EVALUATION OF PLANAR AND CYLINDRICAL DIODE ARRAY FOR IMRT AND VMAT PLAN VERIFICATION

PORNPIROM LAOJUNUN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (MEDICAL PHYSICS) FACULTY OF GRADUATE STUDIES MAHIDOL UNIVERSITY 2014

Thesis
entitled

EVALUATION OF PLANAR AND CYLINDRICAL DIODE ARRAY FOR IMRT AND VMAT PLAN VERIFICATION

……………………………………..
Mr Pornpirom Laojunun
Candidate

....
Assoc. Prof. Lalida Tuntipumiamorn,
M.Sc. (Radiation Science)
Major advisor

....
Assoc. Prof. Yaowalak Chansilpa,
M.D.(Radiotherapy & Nuclear Medicine)
Co-advisor

…………………………………
Prof. Banchong Mahisavariya,
M.D. Dip Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

....
Lect. Paungpen Tangboonduangjit,
Ph.D.
Program Director
Master of Science Program
in Medical Physics
Faculty of Medicine
Ramathibodi Hospital
Mahidol University

Thesis
entitled

EVALUATION OF PLANAR AND CYLINDRICAL DIODE ARRAY FOR IMRT AND VMAT PLAN VERIFICATION

was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science (Medical Physics)
on
July 4, 2014

……………………………………..
Mr. Pornpirom Laojunun
Candidate

……………………………………..
Assoc. Prof. Lalida Tuntipumiamorn,
M.Sc. (Radiation Science)
Member

…………………………………….
Assoc. Prof. Sivalee Suriyapee,
M.Eng. (Nuclear Technology)
Chair

………………………………
Lect. Paungpen Tangboonduangjit,
Ph. D.
Member

……………………………………..
Assoc. Prof. Yaowalak Chansilpa,
M.D.(Radiotherapy & Nuclear Medicine)
Member

………………………………
Prof. Banchong Mahaisavariya,
M.D., Dip Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

....
Prof. Winit Phuapradit,
M.D., M.P.H.
Dean
Faculty of Medicine
Ramathibodi Hospital,
Mahidol University

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and deep appreciation to my major advisor, Assoc. Prof. Lalida Tuntipumiamorn for her guidance, supervision, encouragement and assistance throughout the course of this research. In addition, I am equally grateful to Assoc. Prof. Yaowalak Chansilpa, Asst. Prof. Chumpot Kakanaporn, and Asst. Prof. Porntip Iampongpaiboon, my co-advisors for their kind suggestion and beneficial comments.

I also express my appreciation to Asst. Prof. Silvalee Suriyapee, chief physicist at Division of Radiation Oncology, Department of Radiology, Chulalongkorn memorial hospital, for providing suggestions for improvement and benevolent in examining this thesis.

I would like to express sincere thanks to Dr. Paungpen Tangboonduangjit, Director of school of Medical Physics for constructive advice and comments in the research proposal.

I am grateful for the technical help during data collection and good cooperation from all therapists, engineering and staffs in Division of Radiation Oncology, Department of Radiology, Faculty of Medicine, Siriraj Hospital. Specially thank is express to Miss Lukkana Apipunyasopon, Miss Khummook Krongyuth and Miss Piyanan Liammookda for their assistance and providing me facilitate.

I wish to immensely thank to all teachers, lecturers and staffs in the School of Medical Physics at Division of Radiation Oncology and Nuclear Medicine, Ramathibodi hospital for the valuable experience and boundless knowledge on Medical Physics.

Finally, I have to sincerely regard mention to my family for their infinite love, assistance, carefulness and entirely support throughout my whole study.

Pornpirom Laojunun

EVALUATION OF PLANAR AND CYLINDRICAL DIODE ARRAYS FOR IMRT AND VMAT PLAN VERIFICATION

PORNPIROM LAOJUNUN 5236472 RAMP/M

M.Sc. (MEDICAL PHYSICS)

THESIS ADVISORY COMMITTEE: LALIDA TUNTIPUMIAMORN, M.Sc. (RADIATION SCIENCE), YAOWALAK CHALSILPA, M.D. (RADIOTHERAPY AND NUCLEAR MEDICINE)

ABSTRACT

The aim of this study was to evaluate the use of the planar and cylindrical diode arrays for IMRT and VMAT plan verification. Two diode detector arrays were compared for their use in the patient-specific quality assurance of IMRT and VMAT treatment plans: one diode array is a flat panel of diodes (MapCHECK2) positioned with a MapPHAN phantom, while the other is a cylindrical phantom with the diodes placed in a spiral array (ArcCHECK). Both devices were tested for the dose linearity over a range of 20-400 MU and a repetition rate over the range of 100 to 600 MU/min of 6 and 10 MV, photons delivered via a static 10x10 cm^2 field. The dependence of the response of detectors on field size was measured and compared with Farmer-type ionization chamber. The short-term and long-term reproducibility and the array calibration were also examined to understand the stability and uncertainty of the systems and the angular dependence was studied. The performance of the dosimeter system was then evaluated using IMRT and VMAT plans. The study included the planning of 7 coplanar plans (head and neck, pelvic, abdominal region) and 3 non-coplanar plans (brain) with IMRT and VMAT which were performed using a Varian Clinac iX. The measured doses were compared to the TPS dose and analyzed using gamma analysis with criteria of 3%/3 mm. No repetition rate or field size dependence was observed within the range of the field sizes and dose rate used in the study for both 6 and 10 MV photon energies. Both detector arrays showed linearity of dose and a stable short-term and long-term reproducibility. We found relatively large discrepancies in angular response (up to 39%) for MapCHECK2 and 17% for ArcCHECK. For IMRT plans delivered at planned angles, MapCHECK2 results showed a lower average gamma passing rate (93.4%) compared to measurements (97.8%) delivered at fixed 0 degree gantry angles. The ArcCHECK results showed average differences between measured and calculated values of 93.8%. For VMAT plans, the average passing rate was 99.3% and 97.8% using MapHECK2 and ArcCHECK respectively. The measured differences between IMRT and VMAT QA results for non-coplanar were small, except the MapCHECK2 results showed averages of 63.9% for the IMRT plans delivered at a planned angle. ArcCHECK is an efficient and valuable tool for both IMRT and VMAT QA, it achieved an above 95% pass rate. With MapCHECK2 an excellent agreement was observed between the measurement and the verification dose for VMAT and IMRT QA when measured at gantry zero degree. But the application of the array to planned gantry angle IMRT QA requires careful consideration.

KEY WORDS: IMRT/ VMAT/ TREATMENT VERIFICATION/ QUALITY ASSURANCE/ DIDODE ARRAY

79 pages

การประเมินคุณภาพหัววัดรังสีชนิดสารกึ่งตัวนำแบบระนาบและแบบทรงกระบอกเพื่อตรวจสอบแผนการรักษาในเทคนิครังสีปรับความเข้มชนิดแกนเครื่องฉายคงที่และหมุนต่อเนื่อง EVALUATION OF PLANAR AND CYLINDRICAL DIODE ARRAYS FOR IMRT AND VMAT PLAN VERIFICATION

พรภิรมย์ เหล่าจันอัน 52363472 RAMP/M

วท.ม. (ฟิสิกส์การแพทย์)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์ : ลลิดา ตันติภูมิอมร, M.Sc. (RADIATION SCIENCE),
เยาวลักษณ์ ชาญศิลป์, M.D. (RADIOTHERAPY AND NUCLEAR MEDICINE)

บทคัดย่อ

งานวิจัยนี้จุดประสงค์เพื่อประเมินประสิทธิภาพ และความถูกต้องของหัววัดรังสีชนิดสารกึ่งตัวนำที่เรียงตัวแบบระนาบ (MapCHECK2) และแบบทรงกระบอก (ArcCHECK) ในการตรวจสอบความถูกต้องของแผนการรักษาในเทคนิครังสีปรับความเข้มชนิดแกนเครื่องฉายคงที่ (static angle) และแกนเครื่องฉายหมุนต่อเนื่อง (VMAT) โดยการศึกษาจากค่าเปอร์เซ็นต์ของดัชนีแกมมา (Gamma index) ที่ผ่านเกณฑ์ระดับยอมรับได้ที่ 3% และ 3 มม. จากการเปรียบเทียบค่าปริมาณรังสีที่ได้จากการคำนวณด้วยเครื่องคอมพิวเตอร์วางแผนการรักษาและจากการวัดด้วยหัววัดรังสีดังกล่าว รวมทั้งศึกษาคุณลักษณะของหัววัดทั้งสองในส่วนที่เกี่ยวข้องกับปริมาณรังสี อัตราปริมาณรังสีต่อหน่วยเวลา ขนาดลำรังสีและทิศทางการฉายของลำรังสี เพื่อนำมาตรวจสอบแผนการรักษา IMRT และ VMAT ในผู้ป่วยรวมเจ็ดแผนการรักษาในบริเวณอวัยวะต่างๆกัน และสามแผนการรักษาที่มีระนาบแตกต่างกัน (non-coplanar technique) ที่ฉายด้วยลำรังสีโฟตอนพลังงาน 6 และ10 เมกกะโวลต์ ผลการศึกษาพบว่าหัววัดรังสีทั้งสองไม่มีผลกระทบของรังสีเมื่อเปลี่ยนแปลงอัตราปริมาณรังสีต่อหน่วยเวลา และขนาดลำรังสีที่ใช้ทั้งสองพลังงาน มีการตอบสนองต่อรังสีปริมาณต่างๆได้ดี รวมทั้งมีความคงที่ของการวัดรังสีในระยะเวลาสั้นและยาว แต่สำหรับทิศทางการฉายรังสีในมุมต่างๆ พบความแตกต่างสูงมากถึง 39% ใน MapCHECK2 และ 17% ใน ArcCHECK สำหรับการตรวจสอบแผนการรักษา IMRT ของ MapCHECK2ให้ผลความแตกต่างของค่าดัชนีแกมมาเฉลี่ย 93.4% เมื่อวัดที่ทุกมุมฉายรังสีตามแผนการรักษา ซึ่งน้อยกว่าเมื่อวัดที่มุมศูนย์องศา 97.8% ส่วน ArcCHECK ให้ผลค่าดัชนีแกมมาเฉลี่ย 93.8% สำหรับการตรวจสอบแผนการรักษา VMAT หัววัดรังสีแบบระนาบและแบบทรงกระบอกให้ผลค่าดัชนีแกมมาเฉลี่ย 99.3% และ 97.8% ตามลำดับ ส่วนการตรวจสอบแผนการรักษา IMRT และ VMAT ที่มีระนาบแตกต่างกัน พบว่าหัววัดรังสีแบบระนาบให้ผลค่าดัชนีแกมมาเฉลี่ยต่ำอย่างมีนัยสำคัญ คือ 63.9% เมื่อวัดที่ทุกมุมฉายรังสีตามแผนการรักษา จากการศึกษานี้พบว่าหัววัดรังสีแบบระนาบและแบบทรงกระบอกมีความถูกต้องเหมาะสมสำหรับนำมาตรวจสอบความถูกต้องของแผนการรักษา IMRT และ VMAT แต่หัววัดรังสีแบบระนาบต้องระมัดระวังในการนำมาตรวจสอบเมื่อวัดที่มุมฉายรังสีตามแผนการรักษาโดยเฉพาะเมื่อมีระนาบการฉายรังสีแตกต่างกัน

79 หน้า

CONTENTS

LIST OF TABLES

LIST OF TABLE (cont.)

LIST OF TABLES (cont.)

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF ABBREVIATIONS

Abbreviation	Term
%	Percent
γ	Gamma
2D	Two Dimensions
3D	Three Dimensions
3D-CRT	Three dimensional conformal radiation therapy
4D	Four Dimensions
AC	Alternating cuurent
cc	Cubic centimeter
cGy	Centigray
cm	Centimeter
cm^2	Square centimeter
cm^3	Cubic centimeter
CT	Computed tomographay
°C	Celsius
DC	Direct current
DICOM	Digital Imaging and Communications in Medicine
DTA	Distance to agreement
%Diff	The percent difference
EPID	Electronic portal imaging device
eV	electronvolt
GB	Gigabyte
Gy	Gray

LIST OF ABBREVIATIONS (cont.)

Abbreviation	**Term**
IC	Ionization chamber
IEC	International electrotechnical commission
IMAT	Intensity modulated arc therapy
IMRT	Intensity modulated radiation therapy
MeV	Megaelectronvolt
MLC	Mulitleaf collimator
MU	Monitor units
MV	Megavoltage
min	Minute
mm	Millimeter
nC	Nanocoulomb
PMMA	Polymethyl methacrylate
QA	Quality assurance
RA	RapidArc
RT	Radiation therapy
SAD	Source axis distance
SD	Standard deviation
SSD	Source to surface distance
s	Second
TPS	Treatment planning system
VMAT	Volumetric modulated arc radiotherapy

CHAPTER I
INTRODUCTION

The goal of radiation therapy is to deliver high curative radiation dose to the target volume while controlling normal tissue and critical structure complications. The rapid advancement in treatment planning and delivery systems combined with state-of-the-art imaging systems in the treatment room has increased the potential use of intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) for routine clinical practice. These developments potentially improve the effectiveness of the treatment, but they also increase the complexity, requiring more careful evaluation of treatment plans before clinical delivery.

The routine clinical uses of IMRT have increased rapidly over the past decade. IMRT is generally delivered from several fixed beam angles in order to create a more conformal dose distribution while spare surrounding healthy tissue through the use of multileaf collimators (MLC) [1]. VMAT is a method of delivering intensity modulated fields that is currently gaining widespread use. VMAT [2] is distinguished from fixed-beam IMRT in that the radiation is delivered while the gantry rotates around the patient. The dose is shaped using three variables: MLC shape, gantry rotation speed, and dose rate can be continuously varied to deliver the prescribed dose to the planning target volume. The primary advantage of VMAT over fixed-beam IMRT is that VMAT treatments can be delivered significantly faster. RapidArc is the name of the commercially available version of VMAT from Varian. IMRT and VMAT treatments are considerably more complex than traditional treatments, and have a greater potential for delivery errors.

Quality assurance (QA) in radiation therapy is the method used to ensure that the correct amount of radiation is being delivered to the correct location. QA is performed routinely on all parts of the treatment process, from planning to delivery. And the dosimetric verification of treatment plans is critical in order to ensure accurate and safety delivery of precise patient treatment plans. The necessity for an easy-to-use and reliable QA system to ensure the accuracy of dose delivery before clinical use is required. In the past, IMRT QA was performed with relative dosimetry using film and the small ion chamber in a phantom for absolute point dose measurements [3], but the process is time consuming, because of increasing patient load combined with traditional QA methods would extend the time required for the treatment verification. Thus in recent years, most clinics have moved to fast and reliable QA system such as 2D-dosimetric phantom, this is required for delivery verification due to shortened the time for delivery verification with their easy of set up and instantaneous absolute dose readout and dose distribution display. In the past few years, 2D arrays of electronic detectors have become available and have been studied in some detail: the MapCHECK diode array Model 1175 (Sun Nuclear Corporation, Melbourne, FL) [4], and two commercial models of the ionization chamber array MatriXX [5] (Scanditronix Wellhofer GmbH, Germany) and PTW seven29 [6] (PTW, Freiburg, Germany). These 2D plane of detectors which work fine for fixed gantry IMRT, but may be less well suited for rotational IMRT. Recently, there have been attempts to extend electronic detector systems for use with VMAT verification such as the Delta4 phantom (Scandidos, Uppsala, Sweden) [7] has 1069 p-type silicon diodes in a crossed array inside a cylindrical polymethylmethacrylate (PMMA) phantom and the cylindrial phantom, ArcCHECK(Sun Nuclear Corporation, Melbourne, FL) [8] with 1386 diodes embedded in it.

In this study, we aim to evaluate and compare the dosimetric performance of MapCHECK2 and ArcCHECK. (Sun Nuclear Corporation, Melbourne, FL). The evaluation of these dosimetric systems was applied to IMRT and RapidArc and deliveries using a Varian iX linear accelerator with IMRT plans generated using the Varian Eclipse (ver. 8.6) treatment planning system.

1.1 IMRT

Intensity-modulated radiation therapy (IMRT) is an advanced form of three-dimensional conformal therapy (3D-CRT). Unlike conventional conformal therapy, the beam intensity of each IMRT field is modulated in a rather complex way. Delivery of intensity-modulated fields relies on the use of computer controlled multileaf collimators (MLCs) equipped on modern linear accelerators. Because of the complex beam intensity modulation, each IMRT field often includes many small, irregular, off-axis fields resulting in isodose distributions for each IMRT plan that are more conformal to the tumor target volume than those from conventional treatment plans. IMRT can be divided in to two type are;

1.1.1 Static MLC IMRT (Step and Shoot)

In step and shoot IMRT, the MLC leaves remain fix during irradiation and the beam is turned off between consecutive MLC shapes, several small static fields are added up to create the dose distribution.

1.1.2 Dynamic MLC IMRT (Sliding window)

In dynamic IMRT, the leaves are in continuous motion during radiation delivery, moving in and out of the field to create the desired dose distribution.

1.2 VMAT

Volumetric modulated arc therapy (VMAT), is a subset of IMRT with the gantry in constant motion, has been implemented in the past few years. VMAT can potentially deliver a radiation field that better conforms to the tumor volume while reducing treatment time. This advancement is possible due to the ability of VMAT to modulate dose rate and gantry speed while the MLC adjusts the shape of the field, creating more opportunities for optimization [9]. Since the radiation is distributed over one or more arcs, the dose to healthy tissue is spread across a much larger volume. Additionally, the gantry rotation allows dose to be reduced in areas that penetrate sensitive organs while increasing the dose that passes through less sensitive tissue.

RapidArc (RA) is a clinical application of rotational IMRT based on the VMAT method on Varian medical systems Inc. (Palo Alto, CA, USA), while on Elekta system, it is simply called VMAT. RapidArc planning uses progressive sampling by adding groups of control points during optimization. As the optimization advances, the MLC leaves are restricted to smaller movements and the gantry angles are sampled at a finer resolution. The number of control points is doubled at each level of resolution until the final number achieved is 177 per arc [9]. This result in a control points approximately every 2° of gantry rotation in the final plan.

1.3 Quality Assurance (QA) for IMRT and VMAT

The complexity of the IMRT and VMAT treatment delivery does not come without a risk. The clinical efficacy of IMRT and VMAT relies on the ability of the planning system and delivery system to accurately deliver planned dose to the target. And also the complicated motion of MLC leaves to modulate beamlets makes leaf positioning accuracy more critical than conventional 3D-CRT technique. In addition to the machine QA program, a patient-specific QA program is also in place to ensure the quality of each individual patient treatment. The main purpose of patient specific QA should be to assure that the clinical impact of the treatment on the patient, due to the overall performance of the machine and all human factors, does not deviate significantly from what is planned. Patient specific QA has become an integral part of IMRT and VMAT treatment process.

A number of methods have been routinely employed for pre-treatment patient specific QA. These methods include film, 2D-diode array, ionization chamber array, electronic portal imaging devices (EPID), multiple plane 2D detectors and 3D dosimetry. Ionization chamber combined with film is the early popular choice. An ionization chamber could be placed in a high dose and low dose gradient region for absorbed point dose measurement. Film can be irradiated to measure a relative dose distribution and permits high spatial resolution; however in can be time consuming. Film is gradually replaced by online 2D detectors such as diode arrays and ionization chamber array. Absolute planar dose distribution could be obtained during a single delivery which makes measurement more accurate. Diodes are often used because of their small size and extreme sensitivity. There are various 2D detectors commercially available such as the MatriXX (IBA dosimetry, Germany) and the Seven29 (PTW, Germany). 2D-ion chamber or the diode-based device MapCHECK (Sun nuclear corporation, USA), 3D-diode QA tool ArcCHECK (Sun nuclear corporation, USA), and Delta4 (ScandiDos AB, Sweden). Portal dosimetry based on electronic portal imaging device (EPID) is an alternative for patient specific QA measurement. Each type of detector has tradeoffs that much be considered when choosing a device for QA measurements.

1.4 Plans evaluation

There are several qualitative methods to evaluate adsorbed dose distributions, e.g. dose difference, the distance-to-agreement and the percentage of points, area or volume passing a pre-selected criterion is used to indicate the quality of the whole planning and delivery procedure.

1.4.1 Dose difference

The dose difference test, wherein the differences between two dose distributions is calculated point by point in dose domain, is the most straightforward method. This technique, most frequently used by medical physicist to compare calculated and measured dose distributions. The method superposes the calculation and measured isodose curves with a subsequent qualitative assessment of the acceptability of the calculation algorithm.

1.4.2 Distance-to-agreement (DTA)

The DTA is the spatial distance between calculated and measured data points that receives the same absorbed dose. A criterion of maximum acceptable DTA can be chosen by the user. The distance between the measured and the reference data points with the same absorbed dose must not exceed the chosen maximum DTA to pass the evaluation. DTA is a useful complement to dose difference measurements, especially when it comes to high dose gradient regions.

