การใช้ซอฟต์แวร์อิสระสำหรับตรวจสอบปริมาณรังสีในผู้ป่วยมะเร็งปากมดลูกด้วยวิธีการรักษาแบบรังสีระยะใกล้

นางสาววัชราภรณ์ แสนกล้า

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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ปีการศึกษา 2557

Independent software for dose verification in cervical cancer brachytherapy

Miss Watcharaphawn Sanklaa

A Thesis Submitted in Partial Fulfillment of the Requirements

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Thesis Title	Independent software for dose verification in cervical cancer brachytherapy
By	Miss Watcharaphawn Sanklaa
Field of Study	Medical Imaging
Thesis Advisor	Associate Professor Sivalee Suriyapee, M.Eng
Thesis Co-Advisor	Taweap Sanghangthum, Ph.D.

Accepted by the Faculty of Medicine, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

.....Dean of the Faculty of Medicine

(Associate Professor Sophon Napathorn, M.D.)

THESIS COMMITTEE

.....Chairman

(Associate Professor Kanjana Shotelersuk, M.D.)

.....Thesis Advisor

(Associate Professor Sivalee Suriyapee, M.Eng)

.....Thesis Co-Advisor

(Taweap Sanghangthum, Ph.D.)

.....External Examiner

(Professor Franco Milano, Ph.D.)

วัชราภรณ์ แสนกล้า : การใช้ซอฟต์แวร์อิสระสำหรับตรวจสอบปริมาณรังสีในผู้ป่วยมะเร็งปากมดลูกด้วยวิธีการรักษาแบบรังสีระยะใกล้ (Independent software for dose verification in cervical cancer brachytherapy) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ศิวลี สุริยาปี, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ดร. ทวีป แสงแห่งธรรม, 113 หน้า.

การใช้ซอฟต์แวร์อิสระ (MuCheck) เป็นวิธีที่ใช้ตรวจสอบปริมาณรังสีในซอฟต์แวร์ Oncentra ในการวางแผนการรักษาของรังสีรักษาแบบระยะใกล้ที่อัตราปริมาณรังสีสูง ที่ตำแหน่งใดๆโดย MuCheck เป็นเครื่องมือที่ใช้ในการตรวจสอบปริมาณรังสีที่ได้จากการคำนวณด้วยแผนการรักษา ซึ่งใช้สูตรการคำนวณจาก AAPM TG-43 ที่เป็นสูตรเดียวกันกับซอฟต์แวร์ Oncentra วัตถุประสงค์ของงานวิจัยนี้เพื่อตรวจสอบปริมาณรังสีที่ตำแหน่งอ้างอิงในผู้ป่วยมะเร็งปากมดลูกด้วยการรักษาแบบรังสีรักษาระยะใกล้ ซึ่งคำนวณได้จากซอฟต์แวร์ที่ใช้วางแผนการรักษา (Oncentra) โดยใช้ซอฟต์แวร์อิสระ (MuCheck)

