatment room. Because the LA4's roof is the floor of LA3. When survey location 8 is in LA3(LA4) treatment room, only LA4(LA3) is turned on.

3.2.2 Survey for primary barriers

The following procedure survey was followed for primary barrier survey:

1. Turn the gantry directly towards the primary beam barrier
2. For each gantry angle, set field size is $40cm \times 40cm$ and rotate the collimator to be 45 degree. One medium field size , $15cm \times 15cm$, and one small field size, $5cm \times 5cm$ are also used for survey.
3. The same radiation conditions are repeated for both 6MV and 15MV photon beams.
4. Hold the photon and neutron survey meters behind the primary barrier. Move the location until find a maximum readings.
5. The junction between primary barrier and secondary barrier was also surveyed to evaluate effect of small-angle scattering of photon form primary barrier.

3.2.3 Survey for secondary barriers

The secondary barrier was surveyed as follows:

1. Place the 48cm long and 19.2cm wide perspex slab phantom on the couch to simulate the patient scattering. This phantom is used for IMRT verification. Adjust the

phantom and couch height so that the isocenter of machine coincides with the center of phantom.

2. For each secondary barrier, the survey was performed for the gantry angle of 0, 90, 180, 270 and the angles letting beam towards the junctions between roof and wall, and between floor and wall.
3. For each gantry angle, set field size is $40cm \times 40cm$ and rotate the collimator to be 45 degree. One medium field size , $15cm \times 15cm$, and one small field size, $5cm \times 5cm$ are also used for survey. The same radiation conditions are repeated for both 6MV and 15MV photon beams.
4. Hold the photon and neutron survey meters behind the secondary barrier. Move the location until find a maximum readings.
5. The same radiation conditions are repeated for both 6MV and 15MV photon beams.
6. The junction between primary barrier and secondary barrier was also surveyed to make sure whether or not there is any leakage from small-angle scatter at the extremities of primary barrier.

3.2.4 Survey for maize entrance and egress of ducts

The neutron dose(15MV only) and photon dose was also surveyed at the maze entrance with the following procedure:

1. The photon dose and neutron dose survey was performed for the gantry angle of 0, 90, 180, 270 without phantom in beam path.
2. For each gantry angle, set field size is $40cm \times 40cm$ and rotate the collimator to be 45 degree.
3. Place the 48cm long and 19.2cm wide perspex slab phantom on the couch to simulate the patient scattering. This phantom is used for IMRT verification. Adjust the phantom and couch height so that the isocenter of machine coincides with the center of phantom.
4. Repeat the measurements performed with phantom in the beam.
5. The egress of cable duct located under the floor of control room was also surveyed with photon survey meter.

Table A.1: Preliminary survey results with the neutron dose in parenthesis before Siemens Artiste installation.

Energy	Survey photon(neutron)dose(μSv)			
	Door	Halfway	Inner entrance	Isocenter
6MV	0.06	0.06	0.08	0.5
15MV	0.5(1.0)	0.8	1.3	2.5(10.0)

3.2.5 Survey for Skyshine dose rate

LA4 bunker is situated on ground floor, but LA1 and LA4 is on the secondary floor. On the third floor, there are the wards for cancer patient. Although the wards are far away from the roof of LA1 and LA4 bunker, but they are at same level. In addition, the round the LA1 and LA4 bunkers is a public car park. When the beam is directed the roof with maximum field size and dose rate, the skyshine dose rate was measured for 15MV photon beam at the car park and patient wards.

4 Radiation survey results and evaluation of shielding adequacy

4.1 Survey results

4.1.1 Preliminary survey

As mentioned in Sect.3.1, the first preliminary survey was performed before the machine installation. The survey was done in LA4 bunker by turning on LA3. The photon dose and neutron dose were measured at the following locations of LA4 bunker: the door of maize entrance, the halfway of maize entrance and inner entrance of maize and at the isocenter location. The results are shown in Table.A.1. The recorded values in the table are the maximum dose rate measured for various radiation conditions used in survey.

During the installation, when the flattening filter was taken off for beam alignment with the gantry directed at the LA3 floor. The photon dose was surveyed when LA4 was turned on with maximum field size and dose rate. One hottest location was found with the dose rate of $140\mu\text{Sv}/\text{h}$ near the inner entrance of LA3 maize. The averaged dose rate

Table A.2: Full survey results after acceptance test of Siemens Artiste installation.

Locations	Survey dose(μSv)								
	1	2	3	4	5	6	7	8	9
6MV	0.04	0.02	0.03	0.03	0.14(0.1)	0.02	0.02(0.04)	0.08(0.4)	60(15)
15MV	0.5(1.0)	0.7	0.2	0.08	1.4(1.2)	0.6	0.03(0.18)	2.3(8)	163(28)

on other location was $15\mu\text{Sv}/\text{h}$. With the flattening filter, the hottest spot is $7.3\mu\text{Sv}/\text{h}$ in LA3 treatment room.

4.1.2 Full survey

The full survey results for 9 locations are recorded in Table. Only the maximum dose rate found in each location for various radiation conditions during survey are shown here with the flowing annotations:

1. For location 8, the number without parenthesis is survey results in LA4 treatment room when LA3 is running. The number in parenthesis is survey result in LA3 treatment room when LA4 is running.
2. For location 9, the larger number is reading near the door entering into LA1 bunker basement from the basement of LA1 control room. The smaller number is the reading at other area outside the LA1 bunker basement but in the basement of LA1 control room.
3. For the location 5, the larger number is the survey result near the exit of cable duct under floor in LA4 control room. The smaller number is the survey result above the bench in the LA4 control room.
4. For location 7, the smaller number is just behind the primary barrier. The larger number is the junction area between primary bunker and secondary bunker.

4.2 Adequacy of shielding

4.2.1 Estimated Workload

Based on the patient throughout of LA1 and LA3, there are about 30 patient treated every day. Each fraction is usually 2Gy or 3Gy. For conservative consideration, assuming

50 patients treated with 3Gy/fraction on LA4 every day, therefore the weekly workload is:

$$W = 3 \text{ Gy} \times 50/\text{day} \times 5 \text{ day/week} = 750 \text{ Gy/week} \quad (\text{A.1})$$

4.2.2 Time averaged dose rate

What the the survey meters measure is the instantaneous dose rate(IDR). This is the direct reading of the dosimeter that gives a reading in dose per hour, averaged over one minute. When evaluating the adequacy of shielding, it is important and useful to calculate the expected IDR for comparison with direct measurement after the facility has been built. The concept of time-averaged dose rate(TADR) is proposed [2].

TADR is the barrier attenuated dose rate averaged over a specified time. TADR is proportional to IDR, and incorporates the, workload(w), use factor(U) and dose output rate(DR_0) of the unit. For secondary barrier, the U will be unity. The weekly TARD is defined as the TARD averaged over 40 hour/week and can be derived that:

$$R_w = IDR \times \frac{W U}{DR_0} \quad (\text{A.2})$$

where DR_0 is the dose output rate at 1m, in Gy/h.

4.3 Evaluation

4.3.1 Weekly beaming-on time

LA4 operates with the dose rate of 3Gy/min for 6MV and 5Gy/min for 15 MV at isocenter. For megavoltage treatment units, although the unit may be in use for 8 hour per day, it is likely that the total beam-on time per week will be much less. Assume the 750 Gy weekly work load is delivered either with 6MV or 15 MV.

For 6MV and 15MV, the total beam-on timing per week are:

$$T_{6MV} = 750\text{Gy}/3\text{Gy}/\text{min}/60\text{min} = 4.2h \quad (\text{A.3})$$

$$T_{15MV} = 750\text{Gy}/5\text{Gy}/\text{min}/60\text{min} = 2.5h \quad (\text{A.4})$$

If the total weekly work load is equally divided between 15 MV and 6MV, then beaming-time is:

$$T_{6MV} = 375\text{Gy}/3\text{Gy}/\text{min}/60\text{min} = 2.1h \quad (\text{A.5})$$

$$T_{15MV} = 375\text{Gy}/5\text{Gy}/\text{min}/60\text{min} = 1.25h \quad (\text{A.6})$$

4.3.2 Safety of Engineers, physicist and RTs

From Table A.1, it can be seen the maximum dose rate is $12.5\mu\text{Sv}/\text{h}$ for 15MV and $0.5\mu\text{Sv}/\text{h}$ in LA4 treatment room when LA3 is running. If the machine is running with 15MV(6MV), then weekly TADR is $31.2\mu\text{Sv}/\text{week}(2.1\mu\text{Sv}/\text{h})$. If considering the use factor of 1/4, the weekly TADR is $7.8 \mu\text{Sv}/\text{h}$, which is far below the public dose limits of $19.2\mu\text{Sv}/\text{week}(1\text{mSv}/\text{year})$. Therefore the Siemens engineers, physicists and RTs can work safely in LA4 treatment room when LA3 in operation.

When LA4 is running without flattening filter, the maximum dose rate is $140\mu\text{Sv}/\text{h}$ in LA3 treatment room. The total beaming-on time of LA4 is about 1 hour Assuming the RT occupancy factor is 80% for setting up patient, the weekly TADR for RTs working on LA3 is $112\mu\text{Sv}/\text{h}$, which is less than weekly limit for radiation workers, $385\mu\text{Sv}/\text{week}(20\text{mSv}/\text{per year})$. With the flattening filter, the maximum dose rate is only $7.3\mu\text{Sv}/\text{h}$. The RTs can safely work on LA3.

4.3.3 Barrier shielding

Primary barrier shielding

The maximum dose rate behind the primary barrier(location 2 and 7) is $0.7\mu\text{Sv}/\text{h}$. Supposing the the workload is delivered only by 15MV photon beams and occupancy and use factor of 1, then weekly TADR behind the primary barrier is $1.75\mu\text{Sv}/\text{week}$, which is far below the public limit, $19.2\mu\text{Sv}/\text{week}$. Therefore the shielding of primary barrier is adequate.

Secondary barrier shielding

The maximum dose rate behind the primary barrier(location 1 and 3) is $0.5\mu\text{Sv}/\text{h}$. Supposing the the workload is delivered only by 15MV photon beams and occupancy and use factor of 1, then weekly TADR behind the primary barrier is $1.25\mu\text{Sv}/\text{week}$, which is far below the public limit, $19.2\mu\text{Sv}/\text{week}$. Therefore the shielding of secondary barrier is adequate.

Corridor, lifter, reception and waiting area

Location 4 is close to the maize wall and represents these areas. The maximum dose rate at this location is $0.08\mu\text{Sv}/\text{h}$. Supposing the the workload is delivered only by 15MV photon beams and occupancy and use factor of 1, then weekly TADR behind the primary barrier is $0.2\mu\text{Sv}/\text{week}$, which is far below the public limit, $19.2\mu\text{Sv}/\text{week}$. Therefore the shielding of maize wall is adequate.

Control room

The maximum dose rate at the control room and just behind the maize wall(location 4) is $1.4\mu\text{Sv}/\text{h}$. Supposing the the workload is delivered only by 15MV photon beams and occupancy and use factor of 1, then weekly TADR behind the primary barrier is $3.5\mu\text{Sv}/\text{week}$, which is far below the public limit, $19.2\mu\text{Sv}/\text{week}$. Therefore the shielding of maize wall is adequate.

Door of maize entrance

The maximum photon and neutron dose rate at the door of entrance barrier(location 5) is $0.6\mu\text{Sv}/\text{h}$. Supposing the the workload is delivered only by 15MV photon beams and occupancy and use factor of 1, then weekly TADR behind the primary barrier is $1.5\mu\text{Sv}/\text{week}$, which is far below the public limit, $19.2\mu\text{Sv}/\text{week}$. Therefore the design and length of maize is adequate.

Location 9

The maximum dose rate($163\mu\text{Sv}/\text{h}$)during the survey is in the basement of LA1 control room and near the door between LA1 bunker basement and LA1 control room basement. This is the maximum dose rate when only LA1 beam is pointed at the floor with maximum field size. Considering the use factor of $1/4$ and occupancy factor, then the weekly TADR is $101.8\mu\text{Sv}/\text{week}$, which is below the radiation work limit, $385\mu\text{Sv}/\text{week}(20\text{mSv}/\text{year})$.

During the LA1 and LA4 running, the door entering the area of location 9 is always locked.

skyshine dose rate

The maximum skyshine dose rate found in the car park and ward floor is $0.03\mu\text{Sv}/\text{h}$. Therefore it is negligible.

Therefore the shielding and design of LA4 bunker satisfies the international requirements [3] and national regulations of radiation protections [4].

5 Conclusions

After the new Siemens Artiste linear accelerator was installed in Palmerston North Hospital, the full survey was performed. The survey results shows the design and shielding of LA4 bunker are adequate.

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Part III

Radiotherapy Equipment Specification, Commissioning & QA

Chapter 1

MODULE SUMMARY

The following clinical experiences were gained for this module:

1. **Deep knowledge and experience of treatment and medical imaging equipment and their specification** via attending equipment maintenance and repair or replacement of linac component performed by Siemens engineers etc.
2. **Quality Assurance of External Beam Equipment I Acceptance Testing** via participating acceptance test of Gulmy x-ray Unit and new Siemens Artiste linear accelerator etc.
3. **Adoption of radiation safety and protection procedure in routine work** via annual wipe test of cesium sources, source calibration etc.
4. **Quality Assurance of External Beam Equipment II Commissioning** via commissioning Gulmy x-ray unit and new Siemens Artiste linac etc.
5. **Quality Assurance of External Beam Equipment III Quality Control** via daily, weekly, monthly QA of linac, superficial, CT simulator etc.
6. **Operational Procedures for External Beam Equipment** via a comprehensive routine QA program performed in oncology department etc.
7. **Treatment Techniques** via routine patient QA of IMRT, electron arc, 3D-CRT verification etc.
8. **Patient Positioning and Treatment Verification** via routine in vivo dosimetry with TLD and MOSFET, IMRT verification etc.

Note that module reports can not cover all these experiences and only a few representative experiences are presented as reports here.

Chapter 2

MODULE REPORTS

Grey's anatomy of Siemens

Artiste linear accelerator:

experience of acceptance test

Abstract. I was lucky to participate in acceptance test of new installed Siemens Artiste linear accelerator. This report described this experience. However it is not a copy of acceptance document and results. I want to express the great thanks for two Siemens engineer, Andrew and William, to show bisect the linac and show me how each part or component works and effect the beam dosimetric features. Therefore this report focus on how to chose proper phantom and dosimeter and how to setup to obtain the acceptance data. More importantly, this report will emphasize how to adjust to make performance parameters within specification. Although it is job of engineer, but having the this type of knowledge also benefit physicist as the overall performance will be effected by individual performance of each part.

Period: 9/2008-11/2008

1 Acceptance test and Structure of Siemens Artiste linear accelerator

Acceptance test of a new linear accelerator is a procedure of check if its performance satisfies the manufacture's specification. The acceptance test is performed by physicist or physics registrar along with installation engineers from manufacturer. The role of physicist

is to perform or monitor the tests, whereas the engineers perform or monitor the tests to shows or make sure the performance is within the manufacturer's specification [1].

The performance of a linac is characterize by a series of performance indices. Linac is a composite system compromised of several components (subsystem). The acceptance test is to check performance of each subsystem or component and the overall performance as a whole. Before the linac parts are shipped to the customer, the manufacturer has already thoroughly checked its performance and provides reference values. Therefore acceptance test is an linac-component oriented procedure. If any component's performance is out of the specification, the engineers will do all necessary adjustment or even replacement or repair to make sure it functions correctly and properly.

Therefore acceptance test provide a good chance of not only having practical experience of acceptance testing of new machine but also a good opportunity of learning the anatomy and its functioning of each part or component of linac in a live way. The acceptance tests are the basis for the ongoing QA program. After acceptance test, the experience also enables me to make a comprehensive and practicable quality insurance program.

I want to express my great thanks to two Siemens Engineer, Andrew and William for answering my numerous questions, showing me the working mechanism of component and how to adjust to make sure the each component works within their specification.

This report recorded the acceptance of Siemens Artiste linac over a period of one and half months through hard working together at daytime, night and weekend. This is a treasurable experience which will benefit my whole career.

2 Acceptance setup, procedure and results

Acceptance test of linac is a component-oriented procedure. In other words, each component of linac needs to be checked from five aspects of its performance: safety, mechanics, electronic, optical and dosimetry.

For example, the collimator is a component of linac head. The safety check of collimator is to check the leakage and neutron dose production of collimator outside the field size is within the safety limit. It is important for sparing the healthy tissue and patient safety and RT staff. Its mechanics check is to check the linearity of collimator movement and the accuracy of movement positioning relative to radiation field size. The optical checking of collimator is to check the coincidence the central axis, field size between radiation field

and light field. The dosimetric check, the most important one, is compromised of radiation field size, flatness, symmetry and penumbra.

Before the linac was shipped here, the manufacturer did all acceptance tests for new machine and recorded results as a golden reference. The acceptance test at user center is essentially to repeat the the test with the phantom or dosimeter chosen by customer or provided by manufacture. In principle, the acceptance test is to repeat all these tests in factory with the customer chosen or manufacturer chosen dosimeter or phantom.

The acceptance test were performed mainly using the test equipments provided by linac manufacturer. They are many ways to do each test with other phantom and dosimeters available in department. The setup and procedure for each test were described in details in the acceptance document provided by linac manufacturer. **The rest of report is not to repeat or copy the results but focusing on:**

- Acceptance test equipment and other choice of dosimeter and phantom
- brief of test setup and procedure
- What and how to adjust to make sure each test parameter is within the specification.
- Some typical results but not all

2.1 Radiation safety

Once the new linac is assembled and starts delivering the first beam, radiation safety check is the first things to do. The purpose of radiation safety check is to make the sure installation engineers, medical physicist and RT works within the dose limits recommended by ICRP60 and 2007 as well as the safety of patient. The radiation safety check include the radiation survey, head leakage and interlock.

2.1.1 Radiation survey

There are two types of radiation surveys: preliminary survey and full survey. The preliminary survey is usually performed after the delivery of first radiation but before the acceptance test, ensuring the safety of engineers and physicists working on installation and acceptance test. The full survey was performed after the acceptance tests. The pur-

pose is to do thorough investigation to meet the safety dose limits of public, radiation staff and patient.

The survey instrument, procedure and instrument were described in details in another report.

2.1.2 Interlock

Interlock system looks as if an immune system of linac. The parameters characterizing the performance of each component or linac as a whole has a dynamic range when the machine is running. Each parameter varies but should be within a specified range also called window if the machine is turned on. When any of them is running out of range, the interlock system should trigger an interlock and stop the linac immediately. Therefore it is important to check the correctly functioning of each interlocked.

The acceptance test procedure for each interlock is very simple by creating conditions that can trigger that interlock. Here it is not necessary to describe the test procedure for each interlock. All interlocks listed in Siemens acceptance test document and protocol were tested and found they all functions correctly.

2.1.3 Head leakage

Head leakage check is to make sure the leaked radiation outside the field is within the specified limits, which is important for patient safety by protecting the healthy tissues.

Dosimeter, setup and procedure

The head leakage was measured with Kodak XV film. As shown in Fig.1. The gantry angle was 270 degree and 10 films were used to wrap up the gantry at different locations. The main location is chosen near the gun, cross the wave guide, around the bending magnet, near and around the collimator and MLC.

The jaws and MLC were closed and 7500MU with 15MV were delivered to the films aiming at approximately 30cGy to the film. A reference film was chosen from same film batch. Its optical density was used as a reference value. 30 cGy dose was delivered to the reference film using 10×10 field size under the reference conditions used for reference dosimetry.

All films were processed with a Kodak film processor and scanned as BMP images using a Vidar film scanner. The optical density of films were converted into dose using a



Figure 1: Photo of some film locations used for head-leakage test.

Date: 24/10/2008 Measured by: Aitang

Head leakage survey results

MU for reference film: 30 MU for field film: 7500

Location	dose(cGy)	dose(cGy)	Dose-per-MU ratio(%)	At-1m-ratio(%)
Reference film	64.24			
Film 1		15.82	0.0985	0.025
Film 2		18.04	0.1123	0.028
Film 3		74.82	0.4659	0.075
Film 4		7.8	0.0486	0.012
Film 5		5.49	0.0342	0.009
Film 6		11.63	0.0724	0.018
Film 7		19.22	0.1197	0.030
Film 8		6.33	0.0394	0.0099
Film 9		6.24	0.0389	0.0097
Film 10		17.34	0.1080	0.027

Figure 2: The head-leakage test results measured with Kodak XV film.

calibration curve. The calibration curve was obtained using calibration wedge for IMRT patient QA.

Head leakage results

Fig.2 shows measurement results of head leakage. The dose measured by field film is the maximum dose that could be found on the film. The dose-per-MU ratio is the leakage at the film location. Depending the film location, the distance between film and electron beam path or photon beam path is between 15 cm and 50 cm. The leakage at 1 meter was obtained using inver square law.

It can be seen that the largest leakage location is around bending magnet. Leakage from all locations is far below the specification of less than 0.1% of dose at isocenter. The specific leakage quantity is different from those measured by manufacturer. The manufacture did the head leakage test using a chamber which is attached on an arm. This arm is part attached to the machine head and cab be rotate around the central axis of wave guide and the central axis of the beam.

2.2 Mechanic and optical check

2.2.1 Isocenter verification

Ideally the central axis of gantry, collimator and couch intersects at one point in space, which is usually called isocenter. In reality, three axes intersects at one small sphere. The isocenter verification is to check if the diameter of this sphere is less than 2mm. If not, some adjustment should be done to satisfy this specification.

The virtual machine in TPS assume that three axes intersects at exactly one point. To accurately implement treatment plan, it is an important to check the diameter of isocentric sphere at the time of acceptance test and as an important part of ongoing quality assurance program.

There are three types of isocentric check for couch, collimator and gantry: mechanic isocentricity , dosimetric isocentricity and optical isocentricity. The optical isocentricity can be regarded as part of optical system check.

Collimator

For the mechanical check of collimator rotation, the flowing most common way was used for the acceptance test: attaching a blank paper on the couch surface, then finding and mark inplane axis of field by turning gantry at several position and setting $SSD \neq 100\text{cm}$, installing the mechanic pointer, rotating the collimator to draw a circle on the paper.

If the mechanic isocentric circle of collimator is out of the range, as shown in Fig.3, there are screw in side the head, which can be used to refine the collimator axis to make isocentric circle within the specification.

For the dosimetric isocenter check, Star-shot, the most common method, was used to check the dosimetric isocenter of collimator. The Kodak EDR2 film was used, sandwiched between 10cm Plastic water as backscatter material and 5cm plastic water as build-up materials. The film was developed and scanned with Kodak film processor and a Vidar film scanner, respectively. The scanned film was analyzed using the IMRT checker, an in-house program. Fig.4 shows the test results for dosimetric isocentric check for 6 MV beam.

If the dosimetric isocenter is out of specification, the following things needs to be checked in the order:

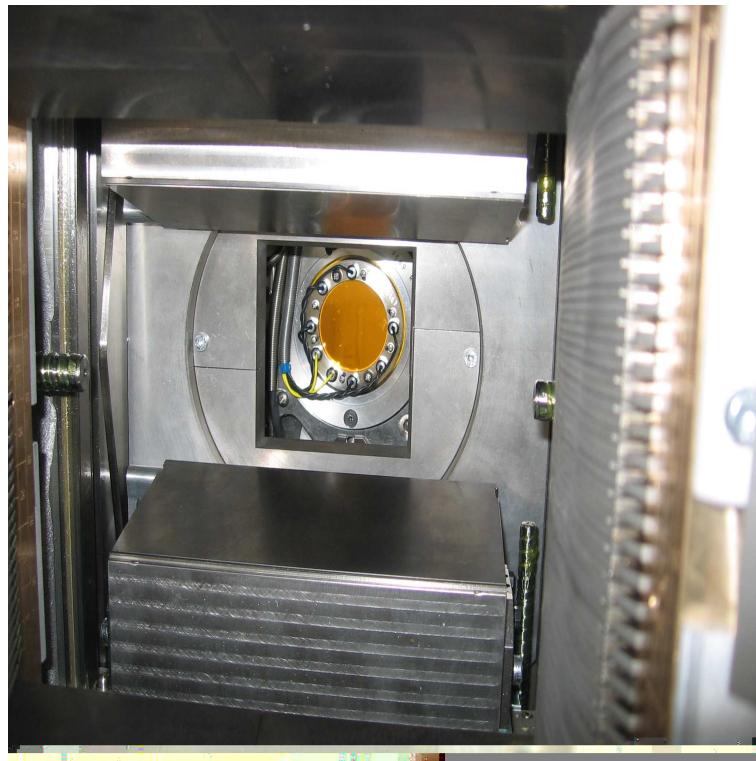


Figure 3: The screws used for adjusting the mechanic isocenter for collimator.

check the mechanical isocenter using the front pointer

check if the center of focal spot sit on the central axis of attenuating Iter, collimator and target by blocking half of a thimble chamber and rotating the collimator to see if the reading from chamber positioned at isocenter is same if it does, it means the focal spot of target positioning is same.

Check if the center of radiation field aligns with the center of cross hair.

The above checks should pinpoint the factor causing the dosimetric isocenter to be out of the tolerance. If necessary, position and angle of electron beam just comes out of waveguide, the attenuating Iter, the collimator can be refined to make sure the beam central axis coincides with the mechanic central axis of target, attenuating Iter and collimators. As for how to adjust them, see below discussion.

Gantry

For Gantry's mechanic isocentric check, the most common way as does for weekly QA is to attach a very thin and round needle to the edge of couch ensuring the tip of

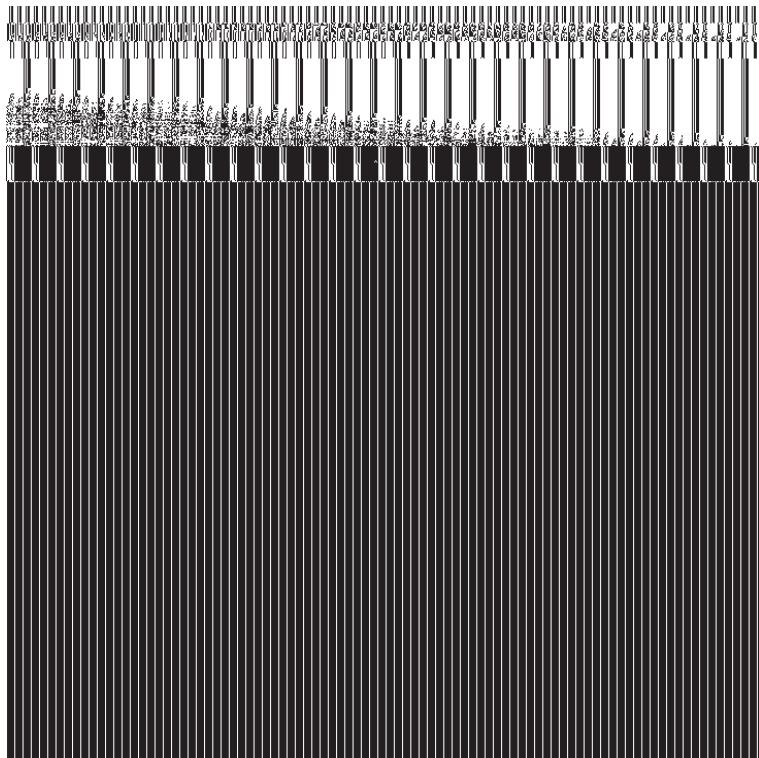


Figure 4: The collimator starshot for collimator and IMRT checker used for automatically measuring the diameter of isocentric circle. The diameter of isocentric circle is 0.33mm.

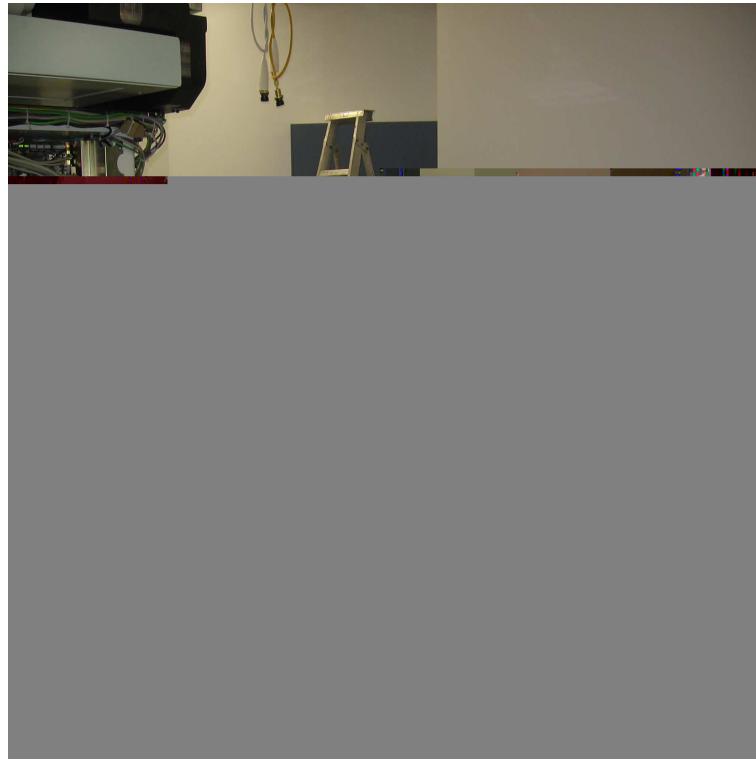


Figure 5: The telescope-like device to measure the mechanic isocenter of gantry.

needle is touching the tip of front pointer. Rotate the gantry over a circle to measure the distance between two tips. The largest tip is used as the diameter of mechanical isocenter.

For acceptance test, as shown in Fig.7, a telescope like device brought by manufacturer was used along with a specially designed software that will automatically calculate the diameter of mechanic isocenter.

If the mechanic isocenter is out of the tolerance, there are several screw at both side of weight-count end of gantry as shown in Fig.6. These screws can be slightly adjusted to make sure the mechanic isocenter of gantry is within specification.

For dosimetric isocenter check of gantry, an upright holder of Kodak attached to the edge of couch was used. A simple way to do this is to put a 5 cm thick plastic at the edge of couch. Tape the film on to the surface of plastic water. No matter which method is used, the film surface should be coincide with isocentric plane. The isocenter is also roughly at the film center. The results of gantry star shot were shown in Fig.8. **If the dosimetric isocenter is out of tolerance,** first the mechanic isocentric rotation of gantry should be checked, then mechanic and dosimetric rotation of collimator should be check. If all these

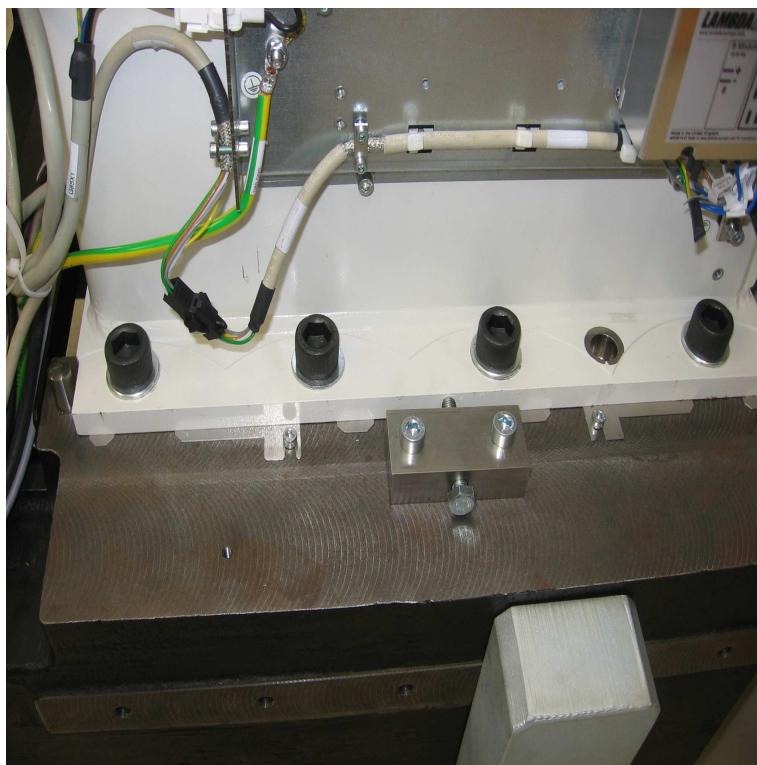


Figure 6: The screws at the counter-weight end of gantry, which is used to slightly adjust mechanic isocentric circle of gantry.



Figure 7: The little device used to measure the dosimetric isocenter of gantry.

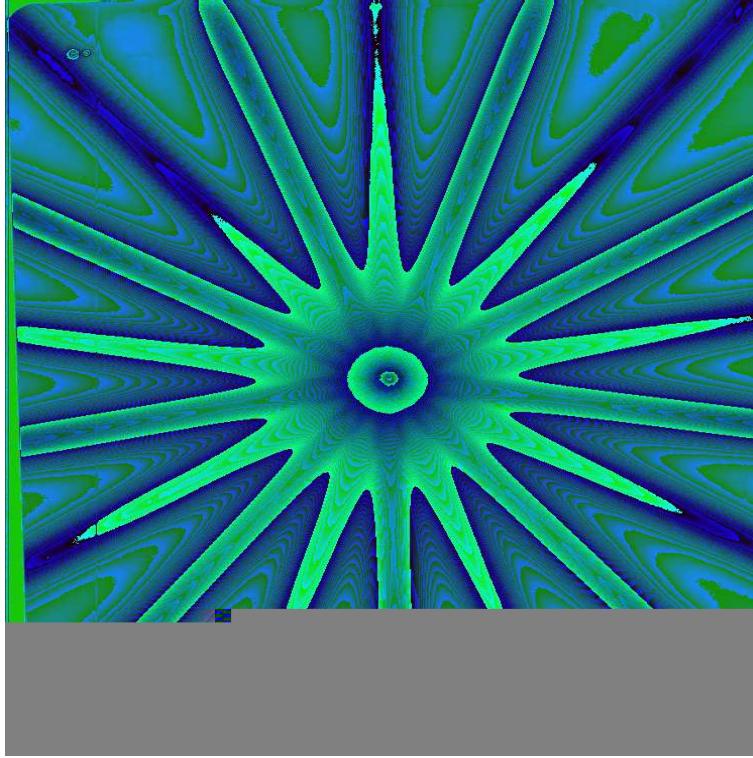


Figure 8: The scanned 12bit BMP film image for gantry star shot.

are right, then the dosimetric should be within the specification.

Couch

For couch's mechanic and isocentric check, the setup and procedure are similar to those used for the collimator check. The only difference is to rotate the couch instead of rotating collimator.

If the mechanic or dosimetric isocenter is out of the specification, there are several screws under the couch base and support. These screws can be adjusted to make sure the diameter of isocenter is within 2mm tolerance. During acceptance procedure, these screws were adjusted as shown in Fig.9.

2.2.2 Calibration of mechanic movement and positioning

Checking and calibration of mechanic movement and positioning are another important part of mechanic and electronic tests. There three rotation and translations associated with the linac: rotation of gantry, couch and collimator, longitudinal, traverse and vertical translation of couch as well as the translation of MLC and collimator along the inplane

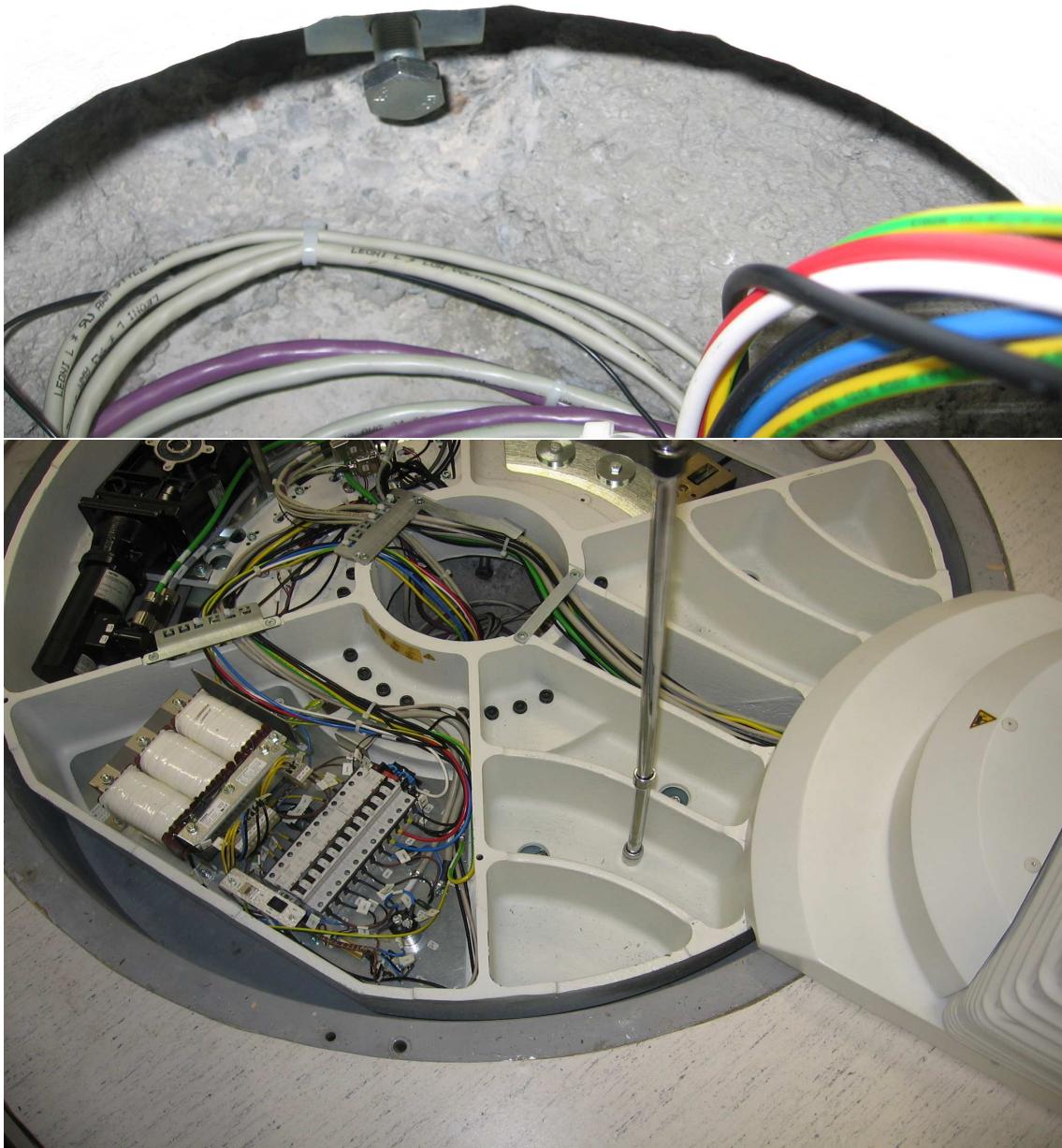


Figure 9: Upper: one adjustable screw at the edge of couch base. Lower: Another type of screw which can be adjustable. Adjustment of two types screws can change the diameter of couch isocenter.

and cross plane direction.