1.4.3 Gamma evaluation method

The use of only dose difference or DTA might be insufficient in some case to decide whether a data point should be accepted or not the dose difference method is not valid in high dose gradient regions due to a small spatial error may result in large absorbed dose difference in contrast to the DTA. Low et al [10] described the gamma evaluation method in which they simultaneously incorporate the dose difference and the DTA criteria. They applied two comparison tools, a direct comparison of dose difference and comparison of the DTA between calculation and measured absorbed dose distribution and provides a numerical index as a measure of agreement of the two dose distribution. The gamma evaluation method sets the criteria for both absorbed dose difference and the distance to the closest data point in the reference plan. A gamma index (γ) is calculated for every measured dose point and if the gamma index is less than or equal to one, the dose point passes. There are a lot of difference choices of dosimeters for QA measurement, there is no consensus on what criteria one should use in evaluating the agreement between measured and calculated dose distribution. A recent survey conducted by Nelms et al [11] showed the majority responding clinical institution use 3%/3mm criterion for IMRT QA analysis can achieve 90%-95% passing rate between calculation and measurement in their practice.

CHAPTER II
OBJECTIVES

In this study, two difference detector arrays were evaluated for IMRT and VMAT pre-treatment patient specific QA; The 2D-diode based MapCHECK2 array and 3D-diode based ArcCHECK.

1. The primary objective was to study detector response dependence on dose, field size, dose rate, the linearity of the detector response, shot term and long term reproducibility.

2. The secondary objective of this thesis was to evaluate and compare the MapCHECK2 and ArcCHECK's ability (for patient related verification of IMRT and VMAT treatment delivery) to measure dose distribution were verified by comparing the measurement with dose distribution from the TPS.

CHAPTER III
LITERATURE REVIEWS

As radiation therapy becomes ever more customizable to each patient, the complexities of the supporting treatment planning system (TPS) and the delivery system increase. This requires a constant evolution of quality assurance (QA) methods used to verify the performance of the systems. These are a lot of different choices of dosimeter for QA measurement.

3.1 Quality Assurance for IMRT

Letourneau et al. [12] evaluated the dosimetric characteristics of the MapCHECK detector, included detector reproducibility, linearity and temperature dependent for high energy photon beams. They found that the diode response is linear within the range of the radiation dose delivered (up to 310 cGy). A temperature dependence of about one-half percent per degree C was also noted. For the clinical performance, their results demonstrate that the MapCHECK can be used to accurately and efficiently verify the dosimetry of IMRT treatment plans.

Another effort at IMRT patient-specific quality assurance by Li. et al. [13] examined two commercially used detector array, an ion chamber-based MatriXX and the diode-based array-MapCHECK before clinical use, they studied the detector response on field size, dose rate and radiation energy and compared to the measurements using a farmer-type ionization chamber. And they evaluated the short-term and long term reproducibility, and also the linearity of the detector response. They found that there was no field size or SSD dependence within the range of the field sizes and SSDs used in their study. Both detector types showed small error (<1%) when they measured for dose of more than 8 cGy, but exhibited large errors when measuring lower dose. The MapCHECK gave a slightly better array sensitivity correction than MatriXX. And they also obtained the excellent passing rate for both detector arrays when compared with IMRT planar dose distributions from TPS for 6 MV and 18 MV photon beams.

3.2 Quality Assurance for VMAT

According to Li et al [14], they evaluated the performance of 3D-diode based ArcCHECK for VMAT patient plan verification. The ArcCHECK was also tested for field size, dose rate, dose per pulse and directional dependence and compared with the results of an ionization chamber. In addition to perform tests for short term reproducibility and dose linearity, The ArcCHECK diodes performed well for all tests except the directional dependence, which varied from a minimum of -3.9% to a maximum of 7.7%. The average gamma analysis pass rates with 3%/3mm for nasopharyngeal cancer, cervical cancer and rectal cancer VMAT plans were 93.5% 95.7% and 97.5% respectively. They conclude that with their proposed calibration method, the ArcCHECK was suitable for VMAT pretreatment verification.

An alternative approach to VMAT patient specific QA was initially presented by Letourneau, et al. [15]. They evaluated a hollow cylindrical phantom which embedded with 124 diodes space 2 cm apart in the walls to form four rings of detectors. For composite dose measurement ability, reproducibility and angular dependence of the diode were assessed, and a correction factor was generated for each diode as a function of gantry angle. The dosimeter tested by Letourneau offers in variant perpendicular incidence on the beam central axis for any gantry angle, being able to measure the beam both to entrance to and exit from the phantom. Their results demonstrated the suitability of the ArcCHECK system for the patient specific QA of VMAT plans.

Another effort at patient-specific quality assurance for RapidArc treatment technique using the MapCHECK diode array by Gloi et al [16]. They compare the absolute dose determinate from the Varian Eclipse treatment planning system to doses measured with ion chamber in the Solid Water plantom. Their study has provided the accuracy obtained with MapCHECK and an ion chamber in phantom. The point dose calculations were within 1% of the treatment planning system predictions. The

MapCHECK analysis showed that 97.5% average passing rate for gamma criteria of 3%, 3mm for most QA plans studied.

Yan, et al. [17] developed the effective calibration procedures for a novel 4D diode array (ArcCHECK) for patient specific VMAT QA, by accounting for diode sensitivity and angular dependence response dependence. A real-time algorithm to derive gantry angle was developed to interpolate corresponding angular correction factors. The diode array has been accurately calibrated and is suitable for clinical applications for demonstration with IMRT and VMAT plans. Excellent agreement was achieved between diode array measurement and TPS calculation. The ArcCHECK was proved to be a valuable tool for both IMRT and VMAT patient specific QA.

The study by Feygelman, et al. [18] evaluated of a new 3D dosimeter array. The array under investigation is a hollow cylindrical phantom with diode detectors fixed in a helical shell forming an “O” axial detector cross section (ArcCHECK), with comparison drawn to previously study 3D array with diodes fixed in two crossing planes forming an “X” axial cross section (Delta^4). In Phase I testing, the ArcCHECK was found to have robust response uniformity between the diode, measurement accuracy for the fields bigger 15 cm in the width is compromised by the diodes, angular response dependence.

In phase II testing, the ArcCHECK had limitations for dosimetry of the fixed-width arcs inherent in the curved detector plane placing all the diodes in the periphery. It has demonstrated good gamma analysis passing rate for the VMAT plans compared to the evaluated by ArcCHECK.

CHAPTER IV
MATERIALS AND METHODS

4.1 Materials

4.1.1 Computerized treatment planning system

The computerized treatment planning system used in this study is Eclipse treatment planning system version 8.6 (Varian Oncology Systems, Palo Alto, CA). The system is based on Windows® operating system and connected with ARIA database server system. The system composes of the Dell Precision 490 workstation, 4 GB memory and network connection devices. The Eclipse TPS have comprehensive option tools to contour, set up plan, evaluate plan and contain beam analysis function for analyzing beam data during beam commissioning and configuration. They have capability to export and import files (image, structure, plan, and dose) in DICOM RT file.

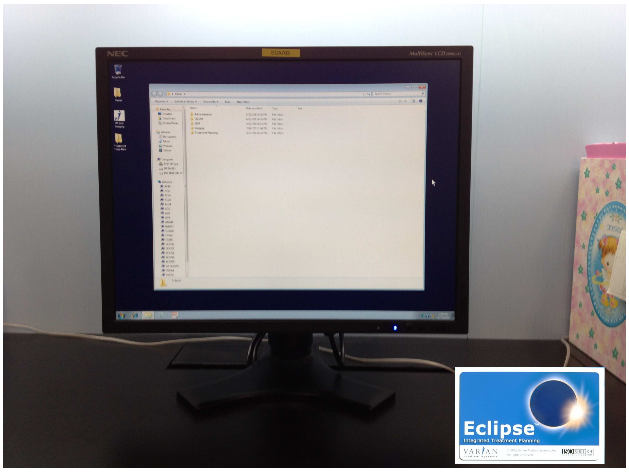


Figure 4.1 Eclipse version 8.6 computerized treatment planning system (Varian Oncology Systems, Palo Alto, CA)

4.1.2 Linear accelerator

The linear accelerator used in this experiment is Varian Clinac iX (Varian Oncology Systems, Palo Alto, CA) as shown in figure 4.2 which produces dual photon beam energies of 6 and 10 MV and six electron beam energies of 6, 9, 12, 15, 18 and 22 MeV. The field sizes are range from 0.3 x 0.3 cm^2 to 40 x 40 cm^2 at isocenter. The machine used double scattering foil system for electron board beam uniformity. The collimator jaws are auto-collimated to optimize field flatness and also minimize collimator scattered electron.

Figure 4.2 Varian Clinac iX linear accelerator (Varian Oncology Systems, Palo Alto, CA)

4.1.3 Ionization chambers and Electrometer

4.1.3.1 FC-65G ionization chamber

A 0.65 cc Farmer type of ionization chamber (Scanditronix, Wellhofer Dosimetries, Schwarzenbruck, Germany) as shown in Figure 4.3 compose with thin walled high purity graphite thimble and pure aluminum electrode which supported by a thin walled aluminum stem. The sensitive volume of chamber is 0.65 cm^3 with 23.1 mm volume length. The chamber was used in dose measurement of output calibration.

Figure 4.3 A FC 65-G (Scanditronix, Wellhofer Dosimetries, Schwarzenbruck, Germany)

4.1.3.2 Electrometer

The electrometer Dose-1 (Scanditronix, Wellhofer Dosimetries, Schwarzenbruck, Germany) shown in figure 4.4 is a portable, single channel, reference class dosimeter according to IEC 60731 for the dosimetry using ionization chambers or semiconductor detectors. The polarization voltage is produced by a AC/DC converter from a 5V internal supply voltage. The polarity and value can be programmed in the range of ±600 V. This electrometer is set at +300 V used with FC65-G. Maximum charge per pulse is approximate ±40 nC/pulse.

Figure 4.4 Dose-1 Electrometer (Scanditronix, Wellhofer Dosimetries, Schwarzenbruck, Germany)

4.1.4. Diode array

4.1.4.1 MapCHECK2 and MapPHAN

2D diode array measurements were taken using the MapCHECK2 with MapPHAN (Sun Nuclear Corporation, Melbourne, FL). The MapCHECK2 model 1177 (Figure 4.5) is a 2D diode array, consists of 1527 diode detectors with a uniform detector spacing thought the array of 7.07 mm, equally a total detector array size of 32 x 26 cm^2.

The MapPHAN is a water equivalent case designed to house the MapCHECK2 for rotational delivery measurements. The MapCHECK device is connected to a computer during delivery.

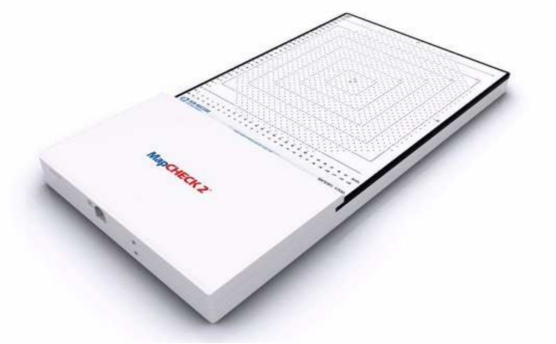


Figure 4.5 MapCHECK2 (Sun Nuclear Corporation, Melbourne, USA)

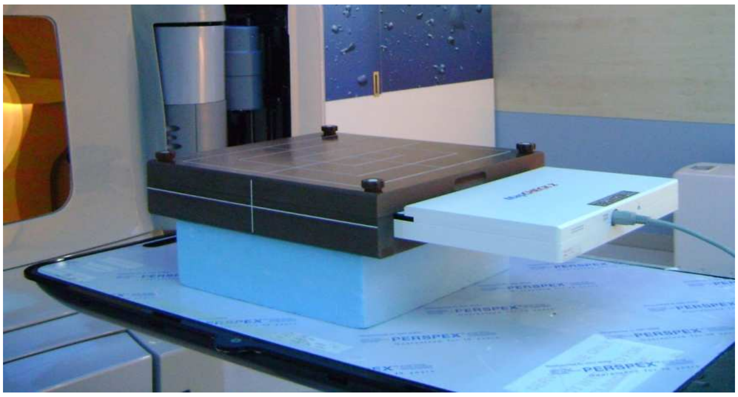
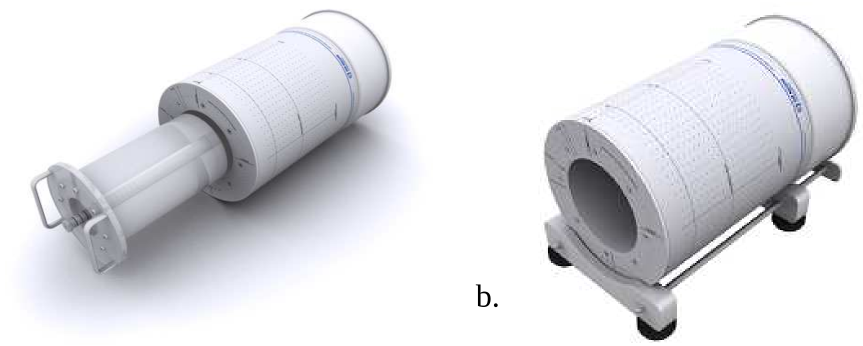


Figure 4.6 The MapPHAN with the MapCHECK2 inserted (Sun Nuclear Corporation, Melbourne, USA)

4.1.4.2 ArcCHECK

The ArcCHECK is a cylindrical with a special array of 1386 diodes. The diodes are placed between two layer of solid water or acrylic and spaced 1 cm apart. The phantom has an outer diameter of 26.6 cm and inner hole diameter of 15.1 cm. with the curve plane of diodes at a distance of 10.4 cm. from the center. Detectors are arranged on a heligrid which increase the sampling rate and reduce rotational response dependent by making the detector array. The overall length is 44.3 cm, of which 11.9 cm is taken up by the electronics section and remaining 32.4 cm is the length of the PMMA phantom; the active area length is 21 cm. An optional PMMA insert is used to eliminate the central cavity inhomogeneity when desired. The ArcCHECK Model 1220 with and without insert (Sun Nuclear Corporation, Melbourne, FL) are shown in Figure 4.7



a. b.

Figure 4.7 The ArcCHECK with and without homogeneouse acrylic insert (Sun Nuclear Corporation, Melbourne, USA)

4.1.5 Computed tomography (CT) system

Figure 4.8 shows a Philips Brilliance Big Bore CT scanner (Philips Medical Systems, Madison, WI) is a modified third generation scanner. It has scanning field of view from 5 to 60 cm. This facility designed for CT imaging for radiation treatment planning can afford patient positioning flexibility. The CT operates with spiral scan to create volumetric image in RTPs which account for inhomogeneity correction with corresponding to CT number on CT images. The image data was imported to Eclipse via DICOM 3 file. The 3 located moving lasers used to define reference marks of isocenter for plan set up.

Figure 4.8 The Philips Brilliance Big Bore CT scanner (Philips Medical Systems, Madison, WI)

4.1.6 Solid water phantom

The solid water phantom (Gammex RMI, Middleton, WI) is made in square slab of 30 × 30 cm^2 with thickness of 0.2, 1.0, 2.0 and 5 cm. This solid water phantom is created from a mixture of solid and liquid components, which are stored in a temperature and humidity controlled environment. The components are combined in an industrial mixture under vacuum to reduce air bubbles. It has the physical density of 1.043 ±0.005 g/cm^3.

Figure 4.9 Gammex solid water phantoms (Gammex RMI, Middleton, WI)

4.2 Methods

All measurement' were done with 6 and 10 MV X-ray beams from Varian linear accelerator with 120 leaf Millennium MLC (Varian Oncology Systems, Palo Alto, CA) all plans were generated using the Eclipse treatment planning system (Varian Oncology Systems, Palo Alto, CA).

In this study, two difference diode arrays were evaluated for IMRT and VMAT patient specific plan verification: the planar diode array MapCHECK2 (Sun Nuclear Corporation, Melbourne, FL) and the cylindrical diode array ArcCHECK (Sun Nuclear Corporation, Melbourne, FL). For dosimetric device, it is necessary to investigate how accurately each detector measures the radiation dose.

The study was divided into 2 parts

Part 1: to study the performance of 2 detector types.

Part 2: to evaluate these two diode arrays types for IMRT and VMAT plans verification.

Before MapCHECK2 and ArcCHECK could be used for measurements for patient specific QA for IMRT or VMAT. It had to be calibrated the detector array both MapCHECK2 and ArcCHECK for relative array and absolute dose calibration.

A.) Relative array calibration

Array calibration is a process of determining the relative sensitivity differences between the detectors in the diode array instrument. These differences are stored as individual correction factors to be applied to the raw measurement from each detector. This ensures that all detectors will have the same sensitivity and eliminates response difference between individual detectors. The calibration process is designed by the manufacture.

For the MapCHECK, array calibration consists of five steps, identified as steps A through E according to manual of MapCHECK2 [19]. The position of the 2D diode array was set on the treatment couch. (Figure 4.10) The couch height was adjusted to 100 cm SSD for 37 x 37 cm^2 fields. The cross hairs were aligned with the indicated point which marked on the surface of the 2D diode array. The monitor unit was set at 200 MU for each steps. The 2D diode array was rotated at 90 degree for steps B and C but for step D and E, the center of the cross hairs were shifted to position D and Eon the surface of the array, respectively.

Figure 4.10 The set up of MapCHECK2 on the treatment couch

For the ArcCHECK array calibration consists of eleven steps, identified as steps A through K according to manual of ArcCHECK [20]. The initial position of the 3D diode array was set on the treatment couch. (Figure 4.11) The couch height was adjusted to 100 cm SAD, 86.7 cm SSD for 20 x 28 cm^2 fields. The cross hairs were aligned with the indicated point which marked on the surface and lasers aligned with the indicated point which marked on the top and lateral surface of the 3D diode array. The monitor unit was set at 200 MU for each steps. Step A measurement at rotated the gantry to -57 degrees (303 IEC), step B measurement at rotated the gantry to -8 degrees (352 IEC), step C measurement at rotated the gantry to 8 degrees (8 IEC), step D measurement at rotated the gantry to 57 degrees (57 IEC), step E shift the couch 5 mm toward the target and measurement at rotated the gantry to -8 degrees (352 IEC), step F shift the couch 10 mm toward the gun and measurement at rotated the gantry to -8 degrees (352 IEC), step G changed the ArcCHECK by rotated 180 degrees such that the sagittal line was now faced the couch and measured at rotated the gantry to -74 degrees (286 IEC), step H measured at rotated the gantry to -25 degrees (335 IEC), step I measured at rotated the gantry to 25 degrees (25 IEC), step J measured at rotated the gantry to 74 degrees (74 IEC), step K changed the ArcCHECK by inverted the

ArcCHECK so that the electronics are faced the gun and rotated 180 degrees such that the sagittal line was at the top of instrument, centered the cross hairs on the axial, shift the couch 5 mm toward the target and sagittal line and measured at rotated the gantry to 8 degrees (8 IEC).

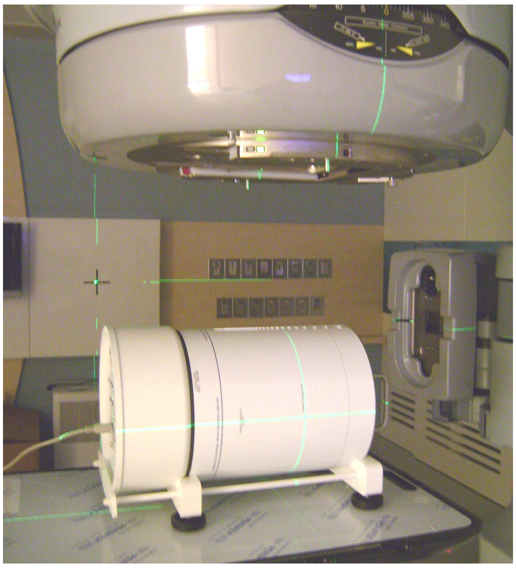


Figure 4.11 The initial set up of ArcCHECK on the treatment couch

B.) Absolute dose calibration

The absolute dose calibration is a process of creating a dose calibration correction factor that is used to convert relative dose values to absolute dose values. The dose calibration correction factor is applied to all detectors in addition to the array sensitivity correction factor.

For the MapCHECK2 absolute dose calibration was performed with 6 and 10 MV photon beam at 5 cm tissue equivalent depth for 10 x10 cm^2 field and 100 cm SDD by integrating with MapPHAN. The delivered dose was 105 MU for 100 cGy at 6 MV photon beam and 100 MU for 100 cGy at 10 MV photon beam. The set up of MapCHECK2 integrated with MapPHAN is shown in figure 4.12.