การสอบเทียบปริมาณรังสีของแร่ด้วย Well chamber เป็นขั้นตอนแรกก่อนเริ่มทำการทดลองการศึกษานี้เพื่อตรวจสอบความถูกต้องของความแรงรังสี พบว่ามีค่าความแตกต่างของปริมาณรังสี 0.2% ซึ่งไม่เกิน ±5% ตามที่ทบวงการปรมาณูระหว่างประเทศกำหนดไว้ นอกจากนี้การตรวจสอบความถูกต้องในการคำนวณปริมาณรังสีด้วยฟิล์มชนิด Gafchromic EBT2 ในซอฟต์แวร์ Oncentra และ MuCheck พบความแตกต่างของปริมาณรังสีเท่ากับ -2.69±4.45 และ-2.37±4.65% ตามลำดับ ในส่วนการศึกษาในผู้ป่วยมะเร็งปากมดลูกจำนวน 253 แผนการรักษา พบว่าปริมาณรังสีที่แตกต่างกันระหว่างการใช้ซอฟต์แวร์ Oncentra และซอฟต์แวร์ MuCheck ขึ้นกับชนิดของอุปกรณ์สอดใส่แร่ โดยพบปริมาณรังสีแตกต่างกันระหว่าง Oncentra และ MuCheck จากชุด Flecther applicator มีค่าเท่ากับ 0.18±0.91%, -0.24±0.97%, 0.49±0.52%, 0.44±0.86% ที่point A, point B, bladder และrectum ตามลำดับ ส่วนชุด Utrecht applicator ซึ่งใช้ร่วมกับชุดเข็มมีค่าความแตกต่างเท่ากับ 0.34±0.58%, 0.37±0.25%, 0.62±0.54%, 0.75±0.91% ที่ point A, point B, bladder และrectum ตามลำดับ ขณะที่ชุด Vaginal cylinder มีค่าความแตกต่างที่ 0.52±0.76% , 0.25±0.51%, 0.55±0.43%, 0.58±0.44% ที่ point A, point B, bladder และ rectum ตามลำดับ ดังนั้น Utrecht applicator มีค่าความแตกต่างค่อนข้างมาก เนื่องจากแผนการรักษามีความซับซ้อน นอกจากนี้ ตำแหน่งที่กำหนดไว้ (mark points) เป็นอีกปัจจัยหนึ่งที่มีผลต่อความแตกต่างของปริมาณรังสี ซึ่งจากแผนการรักษาทั้งหมดพบเปอร์เซ็นต์ความถี่ที่มีปริมาณรังสีที่แตกต่างกันอยู่ภายใน 1% มีค่าเท่ากับ 81.82%, 87.74%, 90.12%, and 82.21% ที่ point A, point B, bladder และ rectum ตามลำดับ ทำให้ point A มีค่าเปอร์เซ็นต์ความถี่น้อยกว่า point B เนื่องจากอยู่ในบริเวณที่มีความแตกต่างทางรังสีสูง (high dose gradient) อย่างไรก็ตามปริมาณรังสีที่แตกต่างกันระหว่างทั้งสองซอฟต์แวร์พบค่าสูงสุดไม่เกิน 3% ซึ่งสอดคล้องกับ AAPM TG-59 ดังนั้นซอฟต์แวร์ MuCheck เป็นเครื่องมืออิสระที่มีความถูกต้องและแม่นยำสูง ซึ่งมีการใช้งานที่รวดเร็วและไม่ซับซ้อนจึงเหมาะในการทำการควบคุมคุณภาพสำหรับการตรวจสอบปริมาณรังสีในการรักษาแบบรังสีระยะใกล้

ภาควิชา รังสีวิทยา ลายมือชื่อนิสิต .....

สาขาวิชา ฉายาเวชศาสตร์ ลายมือชื่อ อ.ที่ปรึกษาหลัก .....

ปีการศึกษา 2557 ลายมือชื่อ อ.ที่ปรึกษาร่วม .....

5674071730 : MAJOR MEDICAL IMAGING

KEYWORDS: BRACHYTHERAPY / INDEPENDENT SOFTWARE / QUALITY ASSURANCE / CERVICAL CANCER

WATCHARAPHAWN SANKLAA: Independent software for dose verification in cervical cancer brachytherapy. ADVISOR: ASSOC. PROF. SIVALEE SURIYAPEE, M.Eng, CO-ADVISOR: TAWEAP SANGHANGTHUM, Ph.D., 113 pp.

An independent software is used to verify the radiation dose of Oncentra software at point doses in high-dose–rate (HDR) brachytherapy. MuCheck is a software tool to validate the dose from the treatment planning calculation, performed by AAPM TG-43 algorithm with the same equation as Oncentra treatment planning system. The purpose of this study is to verify the dose at the reference points in HDR brachytherapy for the cervical cancer patients calculated by Oncentra treatment planning system with the MuCheck independent software.