The mechanic movement check and positioning check is to check:

- The linearity, range and limits of these mechanic movement.
- The accuracy of positioning
- The accuracy between digital reading from screen or display panel.

For check of these mechanic movements, the basic principle are same. An independent calculated 'ruler' or spiritual level is used to check distance or positioning against the digital indication. During acceptance test, the procedures used are exactly same as ones used for daily and weekly QA check. Therefore it is no necessary to describe them in detail here.

The specification by manufacture is $\leq \pm 1\%$ for translation and ≤ 0.5 for rotation. **If the mechanic movement is out of tolerance, the accuracy positioning need to be calibrated. The calibration procedure are same:**

1. Firstly set up independent standard mechanic reference (ruler, spiritual level, etc.)
2. Move the linac component to an accurately known position against the stand mechanic reference.
3. Enter the service mode from linac control console and find corresponding calibration page.
4. Use the 'Capture' function of software to capture the calibrated position.
5. After calibration and back to treatment mode and check accuracy of component positioning at other location.

A typical example is to calibrate the gantry angel. It is assumed that the gantry angle at 270 degree is out of tolerance. The calibration procedure is:

1. Use a calibrated spiritual level as a mechanic standard reference.
2. Turn the gantry to 270 degree, which is carefully checked by spiritual level. The indicator may show, for example, 271 degree.
3. Open linac control console and gantry calibration page.
4. Enter correct angle twice for two digital potential meters.

5. Use software ‘capture’ function to capture the right angel.
6. Exit the service mode and enter into treatment mode. Then check the accuracy of gantry at 270 degree and other position.

The principle and theory behind the calibration of mechanic movement is that Siemens linac uses two digital potential meters or one digital potential meter plus one digital encoder to control and monitor the movement and positioning of couch, gantry and collimator. The service mode of control console provide a software interface to adjust or control these potential meter or digital encoder.

Another example is to calibrate 160 MLC. Compared with Siemens Onco and Primus, Siemens Artiste’s MLC can be calibrated using several calibration block and software. The calibrated blocks are essentially the reference mechanical ‘ruler’. Fig.10 shows the MLC calibration block and the software page of service mode corresponding to the MLC calibration.

2.3 Optical system

There are three types of optical systems associated with linac: ODI, light field and reticle as well as room laser system. They are used to help RT setup the beam and patient. Therefor the accuracy of these optical system are critical.

2.3.1 ODI

The ODI is to visualize mechanic front pointer, hence the accuracy of ODI should be checked against the mechanic pointer and other independent mechanic ruler. So did during the acceptance test for accuracy and linearity of this optical ruler. If the optical ruler is not accurate, there is three screws which can be used to adjust the ODI.

2.3.2 Alignment of Light field and radiation field

Light field and reticle are used to visualize the radiation field, its central axis,inplane and crossplane. The checking light field is to check if the field size and central axis coincides with those of radiation field. The most common method is to use Kodak EDR2 film with proper build up and back up materials. The light field edge was marked on the film envelope with a pin. After film exposed, the light field edge and 50% radiation field edge can be checked.

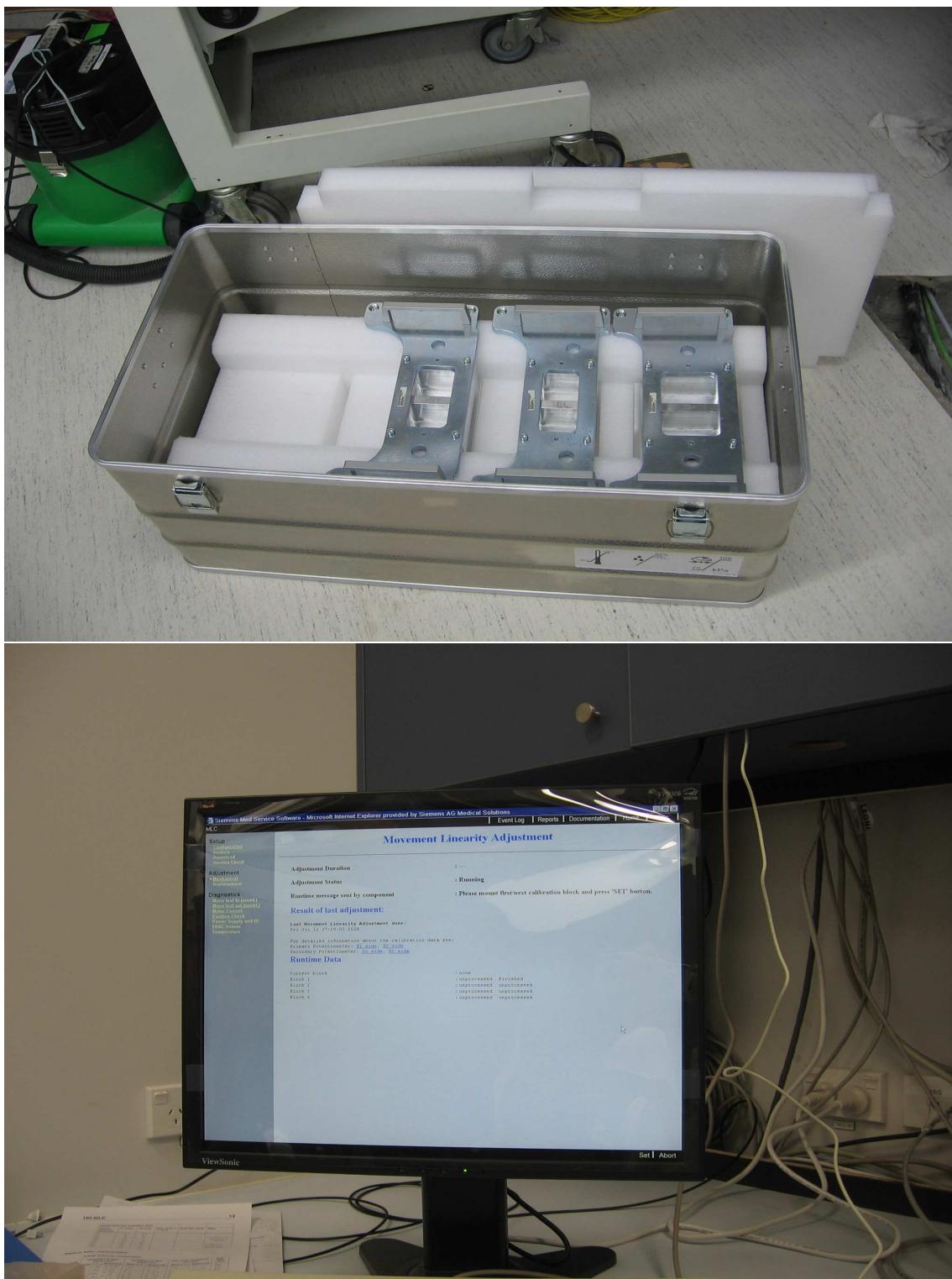


Figure 10: Upper: the MLC calibration used as a standard mechanic reference ‘ruler’. Lower: The software part of MLC calibration page of service mode, which automatically captures the block position.

During the acceptance test, the films were used to check the coincidence between light field and radiation field for a variety of field sizes. Fig.11 shows some typical results. The difference between radiation field size and light field size are less than ± 0.5 mm for field sizes checked. The scratched mark on exposed film caused by pin corresponds to the light field edge.

If the radiation field does not coincide with radiation field, it is usually caused by two following factors:

1. the image of light bulb is not coincident with the focal spot, which is usually caused by the reflection mirror placed in beam path inside the head, as shown in Fig.12. The three screws of mirror support can be adjusted to make sure the light field agrees with radiation field size within the specification.
2. Central axis of reticle does not align with the mechanic and dosimetric central axis of collimator and MLC. Similarly, there are also three adjustable screws attached to the reticle to correct the misalignment of reticle.

2.3.3 Lasers

Laser system is not part of linac but belonging to optical system. Laser system is to visualize the coordinate system of room(linac) with its origin at isocenter. The basic check is to make sure that the optical inplane and cross plane formed by laser should exactly coincide with those of radiation field and light field.

2.4 Dosimetric check

2.4.1 Spectrum and characterization parameters

The dosimetric characteristics of photon and electron beam are determined by its energy spectrum and angular spectrum. The energy spectrum determines the percentage depth dose of beam, while angular spectrum determines beam profiles.

It is very difficult to directly measure energy spectrum or angular spectrum. Therefore, for the acceptance test purpose, the spectrum or beam are characterized by several characteristic parameters. These parameters have reference values obtained in manufacturer before shipped to customer. The dosimetric check as an most important part of acceptance test is to use the manufacturer chosen or customer chosen scanning equipment



Figure 11: Upper: Dose profile with two thin dips at both penumbra region which corresponding the light field edge. Lower: the film image and the penumbra region at one side of field with marked light field edge.

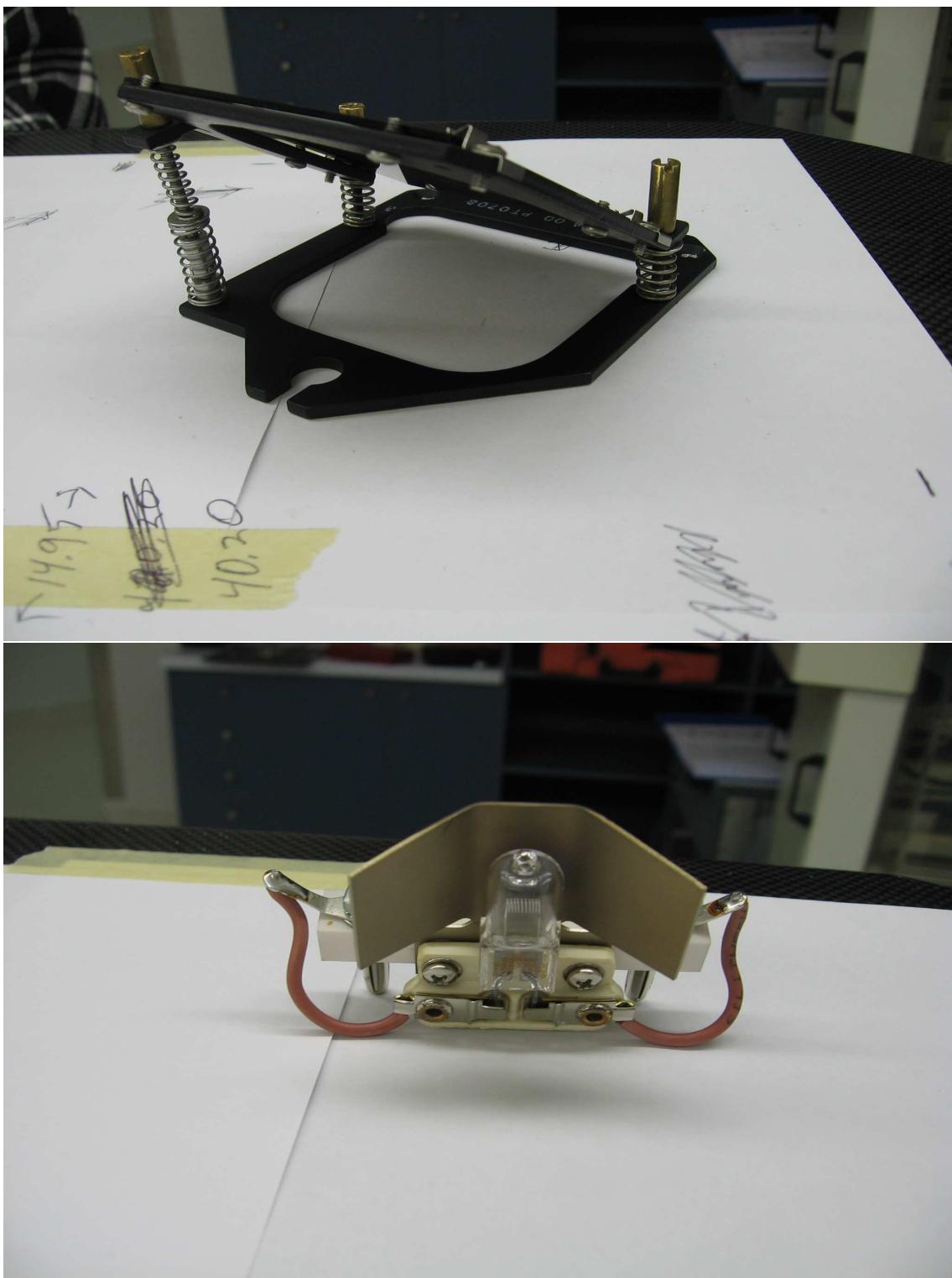


Figure 12: Upper: The mirror placed in head with three adjustable screws to image the light bulb as shown in Lower figure which is placed inside the rotational part of gantry.

to get these parameter and compare them with the reference value. They should agree each other within a certain tolerance.

For photon beam, beam-characterization parameters are:

- The depth of maximum dose(d_{max}), maximum off-axis ratio for largest field size(known as horns) at d_{max} and the % ionization at 10 cm depth and the depth of 80% ionization. These energy represent the energy spectrum.
- Accuracy of radiation field size. Profile 's symmetry, flatness and penumbra at different depth for different field size and gantry angle.
- Absolute dose rate under reference conditions.

For electron beam, parameters characterizing beam are:

- 30% and 80% ionization depths and photon contamination, which are indicator of electron energy spectrum.
- photon contamination
- Accuracy of radiation field size for a variety of fields. The symmetry, flatness and penumbra of profiles for different field sizes. All these parameters are indicator of angular spectrum.
- Absolute dose rate under the reference dosimetry.

The acceptance test of dosimetric parameters characterizing energy spectrum and angular spectrum is to check if these parameter are within the manufacturer's specifications. If necessary, corresponding electronic component or mechanic component need to be adjusted. For instance, the radiation field size should be within ± 0.5 mm against the digital reading. The flatness and dosimetry should be less than 2%.

2.4.2 Equipment, dosimeter and Setup for Relative dosimetric check

Equipment and dosimeter

PDD

The profiles and PDD were checked using two types of water scanning system: Wellhofer radiation field size analyzer(RFA300) and a PTW small water tank. The former belongs to the department and has been using for monthly QA and commissioning new linac. The

latter was brought here by Siemens engineer for doing acceptance tests. Two scanning equipments were shown in Fig.13

Although the Siemens tank is relatively small and could be measured for bigger depth and large field size because of lack of backscattering or later scattering, the advantage of using Siemens tank is that it can be attached to gantry head. Hence the setup is much convenient and easy. The acceptance data was used for measuring acceptance data. The RFA 300 was only used for double check by measuring some of acceptance data.

A PTW thimble chamber with small volume was used to measure the PDDs for electron beam and a small PTW plane-parallel chamber for electron beam. The reference chamber is a thimble chamber for both situations.

Profiles

The profiles measured for acceptance test was measured using a array of 48 small chamber with perspex slabs as shown in Fig.15. This device can be attached to gantry head. Therefore it is easy to check the flatness and symmetry of profile at different gantry angle. Because of gravity and counter-weight, the position of each component in gantry head is slightly different at different gantry angle. For example, the flattening filter may be slightly at different position for gantry angle of zero and 270. This will make the flatness and symmetry are different at these two gantry angles.

If the symmetry and flatness of profiles has problem, they are usually caused by two following factors:

1. The electron beam hitting target is angled. The electron beam should be perpendicular to the target.
2. The flattening filer not in right position. The central axis of flattening filter should coincide with the central axis of electron beam and focal spot on target.

In first case, the angled beam can be slightly adjusted by tilting or translating bending magnet. This can be done by adjust the screws in the gantry head as shown in Fig.14. After the adjustment, the beam was confirmed to hit target at right angle. Once the angle was adjusted, the flattening filter can be translated in inplane and cross plane direction as shown in Fig. The Siemens engineers were refining the flattening filter position. After these two adjustments, the manufacturer's specification were meet regarding the profile symmetry and flatness.

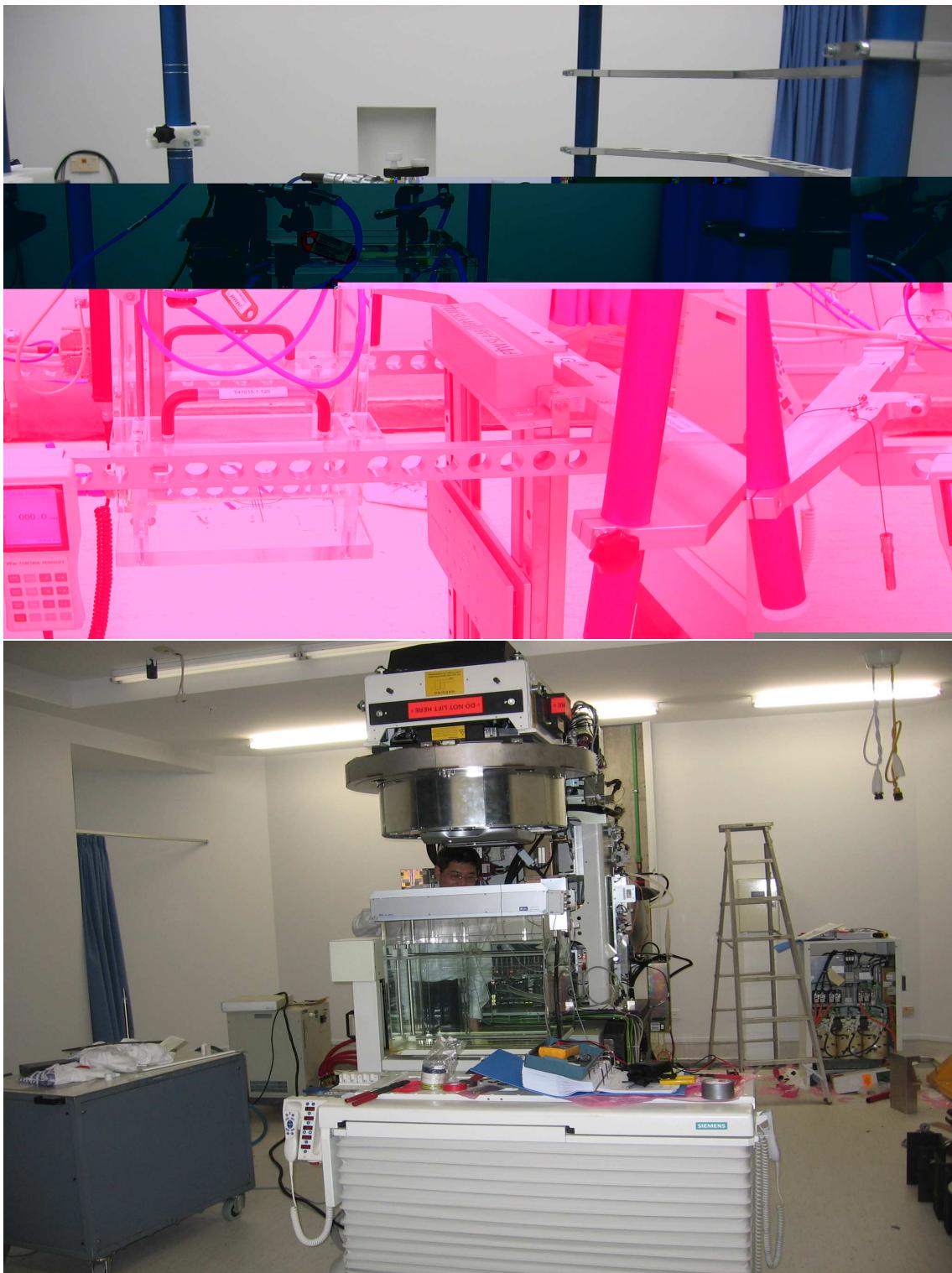


Figure 13: Upper: Siemens' small scanning tank attached to gantry head which is used for scanning PDD for photon and electron beam. Lower: The department's big RFA300 which was used for measuring PDD and profile. Aitang Xing was setting up tank for measurement.



Figure 14: Upper: The screws used for tilting or translating bending magnet in order to get right electron beam angle before hitting target. Gantry angle is at 180 degree. Lower: Siemens Engineer Andrew was adjusting slightly adjusting the physical position.

Setup procedure

As for scanning setup, the procedure and cautions are same as monthly QA and setting up for measuring commissioning data. This was described in details in commissioning report and QA report.

2.4.3 Equipment, dosimeter and Setup for absolute dose rate check

As shown in Fig.15, the dosimeter, equipment and setup for absolute dose rate check is essentially same as reference dosimetry, which was performed on weekly basis. The procedure and cautions were reported in details in commissioning report.

Checking the absolute dose rate followed IAEA TRS398 protocol. The purpose of checking dose rate at acceptance state is to adjust D1G and D2G to make sure these dose gain value are roughly at right value. Note they are dose gain for dose and dose rate.

2.5 Electronic check

The electronic check of Siemens linac referrs to checking the most important software values that directly influence the accumulated dose, dose rate, beam symmetry and flatness, beam energy etc.

These electronic parameter has software interface,which can be easy and convenient to be used to monitor or change the beam dosimetric parameters. A typical example is the BMI, the current of bending magnet. BMI directly determine the electron beam energy,hence the photon beam energy. For a complete list of these parameters,see the acceptance procedure [1].

3 Summary

The experience of acceptance testing the new Siemens Artiste linear accelerator was summarized. Report was written with an emphasis on the link between the properly functioning of each part and the anatomy of linac.

Bibliography

- [1] Simens Artiste linear accelerator: Quality assurance system.



Figure 15: Upper: the scanning chamber array attached to gantry head which was used for measuring profiles. Lower: Aitang Xing was setting up water tank for dose rate check under reference conditions.

Commissioning of new Siemens Artiste linear accelerator

Abstract. After the new Siemens Artiste linac was installed and acceptance test, it was commissioned. As part of my scheduled work, I participated in the whole commissioning procedure. I measured part of scanned data and non-scanned data. All the setup and measured were double checked by other physicist. I also did independent check of other measurements performed by other physicist. The purpose of applying the double-check principle in commissioning the linac is to get highly consistent, highly accurate and precise commissioning data. The data should be independent of who measured and what type of dosimeters were used, taking into account various uncertainties. This report is not a diary recording the the flow of commissioning but a working report described the practical experience and understanding of commissioning a new linac.

Period: 10/2008-01/2009

1 Goal of Linac commissioning

Commissioning a linac is one of key tasks that a clinical physicist or physics registrar often performs. Having clinical experience of linac commissioning is a very important part of physics registrar training program. The department bought a Siemens Artiste to replace the one old Varian 600C. I participated in Linac commissioning of this new linac along with other physicists.

The purpose of commissioning a linac after acceptance test is to prepare the linac for clinical use. Specifically the goals of commissioning a linac are **(1) to characterize the**

beam (2) to calibrate the beam and (3) to collect the beam data for establishing a beam model in TPS (4) provide baseline beam data for QA program through the linac's lifetime.

Characterization of radiation beam is to capture the dosimetric feature of beam under reference conditions or typical range of conditions by obtaining the profiles and percentage depth dose. Beam characterization is a relative dosimetry, which is usually performed after acceptance test. Calibrating a beam is to make the beam deliver usually 1Gy/MU at reference depth under other reference conditions using a local standard dosimeter, which was calibrated by an international or national dosimetry laboratory. Finally the most important step is to collecting the beam data for initialization of beam used in TPS. The specific commissioning data depends on the specific TPS and its algorithms.

This report is not a workflow or a diary of Artiste commissioning but to summarize the commissioning of new machine from eye's view of a physics registrar. Only the results for photon beam are reported here.

2 Preparation prior to beam data collection

Linac commissioning is a systematic and large task. Thus it should be organized very well and well prepared before starting commissioning a linac. The main focus is to prepare the phantoms, dosimeter and optimize the performance of newly installed machine.

2.1 QAing of the RFA300 scanning system and small beam calibration water tank

Water scanning system is the workhorse for commissioning a modern linac and used to collect the scan beam data. Water scanning system is an extremely accurate and precise device. It usually consists of three parts: water pump and reservoir, water tank with alignment mechanism, the scanning mechanism (scanning arm and holder, control electronics and software).

The quality assurance of scanning water tank is to check the integrity of scanning system as a whole and also ensure each part works very well. Specifically, the following check needs to be checked at least for commissioning a linac.

1. Water pump and reservoir:

Check the working conditions of pump and quality and quantity of water, ensuing there is algae in water.

2. Water tank:

Check the alignment and positioning mechanism of water tank, the horizontal leveling and vertical leveling of scanning arm and detector holder, the maximum range of holder's movement.

3. Scanning mechanism:

It is the most important part of water scanning system. The linearity and accuracy of scanning mechanism should be check, specifically checking vertical and horizontal leveling of scanning mechanism, the leakage and quality of cable, connector and electrometer and controlling software, the well fitness of detector holder with scanning arms.

The beam calibration is usually performed with a small tank either purchased or in-house made. The dimension is made according to recommendations of IAEA protocol. The reference dosimetry is performed with this tank on weekly basis. QA of this small tank is to check the physical conditions and the accuracy and reproducibility of chamber positioning.

2.2 Preparing solid phantom and dosimeters

In principle, the commonly used dosimeters in clinical dosimetry can be used for commissioning a new linac. However, in term of accuracy, easy of use and practicability, not all dosimeters is suitable for beam commissioning. The most widely used dosimeters are a variety of air-cavity chambers and diodes designed for electron beam and photon beam dosimetry.

Depending specific application and nature of beam data to be measured, the standard chamber($\sim 10^{-1}$ cc), minichamber($\sim 10^{-2}$ cc) and microchamber($\sim 10^{-3}$ cc) can be chosen for beam data collection. The basic principle of using diode for commissioning is to check its accuracy against the chamber. If the accuracy is acceptable, then it can be used for beam commissioning.

Some solid phantoms are also required for beam commissioning. At least the miniphantom is required for measuring the head scatter factor. As discussed below, the different

mini phantoms are usually needed for different field sizes. Other water-equivalent phantom such as plastic water, perspex slab may also required for verification purpose of point dose measurement.

2.3 Checking the linac performance

Although the beam commissioning is performed after acceptance test, the process of collecting data captures only a snapshot of your machine's operational characteristics during the collection period. Therefore before start collecting beam data, it is very important to ensure that the performance of machine is within the manufacturer's specification against the data of acceptance test. Each test performed at acceptance test should be performed before starting beam collection, which is usually described in acceptance test document.

3 Setup, procedure and results for photon beam data collection

3.1 Beam data required by CMS XIO beam model

Although the beam data required by the beam model in different TPS are slightly different, there are three types of data to commission a linac: the geometric and mechanic data of treatment head and treatment setup, the relative dosimetric beam data(eg, profiles and PDDs), the absolute point dose data(eg. S_p and S_c .). The machine head data can be easily obtained from the manuals of the machine, while the dosimetric data(scan data and all non-scan data except the head scatter factor can be obtained using water scanning system with properly chosen dosimeters.

Commissioning of Siemens Artiste linac is essentially to collect the beam data required by CMS XIO for initializing the beam model parameters. The list of specific beam data required by XIO are showed in appendix.

3.2 Quality of commissioning-beam data

The basic requirements of the beam data used for commissioning are high quality. **Specifically, the beam data should be consistent, highly accurate and highly precise.** This is because the data quality directly influence the accuracy of beam model and thus

the quality of treatment planning for each individual patient.

The basic methodology for ensuring to obtain high-quality data is to optimize the linac performance, correctly setting up the scanning system and properly and carefully choosing the detector and dosimeter based on application of the beam data to be measured.

The additional measures used, the most effective one from the point view of our practical experience, are double-check principle. The double check can be fulfilled by checking by another independent physicist or using another different type of dosimeter. This is a basic principle widely used in radiotherapy to reduce the errors. If the beam data quality is very high, they should be independent on who independently measure the data or by using another type of detector. The second check does not have to remeasure all data again but only do the spot check independently.

3.3 Scanning data

3.3.1 Setting up big tank and detector

Scanitronix water scanning system (RFA30) has been used for monthly QA and commissioning new linac. Setting up a big tank for monthly QA is no difference from setting it up for commissioning a linac. From my experience of monthly QA and linac commissioning over last three years, I think setting the big tank is essentially involving the following steps:

Step 1 Align the tank coordinate system with the machine coordinate system.

step 2 Level the tank and detector so that the distance between the detector reference point or plane and water surface is same along the direction of inplane and cross-plane.

step 3 Align the effective measurement point or reference point with three axes of coordinate system of radiation beam.

Aligning the tank

Aligning the tank is to register the three axes of tank with those of linac. Before doing this, it is most important to accuracy of gantry angle and collimator angle and make sure

they are at zero positions. Then the machine three axes are indicated cross hair and lasers. The three axes of tank is indicated by two cross lines at the bottom of tank.

Firstly align the three axes of tank with the the cross hair of the biggest field size. This is essentially to align the tank coordinate with the axes of light field, provided the light field agree with the radiation field with the acceptance tolerance.

Secondly, the axis alignment should be checked. Install the chamber and set the light field to a narrow rectangular whose narrow width just encloses the chamber while the length equals the dimension of largest field size. The x and y axes can be checked by watching if the shadow of chamber on the ground moves long the field edge.

Thirdly, after check the tank can be filled to an amount of water. The height of water in water is mainly determined by the the largest depth of PDD required by XIO commissioning data. Empirically, move the detector up to the farthest point, then fill the water level to or around the detector.

leveling the tank

There are not many things to say on leveling of the tank. More you do, more quickly level the tank. However, there are several points need to be emphasized here:

1. The purpose of leveling tank is to make sure the distance between the reference point of detector and water surface are kept same cross over the scanning area.
2. Therefore the tank leveling is determined by the leveling of tank, leveling of the moving arm and the leveling of detector and its mount. The misunderstanding on tank leveling is to just use the spiritual level to level the whole tank.
3. The leveling of tank can be easily done by observing the detector and its reflection image while adjusting the level screws.

Aligning the detector

Aligning the detector is essentially to align effective point or reference point of chamber with the origin of tank coordinate system and this point moves along exactly the axes of radiation beam.

Firstly,align the detector with x, y and z axis of radiation beam by the flowing methods: aligning the reference point or effective point of chamber with the the center of cross hair, then checking agreement between axis and this point by observing the shadow of cross

hair on the detector to see if the reference mark or point deviates from the cross hair line. The method used here is similar to the one used in Step 1. This is the further check after the tank is filled with water. And the alignment is essentially to align the detector with the axes of light filed.

secondly, check the alignment of detector with the axes of radiation field although the radiation field and light field are usually aligned very well to each other. The check can be done using the following methods:

- Locate the radiation center and alignment of radiation axes by:
 1. use “locate radiation center” function provided by the software to find its coordinate by measuring the profile at d_{max} for $10cm \times 10cm$ field size.
 2. Manually find the coordinate of profile center using the tool provided by the scanning software.
 3. move the detector to the center coordinate and reset the the detector’s origin.
 4. Checking correctness of new detector center by measuring the profile at a deeper depth such as 20 cm. The measured center of profile should be same as that of profile at d_{max} .
 5. If the centers of two profiles are not same, it means the gantry angle is not at zero position even if the digital reading is zero. In this situation, gantry angle should be calibrated. Another possible reason is that the z-movement of detector or arm is not vertical, thus requiring a further check.
 6. the detector’s alignment with x and y axis can be done by scanning across 10 cm dimension at $\pm 15cm$ off axis using same scanning direction for field size of $10 \times 40cm$. If the detector is well aligned, two profiles should be perfectly overlapped.
- Set reference point or effective point of chamber at the origin of tank coordinate system by:
 1. First, set the the chamber so that it bisect the water surface by observing that the half chamber above the water surface and its reflection image under the surface form a perfect circle. Set this position as origin.

2. Second, if the software is able to automatically correct this offset between the center of chamber and effective measurement point of chamber, then turn on this option.
3. Otherwise, manually move the chamber to the effective point of chamber, then reset the origin.
4. the accuracy of origin setting can be checked by using software to move the chamber to isocenter depth and setting SSD=90cm, then check if the side-wall laser intercept the chamber. If it does, it means the setting of chamber origin is accurate.
5. A useful tip is to tape a paper on side wall of tank, then draw the line flowing the lasers. Then every time when the tank is lifted up or lowered down, then it can be easily back the original position.

3.3.2 Choosing right detector

Small volume chamber and photon diode are most suitable dosimeters for commissioning a linac and recommended by several international protocol. The chamber is used for measuring PDDs while the photon diode for profiles.

The reasons why they are chosen are the perturbation factor and influence quantities associated with these two types of detectors are either kept approximately constant or negligible. They are used to convert the ionization signal into the dose.

Specifically, the criteria for choosing the detector for linac commissioning are:

1. The sensitive volume of detector should be small enough at least along the scanning direction to avoid volume-averaging effect and smearing effect on the profile. On the other hand, sensitive volume should be bigger enough so that the signal is relative strong comparing with the background and noise.
2. The detector should have a minimal number of influence quantities and the variation of influence quantities with the radiation conditions is small or negligible, such as energy dependence, dose rate dependence, accumulated dose dependence, direction dependence, temperature and press dependence etc.
3. The perturbation factors of detector and their variation with the radiation conditions should be very small and negligible, or easily quantified and corrected.

For example, as one perturbation factor of chamber, the stopping power ratio of water to air is changing with depth and field size, however, the change is within 0.1%. Therefore this factor is negligible considering converting the ionization signal into depth dose for PDD measurement.

Based on these criteria, the thimble chamber with a small volume is the best choice for measuring PDDs. We have Scanditronix Wellholfer Scanning RK chamber and a new purchased pinpoint chamber as shown in Fig. Before using them, the following properties of chamber are checked and commissioned:

1. Linearity and reproducibility of chamber and electrometer's response for a long and short time of period.
2. The variation of polarity factor with the depth and field size.
3. The variation of recombination factor with the depth and field size.
4. The leakage, cable and stem effect of chamber and electrometer for a certain period of time after being merged into water.
5. The dependence of chamber response on the energy and direction.

It was found that the signal-to-noise ratio is very low for pinpoint chamber although the its spatial resolution is very high. As a compromise between the resolution and sensitivity, the RK chamber is chosen finally for measuring commissioning data of PDDs.

The similar checks as those for chamber was performed for diode. Because the energy spectrum of photons varies slowly with depth, the stopping-power ratio of water to silicon or air is considered to be constant. Therefore the signal from diode is directly proportional to the photon dose. The energy dependence of diode was checked by comparing the PDDs measured with the diode and chamber for 40cm × 40cm field. If at the deeper depths, the diode depth dose is higher than those of chamber PDD, it means the diode has strong energy dependence. If the difference is more than 0.5%, then the diode should be replaced with another one or another type of detector. Because the diode is shielded for low-energy photon, the energy response is within acceptable tolerance. Other influence quantity such as dose-rate dependence, field and depth dependence were also checked.

Based on these checks, the diode was finally chosen for measuring the profiles and small field PDDs (less than 5cm × 5cm field).

3.3.3 Measurement procedure

There are no need to describe details of measurement procedures. However, based on my experiences, several points are worth to be listed here:

1. Check reproducibility of setup every time when the tank was reset.

The commissioning data usually takes a few days. The tank needs to be reset up. Every time when tank is reset up, the reproducibility of set up can be checked by comparing the PDD and profile at 10 cm measured for 10cm × 10cm field size at beginning each time.

2. Check the stability and constancy of the accelerator and scanning system by repeating 10×10 photon PDD at start, middle and end of scanning.
3. Review the the scan while you take them by looking at the symmetry, flatness and field size to make sure they look correct. Data should be smooth but not hairy or spiky.
4. Check the setup every time when you go to room, especially the origin of chamber.
5. Measure all PDD in one section and the reasonability of measured PDD by looking at if its variation with field size and depth is as expected. The PDD was scanned from bottom up to the surface to avoid the rippling-caused spiky curve.
6. Measure all profiles in another session to avoid overheating by checking the machine temperature from time to time.

For diagonal profile, make sure the scanning distance is multiple of spatial resolution so that the center of profile is at (0,0). It is convenient for editing the profile if necessary. For inplane or crossplane profiles, 4cm margin beyond the projected field edge at deepest scan depth were used.

3.3.4 Measurement results

Setup constancy check

As an example, Fig.1 shows comparison of PDD and profiles measured at different days after the tank was setup and before the data measurement. The agreement between

two PDDs and profiles indicate the setup at different days are pretty much the same. The difference in the build-up region between two PDD curves was caused by different scanning resolution.

Hysteresis check and alignment of detector with x and y axis of radiation field

Hysteresis check was done easily by comparing two profiles measured under the same conditions except the scan direction was reversed. It was found that there was no hysteresis for our scanning system as shown in Fig.2 Checking of chamber alignment with the x axis of radiation field is also shown in this figure, indicating alignment is very well.

Checking the alignment of chamber with Z-axis of radiation field

The check was done by comparing the profiles measured at two different depths. If the coordinates of profile centers are same, it means the effective point of chamber exactly follows the z-axis of radiation field. As an example, the profiles shown in Fig. indicates the the alignment is very well for this setup. If the alignment is not good, it means that either the gantry angle or moving arm of scanning system has a problem.

3.3.5 Commissioning photon data-Profiles and PDDs

As an example, all PDDs and profiles for 6 MV photon beam are shown in Fig.4. These beam data are required by CMS TPS for beam modeling. The maximum depth of PDD is 40cm as suggested by CMS XIO beam modeling guide.

3.4 Non-scanning data

The non-scanning data required by CMS XIO includes head scatter factor(S_c), total scatter factor ($S_{c,p}$), wedge factor and transmission factor of MLC and collimator.

3.4.1 Head scatter factor

Design of miniphantom

Following the common practice, the head scatter factors were measured with miniphantom. Several miniphantom with different radius were made from perspex. The measurements

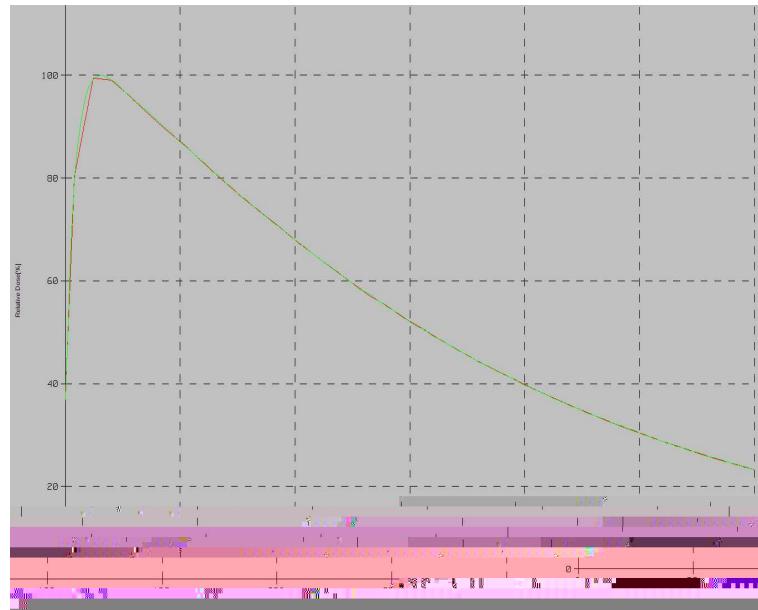


Figure 1: Constancy check of setup and linac by comparing the profiles PDDs after the tank setup on two different days. The comparison shows that the whole setup is pretty much the same.