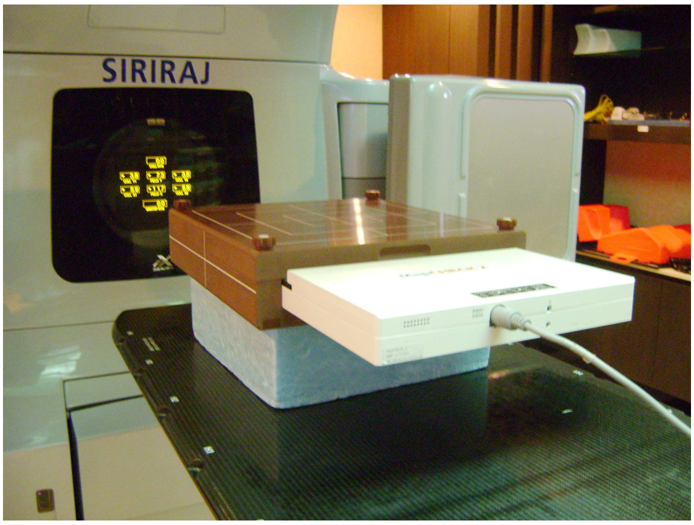


Figure 4.12 The set up of MapCHECK2 integrated with MapPHAN for dose calibration

For the ArcCHECK, absolute dose calibration was performed with 6 and 10 MV photon beams for 10 x10 cm^2 field and 86.7 cm SSD or 89.6 cm SDD of ArcCHECK. The delivered dose was 161 MU for 200 cGy for 6 MV and 152 MU for 200 cGy for 10 MV X-rays. The inherent buildup was 2.9 cm which equals to 3.3 cm water equivalent, the set up position of 3D diode array for dose calibration is shown in figure 4.13.

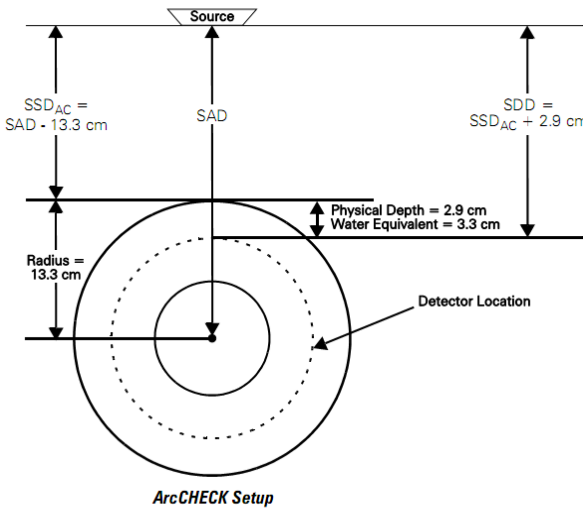


Figure 4.13 The set up of ArcCHECK for dose calibration

4.2.1 Detector performance test

In this part, we studied the characteristics of both diode array systems before clinical use. They included the detector's short term and long term reproducibility, dose linearity, detector response dependent on field size, dose rate and angular dependence of detector array systems.

4.2.1.1 Diode array reproducibility

We studied the diode reproducibility over a measurement period, short term reproducibility was evaluated by repeating the same measurement every 10 minutes over one-hour period and calculated the SD of 10 consecutive reading of five central diodes made by MapCHECK2 and ArcCHECK systems calculated the SD of 10 consecutive reading of two central diodes for 6 and 10 MV photon beams.(show in the figure 4.14 and 4.15) The measurements were performed with 3.3 cm of water equivalent thickness using a 10 × 10 cm^2 field size at a 100 cm SAD for MapCHECK2 and ArcCHECK respectively. In the ArcCHECK were performed with insert core and without insert core.

For our long term reproducibility study, we repeated the same measurements with the reading every week over a four-month period. The reproducibility of the dosimetric system was measured in similar condition for MapCHECK2 and ArcCHECK for comparison.

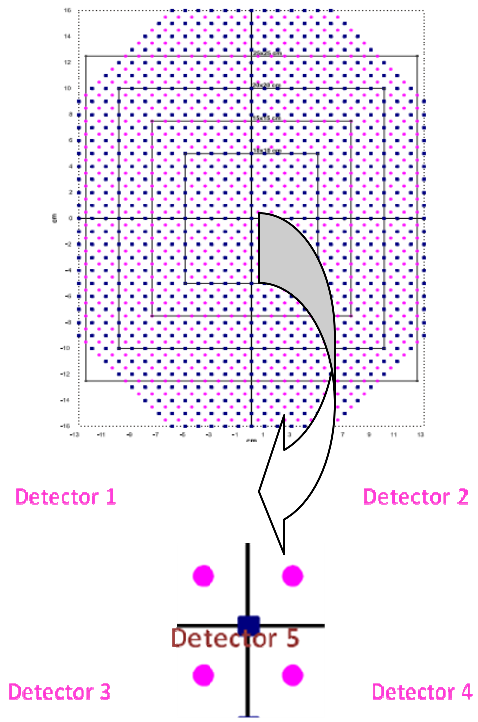


Figure 4.14 The position of five diode readings in the MapCHECK2

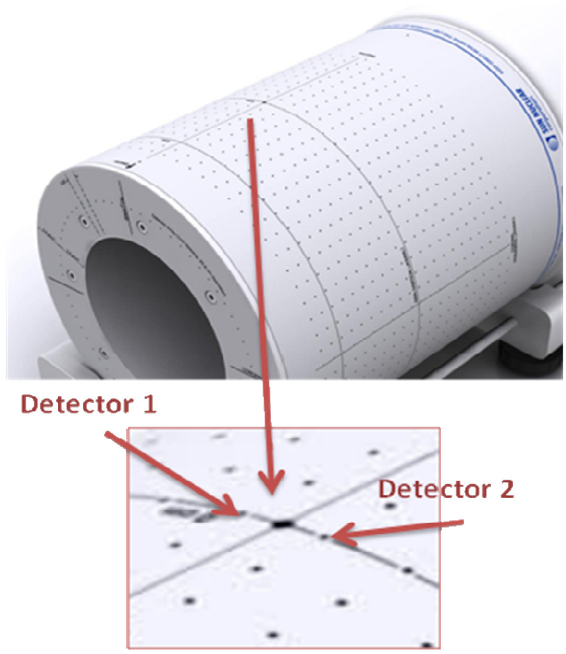


Figure 4.15 The position of two diode readings in the ArcCHECK

4.2.1.2 Dose linearity and energy of the detector response

The linearity of the detectors response was assessed by delivering varying amounts of radiation dose with a 6 and 10 MV photon beams from 20 to 400 MU using a 10 × 10 cm^2 field size at 89.6 cm SDD dose rate of 400 MU/min. The average readings from the five central diode of the MapCHECK2 and two central diode of the ArcCHECK were correlated with the delivered dose. The measurements were performed at 3.3 cm of water equivalent thickness for MapCHECK2 and ArcCHECK similar to set up in 4.2.1.1. And two scatter material configurations were used for the measurement using MapCHECK2. First set up, we used solid water phantom 3.3 cm thickness to simulate ArcCHECK without insert show in the figure 4.16. Another set up, we used 15 cm thickness of solid water phantom to simulate the ArcCHECK with insert show in the figure 4.17.

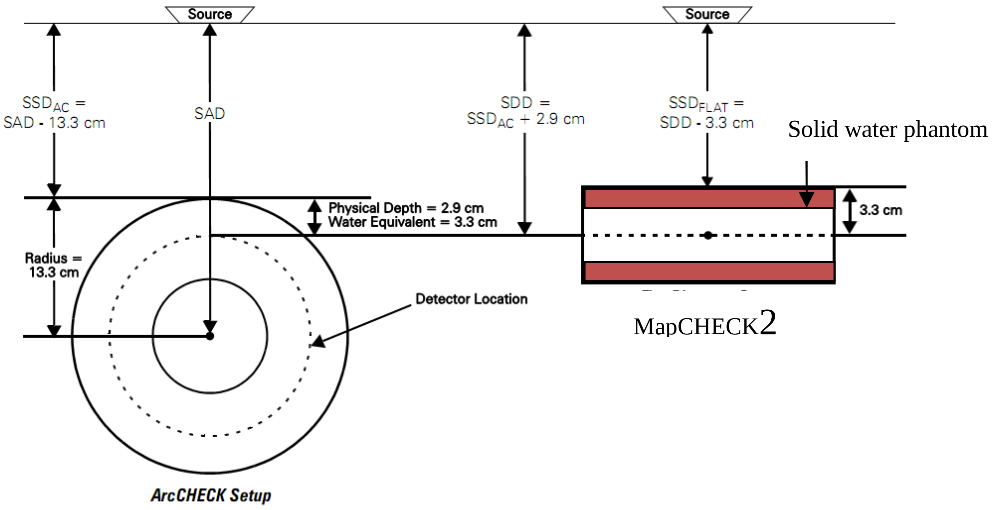


Figure 4.16 The MapCHECK with solid water phantom to simulate the ArcCHECK without insert.

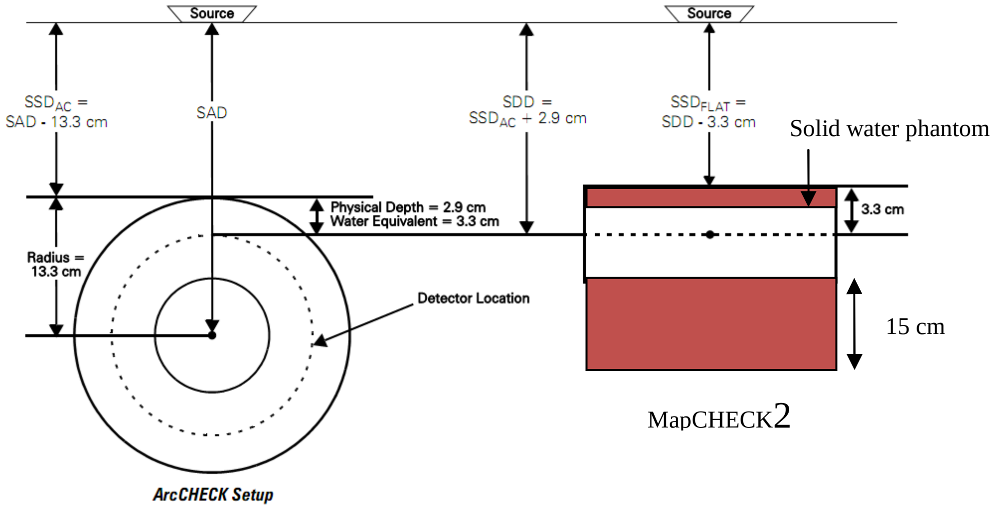


Figure 4.17 The MapCHECK with solid water phantom to simulate the ArcCHECK with insert.

4.2.1.3 Repetition rate dependence

The dose rate effect dependence was performed for both 6 and 10 MV photon beams by varying the repetition rate from 100 MU/min. to 600 MU/min. (100, 200, 300, 400, 500 and 600 MU/min) using the same set-up geometry that used in 4.2.1.2 with a fixed field size of 10 × 10 cm^2 at 89.6 cm source-to-detector distance for both detectors system and for the same set monitor unit on the console. The average readings from the five central diode of the MapCHECK2 and two central diode of the ArcCHECK were evaluated constancy.

4.2.1.4 Detector-response on field size

The response of the detectors as a function of field size for 6 and 10 MV photon beams was assessed by measuring the relative dose output for various square field sizes ranging from 3 × 3 cm^2 to 25 × 25 cm^2 (3 x 3, 4 x 4, 5 x 5, 6 x 6, 8 x 8, 10 x 10, 12 x 12, 15 x 15, 18 x 18, 20 x 20, and 25 x 25 cm^2) at 89.6 SDD, with 3.3 cm depth using the same set-up geometry that used in 4.2.1.2. The average readings from the five central diode of the MapCHECK2 and two central diode of the ArcCHECK were compared with those obtained by a FC 65-G ionization chamber in the same geometry.

4.2.1.5 Angular dependence

For the MapCHECK2 with MapPHAN, the angular dependent was measured by varying the gantry angle from 0 degree to 180 degree every 15 degree interval with a fixed field size of 10 × 10 cm^2 at 100 cm source-to-detector distance. The measurements were performed on both 6 and 10 MV photon beams. The corresponding readings were measured.

For the ArcCHECK system, due to its design, it is aligned with the isocenter and positioned approximately on the central axis. A narrow beam segment can be considered approximately normal to the detector surface. If the segment deviated away from the central axis or the field size increase, the angular dependence of the ArcCHECK system could be an important factor. So it has to be accounted for.

An experiment to test the angular dependence of the ArcCHECK system is to compare the measured and calculated dose profiles for a sets of beams by increasing width, the measurement were made with a series of open fields ranging from 10 × 10, 15 × 15, 20 × 20 and 25 × 25 cm^2 was projected on the ArcCHECK center. The dose profiles along the curved plane of detectors were normalized to the respective central axis dose.

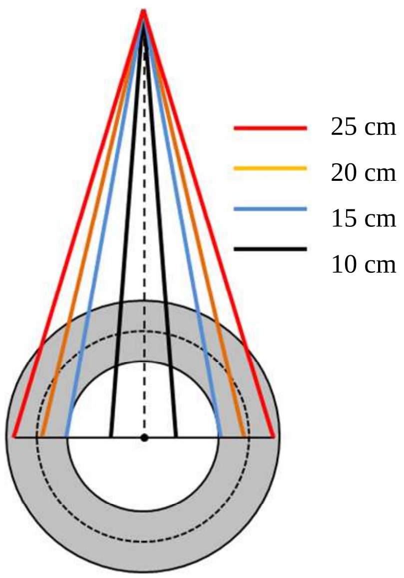


Figure 4.18 The set up geometry for angular dependence test of the ArcCHECK

4.2.2 Dosimetric verification for IMRT and VMAT plans

4.2.2.1 Patient characteristic

For pretreatment patient specific QA, ten dynamic IMRTs were selected randomly and included difference anatomy locations to provide a variety of complexity: two head and neck (H&N) cancers, three prostate cancer, two abdominal regions cancers and three other non-coplanar plans. Then we designed a VMAT plans, we re-planed all the patient data previously with IMRT.

4.2.2.2 Created IMRT and VMAT verification plans

The IMRT and VMAT plans for each patient were then recalculated on the CT images of MapCHECK2 with MapPHAN, ArcCHECK with insert. The percentage of gamma passing with criteria of 3% and 3 mm was then used to compare the dosimetric system with each other.

For the MapCHECK2, we created the verification plans with composite fields at the gantry 0 degree and at the planned gantry for every IMRT QA plans as shown in figure 4.19 and 4.20 respectively. And we also created the IMRT verification plans with composite fields at the planned gantry on the ArcCHECK with acrylic insert for every treatment plans as shown in figure 4.21

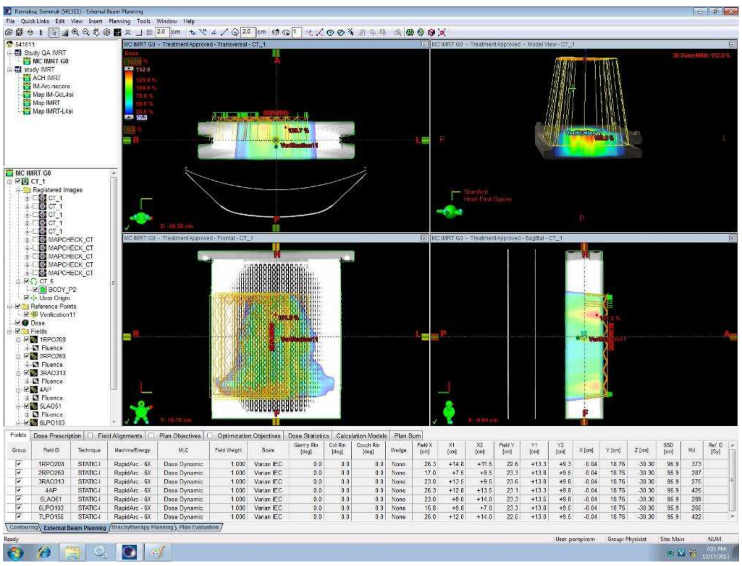


Figure 4.19 IMRT QA plans for the MapCHECK2 at gantry 0 degree

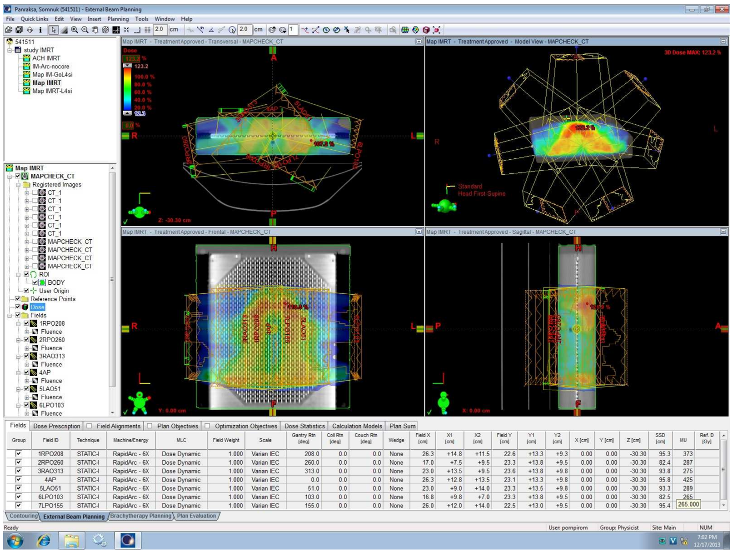


Figure 4.20 IMRT QA plans for the MapCHECK2 at planned gantry

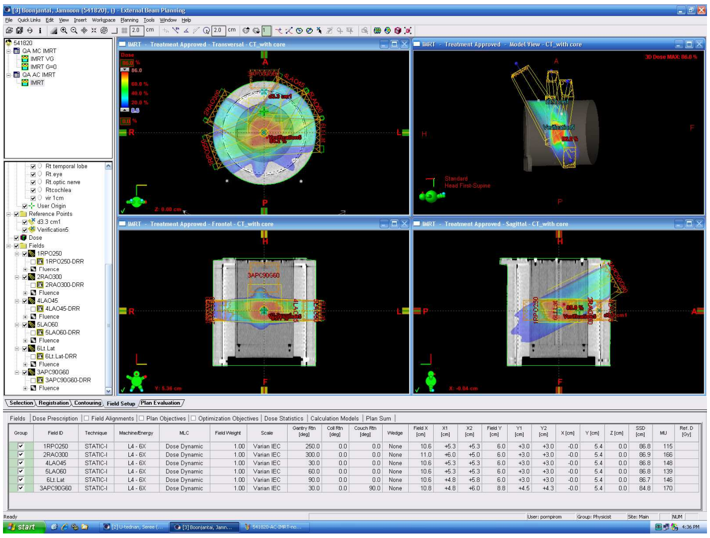


Figure 4.21 IMRT QA plans for the ArcCHECK at planned gantry

The VMAT plans were created for pretreatment verification with composite fields at the planned gantry for all QA plans using both MapCHECK2 integrated with MapPHAN and the ArcCHECK, with acrylic insert that were shown in figure 4.22 and 4.23 respectively.

All treatment plans were exported from Eclipse treatment planning system version 8.6 as DICOM files to the record and verify system ARIA version 8.6

The QA of fix beam IMRT and VMAT treatment generally consists of two major parts: an absolute dose measurement to a reference point and at least on measured plan of dose distribution.

The MapCHECK2 with MapPHAN and ArcCHECK system were set up on the treatment couch. The diode array was then aligned properly with the room laser.

The details of all pretreatment plans for verification are showed in appendix.

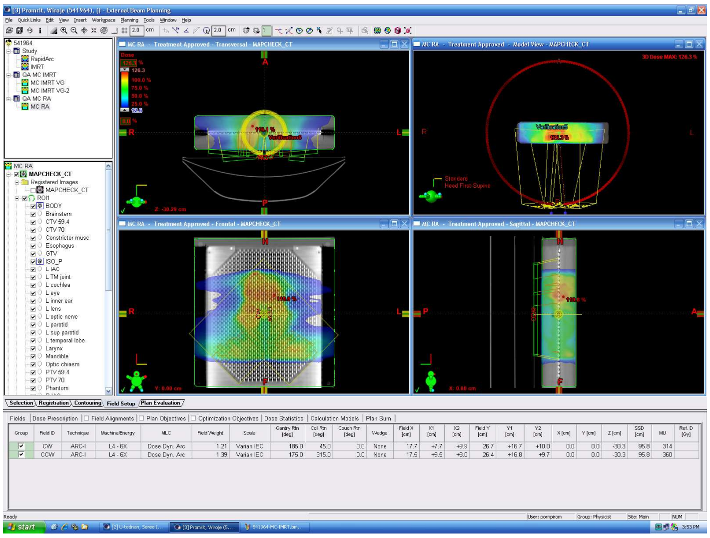


Figure 4.22 VMAT QA plans for the MapCHECK2

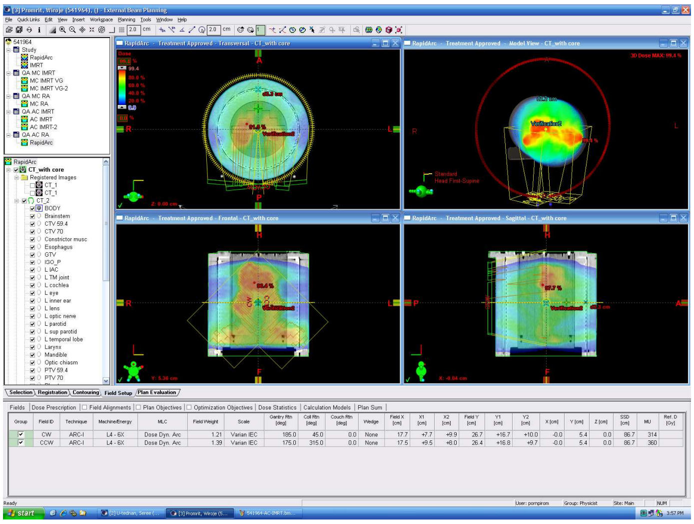


Figure 4.23 VMAT QA plans for the ArcCHECK

4.2.2.3 Data analysis

The delivered doses in the detectors are compared to the planning dose using detector software. We evaluated the dose by the gamma index with criteria 3% and 3 mm for each pretreatment patient specific QA plan. After dose delivering to both detector systems, absolute dose difference between measured and planned dose were analyzed using 3% dose difference and 3 mm distance-to-agreement for each pretreatment patient specific QA plan using MapCHECK2 and ArcCHECK as shown in fig.4.24 and 4.25 respectively.