Source calibration was performed with the well chamber. The result showed 0.2% error from the source certification with less than 5% dose criteria. Furthermore, software verification was implemented with EBT2 film that showed -2.69±4.45% and -2.37±4.65% dose difference from Oncentra and MuCheck, respectively. According to the 253 cervical cancer treatment plans, the results revealed that the dose difference between Oncentra and MuCheck depended slightly on the applicator types. The MR compatible Flecther applicator remained the dose discrepancy that was 0.18±0.91%, -0.24±0.97%, 0.49±0.52%, 0.44±0.86% at point A, point B, bladder and rectum, respectively. The needles combined with Utrecht applicator resulted in 0.34±0.58%, 0.37±0.25%, 0.62±0.54%, 0.75±0.91% of the dose difference at point A, point B, bladder and rectum, respectively. The vaginal cylinder applicator showed the dose difference that was 0.52±0.76%, 0.25±0.51%, 0.55±0.43%, 0.58±0.44% at point A, point B, bladder and rectum, respectively. The needles presented the highest discrepancy due to more complex plans. Another factor for the dose varying was the position of the mark points. Additionally for 253 cases, the % frequency that obtained the dose difference within 1% were 81.82%, 87.74%, 90.12%, and 82.21% at point A, point B, bladder and rectum, respectively. Point A showed lower %pass at 1% compared with point B because it located in the high dose gradient point. The maximum percent dose difference was within 3% according to AAPM TG-59. Thus, MuCheck is an accuracy and precision independent approach, which is suitable to perform the patient specific quality assurance for HDR brachytherapy promptly and expediently.

Department:	Radiology	Student's Signature	.....
Field of Study:	Medical Imaging	Advisor's Signature	.....
Academic Year:	2014	Co-Advisor's Signature	.....

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LIST OF ABBREVIATION

ABBREVIATION	TERMS
cm	Centimeter
m	Meter
Ir-192	Iridium-192
$cGyh^{-1}$	Centi-gray per hour
Ra-226	Radium-226
LDR	Low Dose Rate
MDR	Medium Dose Rate
HDR	High Dose Rate
Cs-137	Cesium-137
EBRT	External Beam Radiation Therapy
ICRU	International Commission on Radiation Units
2D	2-Dimensional
3D	3-Dimensional
CT	Computed Tomography
MRI	Magnetic Resonance Imaging
DVH	Dose Volume Histogram
US	Ultrasound
QA	Quality Assurance

ABBREVIATION	TERMS
RAKR	Reference Air Kerma Rate
μGyh^{-1}	Micro-gray per hour
AP	Antero-Posterior
LAT	Lateral
TPS	Treatment Planning System
AAPM TG-43	American Association of Physicist in Medicine Task Group number 43
^{o}c	Degree Celsius
kPa	Kilo-Pascal
SSDL	Secondary Standard Dosimeter Laboratory
Dicom	Digital Imaging and Communications in Medicine
NRC	Governmental Nuclear Regulatory Commission
CTV	Critical Target Volume
KCMH	King Chulalongkorn Memorial Hospital
GEC	The Groupe Européen de Curie thérapie
ESTRO	The European Society for Radiotherapy & Oncology
Kerma	Kinetic energy release per unit mass
CA	Cancer
mm	Millimeter

ABBREVIATION	TERMS
cm^3	Cubic-centimeter
dpi	Dots per inch
OD	Optical Density
FOV	Field Of View
IAEA	International Atomic Energy Agency
TLD	Thermo-Luminescent Dosimeter
nA	Nano-Ampere
SN	Serial Number
IPSA	Inverse Planning Simulated Annealing
HIPO	Hybrid Inverse Planning and Optimization
sec	Second