Figure 2: Upper: hysteresis check of scanning system by comparing two reversed scanning profiles under the same conditions. Lower: Agreement of two profiles measured at off-axis position shows a good alignment of chamber with x axis of radiation field.

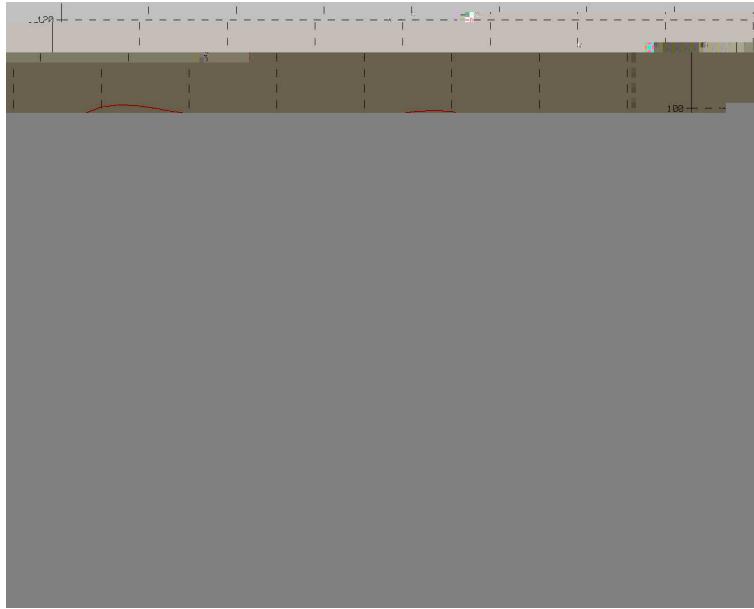


Figure 3: Checking the alignment of chamber with z-axis of radiation field by comparing two profiles measured at two different depths. The centers of two profile shows the alignment is very good.

were performed at 10 cm water equivalent depth. The choice of 10 cm depth is to provide the electronic equilibrium and to remove the contaminated electrons.

In principle, the radius of phantom should be large enough to provide lateral electronic equilibrium and remove the electron contamination. For large field ($\geq 4\text{cm} \times 4\text{cm}$), the radius of phantom is determined by:

$$R_{mini,phantom} = R_{outer,detector} + d_{max} \quad (\text{A.1})$$

where $R_{mini,phantom}$ is the radius of miniphantom. $R_{outer,detector}$ is the water equivalent radius of detector. d_{max} is the depth of dose maximum.

However, for measuring small-field S_c , the field size must at least encompass the miniphantom. Several studies showed that the influence of lateral electronic equilibrium on S_c is negligible [1]. The sidewall has to be enough to prevent electron contamination. It reached a conclusion that the radial sidewall thickness of 0.7cm and 1cm are enough to completely stop the contaminated electrons for 6MV and 18MV, respectively [2].

A small thimble chamber CC13 was used to measure the S_c for field size larger than $4\text{cm} \times 4\text{cm}$. Two perspex cylindrical chambers were made with the radii of 2.5cm for 6 MV photon beams and 4 cm for 18 MV photon beam. For the smaller field less than $3\text{cm} \times 3\text{cm}$, a shielded photon diode was used with a build-up of 10 cm water equivalent depth

Figure 4: Siemens Artiste commissioning data for 6 MV photon beam, which required by beam modeling in CMS XIO.

as shown in Fig.

Measurement setup

The S_c -measurement setup was shown in Fig.5. The setup was pretty simple, but there are several cautions that are worthy to be emphasized here:

1. The chamber and phantom setup was attached to the top of couch but far away from the floor and any other scattering object in order to reduced the scattered photons from them.
2. The stick supporting the miniphantom is also made from perspex and long enough to be extended from the tip of couch.
3. One essential point about the setup is to make sure the central axis of miniphantom aligns with that of cylindrical phantom. The central axis should also be strictly parallel to the radiation axis. This can be achieved by watching the shadow of phantom projected on the floor and by checking the sidewall lasers on the sidewall of miniphantom.

3.4.2 Other factors

All other factors were measured with the big water tank at 10cm depth using the CC13 chamber. Fig.6 also shows the setup of big tank. The a special holder made of perspex was fabricated for this small chamber. The effective point of chamber was positioned at the depth of 10cm. The origin position of chamber was checked from time to time. The depth of 10cm was also often check by observing if the the sidewall laser bisects the chamber.

3.4.3 commissioning data-point dose factors

Phantom scatter phantom, head scatter factor and total scatter factors for 6 MV and 15 MV photon beams were shown in Fig.7.

3.5 Beam calibration following IAEA TRS398

The beam calibration is essentially to adjust the dose gain $D1_G$ and dose rate $D2_G$ to make sure that the dose delivered at d_{max} is exactly 1cGy/MU under the reference conditions recommended IAEA TRS398.



Figure 5: Setup for head scatter factor, phantom scatter factor and total scatter factors. Upper figure: using miniphantom and CC13 chamber for larger field size. Lower figure: diode with buildup cylinder for small field.

Figure 6: The setup with big water tank for measuring $S_{c,p}$ using CC13 chamber and specially-designed holder.

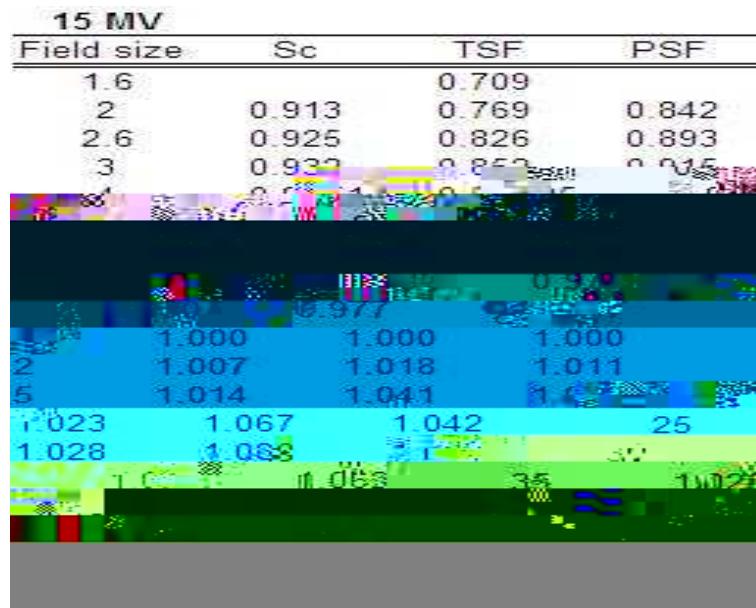
The beam calibration involves in two steps. First step is to calibrate the field chamber with the local reference dosimeter, which was calibrated by IAEA TRS398. The second step is to use the calibrated local field chamber to calibrate the beam and will be performed as a part of weekly QA afterwards.

The first step regarding the chamber calibration was described in other reports. Only the second step was briefly described here. To calibrate the beam after the calibration factor and k_{Q,Q_0} of chamber is known, the following things had to be measured:

1. The percentage depth dose at 10 cm depth, denoted as k_{depth} , is required to convert the dose delivered at 10 cm to 1Gy/100MU. This was measured as the ratio of corrected readings of Farmer chamber at d_{max} to that at 10 cm depth. The chamber reading was corrected for recombination factor and polarization factor.
2. The recombination factor, k_s , and polarization factor, k_p , had to be measured at 10 cm depth.
3. For short, the k_d was introduced as: $k_d = N_{D,W}^{Q_0} \times k_s \times k_p$.

Under the reference condition, the dose delivered at d_{max} is determined by:

$$D(d_{max}) = M_{T,P} \times k_d / k_{depth} \quad (\text{A.2})$$



As an example, the 6MV photon beam calibration results are shown in Fig.13, which provides a basis for ongoing weekly QA of new Siemens linear accelerator.



Figure 8: Upper: Measured k_S and k_{depth} parameters for 6MV photon beam. Lower: the reference dosimetry for 6MV photon beam at time of commissioning.

4 Summary

Experience of commissioning a new Siemens Artiste linear accelerator was described in this report. It is not just description of procedure and results but a practice and understanding

of commissioning a linac.

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Appendix

CMS XIO commissioning data



Figure 9: The geometric data required for establishing a geometric model in CMS XIO-part1.

Photon Machine Parameters

(Page 2 of 2)

Collimator Parameters (continued)

Length jaw is: upper lower none (circle one)

Distance from target to middle of jaw when jaw closed (cm): _____

Width jaw is: upper lower none (circle one)

Distance from target to middle of jaw when jaw closed (cm): _____

Source-to-blocking tray distance (cm): _____

Min blocking tray distance (cm): _____ (if adjustable)

Max blocking tray distance (cm): _____ (if adjustable)

MLC Model (indicate MLC applicable):

MITSUBISHI™ Number of Leaf Pairs: _____

ELEKTA™ Number of Leaf Pairs: _____

VARIAN™ Number of Leaf Pairs: _____

SIEMENS™ Number of Leaf Pairs: _____

SATURNE™ Number of Leaf Pairs: _____

Source to MLC distance (cm): _____

(target to middle of leaf distance)

Couch Parameters

Nominal couch angle (deg): _____

Increasing angle direction (circle one): CW CCW
(as seen from beam's eye view)

Asymmetric Jaw Parameters

Asymmetric configuration (check one):

_____ width only Min width position (cm): _____

_____ length only Min length position (cm): _____

_____ both Min width position (cm) _____
Min length position (cm): _____

(These minimum positions represent the position read-out of the jaw when it is at its maximum CAX over-travel position. e.g. on a Varian unit these numbers are typically "-2" for the width jaws and "-10" for the length jaws, indicating the width jaws (X jaws) will travel 2 cm beyond CAX and the length jaws (Y jaws) will travel 10 cm beyond CAX.)

Figure 10: The geometric data required for establishing a geometric model in CMS XIO-part2.

CMS XIO Beam Data Requirements
Suggested Scanlist Template (Photon Beams)
copy for each photon energy

Accelerator: _____ Energy: _____ Reference Depth: _____

I. Open Field PDD: Use nominal SSD setup. Depth Scan Increment ≤ 0.2 cm
Scan to ≥ 35 cm depth

We recommend collecting the open field PDDs consecutively, in one measurement session without accompanying profiles, in order to minimize excessive beam-on time and enhance consistency between fields. Scan from bottom of tank to surface to minimize ripples and to reduce meniscus related artifacts.

Nominal SSD: _____	Other SSD (Optional): _____																																																								
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II. Wedge Field PDD: Use nominal SSD setup. Depth Scan Increment ≤ 0.2 cm to ≥ 30 cm depth
Suggested field sizes include: 5x5, 10x10, (15x15 or 20x20), and maximum wedge square field.

We recommend collecting the wedge field PDDs consecutively, in one measurement session without accompanying profiles, in order to minimize excessive beam-on time and enhance consistency between fields. Scan from bottom of tank to surface to minimize ripples and to reduce meniscus related artifacts.



Figure 11: The dosimetric data required for establishing a dosimetric model in CMS XIO-part1.

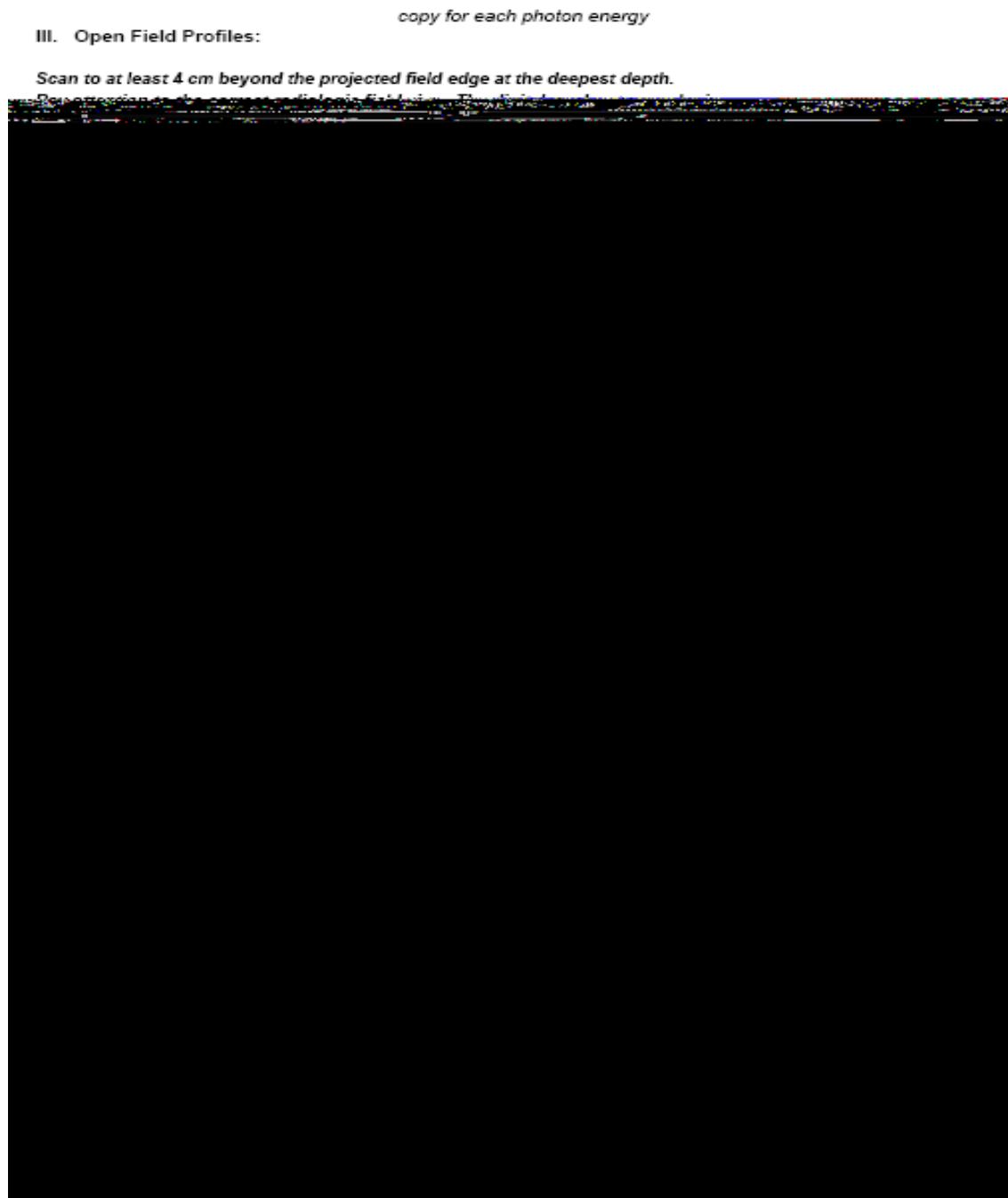


Figure 12: The dosimetric data required for establishing a dosimetric model in CMS XIO-part2.

Figure 13: The dosimetric data required for establishing a dosimetric model in CMS XIO-part1.

Acceptance test of D3000 Gulmy medical therapy x-ray system

Abstract. A new kilovoltage x-ray machine, D3000 Gulmy x-ray system(Gulmy Ltd, Chertsey, UK), was installed on 26/12/2006 in the department to replace the old Pantak orthovoltage unit. The acceptance tests for this new machine were performed. Following customer acceptance test procedure provided by manufacturer, I repeated all acceptance tests as a double check. This report is the result of acceptance tests.

Period: 8/01/2007-12/01/2007

1 Introduction

A new kilovoltage x-ray machine, D3000 Gulmy x-ray system(Gulmy Ltd, Chertsey, UK), was installed on 23/11/2006. For the description of this unit in detail, see the report “Commissioning of D300 Gulmy x-ray system using IAEA TRS-398 protocol”. The acceptance test follows the document provided by manufacturer, **“Customer Acceptance Test Procedure Gulmy D3000 superficial Unit”**.

The tests to be performed fall into four categories: safety check, electronic check, mechanical check and dosimetric check. These tests are usually done in this order by medical physicist from department and the engineers from the manufacture. The safety check is done first for the safety of patient, staff and public according to the ICRP60. Then the electronic and mechanical check are performed because they directly influence the dosimetric performance. The final but most important check is dosimetric, aiming at testing if the dosimetric performance of machine as same as specified in purchase order by

purchaser and the manufacture.

2 Acceptance test procedure and results

2.1 Test equipments and dosimeters

The equipments provided by the engineer from Gulmy Medical Ltd are:

- Focal spot alignment jig
- Storage Oscilloscope
- Digital Voltmeter

The radiotherapy department of Palmerston North hospital supplied:

- One box of ready pack x-ray film Kodak X-OMAT and EDR2
- Kodak M35 X-OMAT processor
- A Vidar film digitizer
- The IMRT checker, a computer program for film dosimetry written by Keith Croft, the chief physicist.
- FC-65-G Farmer chamber(SN:455) and 2570/1 Farmer electrometer(SN:896)
- A survey meter: Victoreen 450P-DE-SI(SN:1243)

2.2 Safety tests

2.2.1 Radiation survey

Once the unit produces the beam, a radiation survey should be performed. The purpose of radiation survey is to protect the patient, medical staff and public. Three area must be surveyed: the area around the treatment head in treatment room, the control room and the public area near the treatment room and control room.

The principle of radiation survey is to create a worst scenario. The largest applicator(15cm ø circulator) and the highest clinical generating potential(150kv) were used to produce the beam. The survey was done with and without 10cm Plastic Water®, which is used as a scattering materials.

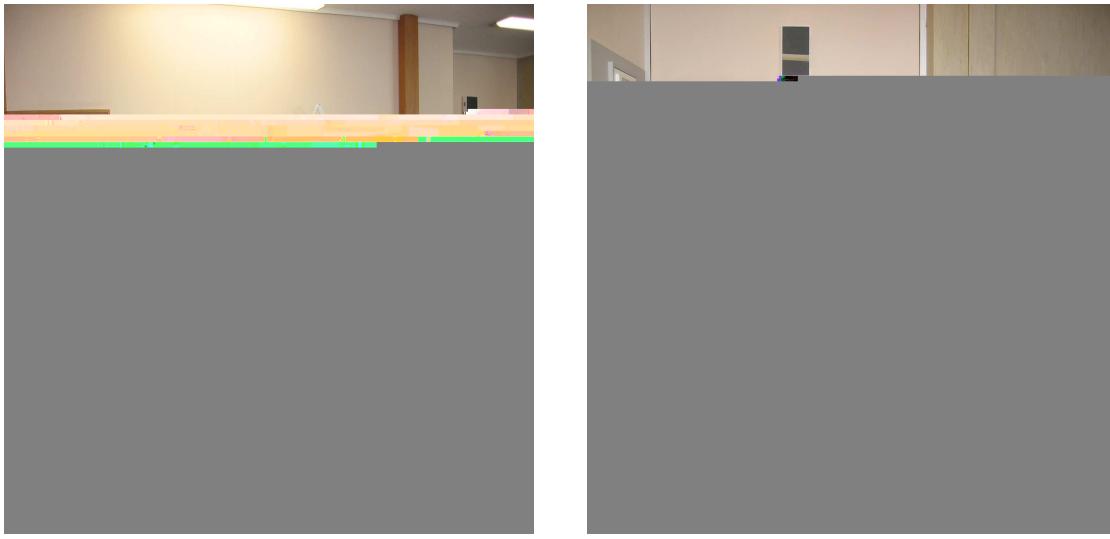


Figure 1: The survey area:(1) control room(left) (2)near treatment room door(right).

For the radiation survey, the following situations were created:

1. Direct the beam towards beam stopper with and without 10cm Plastic water phantom in the beam.
2. Direct the beam towards the wall of control room without attenuation material in the beam.

For each situations, there are two areas chosen: the control room and the area near the door, which are shown in Fig.1 Near the door, there is a tab and sink and staff may often be near the door for washing hands. In the control room, three locations are surveyed: control console, film scanner and the pipe in wall through which the cable passes.

As shown in Fig.2, the survey meter used was calibrated by NRL on the 19th of August, 2005. It gives the readings in term of $\mu\text{Sv}/\text{h}$. The survey results are shown in TableA.1.

The public dose limit is $1\text{mSv}/\text{year}$ over the period of 5 years, which means $20\mu\text{Sv}/\text{week}$. For radiation therapists and medical physicists, the dose limit is $20\text{mSv}/\text{year}$ over five-year period, therefore, $385\mu\text{Sv}$ per week. Assume that 8 working hours per day and 5 days per week, the dose received by medical staff every week are below far below the limits except one case. When the beam is directed toward the beam stopper, the dose received by staff per week are $4000\mu\text{Sv}/\text{week}$ and $1840\mu\text{Sv}/\text{week}$ and far beyond the dose limit. The solution for this is to add more sheets of leads to the beam stopper. After that, the survey shows the weekly dose limits is far below $385\mu\text{Sv}/\text{week}$. In addition, a sign was also made indicating the area near the door is staff area and the public are not allowed to

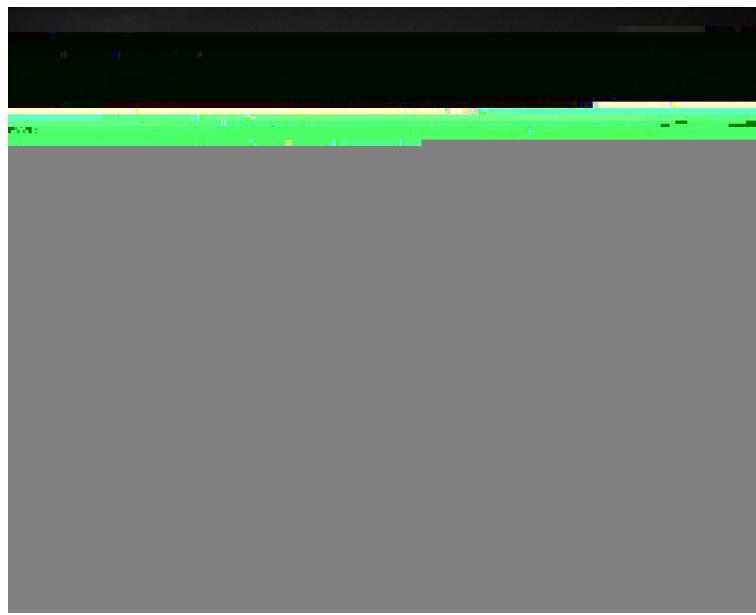


Figure 2: The NRL Calibrated survey meter used for radiation survey.

Table A.1: The radiation survey results near the door and in control room.

Location	Beam direction	Scatter	Dose rate($\text{Sv}=\text{h}$)
Near the door	Toward beam stopper	No	75
Control console	Toward beam stopper	No	4.2
Film scanner	Toward beam stopper	No	0.97
Cable pipe	Toward beam stopper	No	1.29
Near the door	Toward beam stopper	Yes	46
Control console	Toward beam stopper	Yes	2.1
Film scanner	Toward beam stopper	Yes	1.14
Cable pipe	Toward beam stopper	Yes	1.04
Near the door	Toward control room wall	No	0.68
Control console	Toward control room wall	No	0.85
Film scanner	Toward control room wall	No	14.1
Cable pipe	Toward control room wall	No	0.33

go nearby.

2.2.2 Radiation leakage from tube head

Checking the radiation level leaked from the the tube head is not only for the patient safety but also for the staff safety.

Measurements were carried out at the highest tube voltage and current(120kv and 20mA) using the warm-up filter to minimize any scattered radiation. The areas of maximum leakage were identified using Kodak X-Omat verification films wrapped around the tube head and performed a 10 min exposure. The tube head leakage was measured using the Victoreen 450P-DE-SI(SN:1243) survey meter at distance of 1 meter from these points of maximum tube leakage.

Two areas of maximum leakage were identified from film survey, one around the cathode high tension cable and the other at the infront of the filter insert slot. The maximum dose rate at 1 meter from the focal spot averaged over an area up to 100cm² is 168 μ Sv/hour. This value is much less than the specification of 1mSv/hour by manufacturer and ICRP33 [2].

2.2.3 Interlock checks

The interlock of a modern therapy equipment is a built-in electronic system, which will stop the machine running in event of machine having electronic, mechanic and dosimetric faults. It is another mechanism to prevent the patient and medical staff.

The aim of interlock check is to make sure all interlocks work as specified by manufacture. The tests were done with the engineer from the manufacture. The test procedures are not complicated and clearly written in manufacture's test procedure document. For instance, the procedure of testing accuracy of the treatment timer is described as follows:“ Set a treatment time of 5 minutes and switch on the machine. Time the treatment timer over a period of 2 minutes with the independent timer and confirm that they agree with an error of less than 1 second”.

The results of interlock tests are listed in TableA.2.

Table A.2: The interlock test results

Interlock	Check	Specification	Meet spec.?
Timing system check	Timer accuracy	error < 1 sec	yes
	Backup timer	Functions correctly	yes
	Treatment termination	Timer reset correctly	yes
Door interlock		Correct interruption	yes
Emergency o		Work correctly	yes
Filter interlock		Work correctly	yes
Movement under power loss		Movement 1mm	yes
Data under power loss		Reobtain data	yes

2.3 Electrical tests

The modern radiotherapy machine is a complicated electronic equipment, which is composed of a lot of circuit boards. Whether these circuit boards work correctly or not directly determine the mechanic and dosimetric performance of the machine. The functioning of these board can be checked by measuring the electronic parameters (eg. voltage, current and resistance.) at several testing points located and distributed at different boards.

The testing points are designed and designated by the electric engineer. They are also used as a diagnosis tool to pinpoint the problem in the case in which the electronics system does not work properly.

As an important part of acceptance test, the purpose of electric tests is to check if the electronic parameters measured at the designated test points are within the specified range. The electric tests were done by the manufacturer but accompanied by medical physicists. The electric tests for Gulmy D3000 include:

- Input voltage stability
- High voltage rise time
- Voltage accuracy and reproducibility
- Current accuracy and reproducibility
- Earth leakage

Earth bonding

Cable Screen resistance

Warning system

The results for these electric tests are within the manufacturer's specifications. As an example, the test results for input voltage stability are shown in Table A.3. This was measured within the distribution box at connector TB1 at terminals B & C to ensure that the incoming voltage is suitable for effective machine operation.

Table A.3: Electric test results for input voltage stability.

Measured voltage(V)	Spec.(V)	Meet Spec.?
236.1-236.3	198-242	yes.

2.4 Mechanic tests

Like the electronic system, the mechanic parts of radiotherapy machine also are directly related to its dosimetric performance. The mechanic checks to check the mechanical parameters meets the specification of manufacturer.

2.4.1 Focal spot alignment

The center of focal spot on the anode should be on the central axis of applicator and radiation beam. The central axis of applicator and the radiation field should also be coincided with each other.

These alignments are checked using a focal spot alignment jig, as shown in Fig. The test procedure is:

1. Fit the focal spot alignment jig into the tube head with the beam oriented vertically.
2. Tape the Kodak EDR2 film on the top of 10cm plastic water and make two dot marks with a pin indicating the cathode-anode direction.
3. Move the tube head and make sure the end of jig just touches the film. Expose the film with 50kv beam for 0.3 minute, ensuring that the dose delivered to the film is in the linear range of film calibration curve.

Figure 3: The focal spot jig used for checking focal spot alignment.

4. Then rotate the Im by 60 degree and expose it again for same time. Repeat this procedure twice.
5. Develop the Im with a Kodak M35 X-OMAT processor. Then the Im is digitized using the Vidar Im digitizer.
6. The Im image is analyzed using a in-house program called IMRT checker.

Fig.4 shows the image of focal spot and crosshair. Based on the Im, two parameters are checked: the focal sport size and the displacement between the center of the focal spot image and the center of the wire cross images. The displacement was measured using IMRT checker and found to be 0.4mm, which is less than manufacturer's 0.5mm.

To get the actual focal spot size, the magnification factor must be known. The magnification factor(MF) is calculated as $MF = \text{pinhole-end distance} / \text{focal-pinhole distance}$. $MF = 88.12 / 64 = 1.38$. The focal spot image was approximated as a rectangle and measured as 5mm by 3cm. Therefore, the size of actual focal spot is about 4mm by 2mm.

From the focal spot image, it is also noticed that the image is the darkest in its center and has a blurred edge. This is because the intensity of electrons emitted from the filament is not uniformly distributed across the filament.

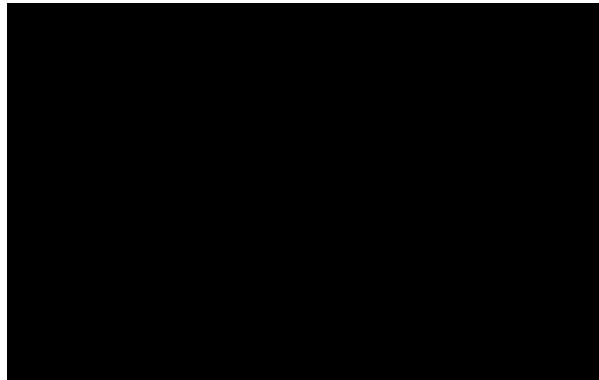


Figure 4: The film image for the focal spot.

2.4.2 Applicator acceptance

The applicators define the field size and treatment SSD. Therefore doing a thorough test for each applicator is vitally important for delivering the prescribed dose to the patient. There are two types of checks for each applicator: mechanical check and dosimetric check.

The mechanical tests are:

1. Lock the movement of tube head. Insert each applicator into head and let applicator touch a graph paper which is on the top of 5cm plastic water slab. Then check the lateral movement of applicator. It was found that the lateral movement of all lateral applicators is less than manufacture's specification(0.5mm).
2. Use a depth gauge to check the maximum and minimum height of plastic end piece above the steel applicator base. The manufacture's specification is 0.5mm. This check is important because the the plastic base is attached to the steel based and easily become loose or slightly moved. As a consequence, the dose rate will be changed.
3. Measure the FSD of each applicator with reference to the position of focal spot as indicated on the tube housing. The actual distance from the focal spot as indicated to the top side of the applicator is 6.4mm. Compared with the nominal FSD of 15cm and 25cm, the measured FSD is $15\text{cm} \pm 0.1\text{cm}$ and $25 \pm 0.1\text{cm}$, which is specified by manufacturer.

The dosimetric checks were done using the EDR2 films. Lay and tape the film on the top of 10cm plastic water phantom. Mark four orthogonal points corresponding to the outside edge of the applicator. For 120kv and 80kv beam, the film was exposed for 0.2

minute for 25cm FSD applicator and 0.1 minute for 15cm FSD applicator. The choice of exposure time is based on the consideration ensuring the dose received by film is within its linear response range.

The developed and digitized films were used for the following dosimetric checks:

1. Inspect the field for any irregularities larger than 2mm or any obvious leakage outside the main field.
2. Measure the difference between the center of the points and geometric centre of the radiation field. Spec:< 2mm.
3. Measure the difference between actual radiation field and the nominal size. Spec:< 2mm.

As an example, Fig.5 shows two digitized film images. The film images for each applicator were carefully checked using IMRT program. There are no obvious leakages outside the main field. The difference between geometric field centre and radiation field center less than 1mm.

The field size is measured as the full width at 50% relative OD value. The symmetry of profile is defined as:

$$\text{Symmetry} = \left(\frac{OD_1}{OD_2} + \frac{OD_3}{OD_4} \right) \times \frac{1}{2} \times 100 \quad (\text{A.1})$$

The measured field size and beam symmetry are shown in Table A.4. The difference between the measured field sizes and nominal field size for each applicator is within 2mm. The beam symmetries are quite good and far less than the manufacturer's specified limit of 1.1.

2.4.3 Movement and brakes

The movement of tube head in vertical, horizontal and clock or anti-clock direction is controlled by the brakes on the tube head. Checking the mechanical movement of tube head is also an important part of mechanical tests.

All movement should be smooth. Movement should not be possible with reasonable force when brakes are applied. No movement >0.5mm should occur as the brakes are locked. All brakes and movements were checked and found to meet this requirement.



Figure 5: The digitized film images for 120kv beam using 1.5cm applicator(left) and 15cm applicator(right).

Table A.4: Measured field size and beam symmetry for each applicator.

Energy		80kv			120kv		
App.(mm)	FS(mm)	Symm.A-C	Symm.E-W	FS(mm)	Symm.A-C	Symm.E-W	
15	15.9	1.00328	1.00326	16.07	1.00321	1.00322	
20	21.35	1.00322	1.00325	21.29	1.00317	1.00312	
25	26.35	1.00978	1.00659	26.52	1.00636	1.00635	
30	31.8	1.00648	1.00668	31.42	1.00929	1.00321	
40	41.4	1.00969	1.00330	41.5	1.00311	1.00312	
50	51.6	1.0132	1.00641	51.5	1.00310	1.00323	
100	101.4	1.00966	1.00641	101.6	1.00277	1.00643	
150	151.6	1.00641	1.00794	151.37	1.00623	1.00625	

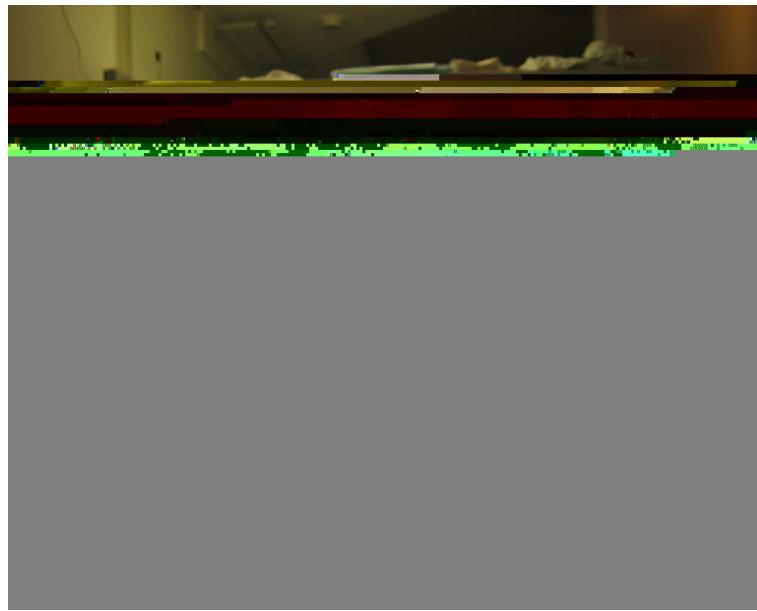


Figure 6: The measurement setup for radiation performance test.

2.5 Radiation performance

From the point view of clinical user, the most important and final check is to check the radiation performance of machine. The aim of the radiation performance check is to verify the dosimetric characteristics of beam. Specifically, the following checks were done:(1)the measurement of HVLs for each beam;(2) Timer error check; (3)the reproducibility and linearity of output with time unit, the axial rotation of tube head and the treatment interruptions. For the HVL measurement, see another report on the commissioning of Gulmy medical x-ray system.

For other checks except timer error check, the Farmer chamber(SN:455) and electrometer(SN:896) were used. The 10cm \varnothing applicator was chosen for all in-air measurements. As shown in Fig.6, a special holder for the chamber was designed, which is attached to the end of applicator. The leveling of tube head was checked with a spiritual level. The chamber was carefully positioned so that the effective measurement point of chamber is on the central axis at the center of cavity volume.

Timer error

For superficial x-ray unit, the radiation duration is controlled by a treatment timer and a backup timer. The accuracy of timer directly influence the accuracy of dose delivery.

Table A.5: The timer error for 80kv and 120kv beams.

Time	80kv(nC)	Average(nC)	120kv(nC)	Average(nC)
3min	30.45	30.45	30.45	12.05
$3 \times 1\text{min}$	30.45	30.45	30.45	12.05
Timer error(min)	0		0.0031	

Testing timer accuracy is an important part of radiation performance test.

The timer error takes into account the build up time of voltage before beaming on. The error is determined using the formula:

$$\tau = \frac{M_B t_A - M_A t_B}{n M_A - M_B} \quad (\text{A.2})$$

where M_A is the integrated reading in a time t_A , whereas M_B is the integrated readings in a short exposure of time t_B/n each($2 \geq n \leq 5$). Then the corrected reading for treatment time t_A is $M = M_A/(t_A + \tau)$.

The timer error was measured with Markus chamber flushed with the surface of 10cm plastic water phantom. The 10cm applicator used for 120kv beam and 3cm applicator for 80kv beam. The Farmer dosimeter(SN:896) was used to collect the integrated charges for the following conditions: $t_A = 1\text{min}$, $t_B = 3\text{mins}$ and $n = 3$. The results are shown in Table. There is no timer error for 80kv beam. For 120kv beam, the timer error is negligible so that there is no timer error correction for the treatment time.

2.5.1 Linearity

The reproducibility and linearity of machine output are directly related to the accuracy of delivering the prescribed dose to the patient.

Three consecutive readings were recorded with the exposure time of 0.5min, 1min and 3min. The results are shown in Table A.6. It can be seen that the linearity of machine output for both energies are very good.

2.5.2 Reproducibility with treatment time

Set the applicator at zero and exposure time to be 1.00 min. Then make ten consecutive exposures while measuring the external ion chamber readings. The reproducibility

Table A.6: The linearity of machine output for 80kv and 120kv beams.

Min	80kv(nC)				$\frac{AVG}{AVG_{1min}}$	120kv(nC)				$\frac{AVG}{AVG_{1min}}$
	AVG					AVG				
1	53	53	53	53	1	42.6	42.6	42.6	42.6	1
0.5	26.5	26.5	26.5	26.5	0.5	21.3	21.3	21.3	21.3	0.5
3	159	159	159	159	3	127.85	127.95	128	127.9333	3.0031

Table A.7: The reproducibility of machine output with time for 80kv and 120kv beams.

Exposure(Mins)	80Kv(nC)	120kv
1	52.90	42.55
1	52.90	42.55
1	52.90	42.6
1	52.95	42.6
1	52.95	42.55
1	52.90	42.55
1	52.95	42.60
1	52.95	42.65
1	52.90	42.60
1	52.90	42.60
Coefficient of Variation(%)	0.05	0.08

is quantified using coefficient of variation. The results are recorded in TableA.7. The reproducibility with time is well within 1% as specified by manufacturer.