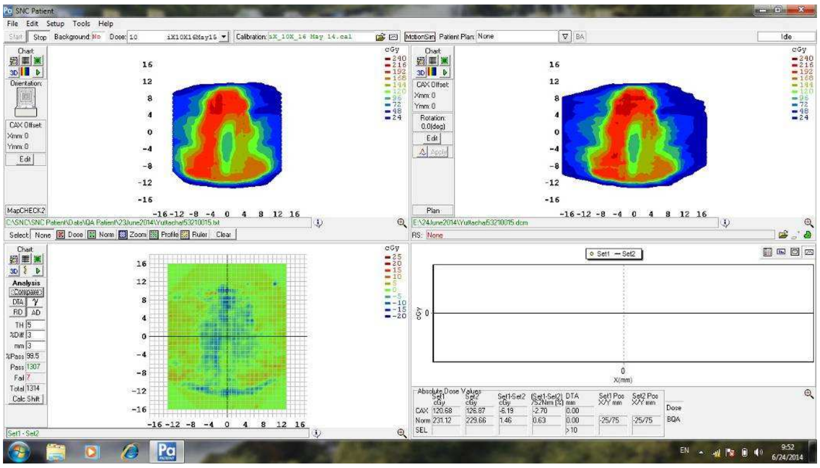


Figure 4.24 QA plans verification for the MapCHECK2

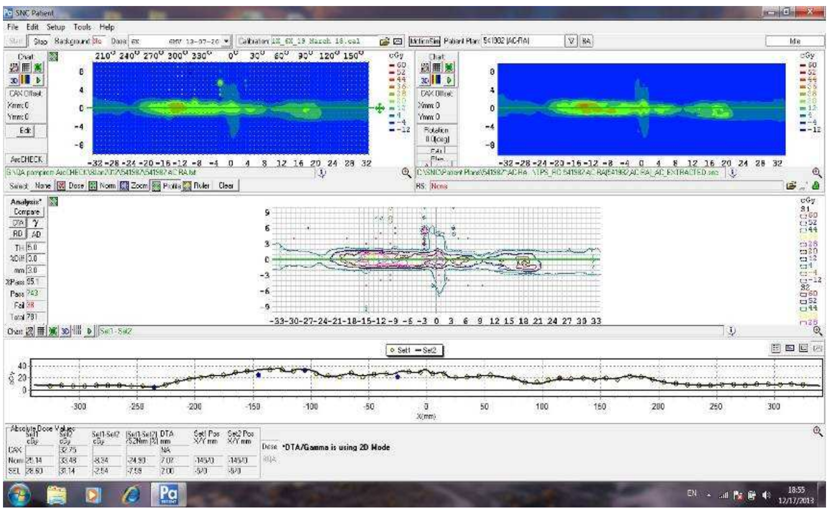


Figure 4.25 QA plans verification for the ArcCHECK

CHAPTER V
RESULTS

5.1 Detector performance test

5.1.1 Diode Array Reproducibility

The short-term and long-term reproducibility of both MapCHECK2 and ArcCHECK were evaluated by repeating the same measurement at every 10 minutes over a one-hour period and every week over a four-month period respectively, the results of MapCHECK2 reproducibility for 6 and 10 MV photon beams are shown in table 5.1, 5.2, 5.3 and 5.4.

The maximum standard deviation of short term reproducibility for MapCHECK2 is 0.15 and the long term reproducibility is not more than 1.63 for 6 and 10 MV photon beams.

Table 5.1 The short term reproducibility of MapCHECK2 for 6 MV photon beams, the data were measured every 10 minutes over one hour period.

No. of measurement	Diode number				
	1	2	3	4	5
1	90.14	90.03	91.09	90.26	92.56
2	90.11	89.94	91.08	90.25	92.55
3	90.13	90.03	91.12	90.36	92.63
4	90.14	89.89	91.07	90.17	92.53
5	90.21	89.91	91.06	90.25	92.52
6	90.21	90.00	91.13	90.33	92.54
7	90.23	89.96	91.12	90.35	92.59
8	90.16	89.96	91.07	90.26	92.58
9	90.17	89.99	91.13	90.31	92.53
10	90.23	89.95	91.10	90.29	92.51
average	90.17	89.97	91.10	90.28	92.55
SD	0.04	0.05	0.03	0.06	0.04

Table 5.2 The short term reproducibility of MapCHECK2 for 10 MV photon beams, the data were measured every 10 minutes over one hour period.

No. of measurement	Diode number				
	1	2	3	4	5
1	96.81	96.47	97.53	96.84	99.26
2	96.60	96.42	97.34	96.60	98.98
3	96.51	96.26	97.22	96.58	98.96
4	96.42	96.28	97.14	96.39	98.94
5	96.63	96.41	97.00	96.32	98.84
6	96.55	96.26	97.16	96.42	98.91
7	96.50	96.26	97.22	96.48	98.89
8	96.49	96.28	97.20	96.36	98.90
9	96.43	96.25	97.12	96.44	98.88
10	96.48	96.29	97.24	96.42	98.84
average	96.54	96.32	97.22	96.49	98.94
SD	0.12	0.08	0.14	0.15	0.12

Table 5.3 The long term reproducibility of MapCHECK2 for 6 MV photon beams, the data were measured every week over a four-month period.

No. of measurement	Diode number				
	1	2	3	4	5
1	88.63	88.55	89.02	88.02	90.55
2	89.74	89.72	90.31	88.63	91.79
3	89.92	89.84	90.73	88.90	92.15
4	90.58	90.55	91.34	89.83	92.89
5	90.12	90.00	91.09	90.29	92.58
6	92.95	93.28	94.04	93.95	95.43
7	91.00	91.08	91.88	91.18	93.25
8	90.17	89.86	90.86	89.98	92.46
9	89.85	89.72	90.65	89.80	92.21
10	89.47	89.18	90.09	89.18	91.69
average	90.24	90.18	91.00	90.18	92.50
SD	1.14	1.29	1.32	1.63	1.27

Table 5.4 The long term reproducibility of MapCHECK2 for 10 MV photon beams, the data were measured every week over a four-month period.

No. of measurement	Diode number				
	1	2	3	4	5
1	94.53	94.50	94.69	93.61	96.48
2	96.20	96.20	96.57	95.98	98.28
3	95.98	95.94	96.52	95.79	98.20
4	96.63	96.68	97.19	96.75	98.90
5	96.64	96.38	97.36	96.68	99.07
6	98.99	99.34	99.64	99.54	101.49
7	97.48	97.54	98.02	97.38	99.71
8	96.42	96.20	96.94	96.11	98.80
9	96.11	95.98	96.74	95.88	98.48
10	95.85	95.54	96.21	95.38	98.04
average	96.48	96.43	96.99	96.31	98.74
SD	1.16	1.28	1.27	1.52	1.28

The results of ArcCHECK reproducibility for 6 and 10 MV photon beams are shown in table 5.5, 5.6, 5.7 and 5.8. We found that the maximum standard deviation of short term is 0.34 and long term reproducibility is about 1.0 ever with or without PMMA insert.

Table 5.5 The short term reproducibility of ArcCHECK with and without insert core for 6 MV photon beams, the data were measured every 10 minutes over one hour period.

No. of measurement	Diode number			
	Without insert		With insert	
	1	2	1	2
1	122.78	123.16	122.99	123.16
2	122.83	123.33	122.96	123.15
3	122.96	123.48	123.23	123.35
4	122.73	123.12	122.65	123.87
5	123.20	123.32	123.30	123.40
6	123.01	123.50	123.23	123.33
7	123.20	123.47	123.26	123.44
8	123.98	123.44	122.62	122.84
9	122.79	123.39	122.54	122.73
10	122.87	123.12	122.38	122.59
average	122.94	123.33	122.92	123.09
SD	0.17	0.15	0.34	0.31

Table 5.6 The short term reproducibility of ArcCHECK with and without insert core for 10 MV photon beams, the data were measured every 10 minutes over one hour period.

No. of measurement	Diode number			
	Without insert		With insert	
	1	2	1	2
1	130.84	131.90	131.35	132.49
2	130.90	132.09	131.30	132.39
3	130.88	132.07	131.39	132.55
4	130.88	132.06	131.31	132.34
5	130.90	132.11	131.34	132.41
6	130.79	132.08	131.47	132.44
7	130.83	132.12	131.36	132.40
8	130.81	132.10	131.45	132.43
9	130.88	132.07	131.50	132.49
10	130.90	132.10	131.45	132.52
average	130.86	132.07	131.39	132.45
SD	0.04	0.06	0.07	0.07

Table 5.7 The long term reproducibility of ArcCHECK with and without insert core for 6 MV photon beams, the data were measured every week over four month period.

No. of measurement	Diode number			
	Without insert		With insert	
	1	2	1	2
1	122.83	123.19	122.86	123.33
2	122.15	122.84	122.30	122.93
3	122.42	122.99	122.65	122.78
4	122.42	124.53	124.47	124.54
5	125.52	124.16	125.51	124.09
6	123.85	125.69	124.05	125.49
7	124.37	124.09	124.65	124.48
8	123.52	124.31	123.49	124.16
9	123.52	124.31	124.08	124.64
10	123.55	123.98	123.68	124.05
average	123.62	124.21	123.77	124.25
SD	1.01	1.02	0.99	1.05

Table 5.8 The long term reproducibility of ArcCHECK with and without insert core for 10 MV photon beams, the data were measured every week over four month period.

No. of measurement	Diode number			
	Without insert		With insert	
	1	2	1	2
1	130.85	131.04	130.21	130.54
2	131.56	131.30	129.34	129.95
3	131.89	131.98	129.70	130.21
4	131.02	131.20	130.92	131.12
5	131.43	130.92	132.22	132.64
6	131.02	131.96	131.03	132.20
7	131.40	132.51	131.37	132.55
8	130.80	131.40	130.85	131.63
9	131.19	131.96	131.52	132.26
10	130.64	131.10	130.82	131.33
average	131.18	131.54	130.80	131.44
SD	0.39	0.53	0.86	0.98

5.1.2 Linearity of the detector response

The response of the detectors as a function of delivered dose from 20-400 cGy for 6 and 10 MV photon beams both MapCHECK2 and ArcCHECK are linear, as shown in table 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, 5.15 and 5.16 and also shown in figure 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7 and 5.8. Both detectors show a linear response with regression coefficient of 1.00

Table 5.9 The dose linearity from 20 to 400 cGy of the MapCHECK2 with the backscatter phantom on 6 MV photon beams.

Delivered dose(cGy)	Dose values of diode (cGy)					
	Diode number					Avg.
	1	2	3	4	5	
20	20.15	20.20	20.18	20.19	20.09	20.16
40	40.77	40.89	40.83	40.75	40.65	40.78
50	50.99	51.04	51.06	50.86	50.79	50.95
101	101.99	102.18	102.07	101.88	101.65	101.95
150.5	153.13	153.26	153.12	152.79	152.53	152.97
200	203.99	204.14	204.05	203.66	203.19	203.81
251	254.98	255.28	255.12	254.60	254.09	254.81
302	306.25	306.56	306.23	305.58	304.96	305.92
403	408.17	408.61	408.58	407.40	406.56	407.86

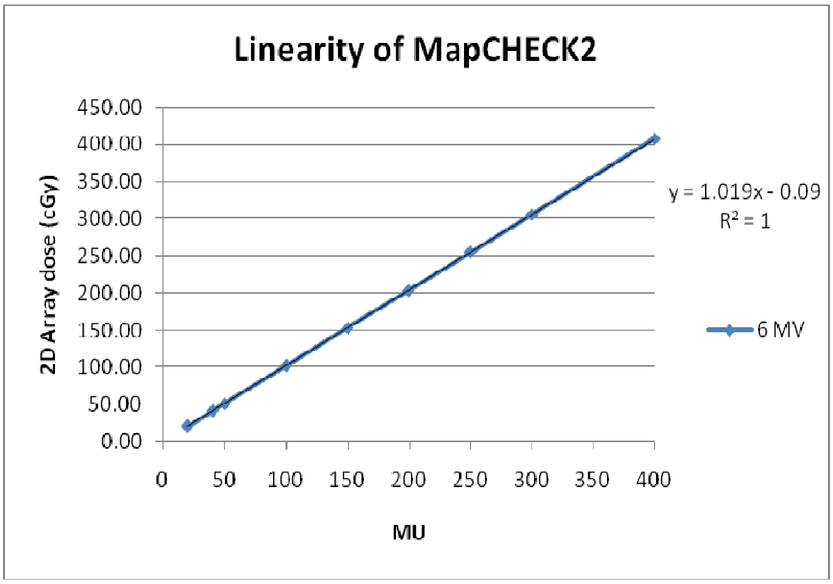


Figure 5.1 The dose linearity of the MapCHECK2 for 6 MV photon beams, with backscatter phantom

Table 5.10 The dose linearity from 20 to 400 cGy of the MapCHECK2 with the backscatter phantom on 10 MV photon beams.

Delivered dose(cGy)	Dose values of diode (cGy)					
	Diode number					Avg.
	1	2	3	4	5	
20	20.86	20.95	21.00	20.88	20.83	20.90
40	41.62	41.71	41.86	41.72	41.63	41.71
50	52.10	52.15	52.36	52.14	52.09	52.17
101	104.17	104.29	104.64	104.24	104.20	104.31
150.5	156.47	156.43	156.87	156.36	156.15	156.46
200	208.57	208.58	209.21	208.39	208.23	208.60
251	260.61	260.67	261.40	260.44	260.24	260.67
302	313.00	312.90	313.78	312.64	312.44	312.95
403	417.07	416.93	418.41	416.73	416.32	417.09

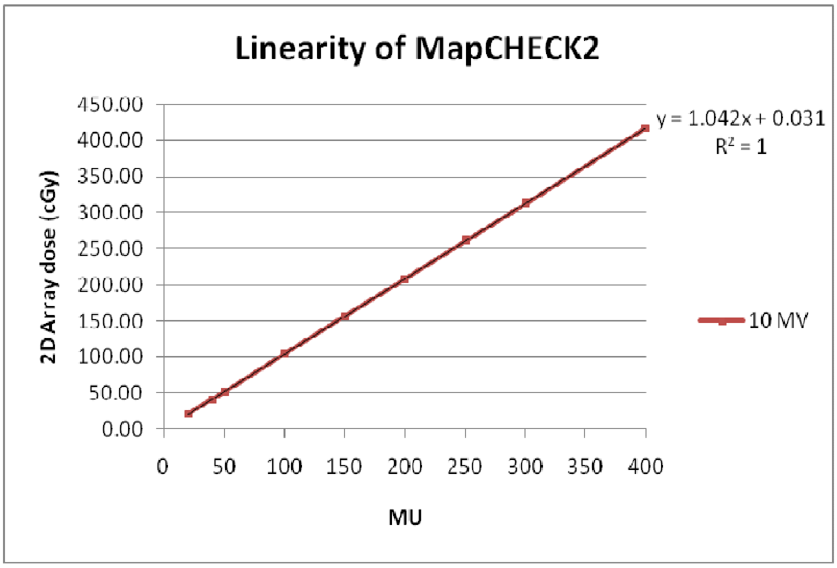


Figure 5.2 The dose linearity of the MapCHECK2 for 10 MV photon beams, with backscatter phantom

Table 5.11 The dose linearity from 20 to 400 cGy of the MapCHECK2 without the backscatter phantom on 6 MV photon beams.

Delivered dose(cGy)	Dose values of diode (cGy)					
	Diode number					Avg.
	1	2	3	4	5	
20	20.31	20.27	20.31	20.26	20.29	20.29
40	40.46	40.42	40.49	40.44	40.40	40.44
50	50.80	50.69	50.75	50.70	50.62	50.71
101	101.52	101.36	101.43	101.15	101.30	101.35
150	152.43	152.03	152.22	152.01	151.92	152.12
200	203.11	202.66	203.06	202.68	202.47	202.80
251	253.75	253.80	253.80	253.25	252.98	253.52
302	304.46	304.82	304.37	303.99	303.51	304.23
403	405.74	406.09	405.85	405.17	404.41	405.45

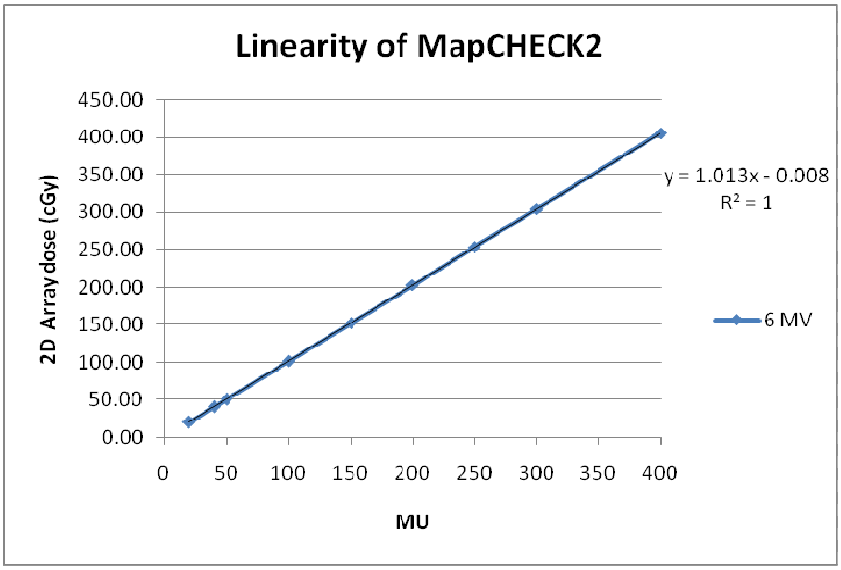


Figure 5.3 The dose linearity of the MapCHECK2 for 6 MV photon beams, without backscatter phantom

Table 5.12 The dose linearity from 20 to 400 cGy of the MapCHECK2 without the backscatter phantom on 10 MV photon beams.

Delivered dose(cGy)	Dose values of diode (cGy)					
	Diode number					Avg.
	1	2	3	4	5	
21.0	20.82	20.85	21.0	20.88	20.92	20.89
41.5	41.35	41.27	41.62	41.40	41.46	41.42
52.0	51.96	51.87	52.25	52.0	52.08	52.03
104.0	103.88	103.68	104.36	103.98	104.07	103.99
156.0	155.66	155.24	156.31	155.57	155.8	155.72
208.0	207.63	206.99	208.39	207.72	207.68	207.68
260.0	259.46	258.76	260.53	259.71	259.85	259.66
312.0	311.2	310.38	312.65	311.60	311.78	311.52
416.0	414.97	413.83	416.81	415.50	415.65	415.35

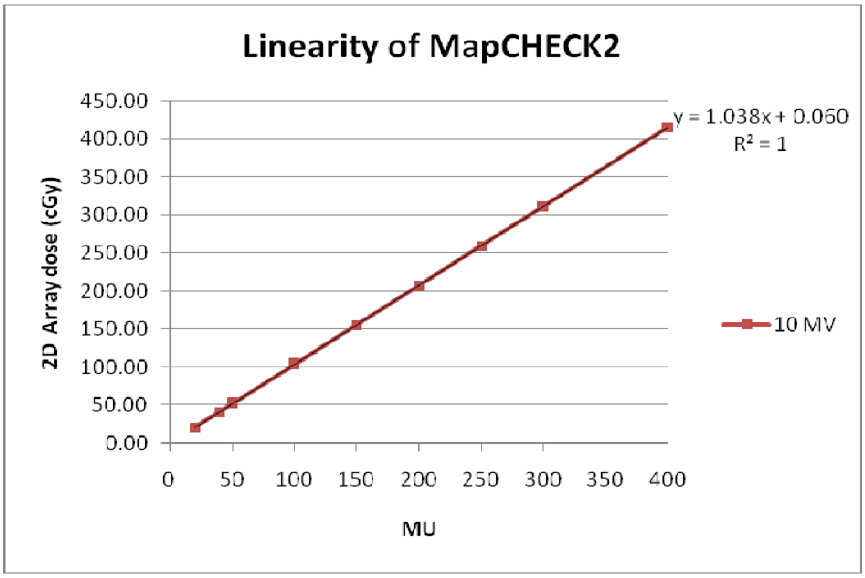


Figure 5.4 The dose linearity of the MapCHECK2 for 10 MV photon beams, without backscatter phantom

Table 5.13 The dose linearity from 20 to 400 cGy of the ArcCHECK with insert core on 6 MV photon beams.