CHAPTER I

INTRODUCTION

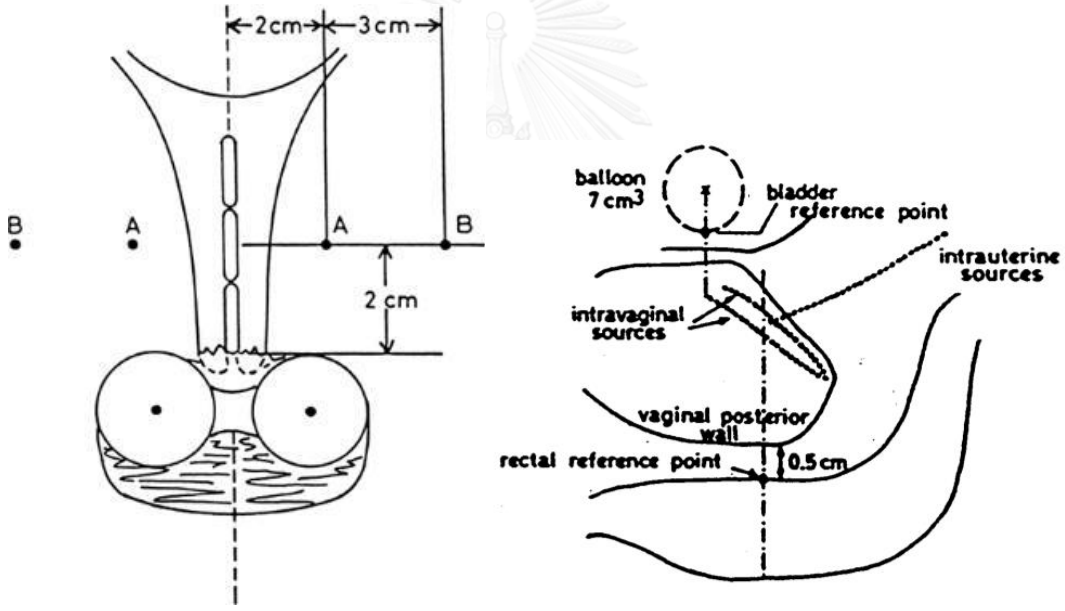
1.1 Background and rationale

An incidence of cervical cancer in woman is the fourth of all cancer around the world with a half of million new cases in 2012. Cervical cancer is the second estimated incidence of about 13.4% for Thai cancer patients in 2012 with the increasing trend every year[1]. The treatment of cervical cancer depends on various factors such as the type and stage of cancer, age and overall health of the patient. This disease can be treated by surgery, chemotherapy and radiotherapy. Due to the radiosensitivity of the tumor of cervical cancer, radiation can be employed to cure the patient in all stage of the cancer, while the surgery dose not. A conventional external beam radiation therapy (EBRT) combined with an irradiation in brachytherapy is the important curative treatment of cervical cancer[2].

Brachytherapy is an advanced treatment with the developed modality. Radioactive source will move straightforward to the tumor in short times while giving high dose rate brachytherapy. The surrounding normal tissue will be spared and the high dose is acquired through the cancer cell. The treatment dose in brachytherapy is divided into 3 categories declared by ICRU report number 38[3]. Low dose rate (LDR) brachytherapy is the lowest in ranges between 40 to 200 $cGyh^{-1}$ with the example of Ra-226 source, which utilize in conventional technique. The dose rate between 200 to 1200 $cGyh^{-1}$ is called medium dose rate brachytherapy (MDR) with the example of Cs-137 source that is usually delivered in automatic afterloading[4]. In clinical routine of King Chulalongkorn Memorial Hospital (KCMH), the treatment was performed by high dose rate (HDR) brachytherapy with Ir-192 source at 1200 $cGyh^{-1}$ or more. HDR has an

advantage of treating the patient within minute range, so it makes minimal risks of applicator movement, also minimal uncomfortable of the patient.

The dose distribution in brachytherapy treatment plan is high gradient[5]. The calculation points are considered at reference point A, point B, rectum and bladder as shown in figure 1.1. The definition of point A is 2 cm lateral to uterine canal and 2 cm from the mucous membrane of the lateral superior fornix of the vagina in the plane of uterus, point B represents 3 cm lateral to point A, bladder is located at the bottom of the Foley bulb, and rectum falls 0.5 cm below the posterior vaginal wall at mid-ovoid[3].



(a) (b)

Figure 1.1 The reference points (point A, point B, bladder and rectum), (a) coronal view and (b) sagittal view[3].