Reproducibility with axis rotation of tube head

Three axial rotation angles of tube head was chosen for the test: 0,-135 and 135 degree. The results are shown in Table. Despite that the outputs at other angles are less than that at zero angle for 120 kv beam and slightly more that at zero angle for 80kv beam, the output difference between zero and other tube angles is less than 0.2%.

Table A.8: The reproducibility of machine output with axis rotation for 80kv and 120kv beams.

Energy	80kv			120kv		
	Angle(degree)	135	0	-135	135	0
Readings(nC)	52.95	52.9	52.95	42.6	42.65	42.6
	52.95	52.9	53	42.6	42.65	42.65
	52.95	52.9	53	42.6	42.65	42.6
AVG	52.95	52.9	52.983	42.6	42.65	42.62
Dif.(%)	0.095	0	0.159	-0.117	0	-0.078

Table A.9: The reproducibility of machine output with treatment interruption.

Energy	Readings(nC)				Average(nC)		
	80kv	52.9	52.95	52.95	52.95	52.9	52.93
Deviation(%)	-0.057	0.038	0.038	0.038	-0.057		
120kv	42.65	42.6	42.6	42.7	42.65	42.64	
Deviation(%)	0.023	-0.094	0.094	0.141	0.023		

2.5.3 Reproducibility with treatment interruptions

The inter-fraction reproducibility was tested by making five consecutive 1 minute exposure, each of which contains two interruptions. The maximum deviation from the mean 1 minute readings was determined. TableA.9 shows the results. The maximum deviation from the mean is 0.141%, which is far less than 1% as specified by the manufacturer.

3 Summary

Following the acceptance test document provided by manufacturer, a comprehensive acceptance test was performed on a newly installed superficial x-ray unit in Palmerston North hospital.

Bibliography

- [1] Gulmy Medical Ltd. Customer acceptance test procedure for Gulmy D3000 superficial unit. 2003.
- [2] International commission on radiological protection. Protection against ionizing radiation from external sources used in medicine, ICRP publication 33. New York: ICRP, 1981.

Commissioning of D3000 Gulmy medical therapy x-ray system following IAEA TRS-398 protocol

Abstract. After the D3000 Gulmy unit was installed and tested, the machine was commissioned for several energies to be used clinically. I involved in the whole commissioning procedure and was assigned to commission 80KV and 120kV x-ray beams. The commissioning followed IAEA TRS398 dosimetry protocol. The commissioning procedure and results are presented here.

Period: 8/01/2007-12/01/2007

1 D3000 Gulmy x-ray system

A new kilovoltage x-ray machine, D3000 Gulmy x-ray system(Gulmy Ltd, Chertsey, UK), was installed on 23/11/2006 to replace the old Pantak x-ray machine.

The Gulmy D3000 is a combined superficial and orthovoltage x-ray therapy unit able to produce generating potentials in the range of 20-300Kv. As shown in Fig.1, the unit comprises:(1)a floor mounted tube stand (2) a bipolar oil-cooled metal ceramic X-ray tube MXR-161 (3) a high stability generator and (4) a software user-interfaced controller.

The available beam energy(energy spectrum) is defined by a combination of tube current, KV, inherent 0.9mm Be exit window and nine external filters. For each beam energy, field size and FSD(source-to-surface distance) are determined by a series of circular applicator, which can be attached to the tube head through mount ring as seen in Fig.2.

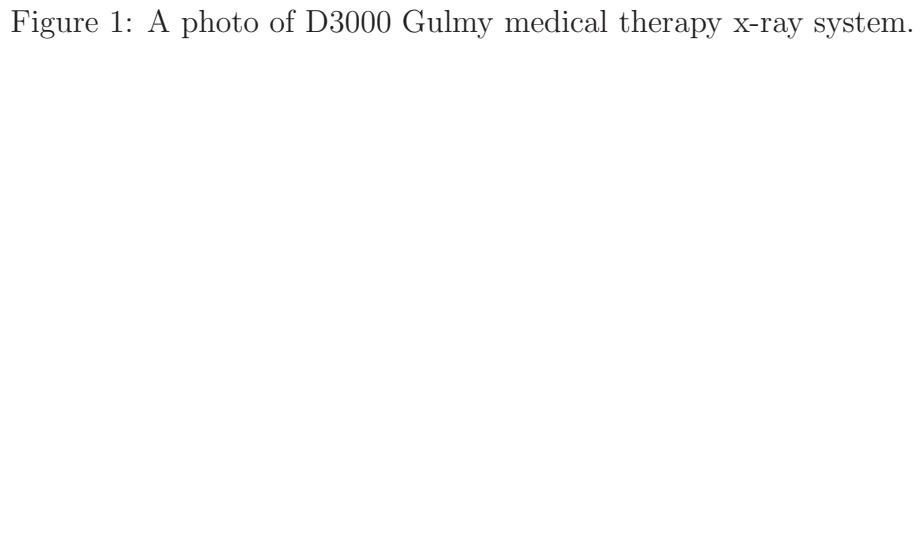


Figure 1: A photo of D3000 Gulmy medical therapy x-ray system.



Figure 2: The applicators and filters used by Gulmy D3000 x-ray unit.

The beam energies to be used in the radiotherapy department of Palmerston North hospital are: 50kv, 80kv, 100kv and 150kv. As a physics registrar, I was chosen to commissioning 80Kv and 120Kv x-ray beam.

2 Commissioning of 80kv and 120kv x-ray beam

2.1 Definition of commissioning

Commissioning of a new radiotherapy equipment is to be done after the installation and acceptance test are finished. Commissioning is a procedure in which the physicists make the physical beams from the therapy unit clinically usable for treatment delivery and

planning.

The goals of commissioning are three folds: (1)Characterizing the beams by measuring percentage depth dose(PDD), profiles, isochart and beam quality index; (2)Calibrating the beam to delivered a precisely known dose to a reference point in accordance to a current protocol; (3)Collecting the beam data required to initialize the beam model used in treatment planning system.

2.2 Characterizing 80kv and 120kv x-ray beams

2.2.1 Beam half-value layer

Half-value layer(HVL) is only beam quality index used in IAEA TRS-398 for Kilovoltage x-ray energy [1]. HVL is used for determining the calibration factor and chamber dependent correction factors for a specific chamber.

A special device was developed in our department for HVL measurement. As shown in Fig.3, the measurement setup is in accordance with the IAEA TRS-398 protocol recommendations as follows:

1. The aperture is placed at 26cm away from focal spot and chamber. The diameter of aperture is 1cm and the 1.5cm circular applicator is used ensuring the narrow beam geometry. The central axis of focal spot, aperture and chamber is aligned using a portable laser beam.
2. A commercial aluminum and copper wedge filter is used alongwith a several aluminum and copper plates of $4\text{cm} \times 6\text{cm}$ to attenuate the beam. The added plates are tightly attached to the wedge filter. The purity of wedge filter and the plates is 99.9%.
3. A small PTW pancake chamber(SN:1333) is used as its energy response was verified to vary with the beam quality range of interest within 2%. Therefore, the HVL can be determined by measuring the integrated charges per minute instead of air kerma rate.
4. The scattering materials or objects within 1cm away from chamber were cleared off, ensuing a scattering-free environment.
5. For each exposure, five minutes was used. Three readings were taken for each

measurement. A Farmer electrometer(SN:896) was used to collect the charges. The HVL was interpolated from the attenuator thicknesses spanning the HVL thickness.

Figure 3: The setup for HVL measurement.

The first and second HVLs for 80kv and 120kv beam are shown TableA.1. The tube current, filter No and homogeneity coefficients(first HVL/second HVL) are also presented.

Table A.1: Measured HVLs for 80Kv and 120Kv x-ray beams.

K _{V_p}	mA	filter No.	First HVL	second HVL	Homogeneity
80	1	1	1.96 mm Al	5.01 mm Al	0.39
120	1	1	6.4 mm Al or 0.47 mm Cu	13.08 mm Al	0.49

2.2.2 Percentage depth dose value at 2cm depth

The depth percentage dose value at 2cm depth is required to link the dose at 2cm depth and the dose at water surface for reference dosimetry. TRS-398 recommends to get this value from the measured PDD curves. We did in a slightly different way by directly measuring this value.

As shown in Fig.4, a special water tank was developed for the measurement. The inner area of tank bottom is exactly known. Therefore, the total external chamber volume is measured using a measuring cylinder by putting some water into the cylinder and then

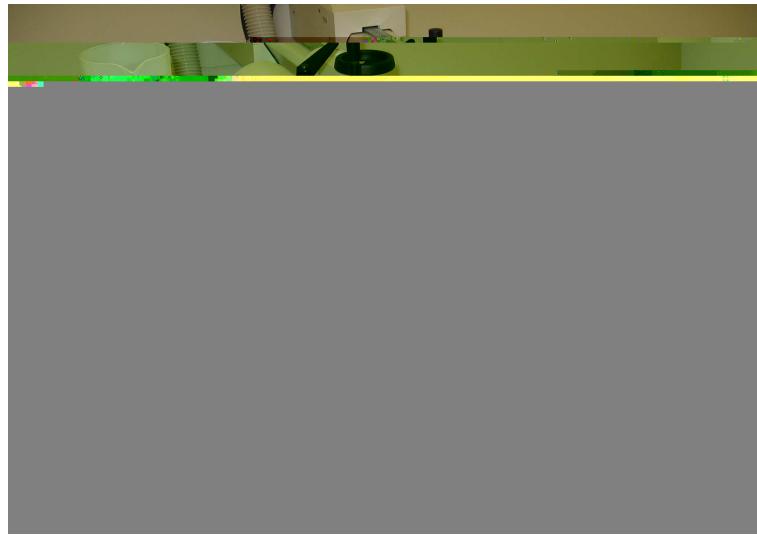


Figure 4: The setup for measuring percentage depth dose value at 2cm depth and output factor at water surface. The measuring cup is also shown here.

inserting the chamber into the cylinder. The external physical height of chamber is known. Then the volume of water required for flushing the water surface with chamber window can be precisely calculated. Similarly, the water volume is exactly known that is required for filling in the tank to make sure that the distance between the chamber window and water surface is 2cm.

The Markus chamber and a Farmer electrometer(SN:896) were used for the measurement. The setup and measurement procedure is as follows:

1. Tightly tape the Markus chamber on tank bottom. Then use 1cm applicator to align the beam axis with the the central axis of chamber.
2. Pour the precisely known volume of water into tank, the water surface flushing with the chamber window.
3. The 10cm applicator is inserted into the tube head as reference field size. Exposure for 1 minute and repeat for three times for each measurement.
4. Pour the required water volume into the tank, the water surface reaching 2cm above the effective measurement point of chamber. Repeat measurement for three times.

For comparison and verification, the 2cm depth percentage dose was also measured using Plastic Water® slabs. As shown in Fig., the Markus chamber is embedded in one slab with the chamber window flushing with the surface of phantom. 2cm thick plastic slab

can also be placed on the top of chamber. The cone end touches the surface of the slab. In addition, 10cm Plastic water phantom slabs are used to provide enough backscattering.

The results are shown in TableA.2. It is noticed that the difference of measured 2cm PDD value between water and Plastic water is about 7%. It is mainly because plastic water is designed to be water equivalent for higher energy beam but not for the kilovolatage beam lower than 80Kv.

Table A.2: Measured 2cm percentage depth dose value using water phantom and Plastic Water® for 80Kv and 120 Kv.

Energy(Kv)	Applicator(cm)	FSD(cm)	Water	Plastic water	diff.(%)
120	10	25	0.767	0.766	-0.13
80	3	15	0.569	0.531	6.62

2.2.3 Percentage depth dose curve

The purpose of measuring PDD for Kilovoltage x-ray beam is to collect the beam data as a reference for the clinical treatment and planning, as well as determining the percentage depth dose value at reference depth for reference dosimetry.

The PDD curve for 80Kv and 120Kv x-ray beams are measured using a small water tank, which is used for reference dosimetry for MV photon beam on the weekly basis. The setup is shown in Fig.5. The protocol recommends use a thimble chamber to measure PDD for kilovoltage x-ray beam or a parallel plate chamber after verification with the thimble chamber. The Markus chamber and PWT electrometer(SN:7524) were used. The Markus chamber has a reasonably constant energy response(less than 5%) by comparing it with another thimble chamber. Fig. shows the PDD measurement setup and results are shown in Fig.6.

2.2.4 Beam profile symmetry

PDD curve shows the beam characteristics along the central axis beam, whereas the off-axis feature of the beam is characterized by the profile at different depths.

The profiles at plastic water surface were measured for all the applicators for each beam energy. The EDR2 film was used for the measurement as the film response was found to be reasonably linear for the beam quality interested here. The exposure time is

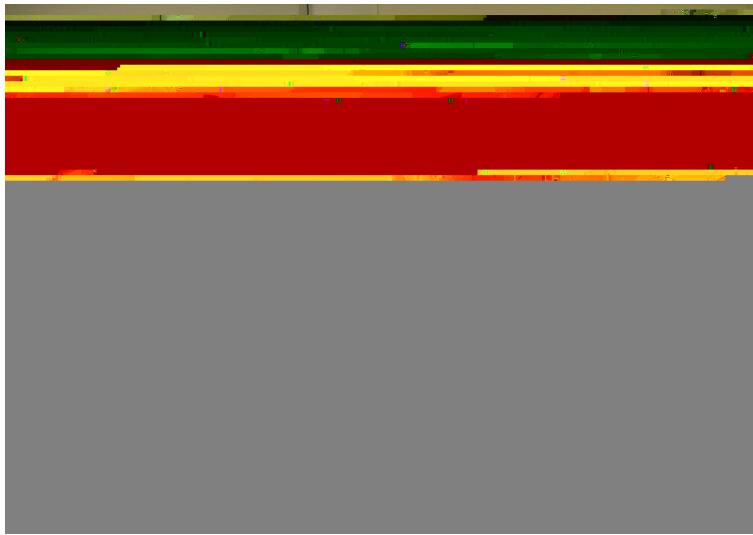


Figure 5: The setup for measuring the PDD curves for both energy and doing the reference dosimetry for 120kv beam.

estimated, ensuring that the dose delivered to the film is within the linear range of film calibration curve. The films were developed by KODAK M35 X-OMAT processor and digitized as BMP image using a Vidar digitizer.

The film is tightly taped on the surface of 10cm thick plastic water slabs. The film is pricked with a small pin at its one corner. Two marks are also made to indicate the cathode-to-anode direction. Fig.7 shows an exposed film image for 120kv beam using 15cm circular applicator.

The film images were analyzed using an in-house program called IMRT checker. This program was written in Delphi programming language by Keith Croft, the chief physicist, for the patient IMRT QA. The dose profiles were easily obtained using the film analysis tool provided in the program. Typical profiles are shown in Fig.8 and Fig.9. It is noticed that, as expected, the heel effect is observed for large applicator for both energies.

2.3 Calibration of 80Kv and 120Kv x-ray beam using IAEA TRS-398 protocol

Calibrating a beam is to use the dosimeter calibrated by an accredited primary standard or secondary standard laboratory to ensure the beam delivers an accurately known dose to a reference point under the reference conditions recommended by the protocol. This procedure is usually called reference dosimetry or absolute dosimetry.

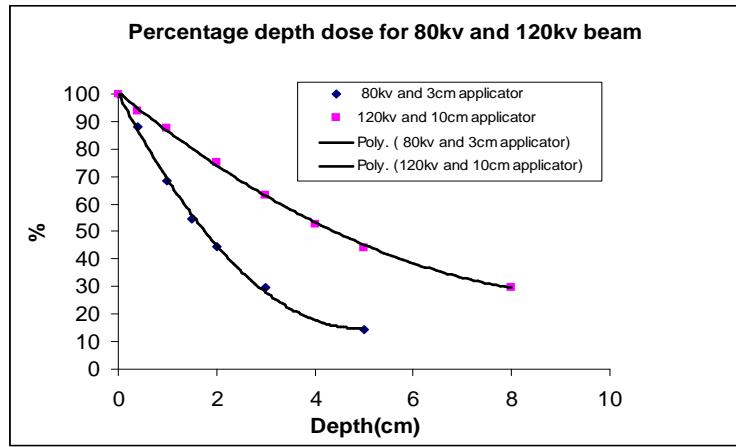


Figure 6: The percentage depth dose curves for 80kv and 120kv beam. The depth dose is measured at 15cm and 25cm FSD for 80kv and 120, respectively.



Figure 7: An image of an exposed film using 120kv beam and 15cm applicator at 25cm FSD.

2.3.1 Reference dosimetry

The IAEA TRS-398 classified as low-energy x-ray and medium energy x-ray. The 80Kv beam is treated as a low energy x-ray beam here.

80kv beam was calibrated using 3cm applicator and PMMA phantom, as shown in Fig.10, following IAEA TRS-398 recommendation. As a medium energy, 120kv beam was calibrated in the small water tank at 2cm depth using 10cm applicator, which is shown in Fig.5.

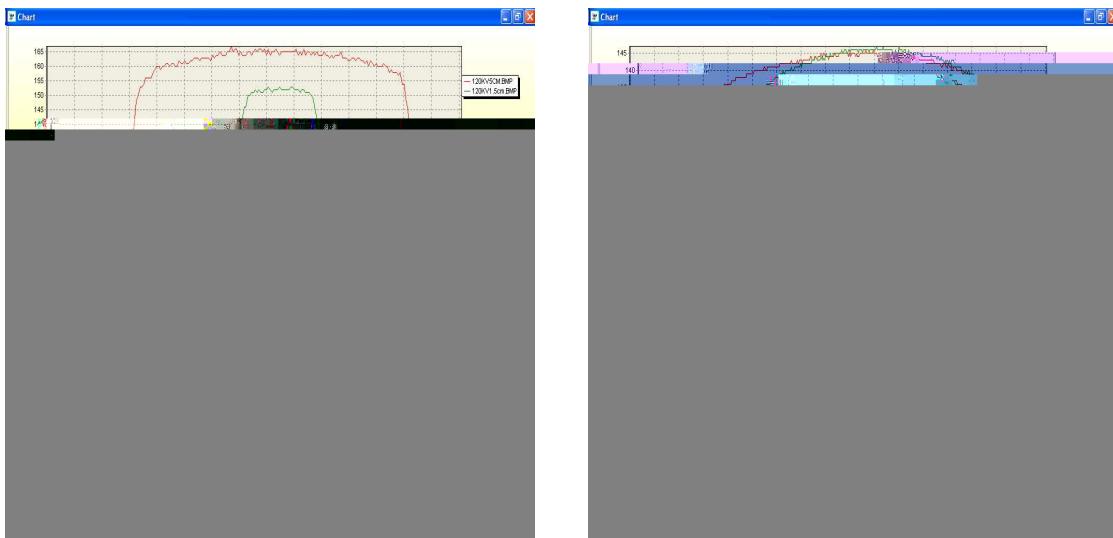


Figure 8: The profiles measured at plastic water surface for 120kv beam using 5cm and 1.5cm applicator(left) and 15cm and 10cm applicator(right).

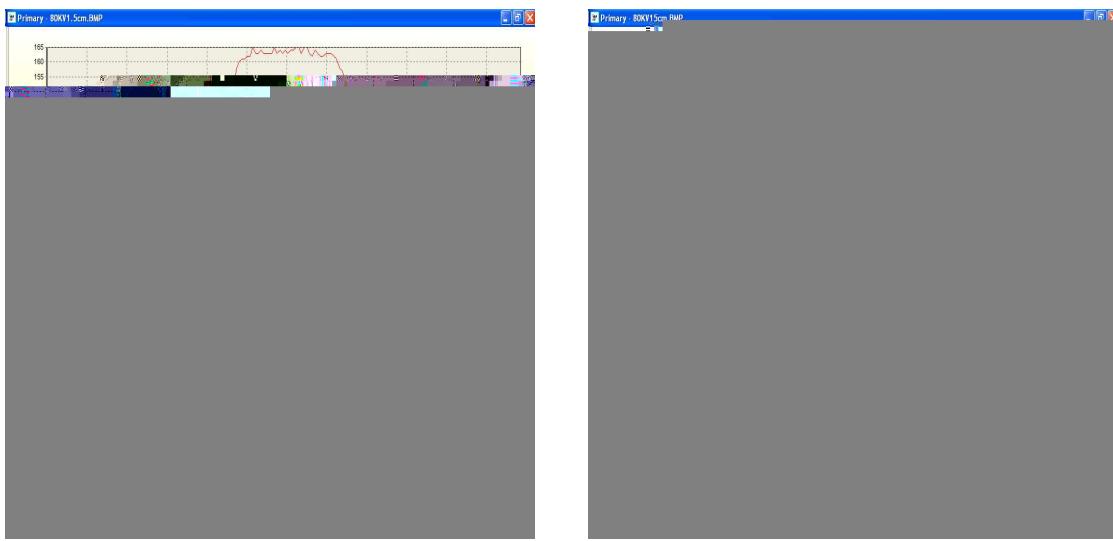


Figure 9: The profiles measured at plastic water surface for 80kv beam using 1.5cm applicator(left) and 15cm applicator(right).

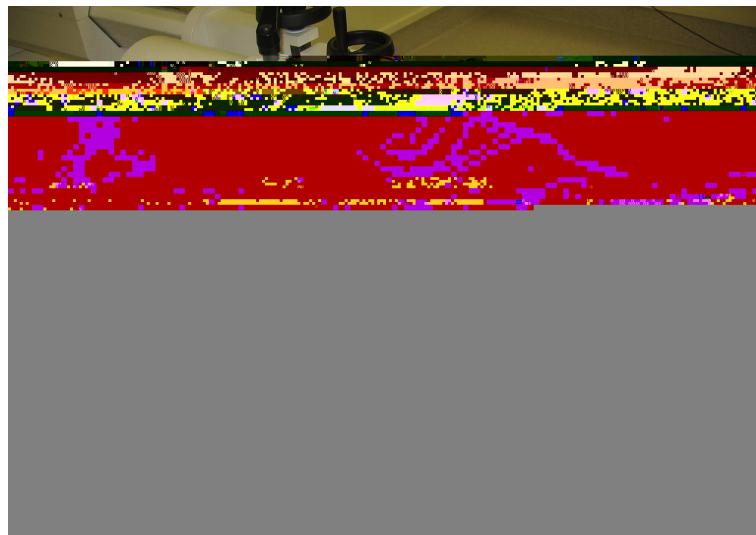


Figure 10: The setup for 80kv reference dosimetry.

The procedure and results are recorded in the following two worksheets provided by IAEA TRS398 protocol:

TRS-398 worksheet for low energy x-ray reference dosimetry**Determination of the absorbed dose to water in a low energy x-ray**User: Aitang XingDate: 12/01/2007**1. Radiation treatment and reference conditions for $D_{w,Q}$ determination.**X ray machine: Gulmy D3000Nominal tube potential: 80kvNominal tube current: 20 mABeam quality $Q(HVL)$:1.96 mAReference materials: PMMA slab phantomReference depth:phantom surfaceAdded foil material: mylarThickness: 0.1 mmReference field size: 3cm circularReference SSD:15cm.**2. Ionization chamber and electrometer**Ionization chamber model: PTW23342Serial No:1233Chamber wall material:polyethyleneThickness: $30\mu m$ **Absorbed dose to water calibration factor $N_{D,W,Q_0} = \underline{22.27896}\text{Gy/nom.Gy}$** Reference conditions for calibration P_0 : 101.325kPa T_0 : 20°C Rel.Humidity:50%Polarizing potential V :245VCalibration and user polarity: positive Corrected for polarity effect: NoCalibration laboratory: National radiation Laboratory in New Zealand Date:19/05/2005Electrometer model: NE2570/1 dosimeter Serial No.: 1311 Calibrated together?: yesRange setting:0.6cc and low rangeDate: 19/05/2005**3. Dosimeter's reading and corrected for influence quantities**Uncorrected electrometer readings at V and user polarity: $M = \underline{0.3882}$ nom.GyCorresponding time: 1 min.(1) Pressure P: 760.3mmHg Temperature T: 20.6 $k_{TP} = \underline{1.002047782}$ (2) Electrometer correction factor $k_{elec} = \underline{1.0}$ Corrected electrometer readings: $M_Q = M k_{TP} k_{elec} = \underline{0.388995}$ nom.Gy**4. Absorbed dose rate to water at the phantom surface**Beam quality correction factor for user quality Q: $k_{Q,Q_0} = \underline{1}$

Absorbed dose rate calibration at phantom surface:

$$D_{W,Q}(\text{surface}) = 100 M_Q N_{D,W,Q_0} k_{Q,Q_0} = \underline{866.64}\text{cGy/min.}$$

TRS-398 worksheet for medium energy x-ray dosimetry**Determination of the absorbed dose to water in a medium energy x-ray**User: Aitang XingDate: 12/01/2007**1. Radiation treatment and reference conditions for $D_{w,Q}$ determination.**X ray machine: Gulmy D3000Nominal tube potential: 120kvNominal tube current: 20 mABeam quality $Q(\text{HVL})$:0.47 mCuReference materials: waterReference depth: 2g/cm²Reference field size: 10cm circularReference SSD:25cm.**2. Ionization chamber and electrometer**Ionization chamber model: Wellhofer FC65-GSerial No:457Chamber wall material:graphiteThickness: 0.36mm**Absorbed dose to water calibration factor $N_{D,W,Q_0} = \underline{0.9732}\text{Gy/nom.Gy}$** Reference conditions for calibration P_0 : 101.3kPa T_0 : 20⁰C Rel.Humidity:50%Polarizing potential V :245VCalibration and user polarity: positive Corrected for polarity effect: NoCalibration laboratory: National radiation Laboratory in New Zealand Date:11/10/2006Electrometer model: NE2570/1 dosimeter Serial No.:1311 Calibrated together?: yesRange setting:0.6cc and low range Date: 14/04/2005-2/05/2005**3. Dosimeter's reading and corrected for influence quantities**Uncorrected electrometer readings at V and user polarity: $M = \underline{2.427}\text{nom.Gy}$ Corresponding time: 1 min.(1) Pressure P: 760.3mmHg Temperature T:21.6 $k_{TP} = \underline{1.005460751}$ (2) Electrometer correction factor $k_{elec} = \underline{1.0}$ Polarity correction $k_{pol} = \underline{1}$ Corrected electrometer readings: $M_Q = M k_{TP} k_{elec} = \underline{2.4403}$ nom.Gy**4. Absorbed dose rate to water at the reference depth, z_{ref} .**Beam quality correction factor for user quality Q: $k_{Q,Q_0} = \underline{1}$ Absorbed dose rate calibration at z_{ref} : $D_{W,Q}(\text{surface}) = M_Q N_{D,W,Q_0} k_{Q,Q_0} = \underline{237.49}\text{cGy/min.}$ **5. Absorbed dose rate to water at water phantom surface.**For 10cm circular field size at z_{max} , $\text{PDD}(z_{max}) = \underline{0.7667}$ Absorbed dose rate: $D_{W,Q}(\text{surface}) = 100 M_Q N_{D,W,Q_0} k_{Q,Q_0} / \text{PDD}(z_{max}) = \underline{309.75}\text{cGy/min.}$

2.3.2 Output factor

Reference dosimetry ensures that the beam delivers an accurate dose to a reference point (usually at d_{max}) under the reference conditions. The dose to this point under the non-reference conditions are defined by output factor.

For the low energy x rays, the IAEA-TRS398 defines the ratio of the corrected dosimeter reading at the surface for a given set of non-reference conditions to that for the reference conditions. On contrast, the output factor for medium energy x rays is the ratio of the absorbed dose at the surface of a water phantom for a given SSD and field size to the absorbed dose measured under reference conditions.

The output measurement uses the same material and method as used for measuring percentage depth dose value at 2cm depth. The output was measured using plastic water and water. TableA.3 and TableA.4 show the output factors for 80kv and 120kv x-ray beams. For 80kv beam, the output factors measured in water and plastic water agree with each other very well. The discrepancy between two output factors may be due to scattered low energy photons by the applicator wall reaching the water surface.

Table A.3: The output factors measured at surface for 80kv x-ray beam.

Circular applicator(cm)	FSD(cm)	Plastic water	Water	Diff. (%)
1.5	15	0.9046	0.903	0.16
2	15	0.9342	0.9362	-0.21
2.5	15	0.956	0.965	-0.95
3	15	1	1	0
4	15	1.052	1.049	0.3
5	15	1.074	1.0764	-0.30
10	25	0.40	0.404	-0.98
15	25	0.412	0.416	-0.85

2.4 Collecting beam data for treatment planning

For kilovoltage x rays, the dosimetric data measured above provide a solid and consistent and reliable data set for treatment planing. Unlike megavoltage machine, there is no need additional data to be measured for initializing and verifying the beam model used by the

Table A.4: The output factors measured at surface for 120kv x-ray beam.

Circular applicator(cm)	FSD(cm)	Plastic water	Water	Diff.(%)
1.5	15	2.12	2.06	2.57
2	15	2.193	2.166	2.11
2.5	15	2.248	2.199	2.15
3	15	2.35	2.284	2.9
4	15	2.495	2.433	2.49
5	15	2.557	2.522	1.38
10	25	1	1	0
15	25	1.54	1.054	-0.017

treatment planning system. For the planning treated with the kilovolatage x rays, the dose distribution inside the patient is usually not calculated.

3 Summary

The procedure and results as commissioning of new installed superficial x-ray unit in Palmerston North hospital are presented. The calibration of the beam follows IAEA TRS-398. This protocol is similar to two other protocols [2, 3].

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Comprehensive and extensive QAs as routine work through training period in Palmerston North Hospital

Abstract. An extensive and comprehensive experience of performing routine QAs for two Siemens linear accelerator, a Varian linear accelerator, a Siemens CT simulator, an orthovoltage KV unit, stability check of all chambers and electrometer, QA of treatment planning and radiotherapy and IMRT patient-specific QA was gained from the beginning to the end of training period.

Period: 20/12/2005-1/01/2010

1 Motivation

Once the radiotherapy equipments are acceptance tested and commissioned, the mechanical, optical and dosimetric characteristics and performance of machines must be kept as the same within acceptable uncertainty through their lifetimes. This is ensured by a comprehensive quality assurance(QA) program performed by medical physicist. This is also by required by regulations [1].

The check and tests performed at the commissioning and acceptance stage provide a baseline and reference data for making a comprehensive QA program. Essentially, establishing a comprehensive QA program essentially distributes these tests and checks into

daily, weekly and monthly QA. Several practical guidelines for making a comprehensive QA program have been published from AAPM and IPEM [2, 3].

2 Comprehensive and extensive routine QAs

2.1 Scheduled roster

In radiotherapy department of Palmerston North hospital, a comprehensive QA program was established and routinely performed for the following equipments: a Siemens Oncol linear accelerator(LA1), a varian linear accelerator(LA2), Siemens primus linear accelerator(LA3), a Siemens Emotion CT simulator, Dulmy 3000 orthovoltage x-ray, chambers and electrometers.

I performed these routine QAs from the beginning to the end of clinical training. Fig. shows a time table for a one period of time. AX means Aitang Xing. For example, from 29/05/06 to 12/06/06, I performed daily QA and weekly QA for LA1, LA2 and LA3 in three consecutive weeks. During this period, I also turned on and warmed up the three linacs for the whole week starting from 05/06/2006. From 02/2006 to 06/2006, I also did monthly QA for LA1, LA2 and LA3, the stability check for all our chambers and electrometers. On 08/05/2006, I gave a talk on the subject I chosen.

2.2 Linac daily QA

The daily QA is quickly check and monitoring the key dosimetric parameters and mechanical/optical parameters. All the parameters are recorded into a database via Lantis, a R&V system. The key dosimetric parameters includes the output, symmetry and flatness of profile, radiation field size for 20 cm 20 cm field and 45⁰ virtual wedge for 6 MV and 15 MV and one electron energy. This was done using either the Profiler(a diode array) or Atlas(a chamber array) as shown in Fig.2.

The optical/mechanical parameters to be checked are the rotation of gantry axis, the coincidence between radiation field size and optical field, the accuracy of jaw travel. The daily check can be finished within half hour during the morning tea time, the alignment of laser, the accuracy of source-to-axis distance.

PHYSICS SCHEDULE

	08 May	15 May	22 May	29 May	05 June	12 June	19 June	26 June	03 July	10 July	17 July	24 July	31 July
Run Up Linacs (7am start)	IK	TO	TG	RM	AX	DB	IK	TO	TG	RM	AX	DB	IK
Daily/Weekly QC & Abs. Dosim. LA1	TO	TG	RM	AX	DB	IK	TO	TG	RM	AX	DB	IK	TO
Daily/ Weekly Abs QC LA2/CT	IK	TO	TG	RM	AX	DB	IK	TO	TG	RM	AX	DB	IK
Daily/Weekly QC & Abs. Dosim. LA3	DB	IK	TO	TG	RM	AX	DB	IK	TO	TG	RM	AX	DB
QC & Abs. Dosim. SXR	JS	JS	JS	JS	JS	JS	JS	JS	JS	JS	JS	JS	
On-call (starting from prev. Friday)	TG	RM	KC	IK	TO	TG	RM	KC	IK	TO	TG	RM	KC
New Case Meeting	TO	TG	RM	KC	IK	TO	TG	RM	KC	IK	TO	TG	RM
Physics Monday Meeting	AX	DB	IK	TO	KC	JS	TG	RM	AX	DB			
							! Change time						
	Feb. 06	Mar. 06	Apr. 06	May-06	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06				
Monthly LA1	AX	DB/KC	IK	RM	TG	TO	AX	DB/KC	IK				
Monthly LA2	TO	AX	DB/KC	IK	RM	TG	TO	AX	DB/KC				
Monthly LA3	TG	TO	AX	DB/KC	IK	RM	TG	TO	AX				
Stability Checks	RM	TG	TO	AX	DB/KC	IK	RM	TG	TO				
Internal QAAudit	IK	RM	TG	TO	AX	DB/KC	IK	RM	TG				

Figure 1: A physics schedule over a certain period in 2006.

2.3 Linac weekly QA

The dosimetric aspect of weekly QA is to calibrate the electron and photon beams following the IAEA TRS277 protocol before 06/2006 and IAEA TRS398 protocol afterwards. The regulation requires the output is 1Gy/100MU within $\pm 2\%$, while the department protocol requires the output of 1Gy within $\pm 1\%$. A Farmer chamber for photon beams and A Roos chamber for electron beams are used along with a custom-made small water tank. The setup is flowing the reference condition recommended by the protocol, as shown in Fig.3. The weekly QA usually takes about two hours.

As a example, a weekly QA report is shown in Fig.4. The dose rate and linearity of built-in dosimeter(monitor chamber+dosimetry board) are also checked. This is important as the Siemens virtual wedge uses the low dose rate. The IMRT is employed here to treat patient. If the output(dose rate) is out of tolerance, the dose 1 gain(D1G)(the dose 2 gain, D2G) is adjusted by running the machine in service mode.

The mechanical weekly checks are shown in the Fig.5, which is recorded in Lantis.

2.4 Linac monthly QA

Monthly Linac QA is to use Scantronix radiation field analyzer(RFA300 and the electron and photon diodes, as shown in Fig.6, to scan the key beam data used for commissioning the machine and establishing the beam model for TPS. They are compared with those commissioning data. The PDDs for each photon and electron beam energy and dose rate for $10\text{cm} \times 10\text{cm}$ field. The two diagonal profiles for $40\text{cm} \times 40\text{cm}$ field was scanned at d_{max} and their horn are checked. The purpose of these scanning is to check if the beam energy spectrum is changed.

The profiles for $10\text{cm} \times 10\text{cm}$ field size at d_{max} and 10cm depth were scanned for all beam energy and dose rate. The profiles were checked an compared with reference data to see if any change regarding beam flatness and symmetry. This is essentially checking the angular spectrum of the beam.

The total time for doing monthly QA is about 4 hours. The RFA setup is shown in Fig.6. The list of profiles and pdds to be scanned for monthly QA is listed in Fig.???. These profiles are the key commission data. After the profiles are scanned, they are saved and compared with those data collected when the machine is commissioned. The total time for doing monthly QA is about 4 hours.

2.5 Monthly CT simulator QA

CT simulator for radiotherapy play a key role in planning a treatment. There are three types of the monthly checks for CT simulator performed in Palmerston North hospital: machine-related check and image-related check.

A perspex phantom is used to check the alignment of zero-planing defined by external lasers and the scanning plane defined by the internal lasers. The coincidence of laser from two side walls is also checked. Align the grooves of phantom with external laser, then move by 650mm to see if the internal lasers still are aligned with the phantom. The phantom is also scanned to check alignment of two planes by observing the lead marks on the CT images. The accuracy of longitudinal movement of couch is also checked by placing a ruler on the table. These mechanical parameters directly influence the quality of images.

The image-related check is to check the quality of images, the accuracy of CT numbers, the uniformity of CT number. This is done, as seen in Fig., using another CT phantom comprising the water, air and perspex.

2.6 Weekly superficial x-ray unit QA

For superficial x-ray unit, the weekly QA is mainly calibrating the beam using IAEA TRS398. As shown in Fig., for low energy KV beam, a thin window pancake chamber is used along with the PMMA slab phantom. The medium to high energy KV beams are calibrated at 2 cm depth in a small water tank, which is shown in Fig.8.

2.7 Monthly stability check of dosimeters

The reproducibility and stability of all dosimeters(chamber+electrometer) directly influence the accuracy of beam calibration and the accuracy of absolute dosimetry.

The long-term stability of all thimble and plane-parallel chambers and electrometers are checked using radioactive source with a proper chamber holder on the monthly based. As shown in Fig, the thimble chambers are checked using Sr-90 box and parallel plate chambers were checked with Sr-90 eye applicator. All the results are recorded into an excel file as shown in Fig.10.

2.8 Patient-specific IMRT QA

The IMRT has been using for treating head and neck patient for several years. It is also a routine work to do patient IMRT QA. IMRT QA is and could not be scheduled as other QA work and distributed equally between the physicist.

The details of IMRT procedure is not described here. The main steps are:(1) First, review the patient IMRT plan approved by oncologist and the head of treatment planning;(2)Second, replan the IMRT treatment plan on the digital IMRT phantom to chose the proper measurement point and plane in which the dose distribution is measured;(3)Third, setup the physical IMRT phantom on the Linac in same way as RTs set up patient. The phantom is exactly same as the digital phantom in CMS XIO. The point dose is measured with CC13 thimble chamber and the plane dose is measured with the Kodak EDR2 film;(4)Finally, analyze the measurement results and write a report. After a second check by another physicist, the report is given to oncologist for approval. If there are any problems, there will be a discussion between physicist, oncologist and RTs.