Delivered dose(cGy)	Dose values of diode (cGy)		
	Diode number		
	1	2	average
24.8	24.56	24.64	24.60
49.7	48.99	49.22	49.11
62	61.24	61.45	61.35
124	122.38	122.80	122.59
186	183.63	184.28	183.95
248	244.98	246.02	245.50
310	306.58	307.49	307.03
372	367.84	369.01	368.43
496	490.56	492.37	491.46

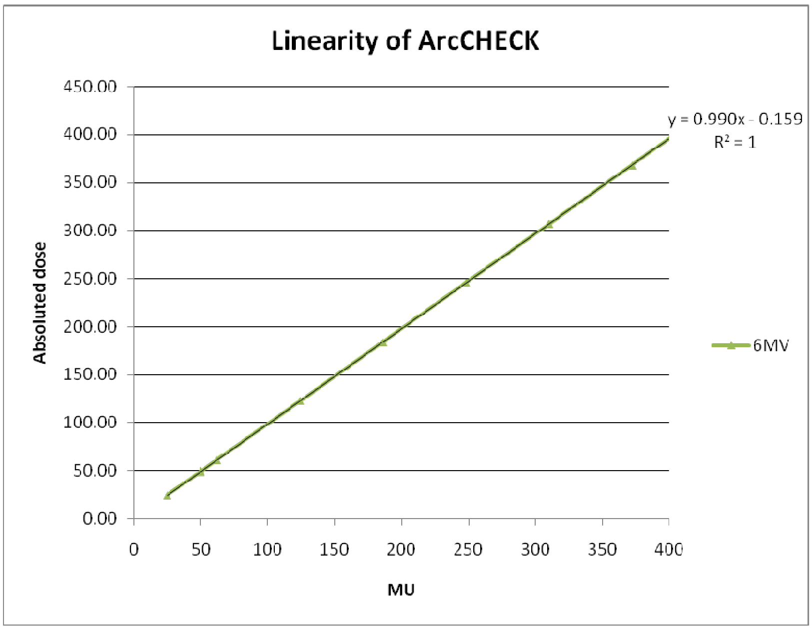


Figure 5.5 The dose linearity of the ArcCHECK for 6 MV photon beams, with insert

Table 5.14 The dose linearity from 20 to 400 cGy of the ArcCHECK with insert core on 10 MV photon beams.

Delivered dose(cGy)	Dose values of diode (cGy)		
	Diode number		
	1	2	average
26.3	26.20	26.48	26.34
52.7	52.43	52.92	52.68
65.9	65.53	66.20	65.86
131.7	131.13	132.27	131.70
197.6	196.72	298.62	197.70
263.4	262.10	264.76	263.43
329.3	327.67	330.78	329.22
395.2	393.32	396.99	395.16
526.9	524.46	529.05	526.76

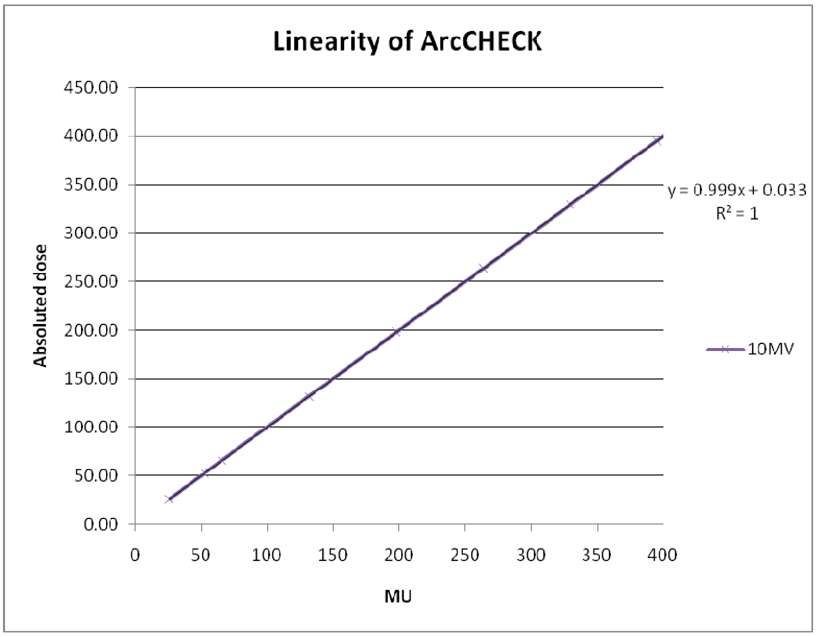


Figure 5.6 The dose linearity of the ArcCHECK for 10 MV photon beams, with insert

Table 5.15 The dose linearity from 20 to 400 cGy of the ArcCHECK without insert core on 6 MV photon beams.

Delivered dose(cGy)	Dose values of diode (cGy)		
	Diode number		
	1	2	average
24.8	24.73	24.74	24.74
49.7	49.25	49.41	49.33
62	61.52	61.66	61.59
124	122.87	123.12	123.00
186	183.86	184.55	184.21
248	245.57	246.62	246.10
310	306.95	308.25	307.60
372	368.45	369.84	369.14
496	491.52	493.46	492.49

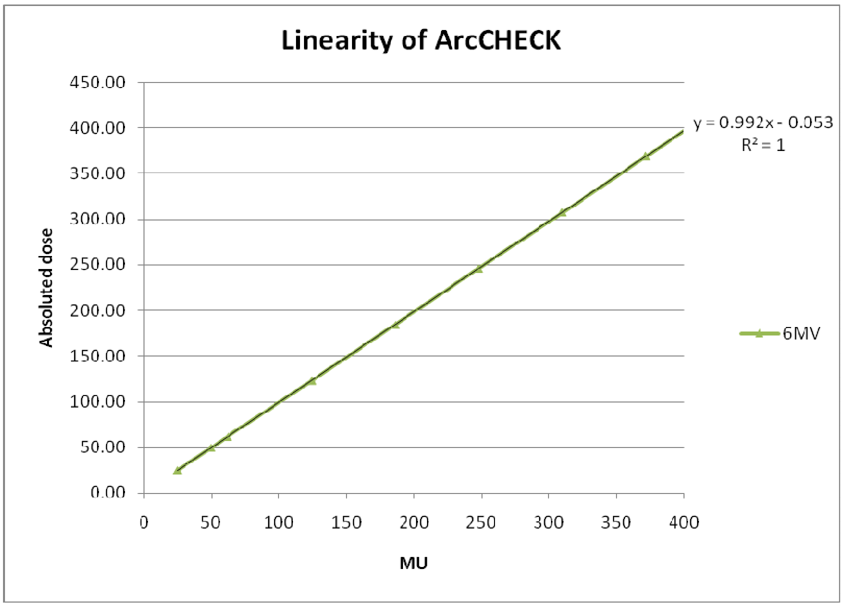


Figure 5.7 The dose linearity of the ArcCHECK for 6 MV photon beams, without insert

Table 5.16 The dose linearity from 20 to 400 cGy of the ArcCHECK without insert core on 10 MV photon beams.

Delivered dose(cGy)	Dose values of diode (cGy)		
	Diode number		
	1	2	average
26.3	26.15	26.37	26.26
52.7	52.35	52.81	52.58
65.9	65.50	66.03	65.76
131.7	131.00	132.12	131.56
197.6	196.42	198.01	197.21
263.4	261.96	264.06	263.01
329.3	327.15	330.02	328.58
395.2	392.57	395.94	394.25
526.9	524.61	528.19	526.40

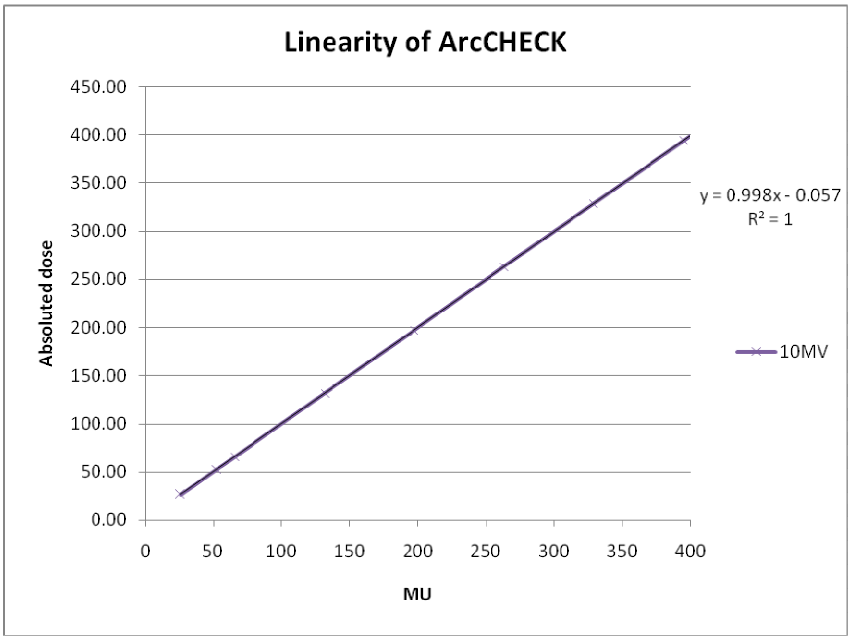


Figure 5.8 The dose linearity of the ArcCHECK for 10 MV photon beams, without insert

5.1.3 Repetition rate dependence

Repetition rate response of MapCHECK2 and ArcCHECK for 6 and 10 MV photon beams with varying of repetition rate from 100 to 600 MU/min are showed in table 5.17 and 5.18 respectively. The average signal around the central of MapCHECK2 and ArcCHECK array were taken and normalized to repetition rate 400 MU/min.

Then the data was plotted to be the graphs between the normalized signal and dose rate (MU/min) as shown in figure 5.9, 5.10, 5.11 and 5.12. The results showed that the dose of MapCHECK2 and ArcCHECK exhibit <0.3% variation with varying repetition rate for both 6 and 10 MV photon beams.

Table 5.17 The repetition rate response of the MapCHECK2 with 3.3 cm and 15 cm thickness of backscatter phantom for 6 and 10 MV photon beams

repetition rate (MU/mins)	Relative dose measurement							
	With 3.3 cm thickness of backscatter phantom				With 15 cm thickness of backscatter phantom			
	6 MV		10 MV		6 MV		10 MV	
100	99.00	0.9997	99.07	0.9989	99.18	1.0000	99.18	0.9990
200	99.02	0.9999	99.14	0.9996	99.11	0.9993	99.22	0.9994
300	99.08	1.0005	99.09	0.9991	99.24	1.0006	99.31	1.0004
400	99.03	1.0000	99.18	1.0000	99.18	1.0000	99.28	1.0000
500	99.07	1.0004	99.28	1.0010	99.25	1.0007	99.28	1.0000
600	99.23	1.0020	99.19	1.0001	99.20	1.0002	99.28	1.0000

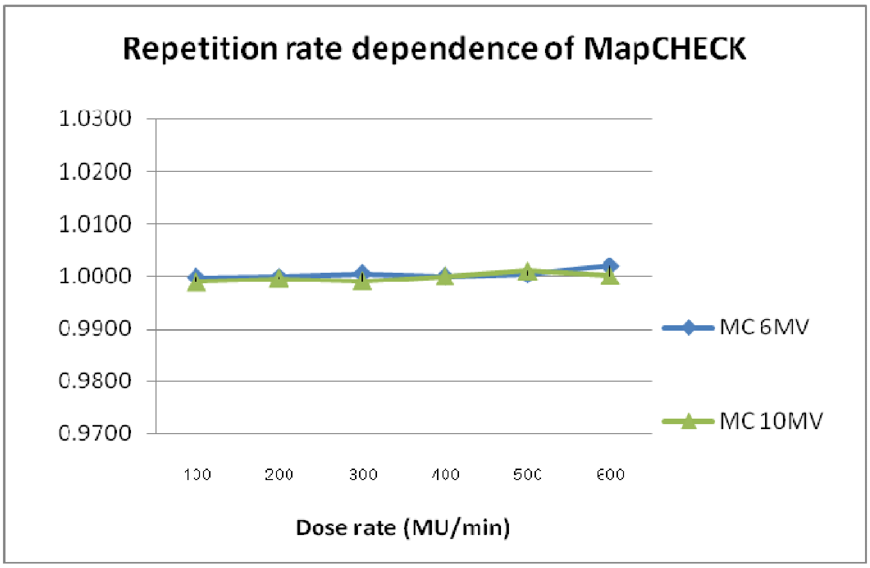


Figure 5.9 The repetition rate dependence of the MapCHECK(MC) normalized at 400 MU/min for 6 and 10 MV photon beams, with 3.3 cm thickness of backscatter phantom

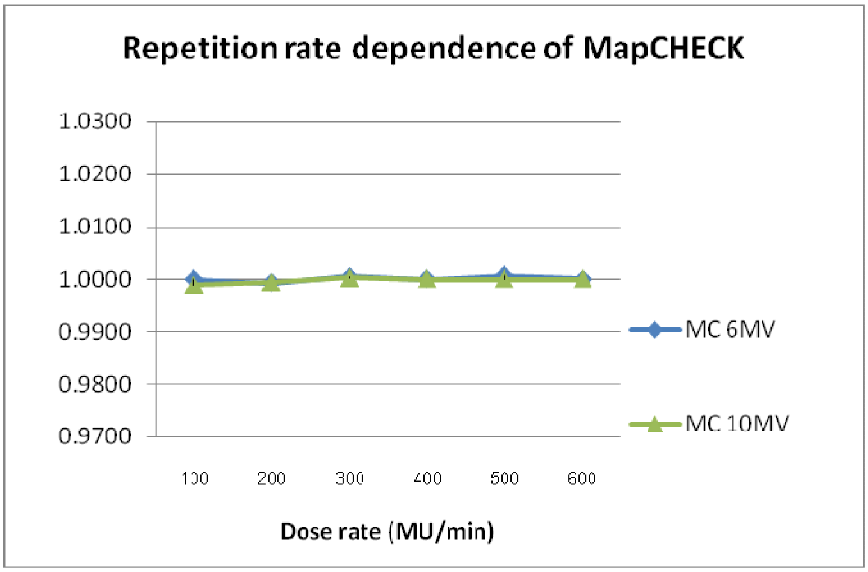


Figure 5.10 The repetition rate dependence of the MapCHECK(MC) normalized at 400 MU/min for 6 and 10 MV photon beams, with 15 cm thickness of backscatter phantom

Table 5.18 The repetition rate response of the ArcCHECK with and without insert for 6 and 10 MV photon beams

repetition rate (MU/mins)	Relative dose measurement							
	Without insert				With insert			
	6 MV		10 MV		6 MV		10 MV	
100	98.528	0.9981	98.408	0.9974	98.312	0.9974	98.661	0.9989
200	98.711	0.9999	98.579	0.9991	98.507	0.9994	98.629	0.9986
300	98.557	0.9984	98.706	1.0004	98.541	0.9997	98.687	0.9992
400	98.717	1.0000	98.664	1.0000	98.571	1.0000	98.767	1.0000
500	98.546	0.9983	98.706	1.0004	98.559	0.9999	98.764	1.0000
600	98.612	0.9989	98.700	1.0004	98.830	1.0026	98.809	1.0004

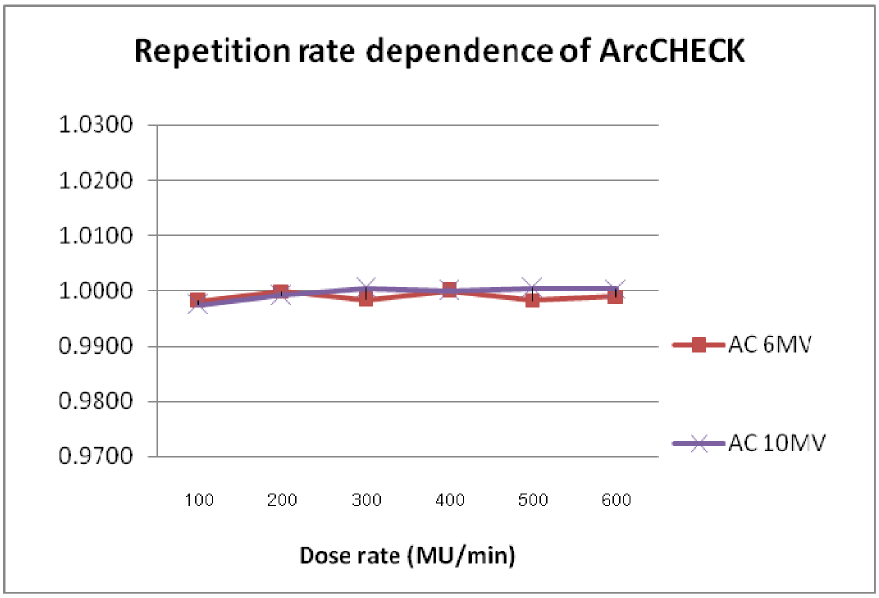


Figure 5.11 The repetition rate dependence of the ArcCHECK(AC) normalized at 400 MU/min for 6 and 10 MV photon beams, without insert

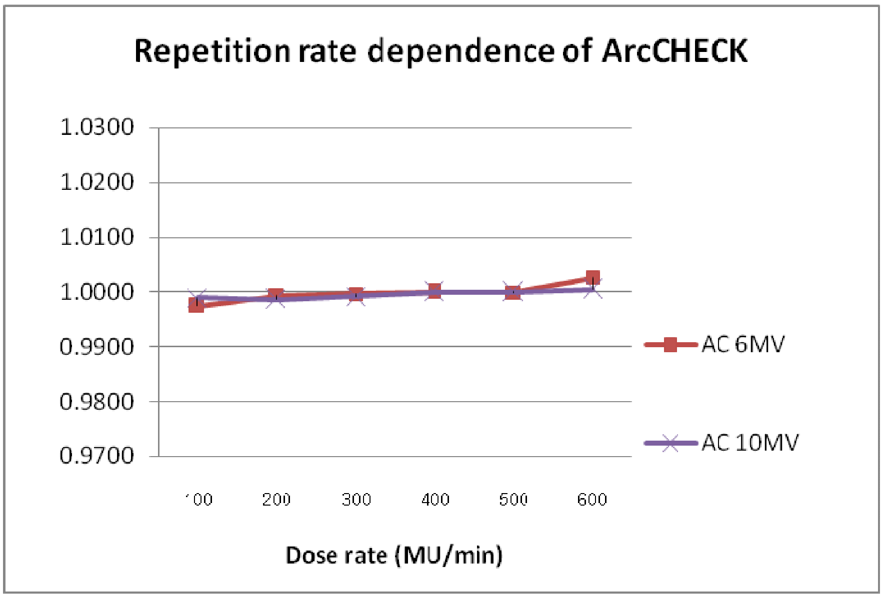


Figure 5.12 The repetition rate dependence of the ArcCHECK(AC) normalized at 400 MU/min for 6 and 10 MV photon beams, with insert

5.1.4 Detector response on field size

The field size response of MapCHECK2 and ArcCHECK were measured for a range of field size from 3 x 3 cm^2 to 25 x 25 cm^2 for 6 and 10 MV photon beams. And the measured signals were normalized to signal of 10 x 10 cm^2 to be field size factors. Then these field size factors were compared to the field size factors measured with Farmer type ionization chamber (FC 65-G ionization chamber). The results of field size factors of 6 and 10 MV photon beams measured with MapCHECK2 and ArcCHECK system and compared to those measured with FC 65-G ionization chamber are presented in table 5.19, 5.20, 5.21 and 5.22 and figure 5.13, 5.14, 5.15, 5.16, 5.17, 5.18, 5.19 and 5.20.

The results showed that the percent difference of field size response of MapCHECK2 compare to Farmer type ionization chamber were less than 0.6% for 6 and 10 MV photon beams. For ArcCHECK, the percent differences were about 1%. For field size smaller than 4 x 4 cm^2 the field size factor measured with Farmer type ionization chamber underestimates the field size factor by 4.1% and 6.3% for 6 and 10 MV photon beams respectively, due to the volume averaging effect.

Table 5.19 The field size response of the MapCHECK2 with various field size ranging from 3 x 3 cm^2 to 25 x 25 cm^2 for 6 MV photon beams.