The era of brachytherapy begins from 2D orthogonal of the AP and lateral images from conventional radiograph X-ray and fluoroscopy to check the placement of an applicator or catheter. The treatment delivery is based on the standard plans with the

routine isodose distribution. The defined dose is just normalized to the point, normally at point A in both right and left directions, and the organ dose can be defined in only the points. When the computer was supplied with the brachytherapy software, the 2D calculation of dose distribution in several planes was available. Recently, CT and MRI images are utilized as a full three-dimensional (3D) treatment planning procedure for brachytherapy. The 3D based brachytherapy is possible to define the dose to target volume easily and to adjust the dose distribution concave to target volume as shown in figure 1.2, and analyze the dose of tumor and organs at risk in dose-volume histogram (DVH). In the 3D based treatment planning, the applicator reconstruction, target and organ at risk delineation should be performed by using modern imaging modality because when using the conventional radiograph, the relation between anatomy and dosimetry can be missed[6]. The 3-dimentional imaging is currently used such as computed tomography (CT), magnetic resonance (MR) or ultrasound (US) for the treatment planning purpose.

In KCMH, the treatment planning system is Oncentra software from Elekta company that used to calculate the dose of tumor for the accuracy treatment[7]. It is uncomplicated to perform brachytherapy treatment plan and undergoes the accuracy of dose distribution via an automated volume based inverse planning optimization for larger efficiency in radiotherapy workflow.

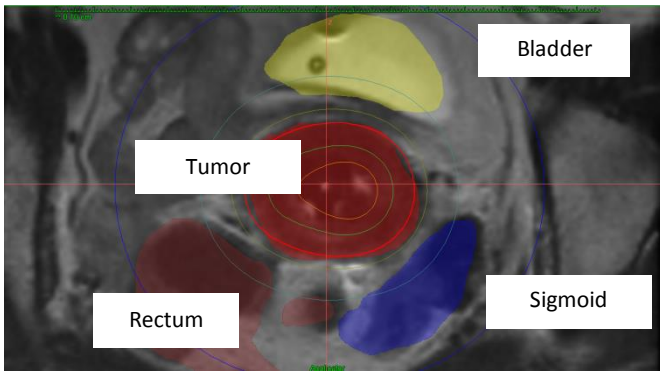


Figure 1.2 Dose distribution in cervical cancer brachytherapy.

In brachytherapy, the quality assurance is the majority due to the high dose gradient of the dose distribution. The aim of the quality assurance is to maximize the probability that each individual treatment is actualized persistently, securely, and accurately[8]. Thus, the dose calibration must be performed before using the new source and the source position check should be done every treatment day. It is not only source calibration and source position check, but the dose calculation check is also important as well.

Pretreatment dose verification at point doses is necessary in order to check the accurate dose calculated with the treatment planning system. The fast patients specific QA by independent software is an interesting issue in brachytherapy because the safety of patient must be obtained.

Independent software is actually used for verifying the dose calculation from the treatment planning system (Oncentra), the dose deviation should be less than the criteria in the report of the American Association of Physicist in Medicine (AAPM) task group number 59[9]. Moreover, it provides a critical piece of the quality assurance process used in Radiation Treatment Center worldwide[10]. Independent software gains a variety of advantages. It has a greater security for the patient and employees. Also, it

can provide a quick and reliable way to verify the dose calculated by treatment planning system (TPS).

MuCheck software is an example of independent software that can be used for external beam radiotherapy and brachytherapy dose verification. MuCheck follows the AAPM TG-43 formalism[11] to calculate the dose using data imported from a variety of TPS[9]. The aim of this study is to verify point doses in cervical cancer calculated by Oncentra treatment plan[7] with MuCheck independent software[10]. Also, the Oncentra and MuCheck software calculations are verified by measurement with the Gafchromic EBT 2 film[12].

1.2 Research objective

To verify point dose calculation in high dose rate brachytherapy by Oncentra treatment planning in cervical cancer with MuCheck software.

1.3 The scope of dissertation

The dose verification at point A, point B, bladder and rectum in 3D based brachytherapy treatment plans using independent software.

CHAPTER II

LITERATURES REVIEW

2.1 Theories

2.1.1 Brachytherapy

The word of brachy means short (distance) in the Greek language so the principle of brachytherapy is to use the encapsulated radioactive sources to deliver a high dose to tissues near the source. Most of the dose distributions in brachytherapy is determined by the inverse square law. The inverse square law in brachytherapy i.e. the source exposure is inversely proportional to the square of the distance from the source; the high-dose region, delivered from a radioactive source is localized and has a very steep dose gradient. Brachytherapy is handled for the small-localized tumor, boosting the area gross tumor after the shrinking of tumor by EBRT irradiation, the recurrent tumor by brachytherapy alone or combined with chemotherapy, surgery or hyperthermia and the palliative cases by brachytherapy combined with EBRT[5].