As an example, Fig.11 shows the first page of an IMRT report for a patient I did in 2008. The comparison of isodose measured with film and RTP calculated, the gamma index map is not shown her. For confidentiality, the patient name was omitted her.

2.9 Monthly QA of radiotherapy procedure

There are two types of QA related to the radiotherapy: equipment oriented and procedure oriented. The QAs mentioned above are mainly equipment oriented. It is also very important to perform the quality control of radiotherapy process and recommended by several protocols.

Quality control of radiotherapy procedure is to check the constancy and consistency of every step of the whole radiotherapy procedure the patient goes through. The radiotherapy procedure QC is usually performed by a specially designed phantom. In our department, as shown in Fig.12, an in-house perspex phantom called RAT is used to fulfill this task. The phantom has precisely know dimension with three embedded inhomogeneities, whose center location, electron density, physical dimension, the distance between center are exactly known.

The procedure of radiotherapy procedure QC is exactly the same as the procedure for treating a patient. For more details, see reference. Briefly, the RAT phantom is first setup

on CT simulator couch as shown in Fig.12 and scanned the phantom using the head and neck clinical scanning protocol. After scan, put a CT marks on center of bone using the moving laser. The second the step is to transfer CT images to Dosimetrist workstation to contour the phantom skin, lung, water and bone as shown in Fig.13 Then the contoured DICOM phantom is transferred to CMS XIO for treatment planning, which is shown in Fig.14. After the treatment planning, then transfer the treatment plan to Lantis(a R&V system) and setup the phantom on the Linac couch to measure the point dose. All the data obtained during the whole process are compared with the reference data.

The purpose of radiotherapy QC is to check:

- the constancy of CT simulator performance and clinically used scanning protocol by checking the distance between scanning plane and laser defined origin plane, the accuracy of CT mark laser.
- the constancy and CT image quality by checking uniformity and accuray of CT number and noise, checking the geometric accuracy of CT images through measurement of known distance between the the lead marker, orientation and the dimension of phantom.
- the consistency of DICOM data transfer between CT simulator, dosimetrist, CMS XIO and Lantis.
- the accuracy and consistency of contouring algorithm, volume-construction algorithm and geometric modeling.
- the accuracy and consistency of anatomic patient modeling, geometric and dosimetric beam modeling, and CMS XIO input and output.
- the overall performance of Linac and patient setup.

3 Summary

An extensive routine QAs for two Siemens linear accelerators, a Varian linear accelerator, a Siemens Emotion CT simulator, an orthogonal KV beam unit were performed through the whole training period in the oncology department of Palmerston North hospital.

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Figure 2: Daily QA setup with ATLAS and associated software.



Figure 3: The weekly QA setup for calibrating the beams with a small water tank following IAEA TRS-398 dosimetry protocol.

Figure 4: A report for weekly reference dosimetry.

Figure 5: The list of mechanic, electronic and optical checks for linac weekly QA.



Figure 6: The RFA300 scanning system setup for linac monthly QA.

Figure 7: The list of profiles and pdds to be scanned for monthly QA. These profiles are compared with those collected when linac was commissioned.

Figure 8: Upper figure: the perspex slab phantom setup for low energy x-ray. Lower figure: the water phantom setup for medium-to-high energy x-ray.

Figure 9: The setup for dosimeter's stability check.

Figure 10: The excel file for recording the stability check results.

Figure 11: The first page of an IMRT patient QA report. The measured and TPS calculated dose distribution, the gamma-index map are not shown here.

Figure 12: Upper figure: the RAT perspex phantom used for radiotherapy procedure QC. The phantom embed water, lung and bone equivalent inhomogeneities whose location, dimension and electron density are precisely known. Lower figure: RAT phantom setup on CT couch for scanning.

Figure 13: Contouring, volume construction and virtual simulation on RAT phantom on Siemens Dosimetrist workstation.

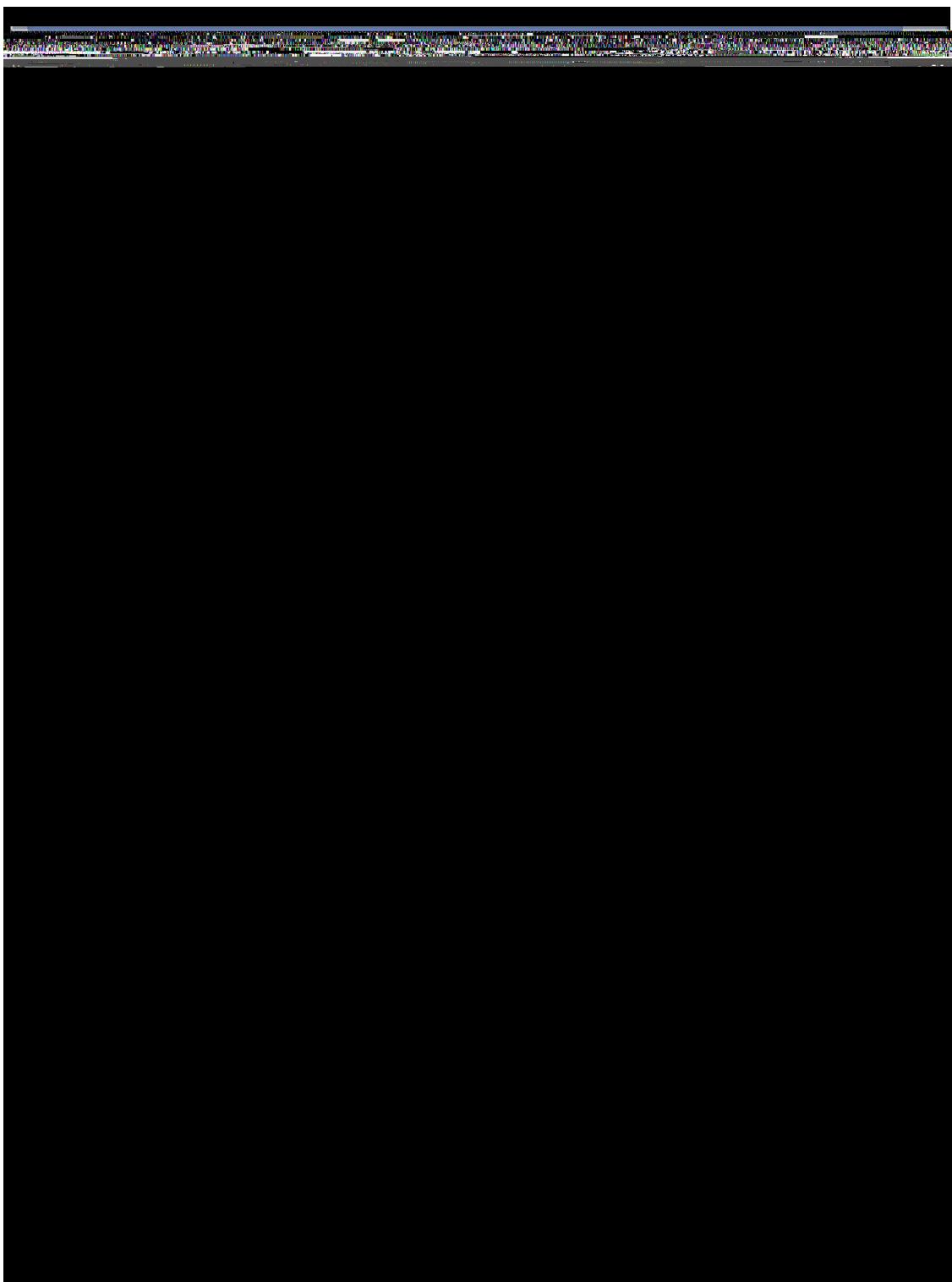


Figure 14: Treatment planning and plan evaluation on the RATphantom using CMS XIO.

Part IV

Brachytherapy

Chapter 1

MODULE SUMMARY

The following clinical experiences were gained for this module:

1. Quality assurance in brachytherapy via periodical QA of Cesium source for manual loading gynecological brachytherapy, NZ registrar workshop on HDR brachytherapy etc.
2. Calibration of Brachytherapy Sources via calibration of Cesium source and iridium-192 HDR source etc.
3. Treatment Planning and plan check via manual planning and point A dose rate calculation, HDR brachytherapy workshop etc.

Note that module reports can not cover all these experiences and only a few representative experiences are presented as reports here.

Chapter 2

MODULE REPORTS

Calibration of ^{137}Cs sources for gynaecological brachytherapy

Abstract. Palmerston North hospital has no high dose rate(HDR) afterloading system. Sealed Cesium-137 sources are still used for the intracavitybrachytherapy. The Cesium-137 sources have not been recalibrated since they were purchased in 1988. I was asked to recalibrate the source against the reference source calibrated by NRL using a well-type chamber. This report recorded the procedure and results of source calibration.

Period: 13/02/2006-20/02/2006

1 Background

Although there is no high dose rate(HDR) afterloading system available in Palmerston North hospital, the sealed Cesium-137 sources are still used for the intracavity brachytherapy.

The Cesium sources were bought from 3M New Zealand Ltd. and delivered in the first of February, 1989. Since then, no calibration was performed. In 2006, the physics department decided to recalibrate them. This report describes the calibration procedures and results.

2 Materials and methods

The activity of our source was determined against a check source, which was calibrated by National Radiation Laboratory(NRL) in New Zealand.

2.1 Phantom and dosimeter

The equipments used for the calibration are the calibrated reference source and its certificates, a HDR1000 plus ionization chamber [1], a Farmer 2570/1 electrometer, the lead shielding blocks, a specially designed source holder and a long-handle forceps.

Fig.1 shows the HRD1000 plus ionization chamber and the source holder. As the chamber response is depending on the source insertion position. The source holder was designed to insert the source to the most sensitive position on the central axis of chamber, namely 65mm away from the bottom of chamber. Two perspex pieces were used to change the source position.

2.2 Equipment setup

The measurement setup is shown in Fig2. The calibration was performed in Cesium source storage room. A shielding cabinet was setup first using the 5cm lead block at sides and lead glass at top. The well chamber was in the cabinet. Behind the chamber is the source draws in which our sources are stored. Because the chamber and electrometer are near the wall and shield blocks, thus in a high-scattering, the background was checked before and after the measurement.

Just for the radiation protection and monitoring the exposure to the hands, LiF TLD chips were taped on the wrists. This is just a typical example of applying the radiation protection principle of time, distance and shielding to the clinical routine work.

2.3 Measurement procedure

The following procedure was followed:

1. Position the well chamber and connect it with electrometer. Stabilize the dosimeter for about 10 minutes. Then fit the source holder into the chamber and cover it by lead lid. Take background measurement for about 15 minutes.
2. Transfer the check source to the holder in well chamber using a long forceps. Set the electrometer to measure charge for one minute. Repeat each measurement for three times. Return the check source to its container and lock it.
3. For each department source, use long forceps to take the source out of the drawer and hold it to read the unique series number marked on cesium tube surface. Then

Figure 1: The HDR 1000 plus ionization chamber:(A)the cover of well chamber.(B)the Cesium source holder, which is made from perspex.(C)0.5cm thick perspex piece used for change the position of holder.(D)0.5cm thick perspex piece used for change the position of holder.

Figure 2: The equipment setup:(A)the check source container(B)the well chamber placed in the shielding blocks. The Cesium source drawer is just behind the chamber.(C)the lead shielding blocks.(D) the 2570/1 Farmer electrometer.

insert the source into source holder and put lid cover on the top of chamber. Repeat three measurement for each source and return source to its original position in the drawer.

3 Results and conclusion

3.1 Calculation of the source activity

The measured activity of the source is obtained using the following equation:

$$A_{\text{measured}} = \frac{R_{\text{reference}}}{R_{\text{department}}} A_{\text{reference}} \quad (\text{A.1})$$

where A_{measured} is the activity to be measured for each department source and $A_{\text{reference}}$ the activity of reference source. See its calibration certificate in Appendix. $R_{\text{department}}$ and $A_{\text{reference}}$ are the averaged electrometer readings for department source and reference source, respectively.

Comparison between the measured and predicted source activity

The activity of cesium source can be predicted using the exponential decay equation, its half-life time and the time interval between the initial date and the calibration date. For department source, the initial date is the 9th of February, 1998 when the source was first calibrated at the time of purchase. The reference source was calibrated on the 14th of February, 2002 by NRL. The calibration measurement was performed on the 13th of February, 2006.

The expected and measured activities of department sources are compared and shown in Table A.1. R_{mean} is the averaged electrometer readings A_{initial} is the activity of the source on the initial date, whereas $A_{\text{predicted}}$ is the source activity predicted using decay equation. The measured activity on the calibration date is denoted by A_{measured} .

From the Table A.1, it can be seen that the measured source activities agree with the predicted activity within 3%. It is also noticed that the measured activities are consistently lower than the predicted ones. It may be caused by the attenuation of thin wall of source holder. The major components in uncertainties include the uncertainty of dosimeter's

Table A.1: The measured and predicted activity for the Cesium source.

Source serial No.	Rmean (nC)	A _{initial} (mCi)	A _{predicted} (mCi)	A _{measured} (mCi)	Di . (%)
Check source	6.925	22.3	20.45	20.45	0
1640	2.99	13.4	8.84	8.83	-0.08
1734	2.855	12.8	8.44	8.43	-0.15
7250	5.635	25.3	16.69	16.64	-0.29
7239	5.748	25.8	17.02	16.97	-0.26
7247	5.730	25.7	16.95	16.92	-0.19
7240	5.680	25.5	16.82	16.77	-0.28
7251	5.755	25.8	17.02	16.99	-0.14
4675	8.760	39.3	25.91	25.87	-0.18

stability, the uncertainty of scattering environment and the source position uncertainty in the well chamber.

3.2 Dependence of the dosimeter's response on the source position in Well chamber

Nominally the check source tube has the same physics size as other sources, but the tube dimension slightly varies from source to source. The difference of source position in well chamber between the reference source and the source measured is considered to be one of major causes for the measurement uncertainty.

The dependence of dosimeter's response on the source position in well chamber was also investigated. The source position could be lifted up by 0.5cm and 1cm by putting the perspex pieces as shown in Fig.1 on the top of chamber before inserting the source holder into chamber.

The results are shown in TableA.2 and TableA.3. The readings of electrometer is normalized to readings obtained with the source holder only inserted into chamber. As expected, the chamber response is sensitive to the source position. However, within 5mm source position range, the uncertainty is less than 1%. This means that source position uncertainty does not contribute so much to 3% difference between the measured and

predicted dose.

Table A.2: The dependence of dosimeter response on the ~~che~~ source position in well chamber

source position	Averaged readings(nC)	Relative readings(nC)
Normal position	6.883	1.00
0.5cm up	6.773	0.984
1cm up	6.660	0.967

Table A.3: The dependence of dosimeter response on the ~~dep~~ source position in well chamber

source position	Averaged readings(nC)	Relative readings(nC)
Normal position	2.970	1.00
0.5cm up	2.950	0.994
1cm up	2.925	0.985

3.3 Monitored dose to the hands

During the measurement, it is very important to protect myself by applying the basic radiation protection principle: time, distance and shielding. Although I stood behind the shielding block and transferred source between chamber and source drawer as fast as possible using a long handle forceps, it is unavoidable to expose the hands to the source.

The dose to the hands were monitored by taping several TLD chips on wrists. The results are given in TableA.4. The total dose exposed to the hands are very small.

Table A.4: The monitored dose the wrists

Position	Left wrist	Right wrist
Dose(mGy)	0.265	0.755

4 Summary

The Cesium source used for intracavity brachytherapy in Palmerston North hospital was calibrated against a reference source. The reference source was calibrated by NRL.

Bibliography

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- [2] International Atomic Energy Agency, Calibration of Brachytherapy Source, IAEA-TECDOC-1079, IAEA, Vienna, 1999.

Appendix

A. The certificate of check source

The check source was calibrated by NRL on the 14th of May, 2002. The calibration data are given in Table A.1.

Table A.1: Check source calibration data.

Nominal source activity	Reference air kerma rate	Uncertainty
740MBq(20mCi)	63.8 Gy/hr	2.9%

B. Verification of the reference air kerma rate

The reference air kerma rate of the reference source was verified by recalculating according to the original data given by NRL certificate.

According to IAEA-TECDOC-1079 [2], the air kerma rate for the reference source K_R is calculated as:

$$K_R = N_k I_m k_{T,P} k_{air} k_n k_s \quad (A.1)$$

In Eq.A.1, K_R is the air kerma rate calibration factor for the dosimeter used in NRL. I_m is the ionization current measured at 1m away from the source minus any leakage current. $k_{T,P}$, k_s and k_{air} are the correction factors for temperature and pressure, to scatter and air attenuation. k_n is the non-uniformity correction factor that corrects for

the variation of the effective measurement point of reference chamber at different source-chamber position. The original values of these parameters provided by NRL are listed in TableA.2.

Table A.2: Original data used for recalculating the reference air kerma rate

Parameter	N_k	I_m	$k_{T;P}$	k_{air}	k_n	k_s
Value	0.3148 $\mu\text{Gy}/\text{s/pA}$	0.05785 pA	0.9970954	1.002	1.00	0.971

Substituting the original into Eq.A.1, one gets:

$$K_R = 0.3148 \quad 0.05785 \quad 0.9970954 \quad 1.002 \quad 0.971 \quad (\text{A.2})$$

$$= 63.6 \mu\text{Gh/h} \quad (\text{A.3})$$

The slight difference between the calculated reference air kerma rate and the one given by NRL is because of the use of different $k_{T;P}$. NRL only provided the temperature range(18.9-19.8⁰) and pressure range(101.3-101.5kPa). 19.35⁰ and 101.4kPa are used for the calculation here.

Manual planning for a patient treated with Fletcher applicator

Abstract. As an import part of brachytherapy module training, a patient originally planned with CMS Xio was replanned manually. An independent tool for checking the dose to point A or treatment time was developed and tested for several patients with the accuracy within 6%. It can be used as an independent QA checklist for brachytherapy plan.

Period: 15/09/2007-20/09/2007

1 Motivation

Manual planning was the only choice for the intracavity brachytherapy before the computerized treatment planning system(TPS) was introduced into radiotherapy. The TPS encapsulates the basic procedure of manual planning with ~~to~~ high accuracy and speed.

In a modern radiotherapy department, it is not necessary and recommend to do manual planning for patient treatment. However, for training purpose, the manual planning for brachytherapy can help the registrar deeply understand:(1)the physics of brachytherapy involved in the planning; (2)the clinical use of intracavity applicator system eg. Fletcher, Vaginal Applicator; (3)the algorithm of dose calculation and dose prescription; (4)what the computer does.

Figure 1: The classical Manchester system with the definition of point A and B.

2 Methods and procedure

The treatment planning for intracavity brachytherapy is more than dose calculation. It starts with the diagnosis and assessment by oncologist. This is followed by the determination of the applicator and source position, reconstruction of source and applicator, the calculation of dose distribution for determination of treatment time and dose rate at interest point. The treatment planning for patient was originally done using CMS Xio, a commercial treatment planning system. The planning was refined manually.

2.1 Oncologist's prescription for the patient

For confidentiality, the patient name is replaced by XYZ. Mrs XYZ was diagnosed as stage 3B adenocarcinoma of cervix. She was treated with the Fletcher with ^{137}Cs sources loaded.

The treatment prescription, as shown in Fig.1, is:(1)The three sources loaded into the tandem were 20mgRaEq at tip,10mgRaEq at middle and 10mgRaEq at end; (2)25mgRaEq and 20mgRaEq were loaded at left ovoid and right ovoid, respectively;(3)30Gy dose was prescribed to point A;(4)the treatment started on 23/01/2007 and the duration of implant is two days 13hours and 50minutes. The source was calibrated in 01/02/1989.

2.2 Manual reconstruction of the source and Fletcher

Followed by the prescription, the fist step of planning is to insert the Fletcher loaded with the dummy source into patient by oncologist and radiation therapist. Once the Fletcher and source positions is determined, conventionally two orthogonal film(one lateral film and one anterior-posterior film) are taken. In radiotherapy department of Palmerston North hospital, the patient is scanned using CT simulator. The images of lateral and AP tomograph are send to radiology department and printed on film using film printer. The planning moves to the next stage, source and Fletcher reconstruction.

The source and Fletcher reconstruction is a procedure in which the coordinates of source and Fletcher defined in film coordinate system are transformed into the ones defined in patient coordinate system in order to calculate the dose in patient. For manual planning, it is assumed that the film coordinate system and patient coordinate system are parallel to each other and have the same origin at the external cervical os. The coordinates of any point two coordinate systems are linked together by the film magnification factor. By contrast, the transformation between two coordinate system used by CMS Xio is much more complicated than this.

The method used to find the coordinates of source and Fletcher is very simple:(1) put the film on a light box (2) then place a big graph paper over the film;(3)locate the origin first, namely the external cervical os;(4) draw two orthogonal axeses passing the origin and find the coordinates of source tip and end for each source. The procedure is shown in Fig2.2.

The AP film is assumed to be x-z plane and lateral film in z-y plane. Two values of z coordinates are obtained for each point, but they should be close together. TableA.1 shows the coordinates of source tip and end for each source in film coordinate system.

The film magnification factor linking the the coordinates in patient and film coordinate systems is calculated in the following way: the length of each source in the film coordinate is calculated from its tip and end coordinates. The physical length of source is 2cm. The ratio of the source length from film to 2cm is taken as the magnification factor(MF). The averaged MF factor is 1.31. The the coordinates of the sources in patient coordinate system is easily obtained. This is the must-have information for the dose calculation in patient in the following step.

Figure 2: Determination of coordinates of source tip and end using graph paper and light box from orthogonal films.

2.3 Manual calculation of dose in patient

Cesium source is a linear source. Suppose there is only one linear source and the coordinates of source tip and end in patient coordinate system is known. The straight line representing the source in three dimension coordinate system is described by a simple mathematical equation. Once this equation is derived, the coordinates of any point lying on the line is known.

The linear source is treated as a linear array of N point sources. Suppose the distance from one point source with activity of $A[\text{mCi}]$ to an arbitrary point P in patient space is r . The dose rate at point P , $\dot{A}(P)$, can be simply calculated as follows:

$$\dot{A}(P)[\text{mCi/h}] = \frac{A[\text{mCi}]/N}{r^2} \Gamma_x[\text{Rcm}^2/\text{hr/mCi}] \times f[\text{Gy/R}] \exp(-\mu_{ft}l_{ft})g(r) \quad (\text{A.4})$$

where Γ_x is the exposure rate constant, $3.27\text{Rcm}^2/\text{h/mCi}$ for Cesium-137. The conversion factor from mgRaEq to mCi is 2.56. $f[\text{Gy/R}]$ is the constant and 0.00968 for Cesium-137. μ_{ft} and l_{ft} is the linear attenuation factor for source filter and effective path length of filter. These parameters are known from the manufactures.

The function $g(r)$ takes into account the attenuation and scattering of tissue and is well-known as Meisberg function [1]:

$$g(r) = 1.0091 - 0.009015r - 0.0003459 - 0.00002817r^3 \quad (\text{A.5})$$

Table A.1: The coordinates of source tip and end in film coordinate system

Source position	Tip(x,y,z)(cm)			End(x,y,z) (cm)		
Tandem tip	-1.9	-2.9	6.5~6.6	-0.8	-1.8	4.3~4.6
Tandem middle	-0.8	-1.8	4.3~4.6	-0.1	-0.7	2.2~2.3
Tandem end	-0.1	-0.7	2.2~2.3	0	0	0
Left ovoid	-3.6	2.4	-0.7~-0.9	-2.6	0.2	-2.1~-2.0
Right ovoid	1.1	3.8	-0.5~-0.7	2.2	1.6	-2.1~-1.7
Left point A	-2.8	-0.7	2.1~2.3			
Right point A	2.4	-0.7	2.1~2.3			

Figure 3: The graphic user interface of BrachyManualPlanning program

The total dose rate to any point in patient is calculated as a sum of dose rate from all point source for all Cesium sources in Fletcher. The dose to any interest point and isodose curves or surface can be easily obtained by hand calculation. However, this is a tedious procedure. A simple program named as “BrachyManualPlanning” was written in python to encapsulate the manual calculation procedure. Its graphic user interfaces are shown in Fig.3. The input data required are the coordinates of source tip and end, left and right point A and the source activity at treatment time. The dose rate and total dose delivered to point A will be displayed.

3 Comparison between manual and CMS Xio planning

The manual planning procedure outlined here is very simple in comparison with the procedure used by CMS Xio. First, the patient coordinate system in CMS Xio is totally different from the film coordinate system. Therefore, a much complicated mathematical transformation is used to localize the source and Fletcher. Second, CMS Xio uses the TG43 formalism to calculate the dose in patient by looking up the stored dose rate table [2].

Table A.2 shows the comparison of prescribed dose and calculated dose to point A by manual planning and CMS Xio.

Table A.2: The calculated dose to point A by manual and CMS Xio.

Point of interest	Prescribed dose(Gy)	Manual calculated	CMS Xio calculated
Point A	30Gy	28 Gy	29.9Gy

Taking into account the simplicity and approximation made in manual planning, the manually calculated dose to point A agrees very well with the value calculated by CMS Xio. The program “BrachyManualPlanning” was tested for several patients. The overall accuracy is within 6%. Therefore, this program can be used as an independent check tool for brachytherapy.

4 Summary

An intracavity brachytherapy for a real patient was planned manually. A program was written in Python programming language and can be used as an independent check tool for intracavity brachytherapy.

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Part V

Radiotherapy Treatment Planning

Chapter 1

MODULE SUMMARY

The following clinical experiences were gained for this module:

1. **Quality Assurance in Treatment Planning** via monthly QA of CMS XIO and radiotherapy procedure with RAT phantom, experience of beam modeling for photon beam from new Siemens Artiste linear accelerator etc.
2. **Planning computer system administration** via periodically archiving of the treated patients.
3. **Acquisition of patient data** via monthly CT QA, monthly TPS QA etc.
4. **Treatment Planning** via manual planning training, routine planning of typical tumor site for real patient, IMRT QA and periodic review of new patient plans planed by RT etc.

Note that module reports can not cover all these experiences and only a few representative experiences are presented as reports here.

Chapter 2

MODULE REPORTS

Manual planning for a three-field prostate cancer treatment

Abstract. Prior to the digit era, all radiotherapy treatments were manually planned. The basic principle, idea and procedure behind the manual planning are essentially same as the computerized treatment planning. As a good introduction into how to plan a radiotherapy treatment, I was trained to do the manual planning. Reported here is the one of several manual planning I performed during the training.

Period: 26/10/2006-5/11/2006

1 Motivation

The CT-based 3D computerized treatment planning system(3D-TPS) dramatically changed the way of how to plan a treatment for a cancer patient. However, as pointed out by John Cunningham, to some extent, the 3D-TPS is a rather literal computer implementation of well-established manual procedure [1].

Manual planning was the only choice and practice in radiotherapy department before 1960s. There is no need to do manual planning for patient nowadays, but doing planning by hand can help deeply understand the essential concepts and basic procedure of treatment planning, which have not been changed. The only difference between manual planning and computerized planning is that the way of achieving the same goal in every step of treatment planning is slightly different.

If you are experienced in manual planning, you will find that computer planning is easy no matter what kind of commercial treatment planning system you are using. This is why

manual planning is still an important part of clinical training for the student majoring in bachelor of health science(radiation therapy) in medical school of Otago University in New Zealand [2].

2 Manual planning procedure for a prostate cancer treatment

2.1 General overview

Treatment planning is a procedure of determining the best method of treating a tumor with radiation. The objectives of treatment planing is firstly to ensure the tumor receives a uniform radiation dose while healthy tissue and critical structures are protected, secondly to develop reproducible setups and maintain patient comfort. To achieve this goal, the manual planing and computer planing follow the same steps: visualization, localization, field selection and placement, dose calculation and verification.

Visualization is to determine the location and extent of the tumor particularly with respect to anatomical landmarks by palpation, medical imaging(plain radiography,mammography, CT, MRI, altrasound) and direct visual examination. The purpose of localization is to determine the position and borders of tumor and organs at risk in cross section with a reference to the setup marks made on the patient skin. Once the tumor and other sensitive organs are localized, a number of beams with a selected size are placed on patient contour with the relation with the tumor and other organs. The dose calculation is to find the optimized dose distribution by changing the variable combination of beam orientation, field size, wedge angle, weighting point and weight. The goal of verification is to ensure what we treat is what we planned by comparing the port film/EPID image with plan check film/DRR image.

2.2 Prostate case

Diagnosis of patient

The patient is a pseudo-patient, assuming my clinical supervisor has prostate cancer. The clinician decided to treat the tumor with Co-60 machine. The treatment was planned manually using the techniques used before 1960s.

Visualization and localization

As shown in Fig.1, the contour of patient was obtained using a piece of exible wire(exicurve)as follows:

1. Put the patient in treatment table and nd a suitable treatment position with head and foot rest.
2. Use the anatomic marks to nd the position of cross sectionpassing through the center of prostate by marking several marks on patient skin.They serve as the setup reference.
3. Bend the exicurve around the marks and just t in the body c ontour carefully to avoid the distortion of wire.
4. Finally carefully transfer the shape of exicurve to the drawing paper and the life-size contour of patient is made.



Figure 1: The cross section of patient passing through the prostate volume center. The contour is obtained using exicurve, whereas the PTV and rectum is located with the reference to cross-anatomy atlas.

The internal structures inside the contour were located with the reference to the atlas of cross section of human anatomy. The target volume(PTV) and one critical struc-

ture(rectum) were marked on the cross section as seen in FigThe AP separation is 22cm, while later separation is 33cm.

Beam selection and placement

Getting the patient contour and internal structures is essentially creating a "virtual simple patient"(only part of the body). To simulate the treatment, a "virtual machine" is required. For the manual planning, the virtual machine is displayed in the form of beam data, a series of isodose charts for each beam energy of real machine and fields sizes including wedge fields. The beam data was created when the machine was commissioned by the medical physicists.

The patient is to be treated with a Theratron Co-60 machine. The beam data for this machine are a series of isodose curves created at stage of ~~entrance~~ test and commissioning. It may use the published beam data [3] but with caution and it is the medical physicist's responsibility to verify the data before clinical use.

Three-field technique was selected to treat the patient: one anterior field and two lateral fields. The anterior field is a 6cm x 6cm square field. The choice of field size was based on the consideration that the PTV should be covered taking into account the penumbra of the field while minimizing the coverage of rectum. The left and right field are same size as the anterior one but with 45° wedge. The later wedge field was chosen to compensate the lateral tissue deficit. The SSD technique was used. As displayed in Fig., the field entry point was determined by ensuring the central axis of beam within PTV and avoid irradiating the rectum as minimum as possible.

Manual dose computation and optimization

The dose distribution in target and critical organ was computed by manually adding the isodose curves. The dose was corrected for the patient ~~contour~~ curvature and inhomogeneity by the well-known isodose shift technique [4]. Two lateral fields were added together first and then the resulted dose distribution was added with the anterior field. Specifically, the manual calculation follows the following procedure:

1. Place the white paper of isodose chart on the light box and fix it with a transparent tape. Then the patient contour paper is overlapped on the beam. The beam entrance

point is determined by ensuring it coincides with field center in the beam entry plane and the beam central axis passes through the center of PTV. This step is shown in Fig.2.

Figure 2: Placement of beam on the patient using light box. The beam entrance point is determined by making sure that beam central axis passes through the center of PTV.

2. Use a pencil to draw all isodose lines of the beam on patient contour including the beam entrance plane. The beam entrance plane is represented by a straight line passing the beam entrance point and perpendicular to the central beam axis.
3. Draw a series of equally spaced fan lines as seen in Fig., which are parallel to the central axis of beam and intersect with the entry plane of beam. The fan lines intersect with the isodose curves, forming a series of intersecting points.

To correct the curvature of patient, the fanline-isodose intersecting points of one isodose curve is shifted away from(tissue deficit)or towards(tissue excess) the surface by the one-third of distance between the fanline-patient's surface intersecting point and fanline-bean entry plane intersecting point. Then reconnecting the new intersecting points smoothly to get the new isodose curve. Repeat it for each isodose curve.

The similar procedure is used for tissue inhomogeneity correction but only for the

part of isodose curve passing the inhomogeneous region. The shift amount is 0.6 away from patient surface for air cavity, 0.4 away from patient surface for lung tissue and 0.5 toward patient surface for hard bone [4].

Figure 3: Manual addition of the isodose charts from two lateral fields. A series of fanlines parallel to beam central axis are drawn for inhomogeneity and patient curvature correction using isodose curve shift technique.

4. Repeat the same procedure for another lateral field. Now two isodose curves superimpose on the patient cross section anatomy. Two curves intersect each other, forming a lot of intersecting points. For each point, the percentage depth dose is the sum of percentage depth dose from each beam. For example, the intersecting points having total 90% consist of a series of points, $(80\%+10\%)$, $(70\%+20\%)$, $(60\%+30\%)$ and $(50\%+40\%)$. Connecting all these intersecting point to form a new isodose curve. Repeat for all the points. Fig.4 shows the new isodose curves as result of adding two lateral fields together.
5. Use the same procedure as above to add this new isodose curve and isodose curve from anterior field together. The final dose distribution from three-field treatment is displayed in Fig.5. It can be seen that the high dose region covers and follow the PTV. Only less 20% of dose delivered to rectum. The dose distribution is acceptable.



Figure 4: The isodose curve obtained by adding two lateral field together.

Verification

One import aspect of verification for manual planing is to calculate the treatment duration or monitor unit for treatment. Assume the treatment and prescription are as follows:

1. Oncologist prescribed 60Gy dose to 130% isodose line in 30 fraction, which covers the PTV.
2. The treatment cycle is 2 days: Day1(anterior field+ right later field), Day2(anterior field+left later field), Day3(anterior field+right later field) Day4(anterior field+left field) and so on. Three beam are equally weighted.
3. The dose rate at d_{max} and 80cm SSD for Co-60 machine is 0.98Gy /min for $6cm \times 6cm$ square field. The wedge factor is 0.97.

The calculation of treatment duration use the following steps:

step1 The average dose per fraction is $60Gy/30\text{ fractions}=2Gy/\text{fraction}$. Then the total dose per cycle is $2Gy/\text{fraction} \times 2=4Gy$.

step2 For anterior field, the 100% weight dose per cycle= $4Gy/1.3=3.07Gy$. It is treated twice per cycle, so the maximum dose at d_{max} per fraction is $3.07Gy/2=1.54Gy$.

step3 For lateral field, one time each per cycle, the maximum dose at d_{max} per fraction is $3.07Gy/1=3.07Gy$.

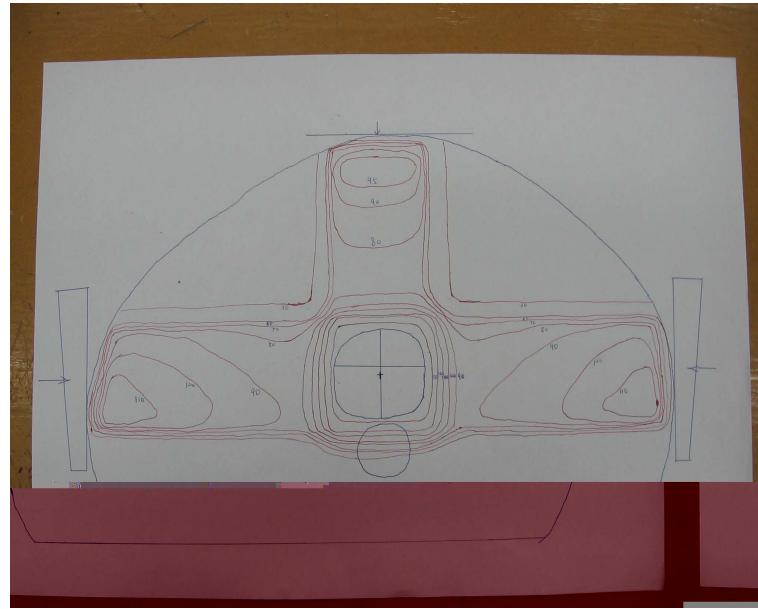


Figure 5: The final dose distribution of three-field prostate treatment.

The treatment during per application is:

$$\text{Anterior field : } T_A = \frac{1.54\text{Gy}}{0.98\text{Gy/min}} = 1.57\text{minitues.} \quad (\text{A.1})$$

$$\text{Anterior field : } T_L = \frac{3.48\text{Gy}}{0.98\text{Gy/min} * 0.97} = 3.66\text{minitues.} \quad (\text{A.2})$$

Similarly, the total dose to the rectum is:

$$D_{rectum} = 60\text{Gy} \times 30/130 = 13\text{Gy} \quad (\text{A.3})$$

3 Comparison between manual, simulator-based and CT-based planning

With the rapid development of techniques of computer hardware and software, the treatment planning evolved from manual planning to simulator-based planning to CT-simulator based planning. However, the goal and procedure are exactly same for three techniques. It is very interesting to compare the main difference between three treatment planning technique for each step.

Visualization

To visualize the location and extent of tumor and critical organs, manual planning mainly uses the x-ray radiograph before 1970s. The simulator-based planning are based on the x-ray imaging along CT,MRI and altrasound as reference, whereas the CT-based planing on the CT that may directly registrar with MRI or altrasound.

Localization

To localize the tumor and other tissues for simulation, manual use mechanical device to get patient contour and internal anatomy was estimated from anatomy atlas or x-ray image. For simulator-based planning, tumor localization and contour is accomplished using orthogonal images by digitizing the image into computer planning system. CT-simulator planning localize the tumor and contour directly from CT image at same time.

Simulation

In manual planning, the beam orientation and field size are determined with reference to the patient contour and internal organs drawn on paper. The beam simulation is done simulator when patient lies on the table using a variety of technique such as field-size defining wire and optical light,reticle and marks on the patient skin. In CT-simulator technique, the beam placement is done after patient scanned. The CT images is used to form a virtual patient. Then the beams is placed on the virtual patient with the aid of DRR, beam-eye view and virtual fluoroscopy.

Dose calculation and optimization

The dose calculation starts from the manual addition of isodose chart in manual planning to algorithm based dose calculation, eg. the Clarkson algorithm, electron pencil beam algorithm and photon superposition algorithm. The optimization techniques are, for example, the inverse planning(eg. IMRT), dose-volume histogram(DVH), beam-eye's view.

Verification

Except the traditional technique such as in vivo dosimetry, many new techniques were developed. These include on-board imaging system, flat panel imaging system,Tomotherapy

and imaging-guided radiotherapy.

4 Summary

A treatment planning is manually planed for a prostate patient treated with three field. The manual planning, simulator-based planing and CT simulator based planning are compared side by side for each step involving in radiotherapy treatment planning.