Field size (cm^2)	Relative dose measurement					
	With 3.3 cm thickness of backscatter phantom			With 15 cm thickness of backscatter phantom		
	MapCHECK	IC	%Difference	MapCHECK	IC	%Difference
3x3	0.881	0.867	1.66	0.876	0.859	1.97
4x4	0.915	0.917	-0.25	0.909	0.914	-0.60
5x5	0.937	0.939	-0.29	0.933	0.937	-0.47
6x6	0.953	0.955	-0.17	0.951	0.953	-0.21
8x8	0.981	0.982	-0.05	0.979	0.979	0.00
10x10	1.00	1.00	0.00	1.00	1.00	0.00
12x12	1.015	1.014	0.05	1.017	1.016	0.09
15x15	1.029	1.030	-0.07	1.034	1.034	0.00
18x18	1.040	1.041	-0.12	1.047	1.047	0.00
20x20	1.048	1.048	0.00	1.055	1.053	0.17
25x25	1.059	1.060	-0.15	1.073	1.070	0.29

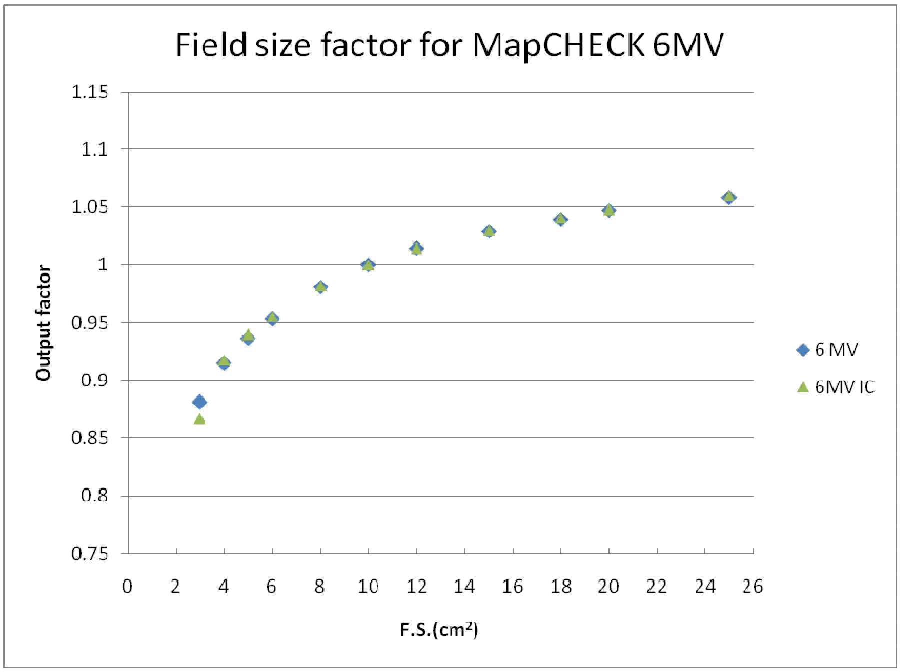


Figure 5.13 Comparison between the field size factor of MapCHECK2 with 3.3 cm thickness of backscatter phantom and Farmer type ionization chamber for 6 MV photon beams

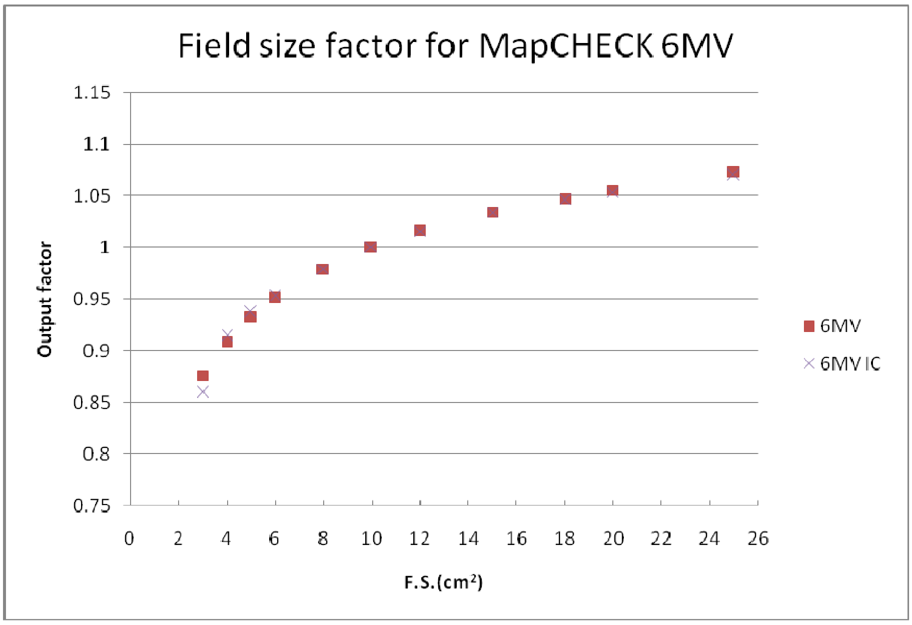


Figure 5.14 Comparison between the field size factor of MapCHECK2 with 15 cm thickness of backscatter phantom and Farmer type ionization chamber for 6 MV photon beams

Table 5.20 The field size response of the MapCHECK2 with various field size ranging from 3 x 3 cm^2 to 25 x 25 cm^2 for 10 MV photon beams.

Field size (cm^2)	Relative dose measurement					
	Without backscatter			With backscatter		
	MapCHECK	IC	%Difference	MapCHECK	IC	%Difference
3x3	0.877	0.897	-2.23	0.874	0.839	4.22
4x4	0.914	0.910	0.38	0.911	0.908	0.36
5x5	0.938	0.939	-0.04	0.936	0.938	-0.20
6x6	0.956	0.957	-0.05	0.954	0.955	-0.06
8x8	0.982	0.981	0.09	0.981	0.981	0.00
10x10	1.00	1.00	0.00	1.00	1.00	0.00
12x12	1.013	1.013	0.00	1.015	1.014	0.02
15x15	1.026	1.027	-0.09	1.029	1.030	-0.05
18x18	1.041	1.041	0.00	1.041	1.040	0.02
20x20	1.051	1.053	-0.18	1.047	1.047	0.00
25x25	1.058	1.060	-0.17	1.060	1.061	-0.13

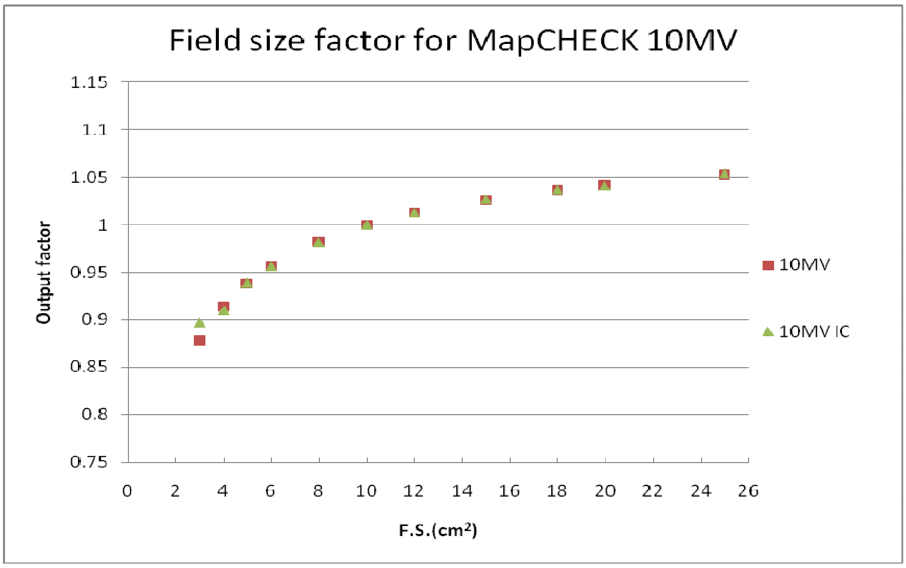


Figure 5.15 Comparison between the field size factor of MapCHECK2 with 3.3 cm thickness of backscatter phantom and Farmer type ionization chamber for 10 MV photon beams.

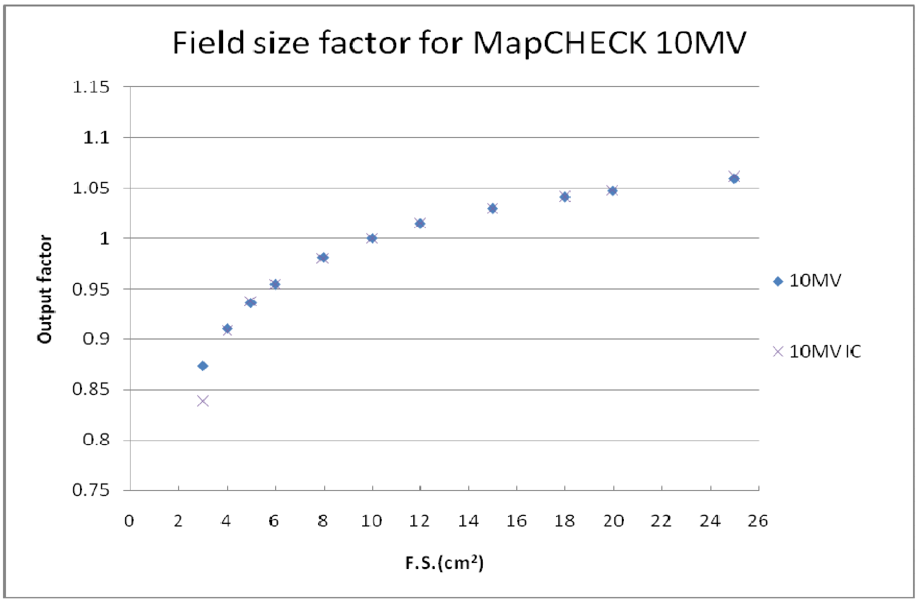


Figure 5.16 Comparison between the field size factor of MapCHECK2 with 15 cm thickness of backscatter phantom and Farmer type ionization chamber for 10 MV photon beams

Table 5.21 The field size response of the ArcCHECK with various field size ranging from 3 x 3 cm^2 to 25 x 25 cm^2 for 6 MV photon beams.

Field size (cm^2)	Relative dose measurement					
	Without insert			With insert		
	ArcCHECK	IC	%Difference	ArcCHECK	IC	%Difference
3x3	0.894	0.867	3.11	0.894	0.859	4.10
4x4	0.923	0.917	0.66	0.922	0.914	0.86
5x5	0.946	0.939	0.66	0.945	0.937	0.81
6x6	0.962	0.955	0.72	0.960	0.953	0.83
8x8	0.986	.982	0.46	0.985	0.979	0.60
10x10	1.00	1.00	0.00	1.00	1.00	0.00
12x12	1.015	1.014	0.04	1.015	1.016	-0.05
15x15	1.028	1.030	-0.23	1.030	1.034	-0.40
18x18	1.040	1.041	-0.08	1.042	1.047	-0.45
20x20	1.045	1.048	-0.23	1.049	1.053	-0.38
25x25	1.062	1.070	0.24	1.070	1.070	0.00

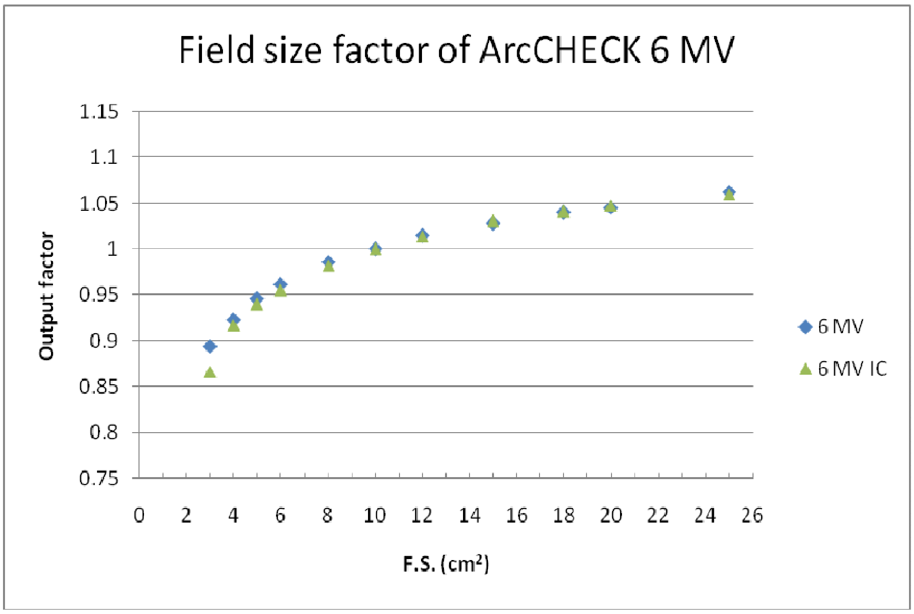


Figure 5.17 Comparison between the field size factor of ArcCHECK without insert and Farmer type ionization chamber for 6 MV photon beams.

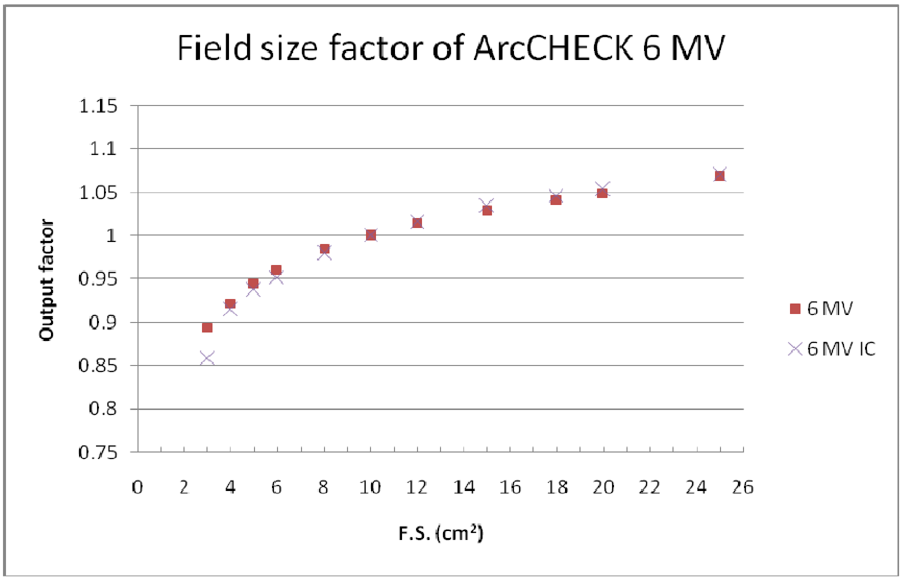


Figure 5.18 Comparison between the field size factor of ArcCHECK with insert and Farmer type ionization chamber for 6 MV photon beams.

Table 5.22 The field size response of the ArcCHECK with various field size ranging from 3 x 3 cm^2 to 25 x 25 cm^2 for 10 MV photon beams.

Field size (cm^2)	Relative dose measurement					
	Without insert			With insert		
	ArcCHECK	IC	%Difference	ArcCHECK	IC	%Difference
3x3	0.892	0.897	3.79	0.892	0.839	6.34
4x4	0.921	0.910	1.20	0.922	0.910	1.59
5x5	0.942	0.939	0.35	0.944	0.938	0.66
6x6	0.958	0.957	0.13	0.959	0.955	0.41
8x8	0.983	0.981	0.17	0.983	0.981	0.22
10x10	1.00	1.00	0.00	1.00	1.00	0.00
12x12	1.013	1.013	0.00	1.014	1.014	0.00
15x15	1.025	1.027	-0.16	1.029	1.030	-0.13
18x18	1.035	1.037	-0.13	1.038	1.040	-0.19
20x20	1.041	1.041	0.00	1.044	1.047	-0.25
25x25	1.055	1.053	0.14	1.060	1.061	-0.11

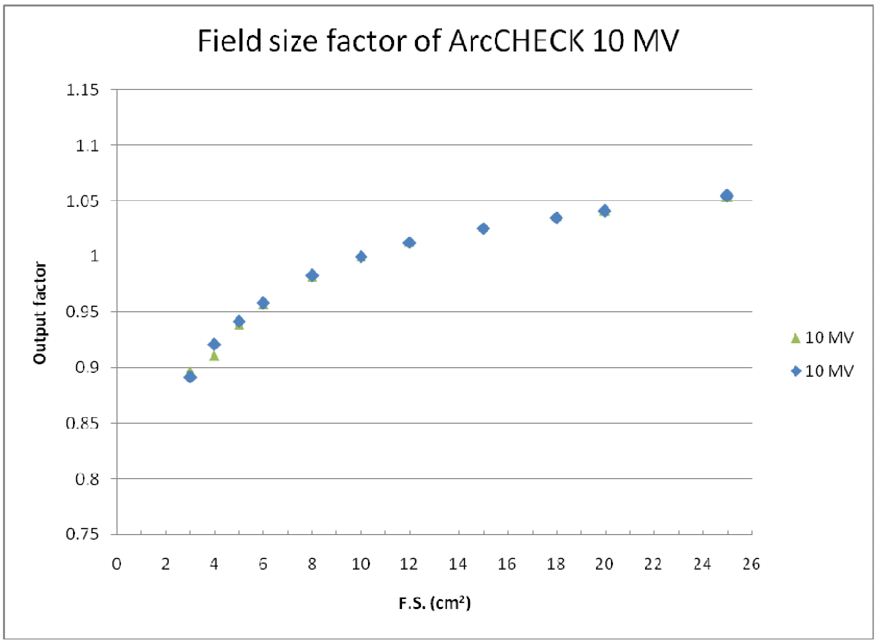


Figure 5.19 Comparison between the field size factor of ArcCHECK without insert and Farmer type ionization chamber for 10 MV photon beams.

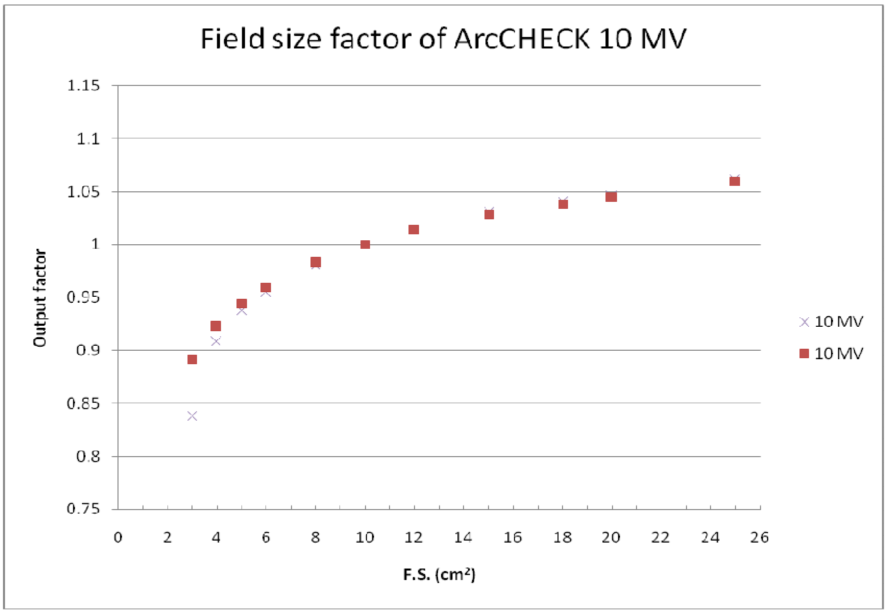


Figure 5.20 Comparison between the field size factor of ArcCHECK with insert and Farmer type ionization chamber for 10 MV photon beams.

5.1.5 Angular dependence

For the MapCHECK2 the angular dependence was measured by varying the gantry angle from 0 degree to 180 degree every 15 degree interval with a fixed field size of 10x10 cm^2 field size at 100 cm SDD. The result showed in table 5.23

Table 5.23 The angular dependence of the MapCHECK2 for 6 and 10 MV photon beams.