The brachytherapy sources consist of photon sources, beta sources and neutron sources. An iridium-192 is used in KCMH. It is the one of photon sources, which emits gamma rays through gamma decay and possibly characteristic x-ray through electron capture and internal conversion. Various types of the sources such as tubes, needles, wires, pellets, seeds ribbons, source train, and a single stepping source connected to a cable are available as shown in figure 2.1 which AL is the active length, PL is the physical length, EL is equivalent active length and s is the spacing between the center of seeds.

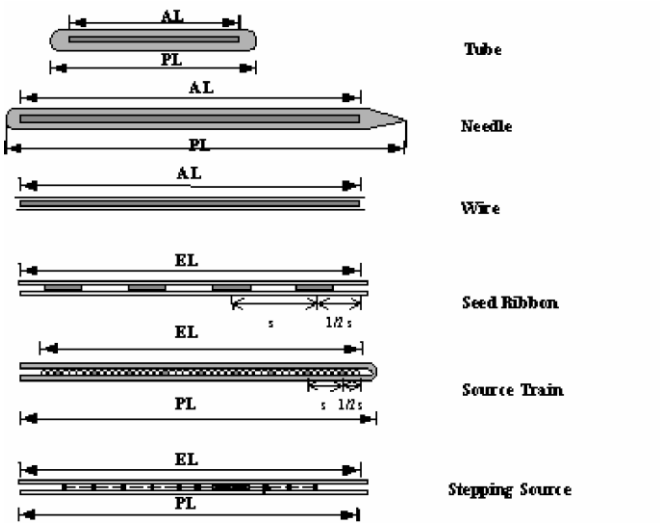


Figure 2.1 Different types of sources used in brachytherapy[5].

Brachytherapy can be characterized by the position of the radionuclides. Intracavitary brachytherapy (ICBT) is apart of that. It is characterized by steep dose gradients in the vicinity of the sources and throughout the tumor and target volume. Intracavitary brachytherapy is mainly used for cancer of the cervix treatment, uterine body and vagina[2]. Many kinds of the applicators are utilized to hold the sources in an appropriate configuration in the tumor volume. The main applicators employed in KCMH for gynecological cancer are divided into three types. The Fletcher applicator with MR compatible composes of central tube (tandem) and lateral capsules (ovoids or copolstats). Secondly, the Utrecht applicator has the same structure with the Fletcher applicator but the needles are inserted inside the tiny holes of ovoids. The last type is only the vaginal cylinder applicator.

Several quantities have been specified to prescribe, to constrain and to report intracavitary therapy of gynecologic malignancies, like the dose to point A the mgRa•h value, the vaginal surface dose, and the treatment time. The major systems for treatment of cervix cancer differ not only in choice of treatment modalities, but also in the

specification of doses, in the applicator design, in the geometry of the insertion and in the packing techniques[5].

2.1.2 Source strength specification in brachytherapy

The strength of brachytherapy may be specified in several ways.

2.1.2.1 Activity

The source strength for any radionuclide may be specified in terms of millicuries (mCi). The exposure rate at any particular point is proportional to the product of activity and its exposure rate constant. Errors, however, may be introduced in this method from the fact that correction must be applied for the source and wall filtration and that the accuracy of the exposure rate constant may not be known accurately. It should be recalled that the accuracy of the exposure rate constant depends on the accurate knowledge of the spectroscopic data and the relevant absorption coefficient[13].

2.1.2.2 Exposure rate at a specified distance

The National Council on Radiation Protection and Measurements (NCRP) recommends that the strength of any γ emitter should be specified activity in terms of exposure rate in air at specified distance such as 1 m. This specification can be carried out simply by measuring exposure rate in free air at a distance sufficiently large that the given source can be treated as a point. Long distance measurement geometry minimizes the dependence of the calibration upon the construction of the source and the detector because both can be treated as a point[13].