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Six-month training in treatment planning using a modified RT training package

Abstract. To gain the practical experience and skills of planing a treatment for a real patient, a systematic training in treatment planning was done over a six-month period. The training started with going through the planing procedure with a Rando phantom, then the quality control of individual patient plan. In the rest of training period, the treatment plan for real patients were repeatedly performed for different tumor sites. At the end of training, I am be able to create a clinically acceptable treatment planning for a typical tumor site.

Period: 09/2007-02/2008

1 Motivation

Planing a treatment for an individual patients is not the routine job of physicist but the radiation therapist. However, the physicist registrar should have planning experiences, which is not only required by the TEAP training syllabus but also, more importantly, by the job of physicist, eg checking the real patient plans in special situation and giving consultant advice to RTs, involving in the clinical trial. Having extensive experiences of treatment planning is not only very helpful for these physicist's job but also valuable for the physicist routine job.

In my opinion, a medical physicist or physics registrar should be able to do planning

for the real patients and not just commissioning, testing and QAing it. **Preparing the physics registrar to have practical experience of doing planing for real patients is the motivation of this training .** The training was done using a training package used for training RTs over about half year and supervised by a RT, who is the tutor for training the RT students.

2 Modified training package for physics registrar

Training package for patient treatment planing was established based on a number of years of clinical training experience. This package was designed to train RT staffs and RT students, who want to work as a treatment planner.

Considering I am training to a physicist, the training package was slightly modified. The core of training package is divided into several components: the competencies achieved after training, skillful performance of a typical treatment planning process, quality assurance of planning procedure and individual patient plan, a series of must-done practices.

2.1 Competencies to be achieved

After going through the training packages, the following tasks should be able to perform with no assistance:

- Understand and demonstrate workflow of typical treatment planning procedure
- Understand and use the quality check list correctly
- Scann the Rando phantom using a proper clinical scanning protocol based on the different scanning body parts and place CT marks on the phantom skin
- Transfer CT image to and between RT archive, dosimetrist, CMS Xio, the practical Lantis
- Contour RT structures on Coherence dosimetrist, a virtual simulation software
- Place fields using the dosimetrist
- Perform virtual simulation
- Perform a variety of palliative patients

- Plan a radical prostate patient
- Plan a radical pelvis patient either volume or Vsim
- Perform a simple radical thorax or brain patient
- Perform an electron calculation and plan
- Perform an initial plan check on all of above patients including dose check, a independent MU check program and Lantis
- Perform a second check on palliative plans

2.2 Workflow of planning a treatment

To achieve the listed competencies, physics registrar or RTs must understand the procedure of planning a treatment. **The trainee must also skillfully operate and use the hardware and software involving in each step of planning a treatment from the beginning to the end.**

The workflow used in Palmerston North Hospital was demonstrated in Fig. The whole procedure is seamlessly networked and digitized. At each step, the tasks are performed based on the graphic workstation and specialized software.

A typical planning procedure is:

Scanning patient: Setup patient and scan patient using CT simulator scanner and its software CT-navigator, a CT image browser and manipulation tool. Scanning of patient follows well-established clinical protocol depending on the site of tumor.

Mark the patient: Once the patient is scanned, the CT images are automatically sent to a dosimetrist 4. A dosimetrist is essentially a Siemens-made virtual simulation software and graphic workstation. Different dosimetrists sit on different rooms.

The dosimetrist 4 is in CT room and linked to the laser control system to mark patient. Marking patient is essentially to establish the origin of patient coordinate system, which is not only used for virtual simulation and dose calculation but also for the patient setup on linac couch.

Archive the DICOM patient RTarchive is just a patient archive and communication system with larger storage capacity, where the DICOM patient(DICOM images,DICOM plan, DICOM dose and DICOM RT objects) is stored.

Contour and define volumes The archived patient is sent to dosimetrist 1, 2, or 3 for virtual simulation. After virtual simulation, then DICOM patient is sent back to RT archive.

Dose calculation and optimization On CMS Xio treatment planning system, the virtually simulated patient is retrieved. The 3D dose distribution is calculated and the treatment plan is optimized. Once the the final plan is approved by the head of planning and oncologist, it is exported to Lantis, a R & V system.

Dose delivery the patient plan is retrieved from Lantis. The lantis communicates with the Linac control and deliver the planned dose to the patient.

I went through the whole procedure using Rando phantom for different tumor sites under the supervision of clinical planning tutor. It took one and half months. At the end of first stage of training, I am be able to skillfully perform the tasks at each step without supervision.

The rest of training focused on practising the virtual simulation and plan optimization for different tumor sites.

2.3 Quality control of treatment planing

Quality control of treatment planning procedure and individual patient is an important part of planning activity, which should be implemented as required by AAPM and IAEA [1, 2]. The purpose of quality assurance program is to make sure each step in treatment planing procedure is correct and accurate, eg. independent check of MU for each patient plan, therefore minimizing the human error and other mistakes.

This quality control program is usually done by RTs. Another type of quality control program is checking the equipment and software and usually performed by physicist,eg. quality assurance of linac and TPS. As part of treatment planning training, I did double check for the treatment plan for several patients.

The basic principle and idea of clinical quality control of treatment planning is to use the well-designed form and double check. The checklist for each patient plan is listed in appendix. The items to be checked fall into 9 categories: Teletherapy source, isodose treatment plan, calculation information, setup reference definition, Lantis, viewstation, complete CT form, complete QCL, A3 pages which are printed from treatment planning system, Dosechek, an independent MU check program.

The checklist is essential to check the key parameters at each step for creating individual patient treatment plan. For example, for checking calculation information, you have to check CT-ED conversion files, CT model=Emotion 6, Calculation mode=volume, heterogeneity=pixel(or blank if heterogeneity off), grid box size & spacing. These parameters are directly influencing the accuracy of dose calculation, thus the quality of treatment. These parameters have to be checked by a second person. The complete list of parameters that have to be checked are shown in appendix.

3 CMS XIO workstation and staff training database

Each clinically used CMS XIO workstation has a staff training database. There are a number of sites and plans saved in this database. They are carefully chosen from the patient treated in the past to represent a variety of clinical situation. The idea is to plan a site that you have not seen clinically or that you want to practice, and then compare it to the one already saved.

For each site, there is information about how to approach it and what techniques to try. At end the plan made by physics registrar, RT students are viewed and discussed with the planning clinical tutor. The plan can be printed if desired, otherwise it should be deleted. A list of patients used for training physics registrar is listed in appendix. This list is modified to suitable for training physics registrar.

4 Training results

Supervisor's comments on training results

Each patient in the training database had been practiced, some of which were planned several times from time to time to gain more practical skills for planning a treatment. At the end of training, planning supervisor's overall comments are:

“ Through the training, Aitang gained good practical experience and skill for planning a treatment. He is able to plan a clinically acceptable treatment for a typical tumor site. ”

5 Summary

Over the period of four months, I was trained to do the treatment planning from the beginning to the end of planning process. The training was supervised under a RT, who is the clinical tutor for RT students.

Bibliography

- [1] B. Fraass, K. Doppke, G. Kutcher, G. Starkschall, R. Stern, J. V. Dyke. American Association of physics in medicine radiation therapy Committee Task 53: Quality assurance for clinical radiotherapy treatment planning. Med. Phys. 25(10), 1773(1998).
- [2] International Atomic Energy Agency, Commissioning and quality assurance of computerized planning systems for radiation treatment of cancer, Technical Report Series No. 430, IAEA, Vienna, 2004

Appendix

A. A modified XIO staff training database for physics registrar

PROSTATE

LQY7769 Prostate PH1 56Gy in 28#, PH2 18Gy in 9#

- Two phase prostate with seminal vesicles included in PH1
- Can be planned with IMRT or 3D
- If IMRT plan completed, compare PTV coverage and critical structure doses
- Finally compare the plans with the actual treatment one and discuss differences with clinical planning tutor

PELVIS

DMB6297 Rectum PH1 45Gy in 25#, PH2,5.4Gy in 3#

- Volumed PH1 and PH2 5.4Gy in 3#
- Plan PH1 with a 4 field brick plan

- Replan and add oblique to get the 95% isodose to conform to the PTV
- Plan PH2 with the standard 5-field arrangement
- Compare the composite plans looking at HOF, bladder and small bowel dose

BREST

LBV1323 Left Breast 50Gy in 25#, Boost 10Gy in 5#

- Average left sided breast patient
- Create the tangents on the Dosimetrist and import the DICOM plan into teletherapy
- Complete the plan and then add the boost. Use electrons and create an appropriate reference, and recreate the field on the dosimetrist.
- Compare the plan with the actual treatment one and discuss the differences with the tutor.

CHEST

BXS2143 Chest 64Gy in 32#

- It is mediastinum and right lung
- Plan this for LA1 using either 6X or 15X
- V20 needs to be below 30% for lung and cord dose below 45Gy
- Finally compare the plan with the actual treatment one and discuss the differences with the clinical tutor.

ABDOMEN

MVX1141 Para-aortic and inguinal nodes 20Gy in 10#

- This is a right sided seminoma
- Plan with POP using LA1
- Aim for 95% coverage of the field, with as little high dose as possible in critical structures
- Discuss final plan with a clinical tutor.

BRAIN

ESU2002 Glioblastoma right temporal lobe Ph1 46Gy in 23#, and Ph2 14Gy in 7#

- Plan this for LA1 using 6X AND 15X
- Dose aims for the lens less than 4Gy, and less than 50Gy for the optic chiasm
- If brain stem and rt optic nerve dose is high, replan

HEAD AND NECK

CDR7435 lt Tonsil with concomitant boost PTV2 60Gy in 30#, PTV1 66Gy in 33#

- This is to be planned using LA2 and 4X
- It is a single sided head and neck, upper and lower, with a superior concomitant boost
- Try and avoid beam through the lips, exit through the parotid and watch the distance between the 45Gy isodose and the cord. Also ensure that rt lens dose remain 2Gy
- Compare the final plan with the actual treatment one and discuss the difference with planning tutor.

B.Quality control checklist

Teletherapy sources:

- Doc number same on all pages
- Patient details correct
- Beam name describes the gantry angle
- Correct machineenergy
- Isocentre=CT marks?=beam iso?
- Correct algorithm
- Number of #s=check Rx and pt schedule

- Reference beam-no dose
- Tray factorcouch factor, or couch contoured(radical only)
- MU rounded
- Calculate actual dose

Isodose treatment plan:

- Patient orientation and doctor
- Calculate TTH(Table top hight), check marker printout, write on iso slice

Calculation information:

- CT-ED conversion file, CT model=Emotion 6
- Calculation mode=volume
- Heterogeneity=pixel(or blank if heterogeneity off)
- Grid box size & spacing

Setup reference definition:

- Correct isocenter
- Highlight if shifts

Printed A3 pages from Xio:

- Isocenter slice, weight point slice, and sagittal slice orientation.
- Calculation information & label global max, CSM, 100% and 94%
- plan approval
- calculation information, scale=0.5
- Calculation OAWF(off-axis wedge factor) and /or inhomogeneities

Dose check and the printout from dose check:

- Patient details, RTP file, dose check version, R_x , weight fan SSD
- Equivalent square(LA2-blocked)

- OAWF(if applicable)
- Skin depth
- Traycouch factor
- inhomogeneities(if applicable)
- MU within tolerance(5%), daily dose

Lantis:

- Correct machine
- Tolerance talbe
- Beam parameters
- Check x jaw rounding
- LA1LA3 ports-MU delta
- Wedge, bolus, shielding
- Hide old fields phase 2
- Field notes: total=prescribed dose
- Import Lantis images and associate assessments-DVH, shifts, in vivo
- Check R_x approved, appropriate name and print

Beam view station:

- Check the document number and associate DRRs
- Check reference beams same as the dosimetrist & Xio
- Print representative field & attach to R_x

Check if the CT form is complete and sign on it
Complete the QCL form and sign on it

Experience of modeling photon beam from Siemens Artiste linear accelerator on student CMS XIO workstation

Abstract. To gain the practical experience and feeling of beam modeling, beam models for photon beam from Siemens Artiste linear accelerator were established on student CMS XIO workstation which is used to train physics registrar and RT students. The raw commissioning data of Artiste Linac were first transferred to the workstation using the XIO provided utility. Before doing beam modeling, the first important things is to understand the beam mode and model parameters as well as the physics behind them,especially their role and effect of changing each parameters on the dose profiles. The model parameters can be categorized into energy-spectrum related parameters and angular-spectrum related parameters. The energy-related parameters are central-axis and off-axis energy spectrum. Energy spectrum determines PDDs and therefore were obtained by fitting the calculated PDDs with measured ones. The angular spectrum determines the profiles. The parameters related to the angular spectrum are depth of incident lateral fluence, beam edge sigma for MLC, collimator and block, the focal and extra focal source sigma and the transmission factor for MLC, block and collimator. These parameters determines three regions of profiles: in-field region, penumbra region and out-of-field region, respectively. From my experience, beam modeling is not difficult but just an iterative process of experimenting and try-error. Although the beam modeling was done with CMS XIO, beam modeling in

other TPS are essentially same with a slight difference. The experience and skill gained here can be directly applied to do beam modeling in other TPSs.

Period: 12/2008-01/2009

1 What is beam modeling ?

Modern radiotherapy treatment planning system (TPS) uses the physics-based beam model to simulate the transport of photon and electron within treatment head and patient.

From the point view of physics and mathematics, the beam model is a mathematical function, whose input variables are patient data, plan data, and initialization parameters. The output of beam model function is 3D dose array (dose cubic). Therefore beam model can be expressed as:

$$D_p(\vec{r}) = f(x_{\text{patient}}, x_{\text{plan}}, x_0) \quad (\text{A.1})$$

where $D_p(\vec{r})$ is the dose array expressed in patient coordinate system (patient space). x_{patient} and x_{plan} are the patient and plan data. x_0 is array of the initialization parameters.

Equation 1 incorporates the general physics process. Therefore the beam model built into TPS is a general model in a sense that it can be applied to the photon beams from a variety of linear accelerators. To make the model works for a specific photon beam, the beam model provides initial input parameters. The role of these parameter are to initialize the beam model and make it simulate a specific beam in terms of physics process and specific beam characteristics.

Commissioning a beam model is to determine initialization parameters from a restricted beam data, ensuring that these parameters accurately fit measured data for other field sizes and demonstrating the reasonable parameter trends as functions of field size.

Beam commissioning is one of important clinical experiences the medical physics registrar should have. **This reports describes the experience and understanding of beam modeling for Siemens Artiste linear accelerator on a student workstation, which is used to train physics registrar and RT students.**

2 Beam modeling methodology and process

2.1 Beam model used in CMS XIO

2.1.1 Mathematical formula

The dose calculation algorithm used in CMS XIO is convolution algorithm. The absorbed dose at a point r , $D(r)$, is expressed as convolution of total energy released at point per unit mass, $T(r')$, with a convolution kernel $K(r, r - r')$ as follows:

$$D(r) = \int_V T(r') K(r, r - r') d^3r' \quad (\text{A.2})$$

where the Terma and polyenergetic kernel are:

$$T(r') = \int_E \frac{d\psi(r', E)}{dE} \frac{\mu}{\rho}(r', E) dE \quad (\text{A.3})$$

$$\bar{K}(r) = \int_E K(r - r', E) \frac{d\psi(r', E)}{dE} dE \quad (\text{A.4})$$

2.1.2 Implementation requirements

As seen from equation A.3 and A.4, to implement the convolution-based dose calculation algorithm, the following parameters are required:

- Energy spectrum at central axis and off-axis
- Angular spectrum (In-air photon fluence at isocenter plane)
- Electron-dose model

Energy spectrum

In CMS XIO and other modern TPS, the photon energy spectrum is represented by a set of relative photon fluence values at 15-20 discrete energies called energy bin.

The relative spectral weight can be varied and modified by the physicist to fit the calculated PDD to the measured PDD for a specific linear accelerator.

Angular spectrum

In order to calculate the TERM at an arbitrary point in patient, the angular spectrum must be known for a specific linear accelerator. The angular spectrum determines the off-axis dose profile at any plane perpendicular to the beam axis.

Once in-air photon fluence at isocenter plane is known, the photon fluence at any point in patient can simply be calculated through primary-ray tracing.

To establish the in-air fluence across the field, modern TPS systems usually uses several analytical mathematical models to simulate in-field, penumbra region and out-of-field region of the profile. Several submodels with variable parameters are often used to model the in-air photon fluence. These parameters for a specific are obtained by comparing the calculated and measured profiles.

Electron-dose model and parameters

The electron-dose due to the contaminated electrons can only be modeled separately from the photon beam model. In most case, an empirical model with one or more adjustable parameters is used to get simulate the electron dose at shallow depth of PDD and profiles.

2.2 Understanding the role and physics behind each model parameter

Before modeling the beam using the linac commissioning data, the most important things is to understand the effect of adjusting the beam model parameters on the profile and Pdds. This can be achieved by reading the related manuals provided by the CMS XIO and changing these parameters to observe their dosimetric influences at the beginning of beam modeling.

The role and effect of each model parameter is briefly described in below:

1. Energy spectrum

- Relative spectral weight:**

—Effect: An increase in the spectral weight of the higher energy components increases the central-axis depth dose at larger depths and decreases the depth dose at shallower depths.

—Range and magnitude: varying the the spectral weight of highest energy bin as little 0.001 will have a noticeable effect on the central-axis depth dose. Different values of spectral weights for the two or three highest energy components are likely to be required for each field size.

2. Angular spectrum

- **Depth of incidental lateral fluence-diagonal profile:**

- Nature: This is an in-field parameter of incident-fluence model
 - Effect: Shallow depth will have a more marked shape(more pronounced horn) than deeper depths, but may contain obvious electron contamination.
 - Range and magnitude: A good starting value is d_{max} for this energy. This depth is then adjusted in very small increment to achieve the best fit for shallow profile depth across primary portion of the beam for large open fields.

- **Penumbra focal radiation sigma:**

- Nature: This is a penumbra region parameter of in-air fluence model. This parameter is used to convolve the incident fluence distribution with various Gaussian function to mimic penumbra effects. It takes into account the geometric parameters of primary beam and source size.
 - Effect: Larger values produce narrower profile with more sloped penumbra, while smaller values produce squared cornered profiles with steep penumbra.
 - Range and magnitude: A good start value is 0.15. For IMRT beam, the value is not larger than 0.2 because it will adversely effect the MU calculation of very small field.

- **Extra focal radiation sigma:**

- Nature: This is a penumbra region parameter of in-air fluence model. This parameter is used to convolve an initial fluence distribution which will be scaled using the head scatter to primary ratio added to the incident fluence to model extra-focal fluence distribution.
 - Effect: Changing this value will have very small change on the field penumbra. You will have to get a magnifying glass and use your imagination to if you want to detect the very subtle change outside the field edge as the value varies from 1 to 25. The good starting value is 8.

- **Fractional transmission(collimator and MLC:)**

- Nature: This is an out-of-field parameter of influence model, which control the dose profile outside the field and under the MLC and collimator.
 - Effect: Calculated transmission is proportional to the direction of parameter change. This value can be determined using on-screen calculation for a small open field($3\times$ or 5×5) at a distance several cm outside the field edge.
 - Range and magnitude: The typical range of this parameter is 0.01-0.02. In-

correctly scanned profiles(eg. inappropriate electrometer, gain setting) can lead to erroneous conclusions. It is better to use measured value for conventional radiotherapy and use the in-air measurement for IMRT beam model.

- **Off-axis spectrum:**

—Nature: This is angular spectrum parameter but taking into account the off-axis softening of energy spectrum. It is used to adjust the disagreement between calculated and measured maximum diagonal profiles at deeper depth. This is because the beam softening effect is much more pronounced at larger depths.

—Effect: Assuming the PDD matches at all depths and d_{max} profiles show a acceptable agreement, then increasing the averaged energy of off-axis spectrum can improve the agreement between measured and calculated profiles at deeper depths.

—Range and magnitude: XIO models the energy spectrum softening within ± 12.5 cm from the central axis. Beyond 12.5 cm, there is only CAX spectrum. In general the, Off-axis energy spectrum should have a lower average energy than CAX spectra. The range of typical ratio is between 89%-97%.

- **Electron-dose model:**

—Nature: This is the electron dose model used by CMS XIO. The modeled electron dose is really only the difference between the calculated photon component of the PDD the measured PDD. Therefore the artifacts or inconsistency in the measurement of PDD can be seen from the graphic representation of electron only component.

—Effect: If the electron dose is significantly high, you can reduce the resultant electron contamination by either increasing the low-energy bin weight or decreasing high-energy bin weight. You also may adjust the energy spectrum after reviewing more open and wedged fields.

—Range and magnitude: CMS XIO provides a table for referenced percentage of contaminated electron dose at d_{max} . The fitted electron dose at d_{max} should be within 1% of the given value in table.

Once understanding the role and the physics behind each beam model parameters,

you will find modeling a beam is much more easy and enjoyable not a boring iterative process of try-adjust-error. For example, the energy spectrum primary effects the central axis profile. Because the calculated depth doses are normalized to fit the measured dose at fixed depth, usually taken to be 10 cm, making beam harder by increasing the relative weights of the high-energy bins increases the dose at large depths and decreases the dose at shallow depths. Softening the beam has the opposite effect on the central axis dose profile, decreasing the dose at large depths and increasing it at shallow depths.

Moreover, because the normalization is at 10 cm, only high energy bin of spectrum appear to have an observable effect on the depth dose profiles. Therefore, if the calculated depth dose are larger than the measured values at large depths, one should soften beam by reducing the spectral weights of only the two or three highest energy components.

2.3 Setting the criteria for the beam modeling

The calculated dose profiles or distribution in patient or phantom can not be exactly same as those delivered by real linac for the following reasons:(1) The beam model only can approximate physic process because the limitation of the model. Moreover, to make the algorithm work clinically and speed up the calculation, several approximations are often adopted. (2)The beam model is established based on a limited set of beam data under limited range of conditions.(3)The characteristics and output of the beam from a real linac is always changing although controlled within 1% or 2% by comprehensive quality control program.

Therefore, the second important thing is to set a clinically meaningful and realistic goal for beam modeling based on the clinical need and situation in a specific centre, the treatment technique used and the recommendation by international protocols such as those published by AAPM TG 56 [1] and IAEA TRS 432 [2].

In our department, most patients were treated with 3D-CRT or IMRT technique. The goal for the new machine beam modeling was to generate photon beam models that reproduce the measured central-axis depth doses and off-axis profiles over a wide range of field size and wedges within the limits of certain criteria. The criteria were set as the followings:

1. Central axis depth dose reproduced to within 0.5% for depth between d_{max} and 20 cm.

2. Central axis depth dose reproduced to within 1% for depths greater than 20 cm.
3. Central axis depth dose reproduced to within 5% for depths less than d_{max} .
4. Off-axis profiles in low-dose-gradient region within the beam (in-field region) reproduced within 2.0% of the central axis value for the depth less than 30 cm.
5. Off-axis profiles in the low-dose-gradient region within the beam (in-field region) reproduced within 5% of the central axis value for the depth greater than 30 cm.
6. Off-axis profiles in the high-dose-gradient region (penumbra region) reproduced within 2 mm of the measured value.

2.4 Beam modeling process

Beam modeling is an iterative process of try-error-modification. To learn how to do the beam modeling, the key is experimenting. Sometimes you just have to sit there modifying the parameters or photon fluence, one or two at same time, iterating, experimenting–learning. Here described are my understanding and experience but not the detailed operational procedure.

2.4.1 Determining the energy spectrum

The CMS XIO built in several default energy spectrum. One of them can be chosen as starting point. In my situation, I chose established energy spectrum for the Siemens Onco linear accelerator as a starting point. From my experience, the following point are suggested:

The energy spectrum modeling should be started by the following order:

1. Firstly evaluating the calculated PDD for a medium to heavy wedge(eg.45 or 60 degree) and for a small field size(eg. 4×4).

Pay much more attention to the dose at deeper depths(beyond 10 cm). If the calculated PDD is below the measured ones, increase the fluence for high-energy bin in the spectrum and try to keep the shape of spectra of generally smooth(nearly straight). Repeat calculation, and continue to modifying the spectra until the acceptable criteria is achieved.

2. Then after the wedge PDD shows an excellent agreement, calculate a small open field (eg. 4×4 and 5×5) and modify the very lowest energy bins to bring this field PDD

into similar agreement. you may find there is disagreement at or around d_{max} but disagreement at 10 cm depth. If the calculated PDD is greater than the measured, it means there is too much low energy in the beam. Reduce the fluence in 1st and 2nd bins only(the lowest MeVs). You also will see the average energy going up. Repeat it until the criteria set are satisfied. After that, recheck small wedged field.

3. Finally evaluate the PDD for large wedged field and continue modifying spectrum if necessary. Then also confirms the agreement for small and large open field by adjusting off-axis spectra, fitting wedge coordinates and tweaking electron contamination at last. These parameters are vital to the overall fit for large field size. Electron dose modeling in CMS XIO is really simple, just the difference between measured and calculated PDDs.

The key things to model energy spectrum is to determine the photon fluence in one or two highest energy bins first with small heavy wedged field, then the most lowest energy bin with small open field, finally adjusting the medium energy bins with medium and large field.

Small heavy wedged field filters lowest energy fluence so we can attain the general shape of spectrum by modifying high energy fluence with some independence. Similarly the small open field has relatively less electron contamination, which is good to be used to tune lowest energy bin of spectrum. For medium size field size, the calculated and measured PDD are mainly determined by a range of medium energy bins.

2.4.2 Optimizing the angular spectrum parameters

The angular spectrum directly determines the beam profile. Thus the beam model parameters are optimized using the measured inplane and crossplane profiles measured at different depths for a range of field size.

Depth of incident lateral fluence

The incident lateral fluence in air at isocenter plane is used to represent the angular spectrum of a photon beam exiting from linac head. This depth is only parameter of an empirical incident fluence model and determined by fitting the calculated diagonal profile with measured profile or interpolated profile from the measured profile at this depth.

The diagonal profile at d_{max} for the largest field is calculated first. Then if the calculated profile at d_{max} need to be flattened, use a deeper depth of incident fluence. For more horn, use some depth shallower. Usually 2 mm incremental change are effective. Notice that if the calculated profile just does not have the right shape, this indicates that some inconsistencies between the measured aligned diagonal profile scan data.

Other model parameters

To optimize other parameters related to angular spectrum, the similar principle and procedure is followed: choosing a good initial start value, then slightly increasing or decreasing this value until the calculated profile fits with the measured profile at all depths within the set criteria. The procedure is pretty simple and straight forward.

2.4.3 Wedge modeling

Modeling physical wedge is a slightly different process from the open-field modeling. As for the wedge modeling, here summarized are several points:

- Firstly make sure that the open fields are fit well first, which means energy spectrum and angular spectrum of open beam are determined first. Essentially the wedge modeling is to model the hardening and scattering of open beam, which are caused by the physical wedge. Therefore the difference between calculated and measured open beam profiles will transfer and manifest themselves in wedge profiles.
- Start the wedge fitting on the largest field size for a particular wedge. Look the overall fitting and difference in mind. Then edit the wedge coordinates in the direction that will provide improvement as required. The coordinate of wedge is defined in beam coordinate system so that editing the coordinates of wedges looks as if you are moving the physical wedge on the linac head so that the calculated and measured profiles agree within a given tolerance.
- Repeat the process until profile agreement is satisfactory. Review small fields (eg. 10×10 , 4×4). If necessary, modify the coordinates slightly for improvement for smaller fields. The coordinate pair can be inserted or deleted.

3 Beam modeling results

3.1 Virtual Artiste linac setup in CMS XIO and data entry

There are already two Siemens machine, Siemens Onco and Primus set up in XIO. Artiste machine geometry is same as these two Siemens machine except a few exception: couch rotation reversed on Artiste, Hard wedge height different(not commissioned) and MLC/X jaw completely different. Therefore as a starting point, the Artiste linac was setup by copying Siemens Onco setup with the little modifications: MLC type and jaw height was changed and couch angel reversed. Scan treatment aids and scatter factors were deleted.

Before transferring the data to the XIO workstation, the raw scanned data were processed a little bit. Surface points on PDDs were edited manually to give a smooth falloff in dose. Profiles were centred and then made symmetric (average of each side). All scans for transfer were saved with XiO in the filenames. The MLC edge scans were transferred to XiO as Crossline and the Y jaw edge scans transferred as Inline.

As an example, only modeling results for 6 MV are shown below here.

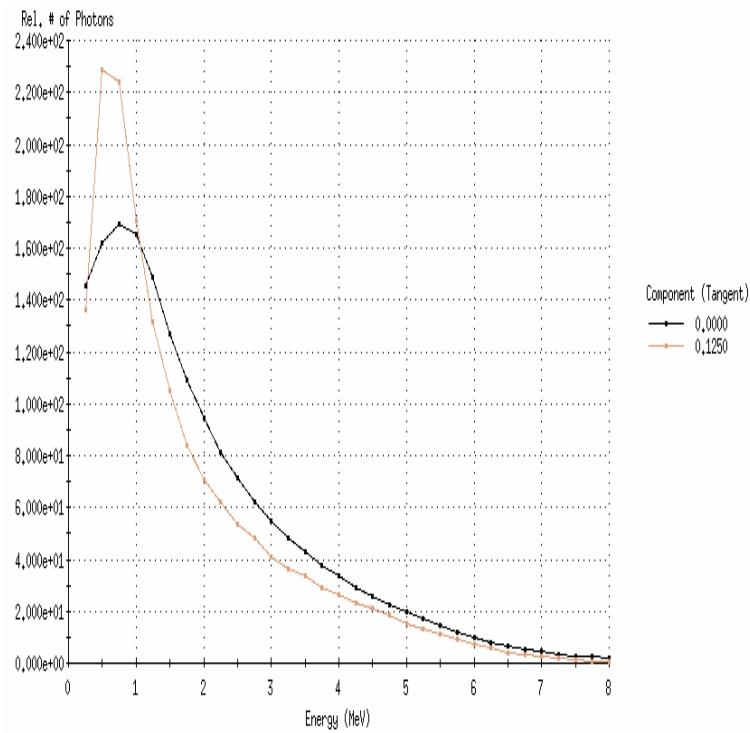
3.1.1 Energy spectrum

The default spectra 3d-06MV-Siemens-DSB-Rog-1-OffAxis 'was used as a starting point. This provided a good starting point. The PDD was low for all fields.

The spectra was adjusted until good agreement was found for the wedged and open beams for 3 to 30cm field sizes. Fluence depth was adjusted to 1cm to give good agreement in profiles at d_{max} , and off axis spectra adjusted to correct profiles at depth. After this the machine was validated and the 45 degree wedge profile(in non wedge direction) checked against measured scan.

Fig.1 shows the final central-axis and off-axis spectrum for 6 MV photon beam from Siemens Artiste linear accelerator.

Fig.2 presents the comparison of measured and calculated data. These results are typical fitting results. It is noticed that the poor fitting at depth beyond the depth of 32 cm for large field is caused by the limited kernel length of 32 cm. The kernel length used in CMS XIO is 32 cm. The calculated PDD beyond this depth is usually lower than the measured because of lack of enough back scatter from beam exit phantom surface. Fig.3. shows the typical fitted profiles for open and wedge field



Energy	Central Axis	Off Axis
0.25	145.5	136.2
0.5	162	228.5
0.75	169.1	224.1
1	165.1	170.6
1.25	149	131.4
1.5	127	105.4
1.75	109	84.03
2	94.6	70.94
2.25	81.5	62.32
2.5	71.1	53.7
2.75	62.4	48.08
3	54.9	41.31
3.25	48.1	36.64
3.5	43	33.47
3.75	38	29.21
4	33.6	26.68

Energy	Central Axis	Off Axis
4.25	29.4	23.29
4.5	26.1	21.28
4.75	22.8	18.57
5	19.9	15.49
5.25	17.1	13.4
5.5	14.6	11.28
5.75	12	8.997
6	9.65	7.174
6.25	7.661	5.714
6.5	6.326	4.21
6.75	5.161	3.265
7	4.43	2.4
7.25	3.523	1.759
7.5	2.875	1.257
7.75	2.345	0.9092
8	2.065	0.6059

Figure 1: The central-axis and off-axis energy spectrum for 6 MV photon beam from Siemens Artiste linear accelerator, which was determined by fitting the calculated PDD with measured PDDs.

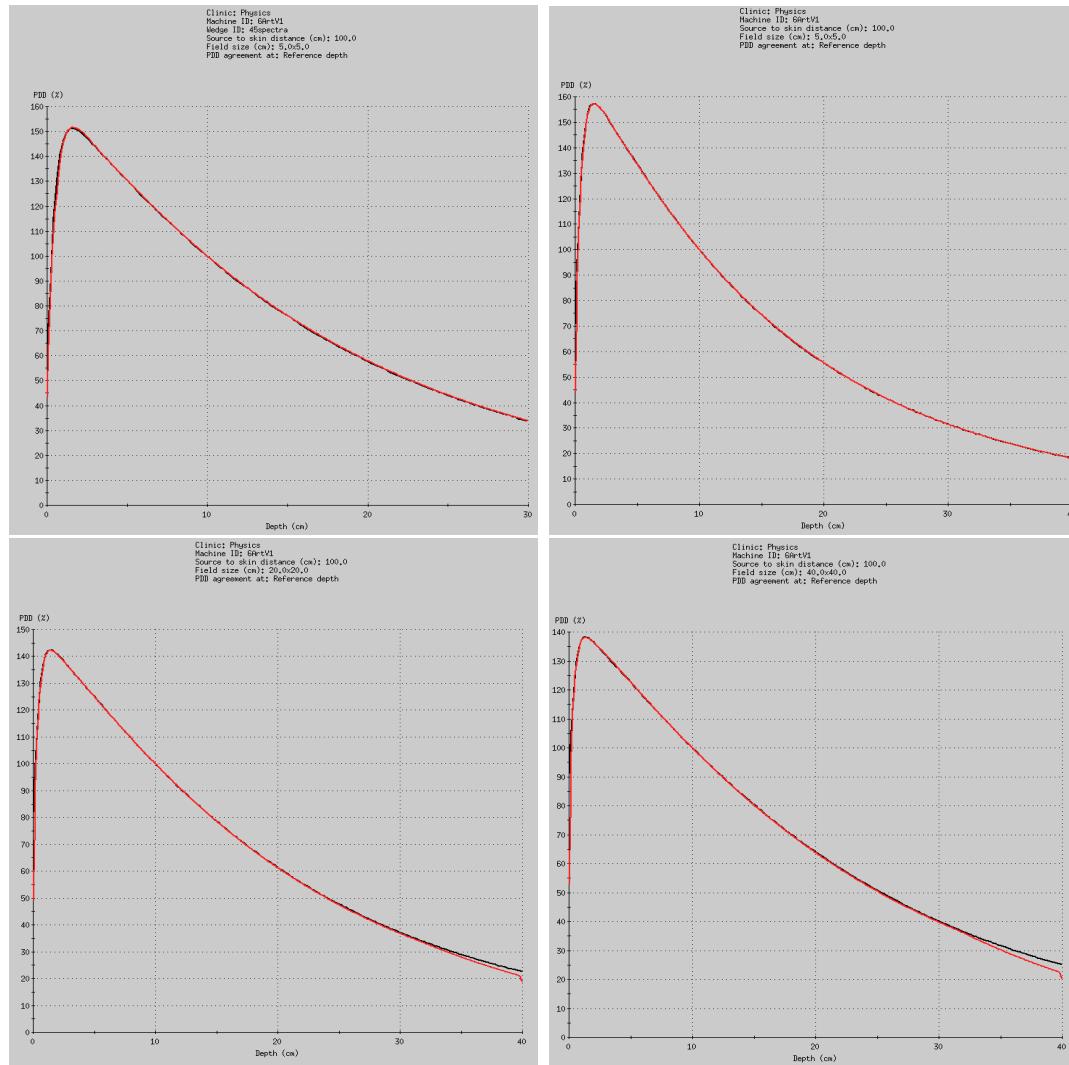


Figure 2: Comparison of calculated and measured PDDs for following field sizes:
Upper row: 5 cm×5 cm 45 degree wedge(left) and 5 cm×5 cm open field(right);
Down row: 20 cm×20 cm open field(left) and 40 cm×40 cm open field(right).

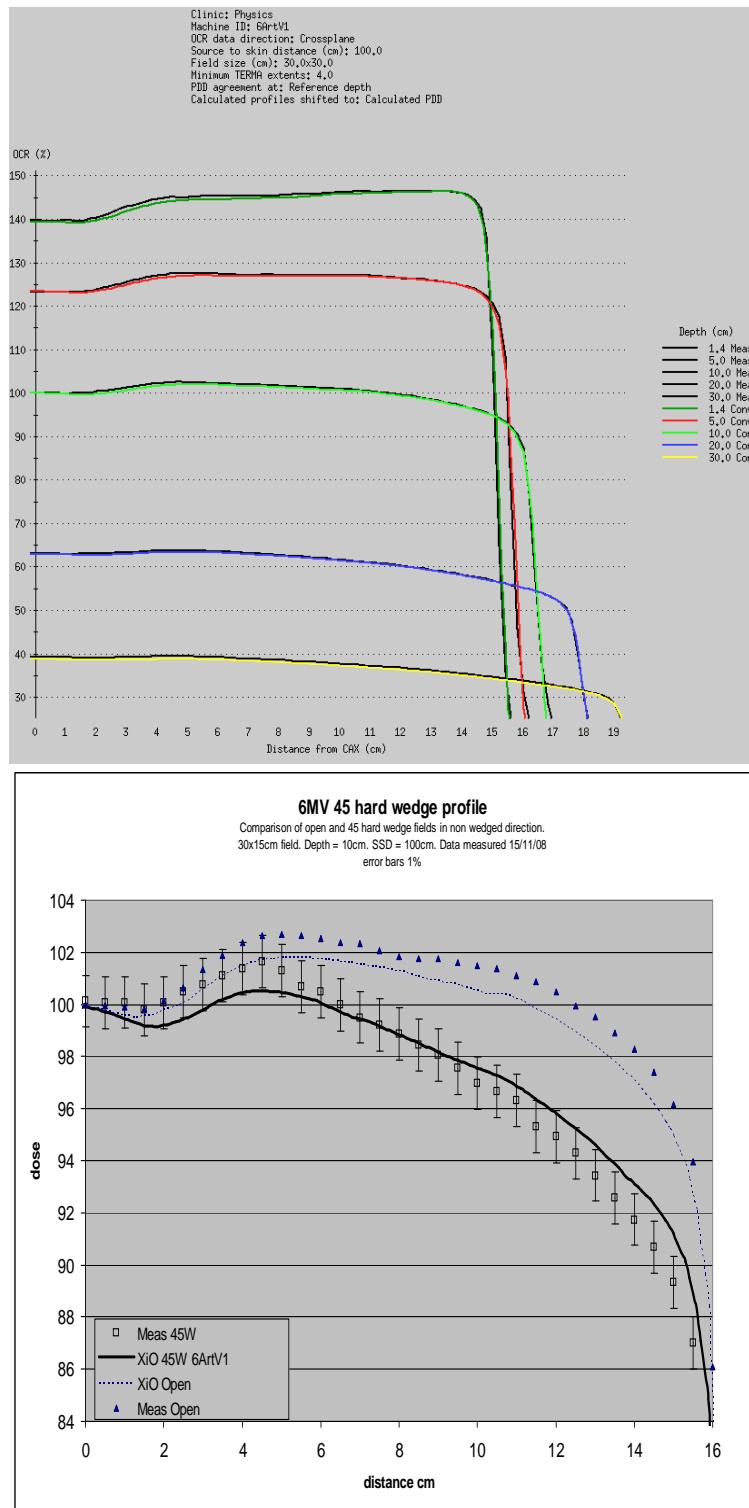


Figure 3: Typical fitted dose profile using the determined energy spectrum for open filed (upper)and 45 degree hard wedge field(lower).