Angular (degree)	Relative dose of measurement			
	6 MV	%difference with 0 degree	10 MV	%difference with 0 degree
0	96.685	0.0	103.308	0.0
15	96.282	-0.4	102.843	-0.5
30	95.364	-1.4	101.637	-1.6
45	92.194	-4.6	99.094	-4.1
60	84.490	-12.6	92.257	-10.7
75	60.273	-37.7	71.384	-30.9
90	58.447	-39.5	66.578	-35.6
105	64.067	-33.7	70.867	-31.4
120	78.997	-18.3	87.929	-14.9
135	85.948	-11.1	94.009	-9.0
150	89.784	-7.1	97.674	-5.5
165	94.776	-2.0	101.635	-1.6
180	95.624	-1.1	102.614	-0.7

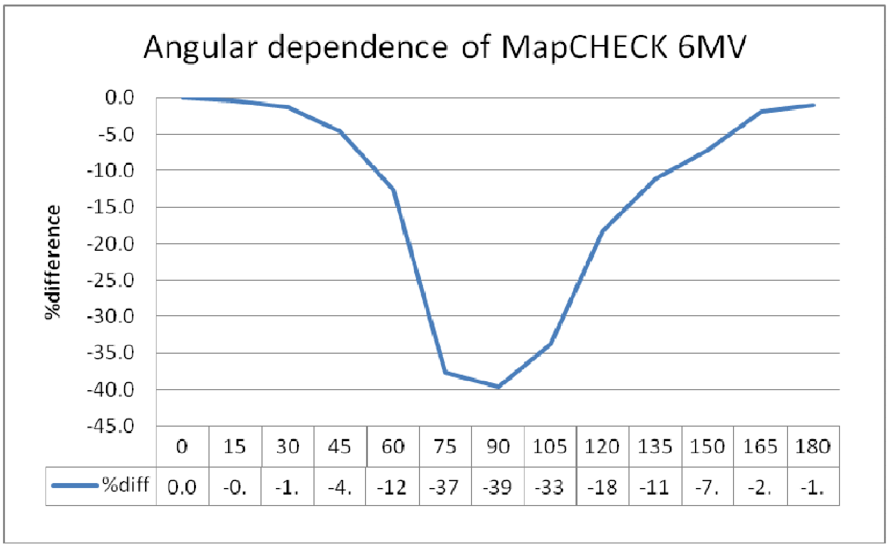


Figure 5.21 The percentage dose difference of the MapCHECK2 versus gantry angle for 6 MV photon beams, normalized to 0 degree

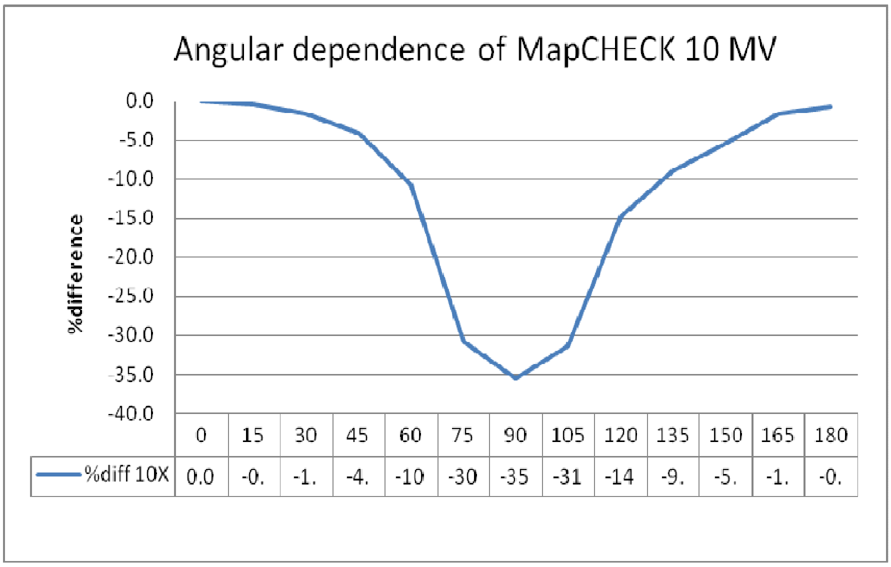


Figure 5.22 The percentage dose difference of the MapCHECK2 versus gantry angle for 10 MV photon beams, normalized to 0 degree

From the result, the MapCHECK2 response is clearly dependent on beam incident angle with under-response of 35% to 39% at 90 degree.

The angular of the ArcCHECK detector is to compare the measured and calculated dose profiles for a series of fields with increasing width. All relative dose profiles of ArcCHECK measurement compared to TPS calculation in homogeneous phantom showed in the figure 5.23, 5.24, 5.25, 5.26 and 5.27.

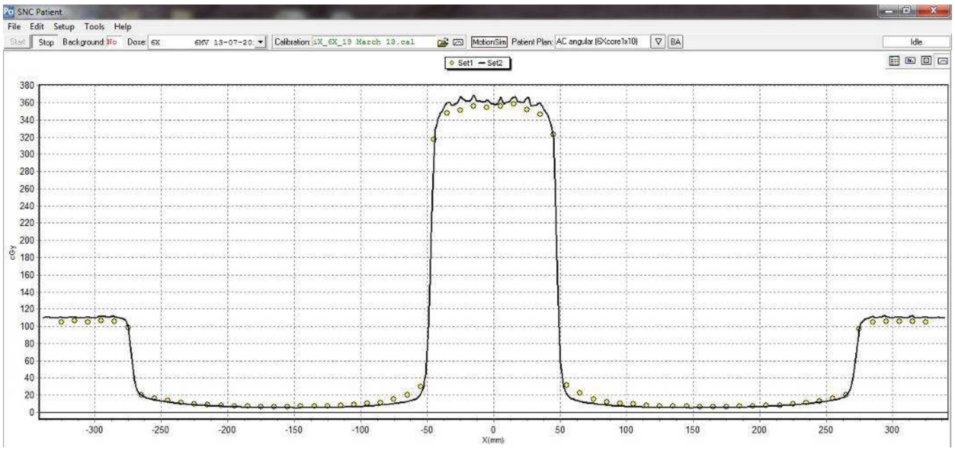


Figure 5.23 The relative dose of the ArcCHECK versus beam profile at 10x10 cm^2 for 6 MV photon beam

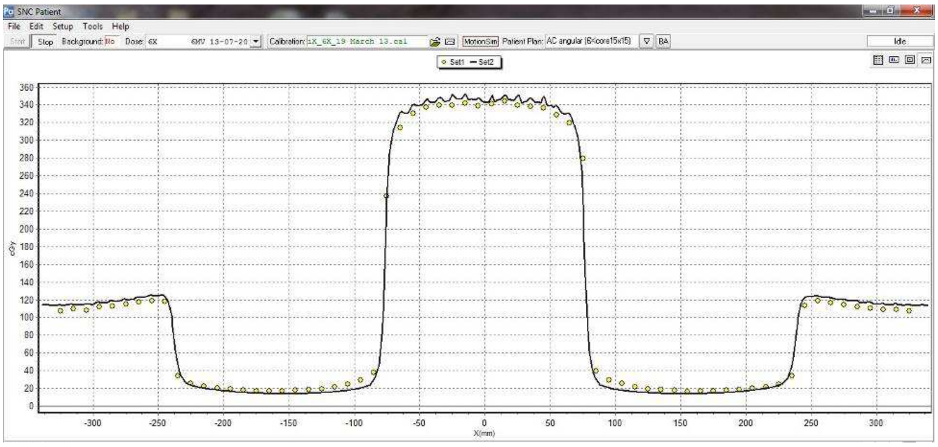


Figure 5.24 The relative dose of the ArcCHECK versus beam profile at 15x15 cm^2 for 6 MV photon beam

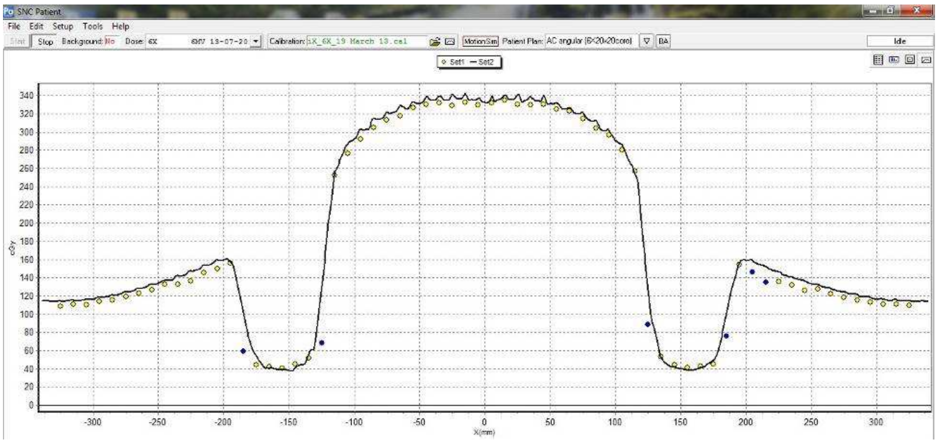


Figure 5.25 The relative dose of the ArcCHECK versus beam profile at 20x20 cm^2 for 6 MV photon beam

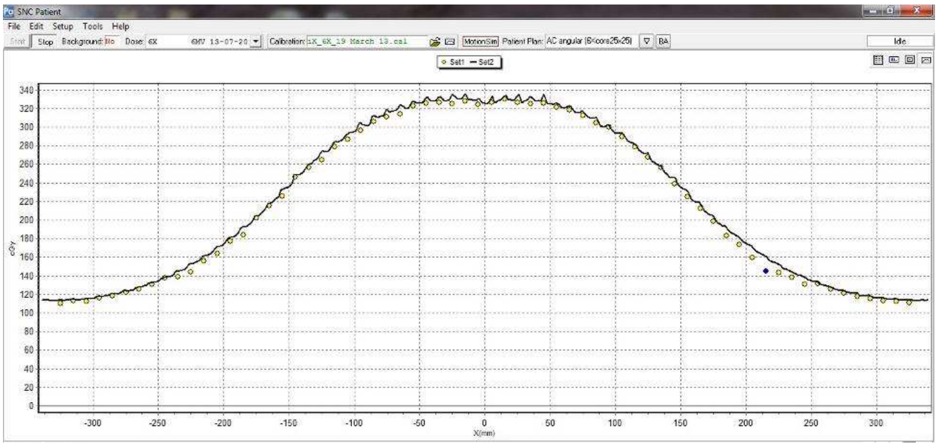


Figure 5.26 The relative dose of the ArcCHECK versus beam profile at 25x25 cm^2 for 6 MV photon beam

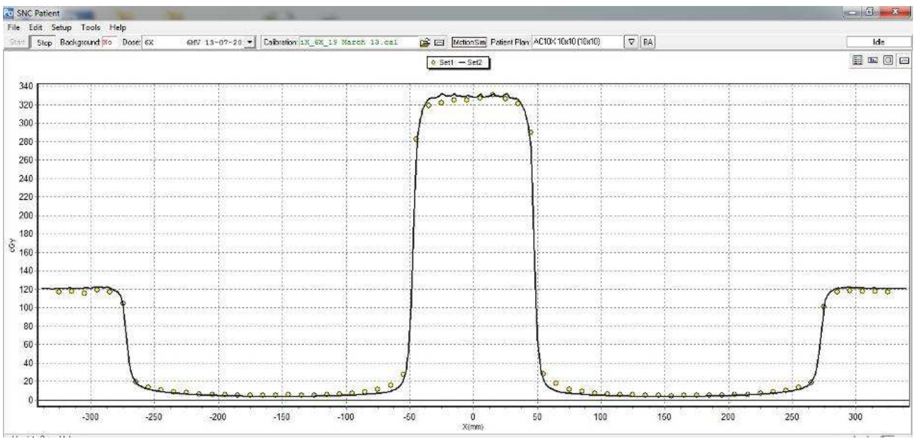


Figure 5.27 The relative dose of the ArcCHECK versus beam profile at 10x10 cm^2 for 10 MV photon beam

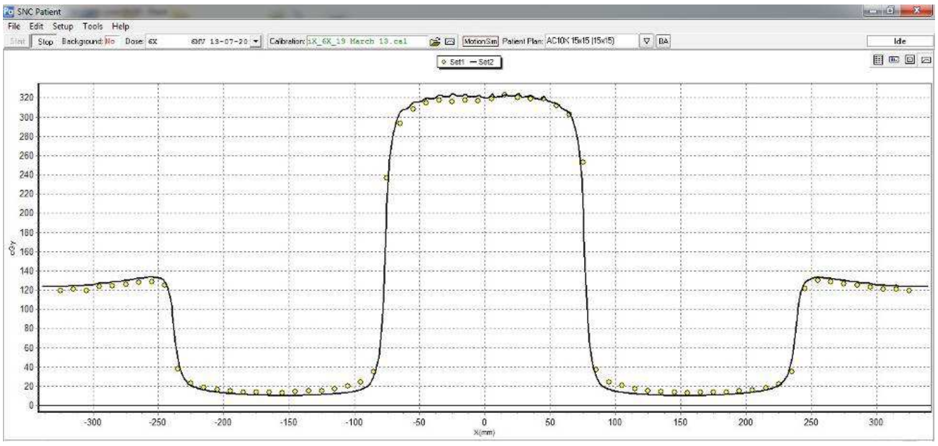


Figure 5.28 The relative dose of the ArcCHECK versus beam profile at 15x15 cm^2 for 10 MV photon beam

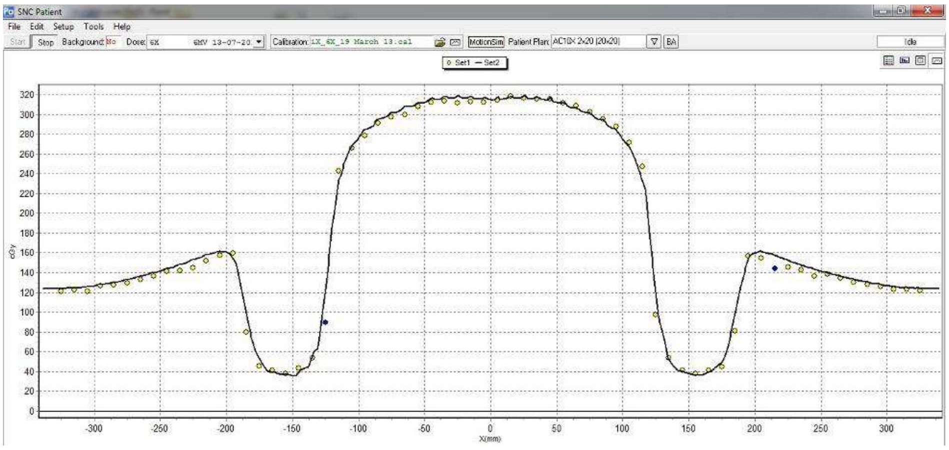


Figure 5.29 The relative dose of the ArcCHECK versus beam profile at 20x20 cm^2 for 10 MV photon beam

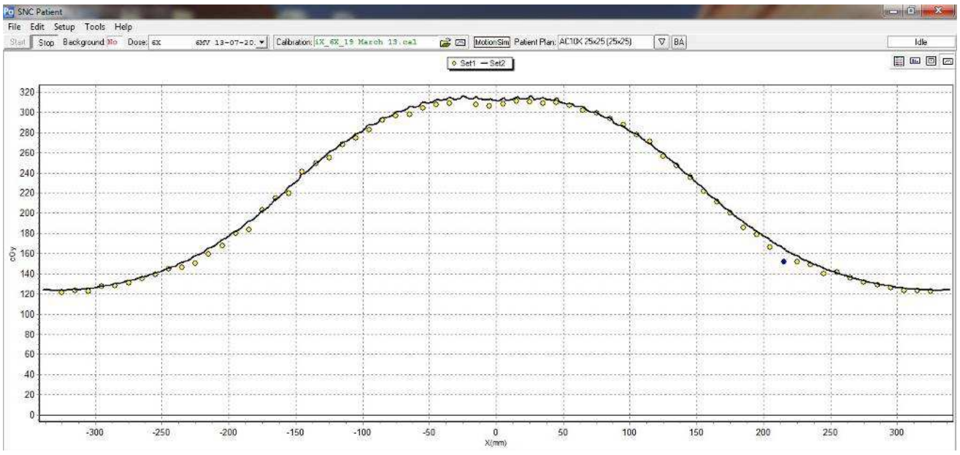


Figure 5.30 The relative dose of the ArcCHECK versus Beam profile at 25x25 cm^2 for 10 MV photon beam

5.2 Dosimetric verification for IMRT and VMAT plans

As the complexity of the IMRT and VMAT delivery techniques, it needs rise to a requirement of pre-treatment patient specific QA for each patient plan. The present study, the patient specific QA for IMRT and VMAT were performed with MapCHECK2 with MapPHAN (the planar diode array) and ArcCHECK (cylindrical diode array). The results showed dose distributions similar in shape to those calculated by the Eclipse treatment machine and also the results of percentage passing for IMRT and VMAT plans verified by MapCHECK2 with MapPHAN and ArcCHECK with insert are shown in table 5.24.

Table 5.24 Percentage of gamma passing (3%/3mm) for ten IMRT and VMAT plans verified by MapCHECK2 and ArcCHECK

Plan	Plan type	IMRT			VMAT	
		MapCHECK2		ArcCHECK	MapCHECK2	ArcCHECK
		Gantry 0	Actual gantry	Actual gantry	Actual gantry	
1	NP1	97.1	94.0	94.8	99.8	98.4
2	NP2	90.9	89.8	90.3	97.7	97.5
3	Prostate+LN	99.5	97.5	93.1	99.8	98.5
4	Prostate	98.7	94.1	96.0	99.6	96.7
5	Prostate+LN	98.2	89.9	86.9	98.3	99.6
6	Pancreas1	100	96.0	98.7	99.8	97.6
7	Pancreae2	100	92.5	96.9	100	96.2
Average gamma pass		97.8	93.4	93.8	99.3	97.8
1	Non-coplanar	99.2	52.0	98.8	97.8	96.8
2	Non-coplanar	100	55.6	99.1	99.5	95.1
3	Non-coplanar	97.4	84.2	97.5	99.2	91.6
Average gamma pass		98.9	63.9	98.5	98.8	94.5

For ten IMRT plan verification results using our gamma criteria fall between 90.9 to 100% for MapCHECK2 at zero degree angle setting-up and 85.1 to 99.1% for ArcCHECK detector in planed gantry angle verification technique, the percent passing rate s were reasonable results for co-planar plans, but gave the low percentage passing for non-coplanar plans. For VMAT plan verification doses measured with MapCHECK2 agreed better with plans, with average pass rate of 99.3%

CHAPTER VI
DISCUSSION AND CONCLUSIONS

IMRT and VMAT treatment technique characterized by the highly conformal radiation dose to the target volume and steep dose gradient, the small error in the process of treatment planning and delivery can lead to a large error at the final treatment. Therefore, every treatment plan of IMRT and VMAT has to be verifying before treatment deliver to the patients in order to assure that the treatment plan can be carried out accurately at the treatment delivery machine.

Before using the QA tool for patient-specific QA, several tests were carried out to examine the performance characteristic of both MapCHECK2 and ArcCHECK QA system. ArcCHECK N-type diodes are similar to these used in MapCHECK2, so the discrepancy of the characteristic of these two QA systems is mainly due to the phantom configuration and the changes of build up and backscatter condition. The present study,

6.1 Detector performance test

6.1.1 Diode array reproducibility

Our results demonstrate that the maximum SD for both MapCHECK2 and ArcCHECK system are less than 0.34% for both radiation beam energy (6 and 10 MV photon beams). Both detector systems should a fluctuation of about 1.6% for the long term reproducibility during four-month period. These measurements include not only the reproducibility of the detector but also the fluctuation of beam output between measurements. The results agree with Letourneau et al [12] who reported the MapCHECK showed maximum SD of about 0.15% in short term reproducibility and Li Gj et al[13] reported that the MapCHECK showed a stable short term response and a fluctuation of about 1% during the one-month period.

The diodes of the ArcCHECK are identical to those used in MapCHECK, so both detector systems showed the same response during one hour and four-month period.

6.1.2 Dose linearity of the detector response

In this study, we examined the response of the detectors as a function of delivered dose. Both detector systems show the dose linearity with regression coefficient of 1 for both radiation beam energies the results agree with Letourneau et al is study [12]. They investigated the linearity of the MapCHECK detectors and found that the MapCHECK diodes is linear within the range of the radiation dose delivered

6.1.3 Repetition rate dependence

Our results show that there is no significant repetition rate dependence was observed within the range of repetition rate for both 6 and 10 MV photon beams employed in this study. Letourneau et al [12] and Li at al [21] reported similar results with regard to MapCHECK diodes and ArcCHECK respectively.

6.1.4 Detector response on field size

Figure 5.13, 5.14, 5.15 and 5.16 shows the field size factor dependence for MapCHECK2 and figure 5.17, 5.18, 5.19 and 5.20 for ArcCHECK. The percentage difference of field size factor of MapCHECK2 and ArcCHECK from ionization chamber FC 65G are less than 0.6% and 1.5% respectively for both energy. Our results agree with Li et al [13] who reported field size factor dependence of MapCHECK with ionization chamber within 1% and our results also agree well with Feygelman et al’s study that reported their maximum percentage difference (ArcCHECK and ion chamber) was 1.7% for hollow phantom and 1.3% when the acrylic insert was inserted into the phantom. For the field size smaller than 4 x 4 cm^2, the field size factor measured by Farmer type ionization chamber underestimated by 4.1% and 6.3% for 6 and 10 MV photon beams respectively, due to the volume averaging effect.

6.1.5 Angular dependence

For present study, when the incident angle is smaller than 45̊, the angular dependence deviation of MapCHECK2 was less than 5%. The angular dependence exhibits as large as 39% and 35% for 6 and 10 MV photon beams respectively. These largest deviations occurs with the beams parallel to the array plane (90̊) unlike Li et al.’s study [21], they reported their highest angular dependence was 9.1%. Our results are much higher than their due to the high-Z material inside MapCHECK2 and also the couch attenuation that we did not take into account.