3.1.2 Model parameters

Fig.4 shows the graphic user interface for entering the model parameters: depth of incident lateral fluence, the transmission sigma for MLC (x jaw), collimator (y jaw) and block. The MLC transmission is significantly lower than the Coll (Y jaws), being 1.8cm thicker at 9.5cm. Note the actual transmission is lower than these values but these work well with the XiO model. The Extra-Focal sigma was left at the CMS recommended value of 8.0. The sigma value for the Coll was determined using the beam modelling tools using inline scans. 0.09 was found to be a good fit over most field sizes and depths.

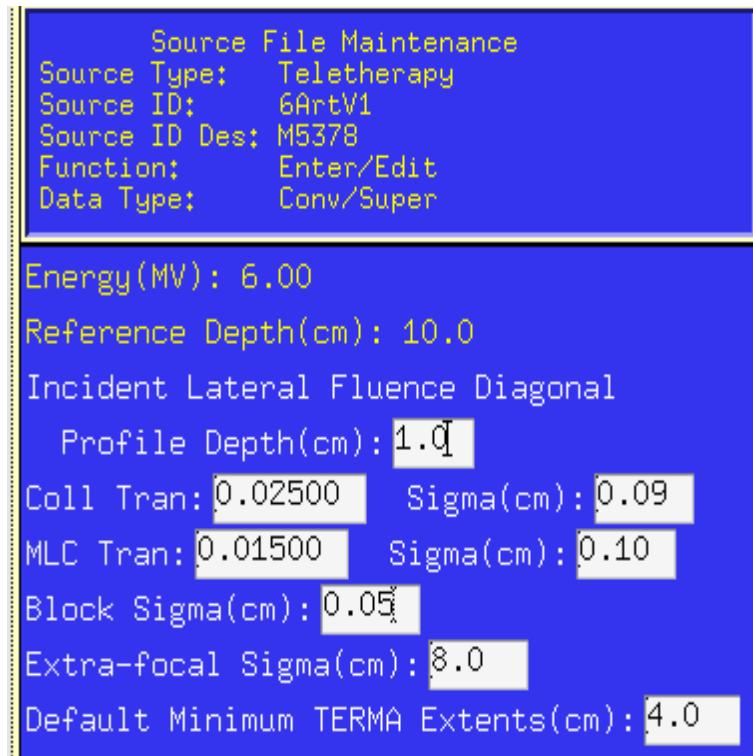


Figure 4: The finally determined beam-model parameters using the profiles at different depths for a range of field sizes.

The comparison of beam-edge profiles are presented in Fig.5-7. shows the comparison of calculated and measured beam edge profiles at 5 cm depth for collimator y for several field sizes. Similar comparison for block edge beam profiles are given in Fig. The beam edge profile comparison for MLC are also shown in Fig.

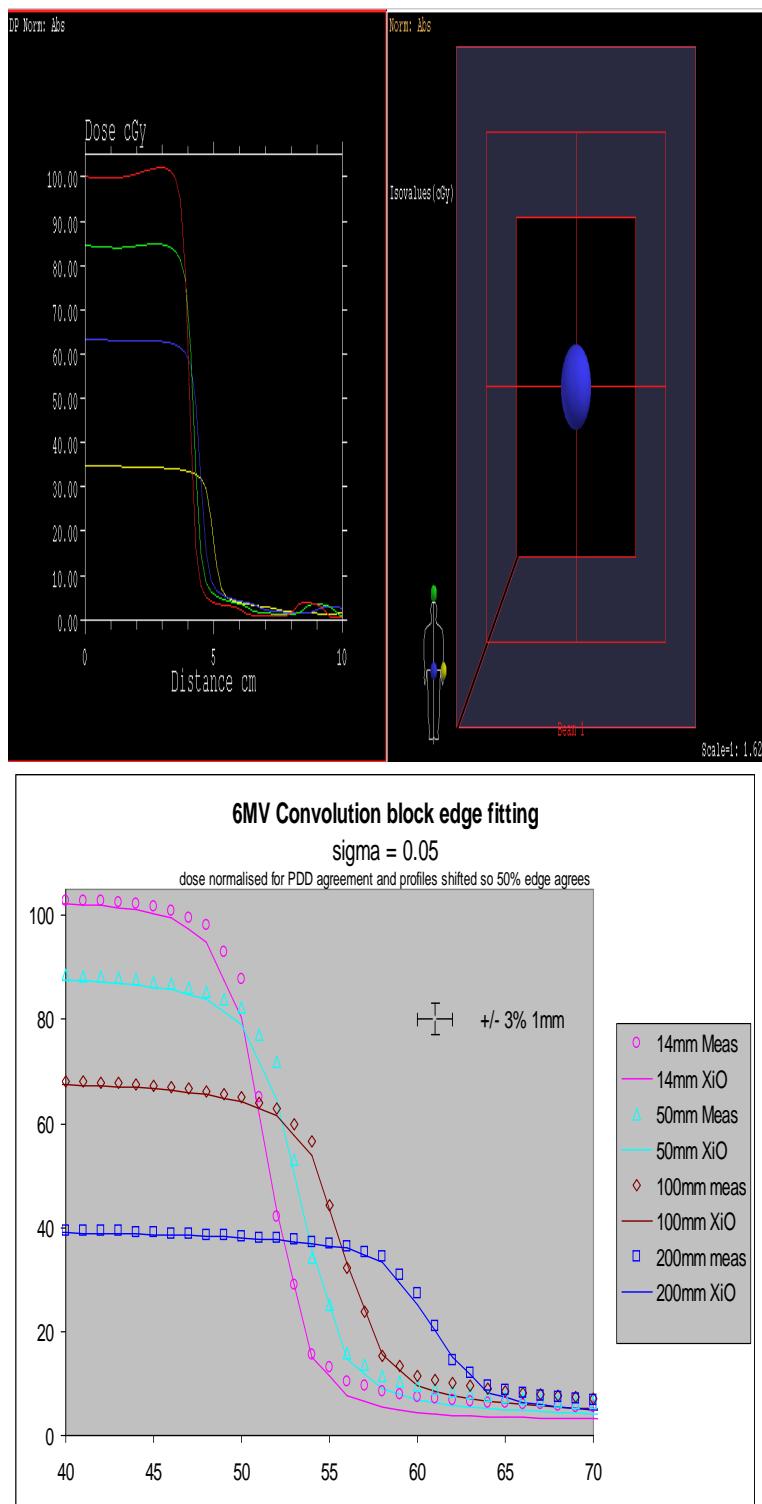


Figure 5: Comparison of calculated and measured block edge profiles.

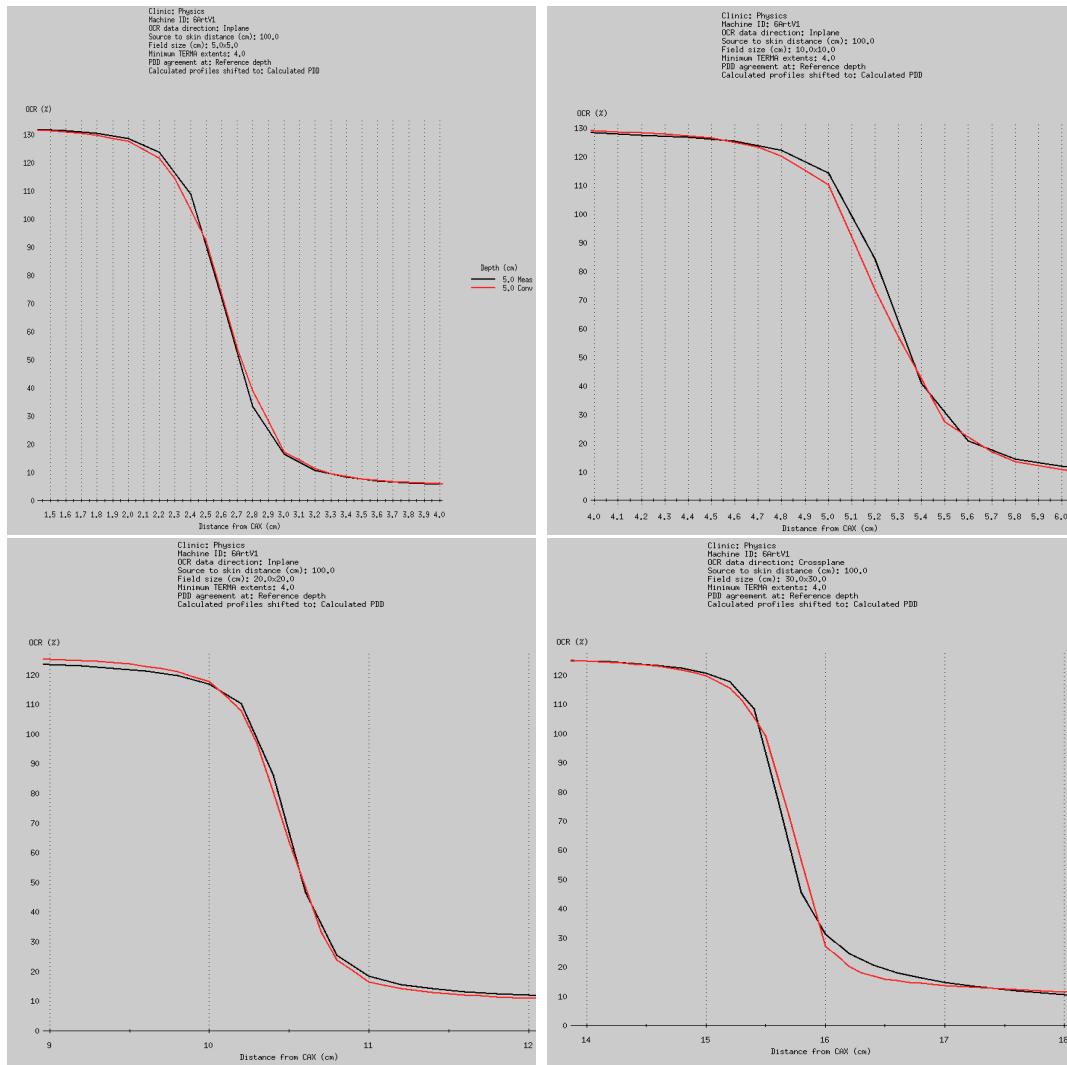


Figure 6: Comparison of calculated and measured y-jaw edge profiles for following field sizes of 5cm×5cm(upper left), 10cm×10cm(upper right), 20cm×20cm(lower left)and 40cm×40cm(lower right).

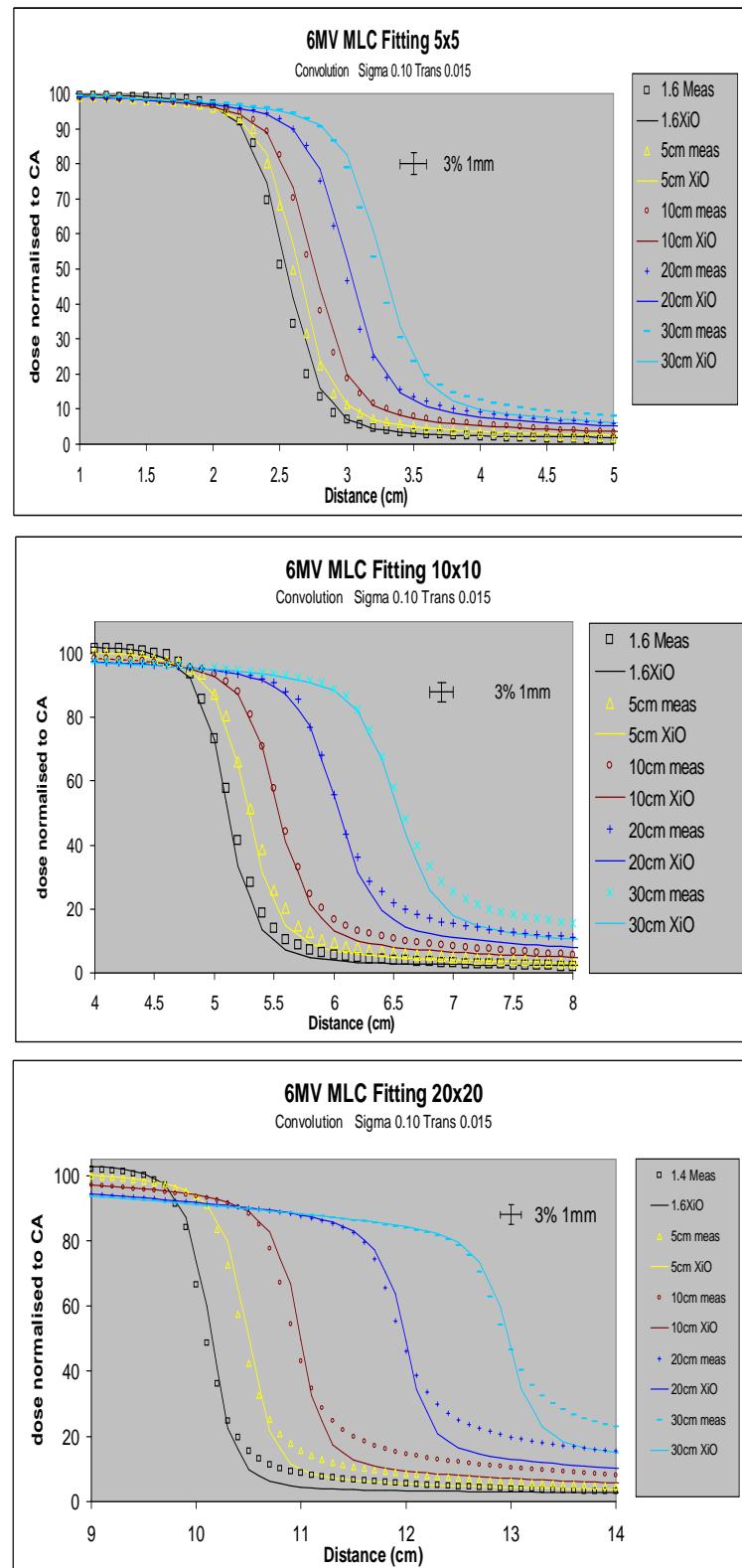


Figure 7: Comparison of calculated and measured MLC edge profiles for following field sizes of $5\text{cm} \times 5\text{cm}$ (upper), $10\text{cm} \times 10\text{cm}$ (middles) and $20\text{cm} \times 20\text{cm}$ (bottom).

3.1.3 Virtual wedge parameters

In CMS XIO, there are two adjustable model parameters related to Siemens virtual wedge: the mean linear attenuation coefficient and C. Changing the values of these two parameters has the similar effect on the wedge factor. The mean linear attenuation coefficient is set the same as on the linac. C was only the value altered. Note that on linac the attenuation is in unit of 1/mm not 1/cm so it is a factor of 10 smaller than on Xio.

Modeling the virtual wedge is relatively simple because it does not involve in the beam hardening and attenuation problem as physical wedge and is based on analytical expression. The virtual wedges were fitted by comparing with measured point doses on a 20cm field, 5cm either side of CA, at a depth of 10cm and an SSD of 90cm. 15, 30, 45 and 60 degree wedges were used. To minimize positioning and beam symmetry errors, measurements were taken for both wedge orientations and also with the collimator rotated 180 degrees.

The final determined virtual wedge parameters and the effect of C value on wedge factor are shown in Fig.8. It was found that C value of 0.99 gives good agreement ($\pm 0.3\%$) with the measured data for all four wedge angles, although the C value on Linac is 1.02.

4 Summary

As an important experience the medical physicist or physics registrar should have, the beam modeling was performed on a student training XIO workstation for new Siemens Artiste linac. The experience and understanding of beam modeling can be directly applied to other commercial TPSs.

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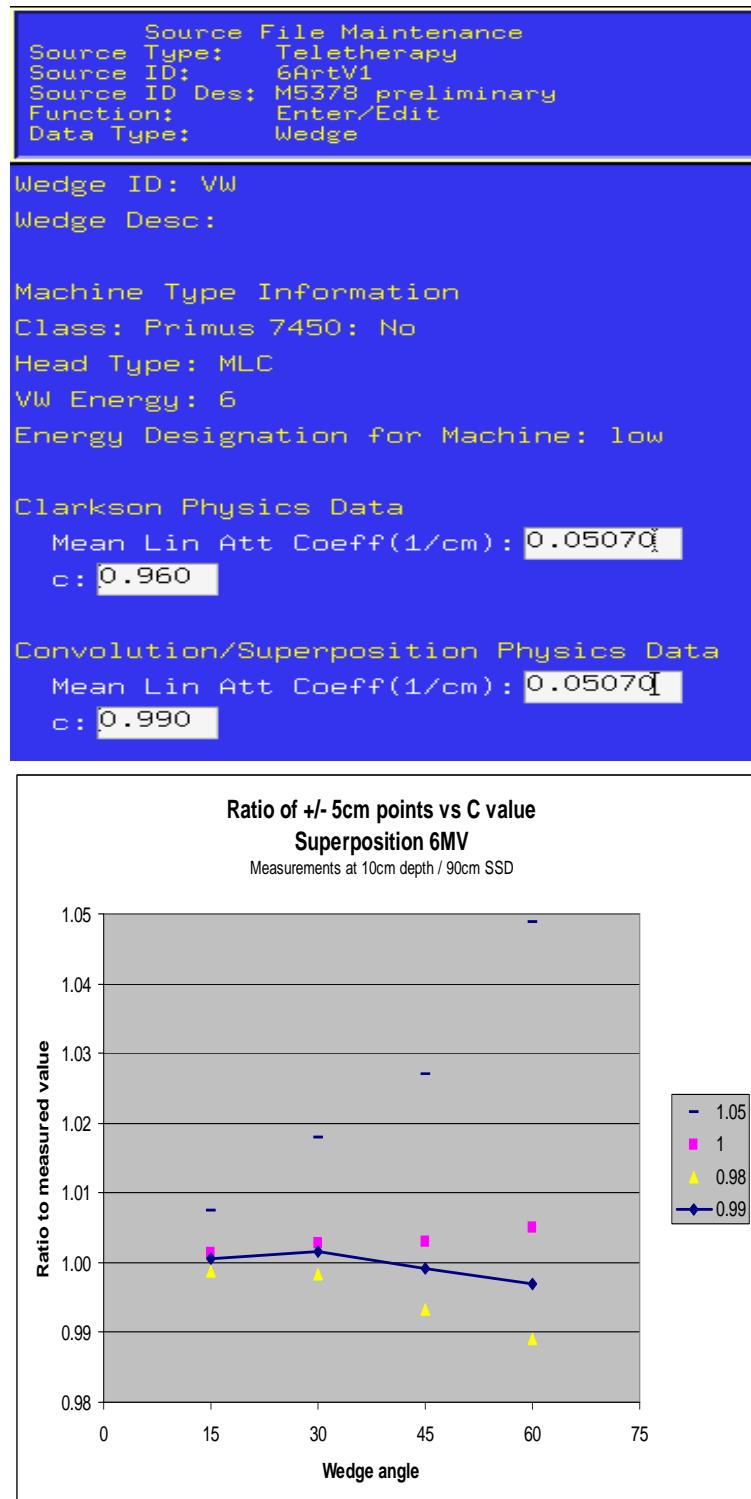


Figure 8: Upper: Wedge parameter entry GUI. Lower: Ratio of calculated dose to measured dose at off-axis of 5 cm for different C values.

Part VI

Clinical Rotation

Chapter 1

MODULE SUMMARY

Clinical rotation was done at the beginning of clinical training along with RT students, the following goals or experience was achieved:

1. Understanding of aim and role of radiotherapy in cancer treatment vs other modality.
2. Understanding of whole radiotherapy procedure from the beginning to end
3. Understanding and applying the academic knowledge of cancer disease and radiation oncology, tumor grading and staging.

Chapter 2

MODULE REPORTS

Roster along with RT students at the beginning of clinical training

Abstract. At beginning of my clinical training, I was roasted in every aspect of radiotherapy as a clinical introduction within a period of three months. The rotation covers patient data acquisition on a Siemens CT simulator, virtual simulation on Siemens Dosimetrist, treatment planning on CMS XIO, a Siemens onco linear accelerator and Gulmy kv X-ray unit, practice in mould room and following the oncologist and oncology registrar about diagnosis and treatment of new patient case. In late years, the in-depth training were done in the aspects of radiotherapy.

Period: 01/2006-03/2006

1 Motivation

The decision of using radiotherapy and the treatment for an individual patient is a complex procedure and involving in the seamlessly cooperation between several professions: medical oncologist, radiation oncologist, radiation therapist and medical physicist. Each plays a unique role.

As a medical physics registrar just having finished academic courses in University of Canterbury, he or she should have the knowledge, clinical experience and understanding related to the radiation oncology. This is motivation of clinical roster at the start of clinical training. I was trained within a two-month period along with a group of new RT students just coming back from their academic training in University of Otago.

The training covered every aspect of radiation oncology. In the following years, the in-depth clinical experiences, knowledge and skill in every aspect were gained gradually. The training was done by clinical observation, question preparation, practice and lectures given by different professions. As an example, a list of questions is shown in appendix, which is need to be answered before, during or after training session on the CT simulator.

2 Patient data acquisition with a Siemens Emotion CT simulator

After medical and radiation oncologist decide to use the radiotherapy to treat patient, the first step of treatment planning is to setup the patient on the CT and get the CT images, which is usually called localization and immobilization. This is the key step towards the treatment planning and treatment because the outcome from this stage directly influences treatment planning and treatment. Essentially, the following three things are established:

- *Establish a treatment position that is highly reproducible and the patient feels comfortable.*
- *Obtain the CT images with high quality and no geometric distortion for virtual simulation and dose calculation. The images are used to localize the tumor and the critical organ at risk.*
- *Establish an patient coordinate system, which is an essential requirement for virtual simulation and setting up patient on linac couch. The origin of this is chosen to be at a location inside the patient and marked outside on patient skin by CT marks.*
- *Obtain the electron density which is required by the physics-model based dose calculation algorithm.*

In radiotherapy department, as shown in Fig.1, a Siemens Emotion CT simulator was used. I spent a week in CT simulator room with RT staff along with RT students. The basic procedure is as follows:

Firstly, RT staff ask the patient if they mind physics registrar and RT student attend the CT exam. If the patient agree, then the registrar and RT students enter CT room and greet the patient.



Figure 1: The Siemens Emotion CT simulator and Rando phantom.

Secondly, one RT staff explains every step and reason behind the what they are doing when two other RTs align and setup patient on the CT couch.

Thirdly, In the control room, the RT staff showed how to chose the different scanning protocol according to the tumor site. After images were obtained, how the CT marks were chosen properly for different situations and tattooed on the patient skin using the moving laser system.

Fourthly, the whole procedure was practiced using Rando phantom by each attended trainee. For each trainee, they chose tumor site like head and neck, scan the phantom and put the CT marks on the Rando skin and transfer the CT images to the virtual simulation software.

3 Virtual simulation on Siemens dosimetrist

After establishing the treatment position and acquiring the CT images, the image transfer to the RT archive, a small patient archive and communication system(PACS)which is used to store the DICOM images, DIOCOM plan, DICOM RT object and DICOM dose.



Figure 2: The Siemens Dosimetrist workstation for virtual simulation.

As shown in Fig.2, the virtual simulation software Palmerston North Hospital is using is the Siemens coherence dosimetrist. There are three workstation called Dosimetrist 1 2 and 3. The virtual simulation is to replace the physical simulator but perform the same functions and task as following:

- Contouring the skin, GTV, CTV and PTV and organ at risk to establish 3D structure.
- Design the beam arrangement. Design the field parameter, shaping the field with block or MLC for each beam.
- Choose the beam weighting point and balance the beam weight.
- Transfer the data between RT archive and dosimetrist and transfer DICOM patient to CMS Xio.

The practice was done using the CT image of Rando phantom under the supervision of RT staff. The one week training enables the trainee to use Dosimetrist virtual simulation software to perform the basic tasks.



Figure 3: The CMS XIO workstation for 3D-CRT and IMRT planning.

4 Planning a treatment on CMS XIO

After the virtual simulation, the DICOM patient is transferred back to RT archive. From the CMS XIO, the DICOM patient(DIOM CT images+DICOM RT object(eg. CT makers, interest-point marker)+DICOM plan(bean parameters). As shown in Fig., the Palmerston North Hospital has five workstations with the latest version of CMS XIO treatment planning system as shown in Fig.3.

There is also a student workstation for training RT students and physics registrar, which is also shown in Fig.3. In the later training, the beam modeling will practices on this workstation. The hardware and CMS XIO are exactly same as those used for the clinic. The only difference is that the student machine is not connected with the patient database but a training patient database. The patient in training data pase was selected carefully from the patient treated in past.

The two-week training on CMS XIO focused on the flowing tasks:

- Retrieve the patient from RT archive and send the final plan to the Lantis, a R& V system.

- Determine the beam arrangement.
- Choose the weight point and move the isocenter.
- Change the calculation setting, eg. calculation volume.
- Optimize the beam shaping with MLC or block using the BEV and DRRs.
- Calculate and display the dose
- Add the interest point or Marker.
- Evaluate and optimize the plan with DVH, isodose distribution , point dose tool and dose profile tool.

In later year, the in-depth training for treatment planning were done with the focus on making a clinically acceptable treatment plan for different tumor sites.

5 Patient treatment on Linac and Gulmy

After the treatment plan was optimized and approved by oncologist, the head of treatment planning, the next important step is to setup and treat the patient on Linac or KV x-ray unit. Setting up on the linac couch is to exactly reproduce the treatment position established on CT simulator at the beginning of treatment planning. Accuracy of setting up patient is critical and directly influencing the treatment outcome.

From mathematics point of view, patient setup on the linac couch is essentially to register the linac coordinate system with the patient coordinate system. Two coordinate systems are visualized by linac laser system and the CT marks on the skin of patient. Specifically, it is important to make sure that the origin and three axes coincide each other.

The training was done in the similar way as those did on CT simulator, one RT explains the procedure in detail while the trainees observe the RT doing their routine job. After training, the trainee practiced the patient setup using a phantom or Rando phantom.

The training focused on the following items:

- Pretreatment checking, eg. check the patient ID, fraction dose, beam parameters , table top height and if there is isocenter shift against the printed treatment plan.
- How to greet the patient and present yourself before and after treatment.

- The patient setup for different site including head neck, breast, prostate and lung with the different immobilization device.
- In control room, how two RTs verify each field by reading screen against the printed treatment parameters from TPS. During the treatment, the patient is kept watching to make sure they are not moving and feel comfortable.
- After treatment, the treatment record is printed out and the file into the patient folder.

The training was rostered on a Siemens Onco linear accelerator, a Varian 600C linear accelerator and a Gulmy kv x-ray unit.

6 Practice in the mould room

The modern MLC equipped with MLC usually does not require to use the block to shaping the photon beam. However, the cerrobend block is still most common way to shape the field for electron treatment. In addition, the varian 600C still used the lead block to shape the field for 4 MV photon treatment. Therefore the physics registrar should have basic skill and knowledge of how to use safely use equipment to make a electron cutout.

One week training in mould room was supervised by Terry and mainly focused on the following things:

- The safety issue related to the operation in mould room
- Use the cutter and lead pouring device to make electron cutout as shown in Fig.
- Check the quality of cutout.

7 Work with oncology registrars and oncologists

From the diagnosis of cancer to the decision of using radiotherapy to contouring the GTV, CTV to prescribe the dose to the followup after patient treatment, the oncologist registrar and oncologist are the profession to these job. They are most important part of radiotherapy.

As a physics registrar, she or he should have a basic understanding of what the doctors are doing. During the whole period of my training in Palmerston North Hospital, this goal was achieved by:

- Regularly attend the new case meeting on Monday morning. The oncologist and oncology registrar have a meeting every Monday morning discussing the new case about the diagnosis and treatment. I often attend this meeting although not every time.
- Attend the teaching session for oncology registrar. During the meeting, one registrar picked a new patient to give a lecture on the diagnosis, advice on the treatment.
- Establish a good relationship with a oncology registrar Dr. David. We help each other by frequently discussing the questions related to radiation oncology, clinical radiobiology and medical physics. The oncology registrar also need to pass the medical physics exam to get registration. I can learn about the radiation from him, whereas he can learn the medical physics from me.

8 Summary

A clinical rotation were done at every step of radiotherapy at the beginning of my clinical training along with new RT students. The training was designed to gain basic clinical experience and knowledge of radiation oncology.

Appendix

List of questions for the CT simulator training session

The following questions were prepared before or after training on CT simulator:

1. What are our standard slice size for head and neck radical brain protocols? why it is so small?
2. What are our standard slice size for all other sites? why not larger?
3. Why does Palmerston North radiation oncology department use extended field of view for all scans?
4. What are the disadvantages for using eFOV?

Part VII

Anatomy and Physiology

Chapter 1

MODULE SUMMARY

The goal of this module is to apply the anatomy and physiology knowledge learned in academic studying in clinical work.

The practical experience and knowledge of surface anatomy and cross sectional anatomy with particular emphasis on the anatomy required for brachytherapy were achieved in routine work such as making a clinically acceptable treatment plan using real patient data, periodic review of anatomy and physiology etc.

Chapter 2

MODULE REPORTS

Application and continuous studying of anatomy and physiology in routine work

Abstract. Medical physicist or physics registrar should have a basic knowledge of anatomy including surface anatomy and cross sectional anatomy and be able to identify key anatomic features on CT cross sectional imaging through body session. This goal was achieved by a series of training schemes in Palmerston North Hospital. This report summarize how I was trained over the whole period of clinical training regarding the module of anatomy and physiology. Specifically, the module objectives were gradually achieved by applying the anatomy knowledge in the regular routine works: regularly contouring anatomic structure on real patient CT images and frequently reviewing the treatment plan of new patient. An overview of anatomy and physiology knowledge through textbook and a teaching software called “BodyWorks” are also performed periodically.

Period: 4/2006-11/2009

1 Motivation

IAEA radiation oncology medical physics clinical training guide just stipulates what kind the anatomy and physiology knowledge should know. However, it did not says why and how.

From my clinical experience in past three years, the physicist or registrar should and must have the basic knowledge of anatomy and physiology because:

1. Physics or physics registrar need regularly check the treatment plan made by RT. The check list does not only include the physics aspect but also the anatomic aspect of patient. In Palmerston North Hospital, the physicist or physics registrar rechecks the treatment plan in two following situations: (a)If the difference between MU calculated by TPS and an independent program is more than 5%. (b)Every month, physicist or registrar pick up two or three patients to have a regular check.
2. Participating in clinical trial is a part of physicist job. It is important to have the anatomy and physiology knowledge to a certain depth.
3. It is required by the effective communication with oncologist and RTs.

The university course “Anatomy and physiology” provided a basic platform for the medical physics registrar, which is not enough. The physicist or registrar needs to apply learned anatomy knowledge in their routine work and continuously improve their knowledge over the period of training and professional career.

In this report, the registrar training regarding anatomy and physiology in Palmerston North Hospital is summarized.

2 Anatomy and physiology in routine work

2.1 Contouring on the real patients on Dosimetrist

The best way to apply and learn the anatomy knowledge is from doing and practice. The contouring on the CT images are the job of RT and oncologist. As a part of training scheme for physics registrar, the following measures have been taking over period of training:

- First, pick up one or two new patient every week from patient list on dosimetrist, which has been contoured by RT and oncologist.
- Second, Save the patient CT images as a AitangCTimage.
- Third, do the contouring following the contouring protocol.
- Finally, compare the contouring with those did by RT, analyze the difference and delete the patient AitangCTimage.

The benefits from regular contouring is not only regularly using the anatomy knowledge but also improving the clinical skill of localization.

2.2 Review of treatment plans on CMS XIO

Every week, I spent about two hours either chosen at one night during the weekdays or at weekend on the CMS XIO planning workstation to review the new plan made by RT for new patients.

The purpose of doing this is not to perform the quality control for a specific plan but to hone the planning skill for a different tumor sites. The advantages of reading the RT made plans are:

- These plans are made or checked by senior planner. Looking through these plans is good for improving the planning skill, e.g. how to arrange the beam especially for special situations.
- Usually there are final plan and other plans for one patient. Comparison of these plans can enhance the experience of judging the quality of plan.
- From the point of view of anatomy and physiology, you need to go through the anatomy to overview these plans. This is continuous learning and applying the anatomy knowledge.

3 Continuous professional study

3.1 Periodic overview of textbook contents

By the end of every year, I spent a few weeks to overview anatomy and physiology knowledge through the following textbooks: **Gerard J. Tortora and Sandra R. Grabowski. Principles of anatomy & physiology. Tenth Edition. John Wiley & Sons, Inc.**

This is a textbook used by University of Canterbury for academic training of medical physics registrar. This is an excellent textbook and used by medical school of Auckland and Otago University as introductory anatomy and physiology for first year student. During the training and late professional career, regular overview of its content is not only helpful for treatment planning practice but also enhancing the understanding of radiation oncology.

3.2 Interactive leaning through BodyWorks

As shown in Fig.1, BodyWork is a commercial software for teaching and learning anatomy and physiology. I installed it into my computer and I can learn or review my knowledge of anatomy and physiology anytime in may different ways.

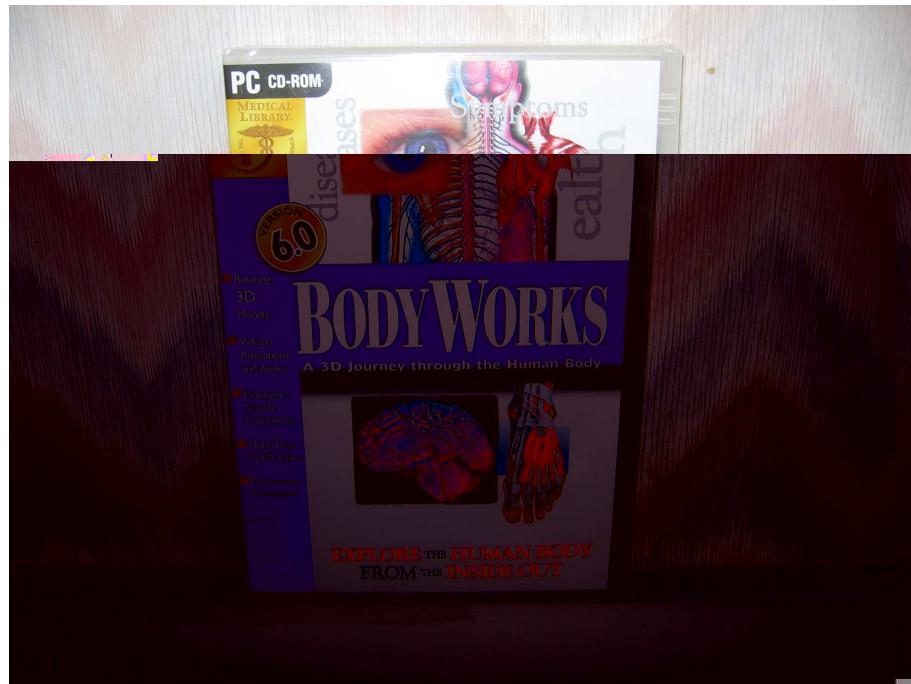


Figure 1: The teaching and learning software, BodyWorks, for anatomy and physiology.

The software provides many useful features helping the leaner learn the knowledge in a vivid way with the aid of computer technology. It look as if you had a experienced tutor always around you. Specifically, it features:

- **Comprehensive database.** More than 1500 topics and 400 000 words of text and easy database search for any word or capabilities.
- **Rotating 3D models.** More than 160 images including 80 rotating 3D models.
- **Video classroom.** 15 lectures presented by your personal instructor, Dr.BodyWorks.
- **Multimedia lessons** Narrated lessons on vital body systems.
- **Audio pronunciations.** Correct pronunciation of more than 1400 anatomic terms.

4 Summary

The knowledge of anatomy and physiology learned from university is a basis but not enough. The practical knowledge of anatomy and physiology were gained during the practical training. The measurements and action to achieve this goal in Palmerston North Hospital were briefly described.

Part VIII

Radiobiology

Chapter 1

MODULE SUMMARY

The goal of this module training is apply the radiobiology learned in University of Canterbury into clinical work and gain a basic understanding of the clinical aspects of radiobiology and apply the radiobiology into clinical work:

1. Understanding of fractionation scheme
2. Perform modified fractionation scheme examples.
3. Re-treatment examples of patient
4. Understanding the rationale behind treatment options with respect to LET protons, heavy ions, etc
5. Dose constraints of normal tissue for treatment planning.
6. Understanding of Biological Treatment Planning parameters for different tumor types and potential for individualized treatment.

These training goal were gradually achieved by a variety of activity over the period of training, such as attending the oncology registrar training seminar, and RT weekly seminar.

Chapter 2

MODULE REPORTS

Clinical radiobiology training for medical physics registrar: Palmerston North way

Abstract. The end point of radiotherapy is the outcome of treatment, which is directly determined by radiation effect on the tissue and organ. Clinical radiobiology is the basis for understanding the radiation oncology, fraction scheme and the dose prescription. In Palmerston North Hospital, the medical physics registrar was trained together with oncology registrar by attending regularly their teaching session, establishing a regular work relationship with an oncology registrar and keeping pace with new advances in radiobiology.

Period: 4/2006-11/2009

1 Motivation

The university course “Radiobiology” is just the starting point for physics registrar. The registrar has to gain experience and deeper understanding of clinical radiobiology from the clinical practice. Many people think that clinical radiobiology is important for oncology registrar but not for physics registrar.

In Palmerston North Hospital, the training for radiobiology module is treated equally important as other modules from the beginning to the end of training period. This is because radiobiology is the end point of radiotherapy. What we finally care about for each treated patient is the treatment outcome, which is directly related to clinical radiobiology.

The fraction scheme is also based on the radiobiology effect of radiation.

The radiobiology training for medical physics registrar is based on series of measurements and actions through the whole training period. This report describes the training scheme for clinical radiobiology module.

2 Regular work relationship with an oncology registrar.

In radiotherapy department of Palmerston North Hospital, there are four oncology registrars. In their five-year training period, clinical radiobiology, treatment planning and radiotherapy physics are also important training modules for them. They also have to pass the exam papers for clinical radiobiology and radiotherapy physics to get accreditation for working as a oncology consultant.

The training modules for medical registrar and physics registrar overlap. The only difference is requirements for the medical registrar and physics registrar. For example, the clinical experience and knowledge on the radiobiology is required more in depth and breadth for medical registrar than for physics registrar. On the other hand, the radiotherapy physics training is much more for physics registrar than for medical registrar. Therefore two types of registrar training are complementary to each other. In other words, physics registrar and medical physics can help each other.

As a training agreement between oncologist group and physicist group, I established a regular relationship with one of medical registrar, Dr. David as shown in Fig. Similar to physics group, the oncologist group organize the teaching session for medical registrars. I regularly attend their teaching. The teaching session usually focuses on radiobiology and oncology aspect of a real patient case.

The benefit of attending these seminar for physics registrar is:

- Gain in-depth understanding of clinical radiobiology and radiation oncology.
- Establish a communication mechanisms between physics group and oncology group.

3 Attendance of oncologist's new case meeting

The oncologist group has a regular meeting every month discussing the new case. The Head of treatment planning, the head of treatment and chief physicist are also invited. For the purpose of training, I also attended the meeting regularly. During the meeting, the following contents are discussed regarding a specific patient case:

- Diagnose and pathology information of patient and the decision on the treatment choice, radiotherapy(electron or photon beam) and chemotherapy.
- Staging of tumor and possible treatment outcome from the radiobiology point view.
- Treatment plan, eg. the number of fractions, IMRT or 3D-CRT.
- Issues related treatment planning and physics, which need to be consulted with physicist or RT.

As a part of training scheme, I gradually gained the following clinical knowledge and experience from attending new case meetings:

- Deepen understanding of clinical radiobiology based on a real patient.
- Obtain a broad view of radiation oncology.
- Learn the anatomical knowledge from a specific case.

4 Keeping eyes on the latest advances in radiobiology

There are several leading journals in the field of radiation oncology and medical physics. The latest advances and research results can be found in the following journals:

1. Radiotherapy and oncology
2. British journal of radiology
3. Medical physics
4. Physics in medicine and biology
5. international journal of radiation, oncology, biology and physics

6. Medical dosimetry
7. Journal of medical physics.

I regularly read the latest issue of these journal online to learn the new development of not only radiobiology but also other topics related to radiation oncology and medical physics.

For example, there are two interesting articles recently published regarding the radiobiology:

1. Robert D. Stewart, X. Allen Li. **BGRT: Biologically guided radiation therapy: The future is fast.** Med. Phys. 34(10), 2007. In this paper, the authors point out:

“Within the next decade, it will be possible to combine such information with advanced delivery technologies to design and deliver biologically conformed, individualized therapies in the clinic. The full implementation of BGRT in the clinic will require new technologies and additional research.”

2. C. P. South, M. Partridge and P. M. Evans. **A theoretical framework for prescribing radiotherapy dose distributions using patient-specific biological information.** Med. Phys. 35(10), 2008. Although the work is theoretical, the authors push the dream of BGRT one step closer to the reality as they stated:

“We present a formalism for using functional imaging both to derive patient-specific radiobiological properties and consequently to prescribe optimal nonuniform radiotherapy dose distributions. The ability to quantitatively assess the response to an initial course of radiotherapy would allow the derivation of radiobiological parameters for individual patients.”

5 Summary

Clinical radiobiology is an important training module and usually not paid much attention. However, it is very important for medical physics registrar to understand the radiation oncology. In this paper, the way how the physics registrar is trained to have a basic knowledge from clinical practice is described.

Part IX

Clinical Study

Chapter 1

MODULE SUMMARY

As one player of radiotherapy team, physicist should have ability to participate clinical trial or study along with RT and oncologist. Hence physics registrar should have some experience of clinical study.

As an example, one clinical study related to 200 patients treated with prostate cancer and verified with MOSFET was presented here.

Chapter 2

MODULE REPORTS

Statistical process control for in-vivo dosimetry with MOSFET over last 3-year clinical history

Abstract. Over last three year, 226 patient were monitored in our in-vivo dosimetry program with MOSFET detector. As a clinical study, the TPS calculated and measured target dose were analyzed using statistical process control (SPC) tool. The objectives of this work are to (1) Review the dosimetric measurements of a large series of consecutive in-vivo measurements for better understanding appropriate dosimetric tolerance;(2)analyze the results with SPC to develop action levels for measured discrepancies. The SPC tools results show that they are valuable tools for improving the quality control of radiotherapy treatment and planning.

Period: 5/06/2008-11/06/2008

1 Introduction

In vivo dosimetry is an important part of treatment quality control [1]. In radiotherapy department of Palmerston North Hospital, in-vivo dosimetry has been using for monitoring the doses delivered to the target for prostate cancer treatment. Before 2006, TLD was used for in vivo dosimetry. However, the accuracy of the measurement depends heavily on the quality control of TLD readings and calibration procedures. Because of the requirement of intensive post-processing and calibration procedure in TLD measurements, the results can not be obtained immediately.

The MOSFET dosimeter offers several advantages over TLD, including its small detector size(0.04mm²), immediate reuse and its ability to conduct multiple point dose measurements. In addition, the MOSFET dosimeter can provide immediate readouts for in-vivo dose measurements. These features appear to be well suited to the requirements of in-vivo dosimetry. In 2006, the department switched the in-vivo detector from TLD to MOSFET.

Over last three years, more than two hundred patients were monitored with our MOSFET in-vivo dosimetry program. As a clinical study, the tools of statistical process control(SPC) to the quality assurance of a large series of in-vivo dosimetry measurements undertaken with MOSFET within last three years.

The objectives of this report are to **(1) Review the dosimetric measurements of a large series of consecutive in-vivo measurements for better understanding appropriate dosimetric tolerance;(2) analyze the results with SPC to develop action levels for measured discrepancies.** In Sect.2, the statistic quantities of statistical process control and in-vivo dosimetry procedure are briefly introduced. The results are presented in Sect.3. Finally the main conclusions are summarized in Sect.4.

2 Materials and methods

2.1 Patient specific MOSFET in-vivo dosimetry

The physicist first established the in-vivo measurement dosimetry program including the the protocols and procedure for how to place and use the MOSFET, the calibration of MOSET and periodical QA of MOSET its reader.

Then as a part of routine clinical practice, a group of RT planner working in treatment planning room produced the prostate plan with the CMX XIO treatment planing system using version 4.4. The prostate treatment plan consists of five beam and optimized with clinically relevant criteria using DVH, BEV and other plan evaluation tools. The dose per fraction is 2 Gy with 37 fractions.

After the treatment plan is approved by the head of treatment planning and oncologist and review by the physicist, the Planner put an interest point usually at the center of target. Then the dose at this point is calculated and to be measured with MOSFET in-vivo dosimetry. The RT planner input the dose into Lantis, an R&V system being used in department. Other parameters include the entrance SSD, field size , the exit and entrance

dose and lateral thickness of patient.

The patient was treated with Siemens Primus or Onco linear accelerator. For the in-vivo measurement, the physicist enters the treatment room with RT and guide the RTs to place the MOSFET on the patient skin in a proper way. After the MOSFET detectors are irradiated, the RT take them off from patient skin and read them with MOSFET reader order. The measured results will be input into Lantis along with the TPS calculated dose in target for the patient.

Finally physicist will calculate the measured target dose and compared it with TPS-calculated target dose. The results were recorded in an excel file. Considering the general accuracy of MOSDET other factors that influencing the results during the measurement, the action level is $\pm 5\%$. If the difference is more than $\pm 5\%$, the physicist will ask RT to do another measurement. If the discrepancy still exist, the physicist will do further investigation, including the recalculating the target dose from measurement, checking the sensitivity change of MOSET and inspecting the position of interest point marked in target.

2.2 Statistical process control

Statistical process control is the conversion of data to information using statistical techniques to document, correct and improve the process performance [2]. The tools of statistical process control have already applied to the treatment planning and delivery process to ensure a consistently high level of performance [3, 4]. In our study, the following two SPC tools were used and the data were analyzed using a commercial SPC software, Qsmart SPC Analyst.

2.2.1 Control chart

Control chart is the best-known SPC tool. The control chart is plot a time series of the data, overlaid with the mean, and upper and lower control limits. The upper and low control limits correspond to the estimated mean, plus a multiple of estimated standard deviation of the measurement. The multiplier of the standard deviation is chosen so that any data falling the control line have a strong probability of being attributable to a cause, rather than due to random variation.

For normally distributed data, 3 standard deviation(3σ)correspond to a 0.00135 probability that the out-of-control variation is due to chance. Roughly speaking, 3σ correspond

to a 1-in-1000 probability that the deviation is due to chance. For variations above and below mean, a 2-in-1000 probability of incorrectly attributing an out-of-control deviation to chance is a risk that is commonly considered economical to manage.

2.2.2 Process capability

Process capability is a measure of the ability of a process to operate within its specification range. It is the ratio of the specification width to the operating range of process.

Two capability indices were calculated: C_p and C_{pk} . The first parameter measures the potential of the process to produce the results within specification without taking into account the mean of the process. The second one uses the mean and standard deviation of the process and is based on the one-sided capability indices. The capability indices are defined from the a normal distribution as

$$C_p = \frac{USL - LSL}{6s} \quad (\text{A.1})$$

$$C_{pk} = \min \left[\frac{USL - \bar{x}}{3s}, \frac{\bar{x} - LSL}{3s} \right] \quad (\text{A.2})$$

where USL and LSL are the upper and lower specification limits, and \bar{x} and s are estimators of the process mean and standard deviation.

3 Results and discussion

3.1 In-vivo data

Until now, 222 patients were monitor in our MOSFET in-vivo dosimetry program. The patient-specific measurements were acquired and retrospectively reviewed. The data recorded are TPS calculated target dose, the measured target dose and percentage difference. These three data sets are summarized in Table 1.1. Out of 222 patients, 87% of patient in-vivo results are within $\pm 5\%$ for the fist time measurement. The rest of measurements were repeated and 97% of repeated patient measurement is within action limits. This indicates the implementation of in-vivo dosimetry program with MOSFET detector is successful. The measurements are consistent over long time of period.

Table 1.1: Summary of the difference between measured and calculated target dose by CMS XIO.

	Measured	TPS calculated	Difference
Number of measurements, N	222	222	222
Mean(cGy)	43.05	43.6	-1.27%
Standard deviation	8.57	7.88	3.8%
Min(cGy)	19.3	19.88	-12.1%
Max(cGy)	129.2	135.6	11.40 %
Upper control limit			+5%
low control limit			-5%

3.2 Process control

3.2.1 Data characterization

Fig.1 and Fig.2 show the correlation plot between three set of data. It is clearly seen that the the target dose calculated by TPS and the measured dose are highly correlated. The dose percentage difference is not correlated with other two data set. It is understandable because there are several random factors contributing the dose difference, eg. the linac output fluctuation, the slowing change of MOSFET sensitivity.

To determine whether the percentage dose difference data set fits a normal or approximately normal distribution, a prerequisite for direct calculation of capability indices. the normal probability plots were produced prior to plotting the control charts. Probability plots can determine whether the distribution of measured data has a shape consistent with a theoretical distribution by assessing whether the measured values match the expected order statistics from a theoretical distribution.

The probability plot for the percentage dose difference data set is shown in Fig.3. The Figure indicates that the percentage dose difference is approximately normally distributed within $\pm 5\%$. This because the data subset can be fitted approximately by a line. However, out of this range the data does not follow the normal distribution.

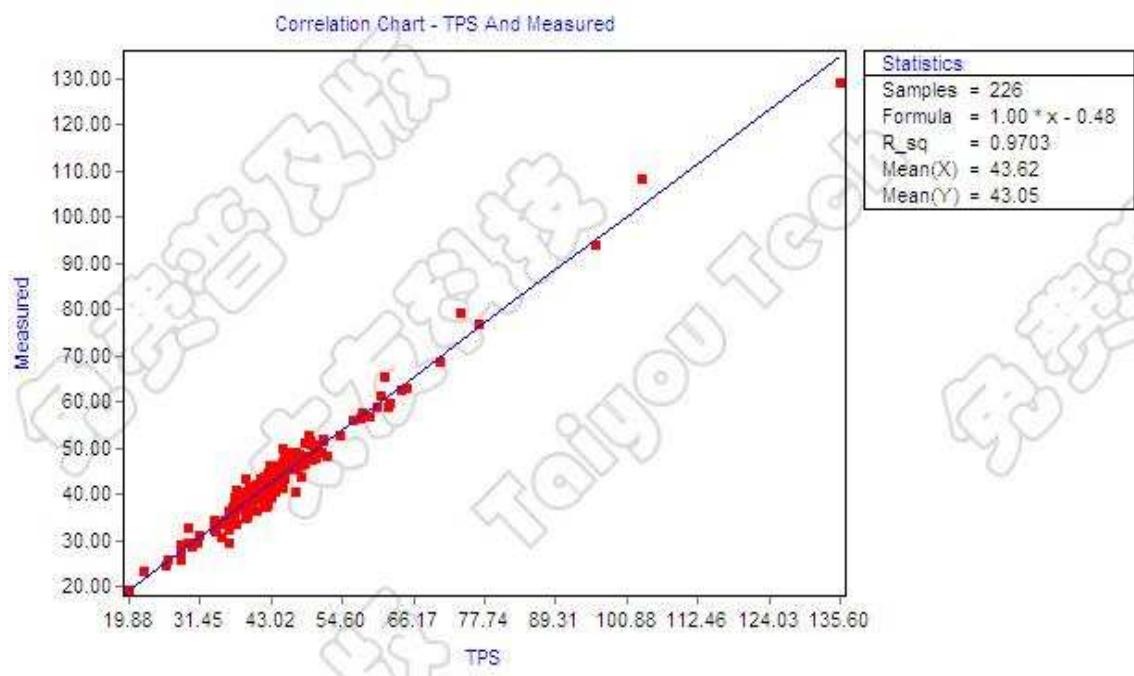


Figure 1: The correlation chart between TPS calculated data set and the measured data set.

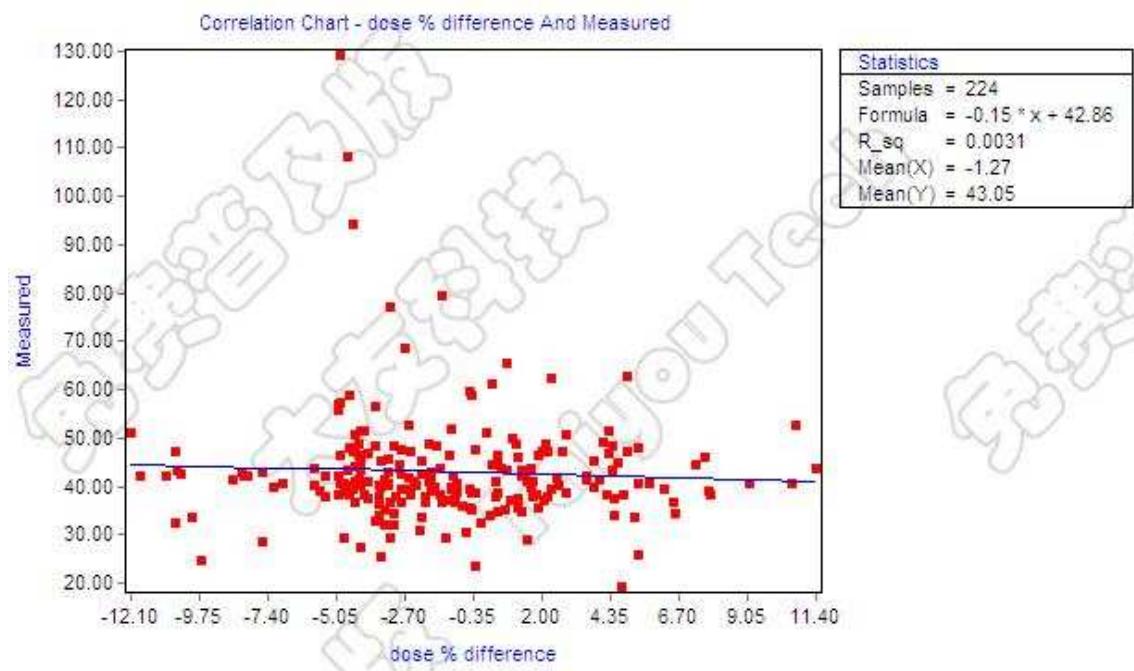


Figure 2: The correlation chart between the % difference data set and the measured data set.

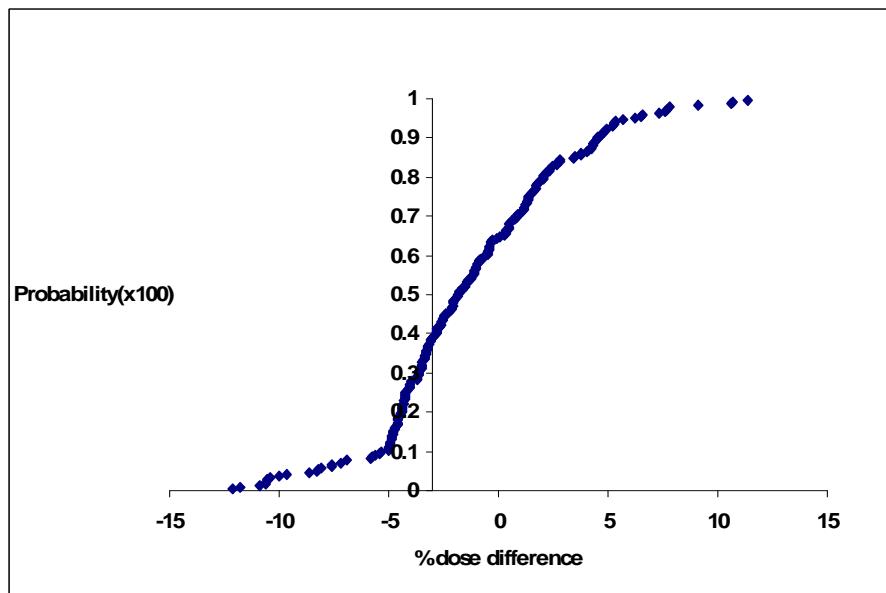


Figure 3: Normal probability plot for % difference data set. The slope of straight line fitting to this curve is inversely proportional to the standard deviation.

3.2.2 Control charts

Fig.4 shows the control chart for percentage dose difference data set. It can be seen from the graph that the process can be described in reasonable control—that is, 88% measurements fall within the upper and lower control lines, meaning the in-vivo process is predictable.

On the control charts, there are 12% of measurements that are out of control. SPC tell us that we should investigate these measurements to determine whether there is an assignable cause, or whether these arise with low probability because of random variation. In the clinical practice, all these individual measurements were investigated and proved to be not random. In most cases, it was caused by the inappropriate placement of MOSFET detector on patient skin or the sensitivity change of MOSFET at near their lifetime end or the bad location of interest point chosen at target. This proves that the SPC tools are very useful for quality control of radiotherapy.

3.2.3 Process capability

The process capability indices were calculated along with process capability plot, which are shown in Fig.5-Fig.7. The implication of a capability index greater than one for a process that is stable, is that the process is largely operating within specification.

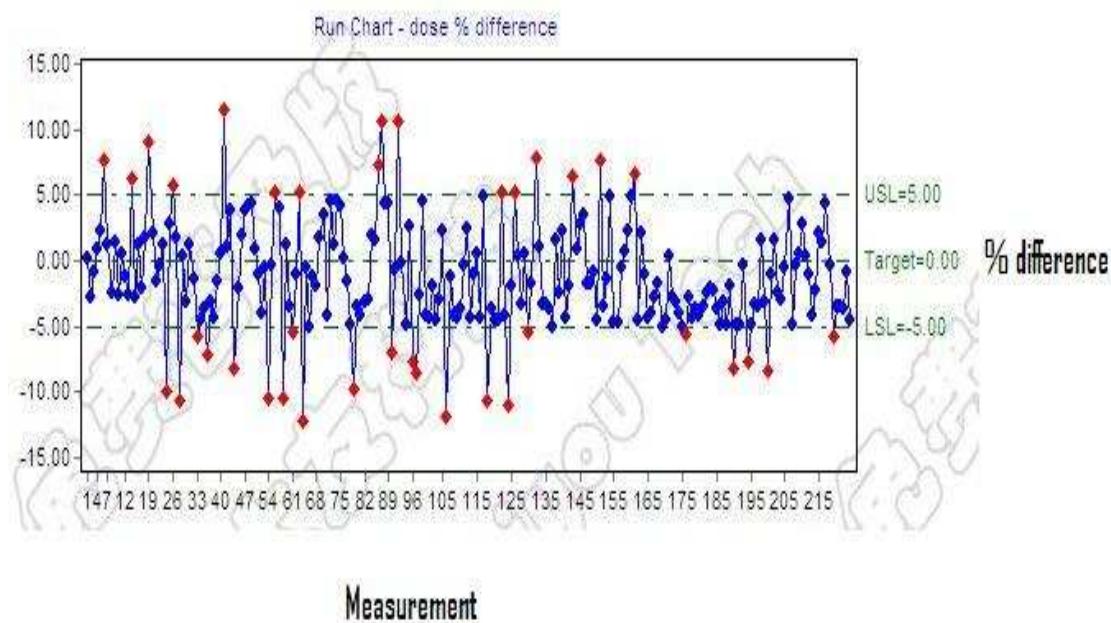


Figure 4: Control charts for the in-vivo data series. The upper and lower control lines are plotted. The line at 0% is target for the process.

The average capability indices for TPS calculated data set and Measured data set are more than 1. It shows the process of choosing the point and calculation, MOSFET calibration and calculation of target dose are reasonably stable. However, the there are several random factors during the in-vivo measurement as pointed out in Sect.3.2.2, the capability indices for % dose difference is less than 1.

4 Conclusions

The in-vivo dosimetry is a process with several components: the commissioning and calibration of MOSFET, the choice of right location in target for dose measurement, the calculation of in-vivo dose and the measurement of skin dose. Over last three years, a large number of measurements were performed. Unfortunately, it is difficult to resist the temptation to evaluate these measurements individually to decide on a case-by-case basis whether the in-vivo dosimetry of particular patient is acceptable, and to form anecdotal observations that become part of routine clinical care. Statistical process control includes a number of tools that allow a further characterization of the entire in-vivo procedure rather than looking only at individual measurements.

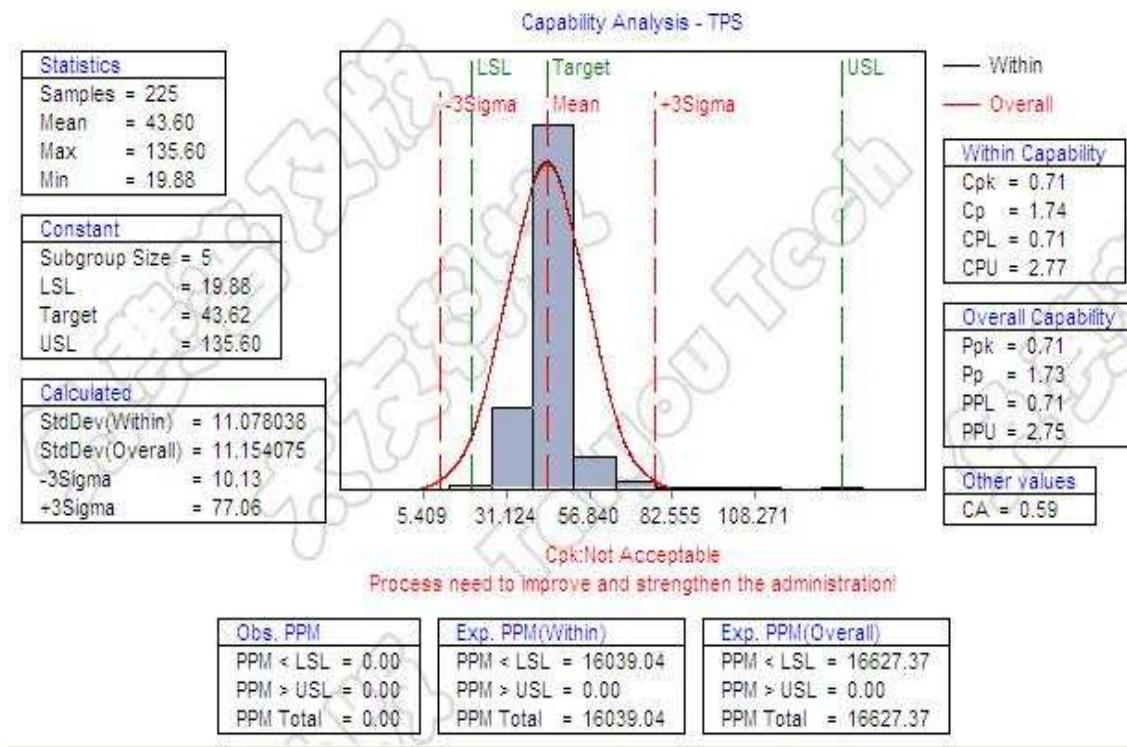


Figure 5: Process capability analysis for the TPS calculated data set.

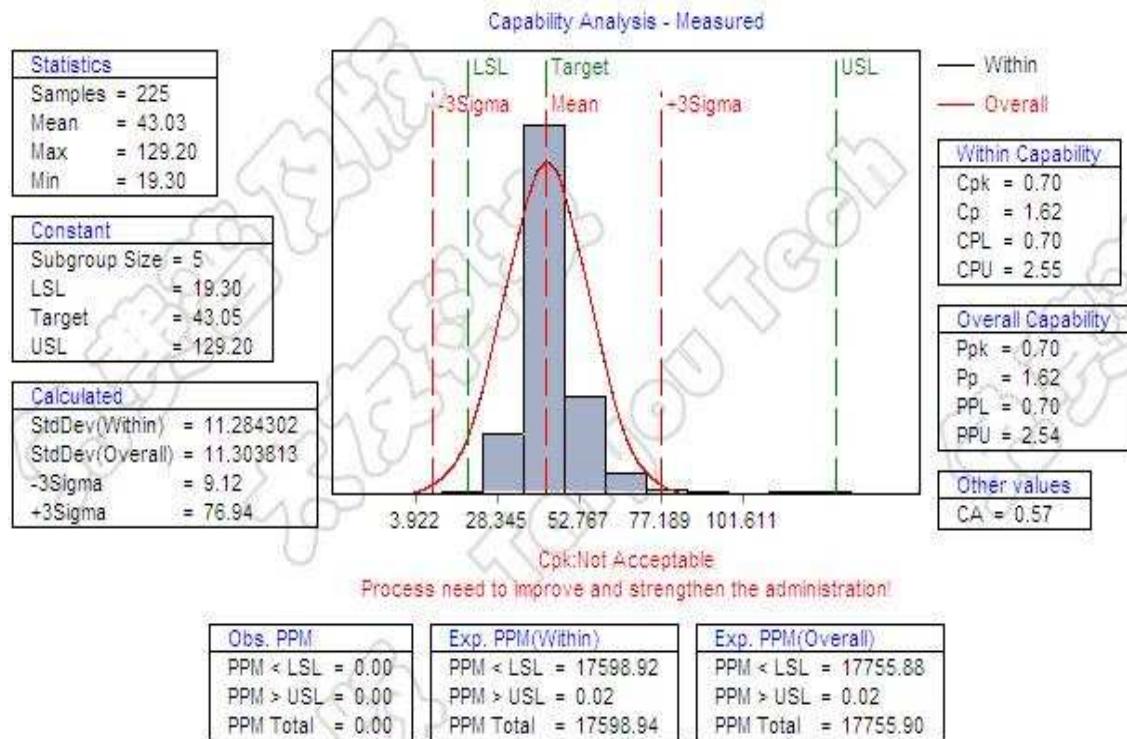


Figure 6: Process capability analysis for measured data set.

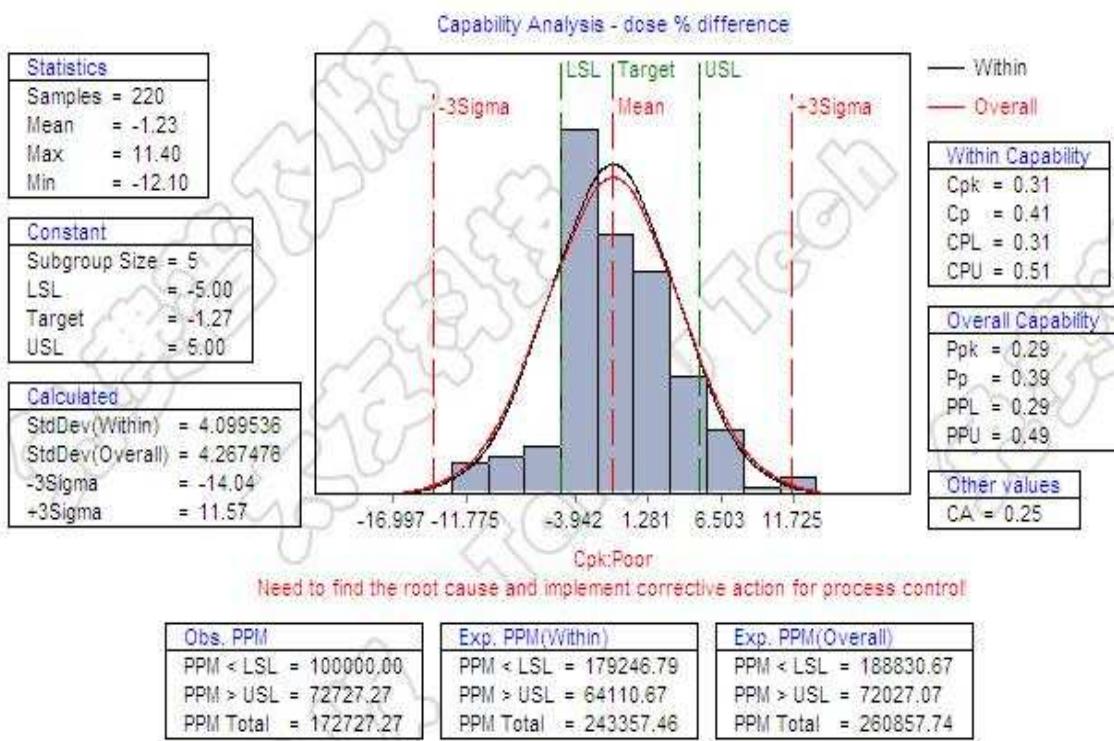


Figure 7: Process capability analysis for the % difference data set.

The application of SPC to in-vivo dosimetry is not a replacement for patient-specific dosimetry. Rather, SPC buttresses our current practice by allowing the observation of trend in mean and dispersion of our measurements, and characterize, through upper and lower control limits, the envelope in which the process operates.

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Part X

Professional Awareness, Management and Communications

Chapter 2

MODULE SUMMARY

As a medical physicist or physicist, it is important to participate in the management of department and seamlessly cooperation with other professions.

The management and communication skills can only be achieved and practiced by involving department management in routine work. This report summarize this aspect of my TEAP training.

Chapter 3

MODULE REPORTS

Active participation in department management, cooperation between professions and internal/ external meetings

Abstract. As one of basic professional requirements, physics registrar should be able to work with other professions and patient in a proper professional way. In addition, the registrar should also have the basic management and communication skills. Regarding this aspect during my clinical training, this report summarizes my training activities.

Period: 4/2006-11/2009

1 Motivation

Radiotherapy treatment is performed by the cooperation with several health profession: Oncologist, radiation therapist, medical physicist, oncology nurse and supporting staff. As one profession among them, medical physics registrar should have the good communication and management for effectively working with other professions. In this report, the management and activities I involved in during my clinical training was briefly described.

2 Appointment as a health and safety representative

I was appointed as a health and safety representative by other physicist to represent the physics group in 2006. The midcentral health board set up a heath and safety committee to deal with the health and safety problem in working place. The health and safety problems includes a broad of range such as the physical injury, the injury caused by chemical, electric, radiation etc.

The chairmen is Mrs Diane Feck. I work also with the representatives from RT group, oncology nurse from the ward. My responsibility is to regularly check the potential hazards in physic lab, physic office and RT meeting area. I also report any incidents happened in physics area and injury of physicist during the work.

As one of important responsibility, I attend the safety and health meeting every two months. Being a representative and part of management, my management skill has been greatly improve. For example, I found several problems, eg the bad air conditions in physic office, the water quality from the tab and the effect of analogy monitor on the health. I worked with Mrs. Diane Feck and other manager of department and all these problem were resolved.

3 Communication and cooperation with other professions

As a routine work, everyday I communicate with radiation therapist, oncologist and other medical physicist in an professional manner.

For daily work, the tasks could not be done without the communication and cooperation with other professions. Here given are two examples:

- For IMRT patient QA, I need first discuss with RT about the tumor site, beam arrangement, the beam weight points before start IMRT planning on IMRT phantom. After making treatment planning, treating the phantom and measuring the results. It is important for physics registrar to give a recommendation to the oncologist and discuss the problem.

Fig.1 shows a part of a IMRT report and my advices. I also discussed

Date		19-Jul-08		IMRT Verification																	
Patient:		ID: BAB3672		Verification patient ID:		Studyset ID:		Verification plan ID:		AitangIMRT QA											
Treatment Plan ID:		1, 0°		P, mm-Hg: 751.3		k_{TP} : 1.022		Number of fractions:		1											
Chamber: Scanditronix/Welchefer C0013, SN 6247 Electrometer: Scanditronix/Welchefer Doseit, SN 7524																					
Total coefficient for dose determination = $k_{TP} \times$ Chamber factor \times Number of fractions = 0.27																					
Isocentre coordinates relative to phantom centre (xyz): -3.6571																					
Measurement point coordinates relative to the phantom center (xyz):		0/-20																			
Beam No:		1	2	3	4	5	6	DVH data													
Gantry angle:		3	75	140	210	201	Mean dose, Gy		100 \times (Max - Mean)												
Dose for each beam, reported by TPS, Gy		0.389	0.28	0.381	0.395	0.397	Mean		Mean												
Doseimeter reading, mC		1.43	1.015	1.371	1.25	1.17															
Measured dose for each field, Gy		0.4	0.3	0.4	0.3	0.32143	1.713														
Difference, TPS-measurement, Gy:		0.006	0.001	0.004	0.013	0.016	0.0														
Difference, (TPS measurement/TPS, %):		1.5	0.4	1.1	3.5	4.6	1.5														

- Ion chamber measurement

The ion chamber measurement is within the 3% limit.

- Film measurement

The film was scaled down by 2% so the ion chamber measurement point and the film correspond.

- Conclusion

The verification results show that the treatment can proceed if the presented differences are clinically acceptable.

The central region appears to be getting somewhat more dose than planned, however, this could be due to the scattering and the over response of EDR2 film to the scattered radiation. The right side appears to be getting slightly more dose than planned.

Physicists:

Aitang Xing(register) _____

Keith Croft _____

Raidation Oncologist: _____

Figure 1: A IMRT patient QA report showing the results and recommendations to the oncologist. When I submitted it to Dr. Chan, I discussed the results in details with him.

with oncology consultant Dr. Chan and recommended him to continue this treatment. For confidentiality, the patient name was omitted.

- For in vivo dosimetry, I enter treatment room with RT and first present myself to the patient in a professional way. When I guide RT to position the MOSFET on the measurement point, I also briefly tell patient the purpose of measurement and make patient feel comfortable.

4 Attendance of internal and external meetings/ trainings

Attending the the internal and external meeting or training does provide not only a chance and platform to communicate with other profession or colleagues but also a good opportunity for me to have open discussion on the topic related to radiotherapy and work. I regular attend the internal meeting or teaching session and the external conference or training course.

4.1 Internal regular meeting

4.1.1 Physics meeting /teaching session

In physics department, we have a meeting every Friday afternoon. The meeting mainly focuses on the issue related to machine, dosimetry and planning in last week. This meeting is also used a teaching session for physics registrar. The physicist usually give a talk about the topic or presents the research results of the project they did.

This is a very effective Palmerston North way to train medical physics registrar. During the meeting, the supervisor and other physicists usually exam the physics registrar by asking the questions related to the training module or check the results of the project or assignment did by registrar.

4.1.2 RT meeting /teaching session

I also regularly attend the meeting of radiation therapists. They have two types of meetings: the teaching session for RT student and weekly meeting for RT.

Every year there are always new RT students coming back from University of Otago for starting their clinical training. The teaching session is organized by a clinical RT supervisor. The training mainly focuses on the patient data acquisition on CT simulator, virtual simulation on the Siemens Dosimetrist and treatment planning on CMS XIO, and patient setup and treatment delivery on the linac.

The RT weekly meeting is organized by RT working in treatment planing room. The meeting mainly discusses the issues related to treatment planing, virtual simulation they met last week.

4.1.3 Oncologist meeting /teaching session

Similarly I also attend regularly the meeting organized by the oncologist group although not every time. The oncologist has two types of meetings: teaching session for oncology registrar and the new case meeting. The oncologists discuss the the new case regarding diagnosis, pathology and treatment scheme etc. The teaching session is mainly for training the oncology registrar.

4.2 External meeting/training

Until now, I attended the following external meetings or training courses:

- **ESTRO Teaching course on “Dose calculation and verification for external beam therapy”, Dublin, 20/04/2008-24/04/2008.**
- **ESTRO Teaching course on “Physics for clinical radiotherapy”, Limassol, Cyprus, 21/10/2007-25/10/2007**
- **The NZ registrar work shop on “HDR brachytherapy with VarianSource”, Wellington, New Zealand, 01/05/2007-06/05/2007**
- **Ucol course “radiation protection and radiobiology”, which was given by my clinical supervisor Dr. John Sutcliffe, Palmerston North, 13/09/2007-18/10/2007.**

As an example, Fig.2 shows my clinical supervisor is giving a lecture in class room of Universal college of learning.



Figure 2: My clinical supervisor Dr. John Sutcliffe is giving a lecture for one-semester course “radiation protection and radiobiology” to UCOL medical imaging students.

5 Training logbook as a working diary

I have been using logbook since the beginning of my training. It is actually a working diary. I have written 13 volumes labeled clearly as shown in Fig. I found the advantages of using the logbook to record are:

- You can quickly write down the key information and results when you do the measurements or being trained. It is easily to draw any diagram on the logbook.
- The logbook provides a permanent training records which you can be looked back anytime.
- The whole portfolio were developed based on original results recorded on these logbooks.

6 Summary

During my clinical training in Palmerston North Hospital, I have been actively involving in the management. As a profession, I have been working with other professions in a professional way as my routine work.