For ArcCHECK, our results showed that largest difference between calculated dose from treatment planning system and measured dose by ArcCHECK was observed for the 20 x 20 cm^2 field up to 17.5% and 10.6% for 6 and 10 MV photon beams respectively. From Feygelman et al [18]’ experiment, they reported the maximum difference the measured and calculated dose for the 25 x 25 cm^2 beam was 7%

6.2 Dosimetric Verification for IMRT and VMAT plans

In this study, we performed a comprehensive investigation comparing IMRT and VMAT patient-specific QA using a planar diode array (MapCHECK2 with MapPHAN) and spiral diode array (ArcCHECK). It was our first comparison of IMRT plan QA and VMAT plan QA. Other investigations have performed QA on IMRT and VMAT plans.

Gloi et al [16] examined the patient specific QA for RapidArc treatment using the MapCHECK system and a Solid Water phantom with an embeded ionization chamber. They obtained a 97.5% overage passing rate with gamma index <1: 3%/3 mm criteria.

Jursinic et al [21] reported MapCHECK with MapPHAN passing rate of 99.5% for fix beam IMRT plans and 99.8% for RapiArc plans, using criteria of 3%/3 mm. These results are slightly higher than our MapCHECK2 with MapPHAN results of 97.8% and 99.3% for IMRT at 0 degree gantry angle and VMAT at planed gantry angle respectively.

For using ArcCHECK system to verify the IMRT and VMAT plans, Li et al [22] performed the comparison of the measured dose distribution by ArcCHECK with the calculated dose distribution by treatment planning system for both IMRT and VMAT plans. And they evaluated the percent gamma passing rate excess 95% and 93% respectively. These results are similar to our ArcCHECK results of 93.8% and 97.8% for IMRT and VMAT QA plans.

We found the corresponding results for the non-coplanar IMRT plans. The percent gamma passing rate exceed 98% for MapCHECK2 with 0 degree gantry angle and ArcCHECK system with planned gantry angle. Except the IMRT plans using planned gantry on MapCHECK2, mean percentage gamma passing rate rapidly fell to 63.9% due to non-coplanar IMRT beams fall outside the planar diode array.

In the present study, the MapCHECK2 and ArcCHECK system were characterized. Both of them were found to have good response linearity and reproducibility, repetition rate and field size dependence were quantified. The angular dependence of both systems varied to a maximum 39% and 17% for MapCHECK2 and ArcCHECK respectively.

And efford has been delicated to get MapCHECK2 with MapPHAN and ArcCHECK QA system working along with the IMRT and VMAT plan verification. Based on the comparative measurements, the MapCHECK2 and ArcCHECK QA system are suitable for clinical IMRT and VMAT plans verification.

REFERENCES

1. Webber S. The physical basic of IMRT and inverse planning. Britist Journal of Radiology. 2003;76(910):678-89.
2. Otto K. Volumetric modulated arc therapy: IMRT in a single gantry arc. Med Phys. 2008;35(1):310-7.
3. Bucciolini M, Bounamici FB and Casati M. Verification of IMRT fields by film dosimeter. Med Phys. 2004;31(1):161-8.
4. Jursinic P. And Nelms BE. A 2-D diode array and analysis software for verification of intensity modulated radiation therapy delivery. Med Phys. 2003;30:870-79.
5. Poppe B, Blechschmidt A, Kollhoff R, Rubach A and Willborn CK. Two-dimensional ionization chamber arrays for IMRT plan verification. Med Phys. 2005;33:1005-15.
6. Van Esch A, Clermont C, Devillers M and Lori M. On-line quality assurance of rotational radioaterapy treatment delivery by means of a 2D ion chamber array and the Octavius phantom. Med Phys. 2007;34:3825-37.
7. Bedford JL, Lee YK and Wai P. Evaluation of the Delta4 phantom for IMRT and VMAT verification. Phys Med Biol. 2009;54:N167-N76.
8. Letourneau D, Publicover J, Kozelka J, Moseley DJ and Jaffray DA. Novel dosimetric phantom for quality assurance of volumetric modulated arc therapy. Med Phys. 2009 May;36(5):1813-21.
9. Cozzi L, Dinshaw KA and Shrivastava SK, et al. A treatment planning study comparing volumetric arc modulation with RapidArc and fixed field IMRT for cervix uteri radiotherapy. Radiother Oncol. 2008;89(2);180-91
10. Daniel AL, William B, Sasa M, and James A. A technique for the quantitative evaluation of dose distributions. Med Phys. 1998;25:656-61
11. Nelms BE, and Simon JA. A survey on planar IMRT QA analysis. J Appl Clin Med Phys.2007;8(3):76-90

12. Letourneau D, Gulam M, Yan D, Oldham M and Wong JW. Evaluation of 2D diode array for IMRT quality assurance. Radiother Oncol. 2004;70:199-206.

13. Li JG, Yan G and Lui C. Comparison of two commercial detector arrays for IMRT quality assurance. J App cli med phy. 2009;10(2):62-74.

14. Li CH, Li GJ, Ji CH, et al. The characteristic and clinical application of the ArcCHECK diode array for volumetric modulated arc therapy verification.Chinese Journal of Radiation Oncology. 2013;22(3):253-57

15. Letourneau D, Publicover J, Kozelka J, Moseley DJ, Jaffray DA. Novel dosimetric phantom for quality assurance of volumetric modulated arc therapy. Med Phys. 2009 May;36(5):1813-21.

16. Gloi AM, Buchanan RE, Zuge CL and Goetter AM. RapidArc quality assurance through MapCHECK. J App cli med phy. 2011;12(2):39-47.

17. Guanghua Yan BL, Jakub Kozelka, Chihray Liu and Jonathan G. Li. Calibration of a novel four-dimensional diode array. Med Phys. 2010;37(1):108-15.

18. Feygelman V, Zhang G, Stevens C, Nelms BE. Evaluation of a new VMAT QA device, or the "X" and "O" array geometries. J App cli med phy. 2011;12(2):146-68.

19. *MapCHECK Model 1177 User’s Guide*, Sun Nuclear Corporation, Melbourne: FL

20. *ArcCHECK Model 1220 User’s Guide*, Sun Nuclear Corporation, Melbourne: FL

21. Jursinic PA, Sharma R and Reuter J. MapCHECK used for rotational IMRT measurement: Step-and-shoot, Tomotherapy, RapiArc. Med Phys 2010;37(6):2837-2846

22. Li G, Zhang Y, Jiang Q, et al: Evaluation of the ArcCHECK QA system for IMRT and VMAT verification. Physica Medica. 2013;29:295-303

APPENDIX

IMRT and VMAT verification plans

For pretreatment patient specific QA, ten dynamic IMRTs were selected randomly and included difference anatomy locations to provide a variety of complexity: two head and neck (H&N) cancers, three prostate cancer, two abdominal regions cancers and three other non-coplanar plans. Then we designed a VMAT plans, we re-planed all the patient data previously with IMRT.

For two nasopharyngeal cancer IMRT verification plans, The first case containes 7 beam directions at gantry angles of RPO208°, RPO260°, RAO313°, AP(0°), LAO51°, LPO103° and LPO155° and the other case has beam directions at gantry angles of RPO200°, RPO250°, RAO300°, AP(0°), LAO50°, LPO100° and LPO150°. Using 6 MV photon beams for both plans. The beam directions are showed in figure A.1 and A.2 respectively.

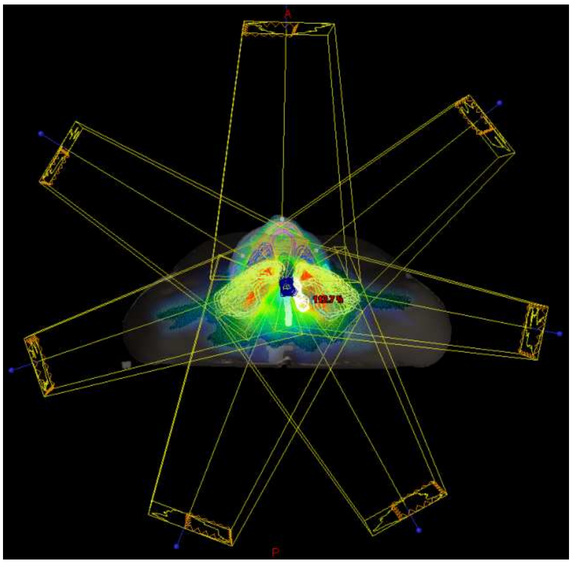


Figure A.1 The beam directions of Nasopharyngeal plan case 1

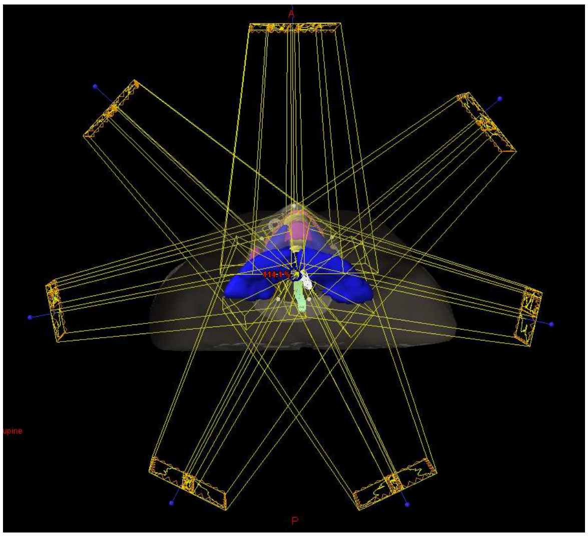


Figure A.2 The beam directions of Nasopharyngeal plan case 2

For the three prostate with lymph nodes IMRT verification plans, The first case containes 7 beam directions at gantry angles of RPO220°, RPO250°, RAO300°, AP(0°), LAO45°, LPO100° and LPO135° and the second case has beam directions at gantry angles of RPO240°, RT Lat.(270°), RAO310°, AP(0°), LAO50°, LPO95° and LPO140° and the third case has beam directions at gantry angles of RPO213°, RPO260°, RAO318°, AP(0°), LAO52°, LPO105° and LPO157° . We planned all plans using10 MV photon beams. The beam directions of three prostate IMRT plans are showed in figure A.3, A.4 and A.5 respectively.

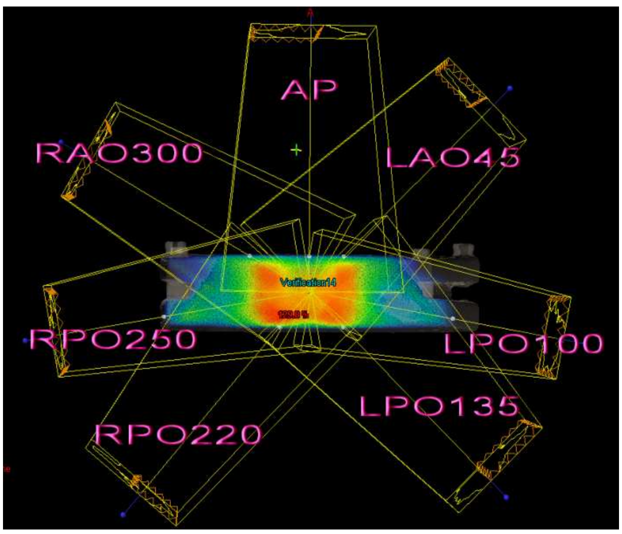


Figure A.3 The beam directions of Prostate with LN plan case 1

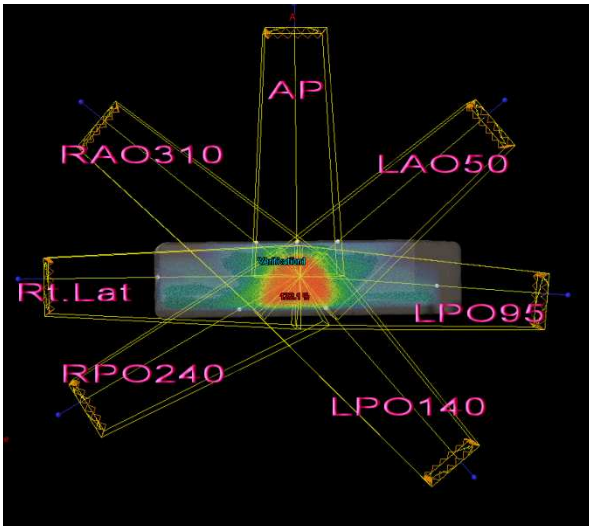


Figure A.4 The beam directions of Prostate plan case 2

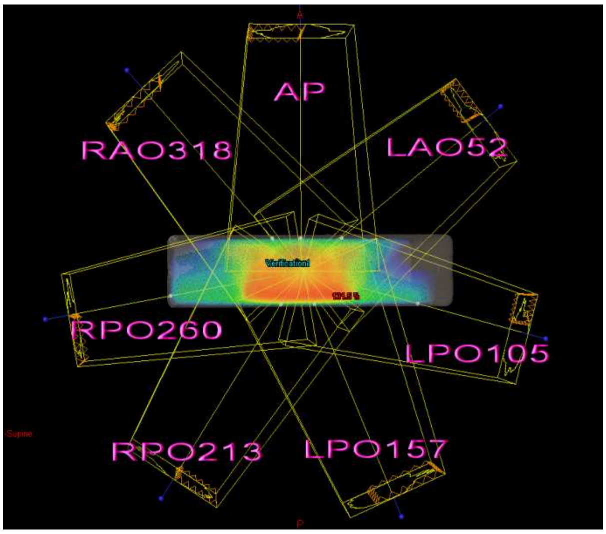


Figure A.5 The beam directions of Prostate with LN plan case 3

For two IMRT verification plans for pancreatic cancer, The first case containes 4 beam directions at gantry angles of RT Lat.(270̊), RAO310̊, AP(0̊), and LAO80̊ and another case has 5 beams at gantry angles of RAO275̊, RAO310̊, AP(0̊), LAO55̊ and LPO160̊ with 10 MV photon beams for both plans. The beam directions are showed in figure A.6 and A.7 respectively.

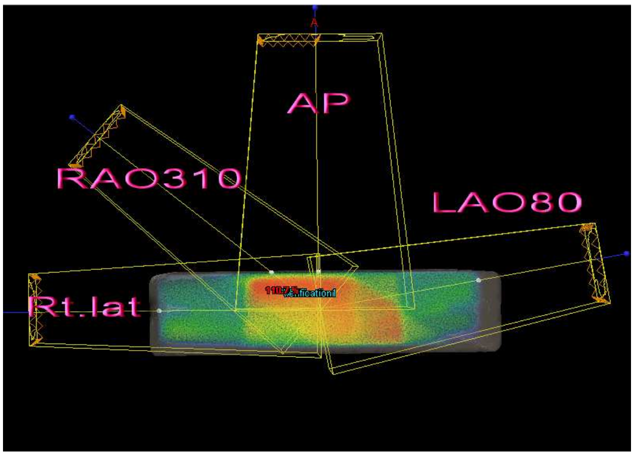


Figure A.6 The beam directions of IMRT plan for Pancreatic cancer case 1

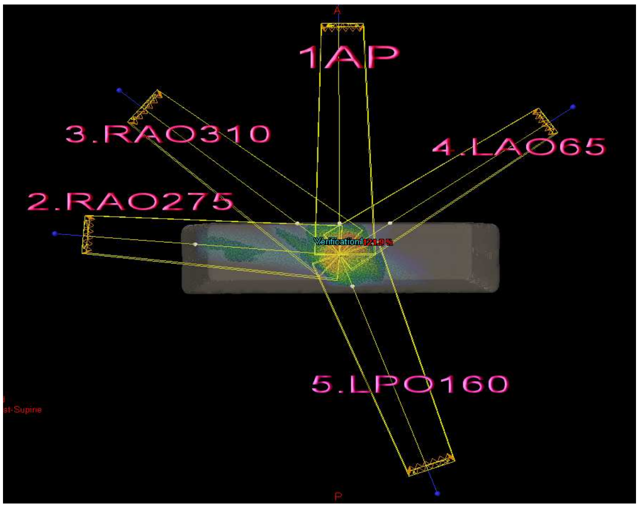


Figure A.7 The beam directions of IMRT plan for Pancreatic cancer case 2

For the three non-coplanar IMRT verification plans, The first case containes 3 beam directions at gantry angles of RPO210°, RT Lat. (270°) and RAO315° for couch rotation at 0 degree and gantry angle at LAO35° for couch rotation at 90 degree, the second case has beam directions at gantry angles of RPO260°, RAO350° and LT Lat (90°) for couch rotation of 0 degree and gantry angle at LAO30° for 90 degree couch rotation. And other case has beams direction at gantry angles RPO250°, RAO300°, LAO45°, LAO60° and LT Lat (90°) for 0 degree couch rotation and gantry angle at LAO60° for 90 degree couch rotation. Both plans were used 6 MV photon beams. All the beam directions are showed in figure A.8, A.9 and A.10 respectively.

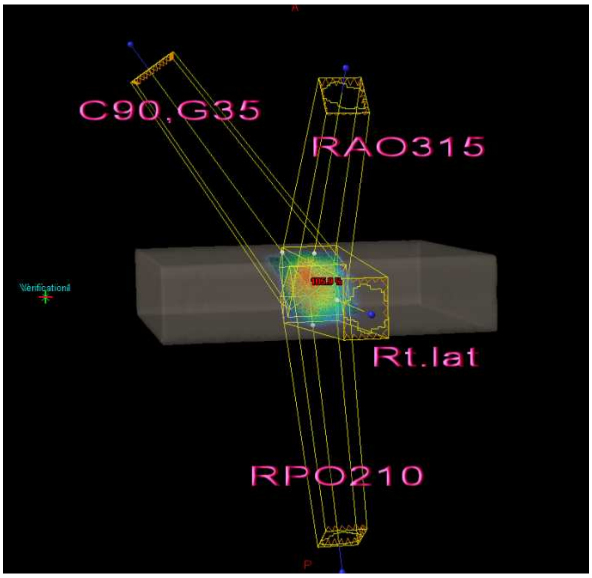


Figure A.8 The beam directions for the non-coplanar case 1

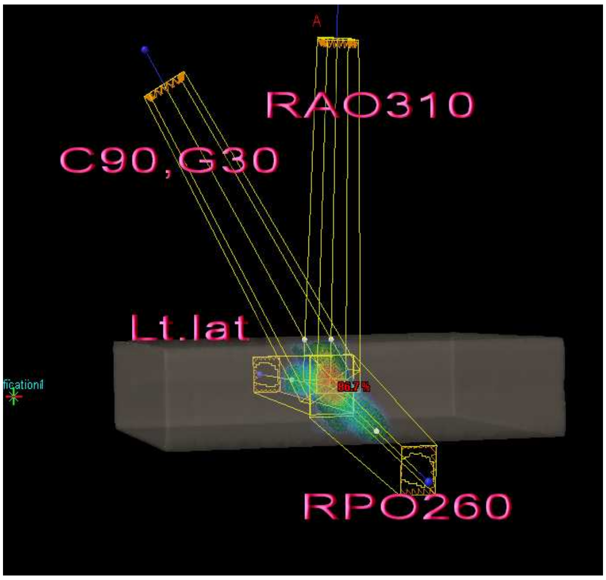


Figure A.9 The beam directions for the non-coplanar case 2

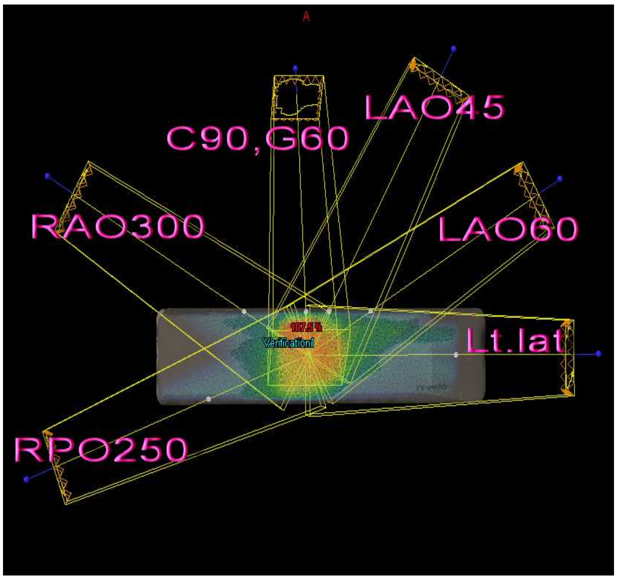


Figure A.10 The beam directions for non-coplanar case 3

BIOGRAPHY

NAME	Mr Pornpirom Laojunun
DATE OF BIRTH	25 January 1978
PLACE OF BIRTH	Udonthani, Thailand
INSTITUTIONS ATTENED	Mahidol University, 1997-2001 Bachelor of Science (Radiological Technology) Mahidol University, 2009: Master of Science (Medical Physics)
OFFICE	Siriraj hospital 2 Arunamarin Rd., Siriraj, Bangkok-noi, Bangkok, Thailand 10700
HOME ADDRESS	29 moo 9 Phosrisumran Non sa-at, Udonthani Thailand 41240 Tel. 081-713-7104 E-mail: pornpirom78@hotmail.com