2.1.2.3 Air kerma rate

The recommended quantity for the specification of gamma sources is the reference air-kerma rate $(\mathrm{K_{air}}(\dot{\mathrm{d}}_{\mathrm{ref}}))_{\mathrm{air}}$ defined by the ICRU as the air-kerma rate in air, at a reference distance of one meter, corrected for air attenuation and scattering. The definition given in this document agrees with that given in the ICRU reports 38 and 58. The SI unit of reference air-kerma rate is $\mathrm{Gy \cdot s^{-1}}$ but for the purposes of source specification is more convenient to use $\mu\mathrm{Gy \cdot s^{-1}}$ and $\mathrm{mGy \cdot h^{-1}}$ for HDR applications. The American Association of Physicists in Medicine (AAPM) recommends photon-emitting sources to be specified in terms of the air-kerma strength $\mathrm{S_k}$. The relation between $(\mathrm{K_{air}}(\dot{\mathrm{d}}_{\mathrm{ref}}))_{\mathrm{air}}$ and $\mathrm{S_k}$ is given by:

$$\mathrm{S_k} = (\dot{\mathrm{K}}_{\mathrm{air}}(\dot{\mathrm{d}}_{\mathrm{ref}}))_{\mathrm{air}}\mathrm{d}^2_{\mathrm{ref}} \tag{2.1}$$

where $\mathrm{d_{ref}}$ is the reference distance at which the reference air-kerma rate is defined (1m). It is apparent from the above equation that the numerical values of the source strength, whether expressed in air-kerma strength or in reference air-kerma rate are identical. The only difference between these two quantities is the unit in which the source strength is expressed. If the reference air-kerma rate of a source is 1 $\mu\mathrm{Gy \cdot h^{-1}}$, then its strength, expressed in air-kerma strength, is 1 $\mu\mathrm{Gy \cdot m^2 \cdot h^{-1}}$. The AAPM TG-43 report recommends a shorthand notation of 1 $\mathrm{U} = 1\ \mu\mathrm{Gy \cdot m^2 \cdot h^{-1}} = 1\ \mathrm{cGy \cdot cm^2 \cdot h^{-1}}$.

Total reference air kerma (TRAK) is the sum of the products of the Reference Air Kerma Rate and the irradiation time for each source. Thus, the TRAK is an important quantity which should be reported for all brachytherapy applications for some following reasons. First, it is simple to calculate and the conversion of the quantity $\mathrm{mg \cdot h}$ to the TRAK is easy and straightforward: 1 $\mathrm{mg \cdot h}$ radium equivalent (0.5 mm Pt filtration) corresponds to 7.2 $\mu\mathrm{Gy}$ at 1 m. Second, the doses to all organs, and thus the

integral dose to the patient, are directly proportional to the TRAK. Moreover, the TRAK, or the sum of the RAKR of all sources, can serve as a useful index for radiation protection of the personnel and nursing staff in charge of the patient[5].

2.1.2.4 Apparent activity

If the source is calibrated in terms of exposure rate at 1 m, its strength may be specified as apparent activity. It is defined as the activity of a bare point source of the same nuclide that produces the same exposure rate at 1 m as the source to be specified. The apparent activity of a brachytherapy source is determined by dividing the measured exposure rate at 1 m with the exposure rate constant of the unfiltered source at 1 m.

It is common practice with the vendors of brachytherapy sources to specify source strength as apparent activity, although the original calibration is done in terms of exposure rate. In order for the user to calculate exposure rate from the apparent activity, the exposure rate constant to be used must be the same as the one used by the vendor. Thus, the exposure rate constant is used as a dummy constant in this conversion; that is, a purely arbitrary value would do, provided its product with the apparent activity yields the same exposure rate as determined by the original calibration[13].

2.1.2.5 Exposure rate constant and air kerma rate constant

The activity of radioactive nuclide emitting photons is related to the exposure rate by the exposure rate constant, Γ_{δ}. In brachytherapy, this constant is usually expressed as numerically equal to the exposure rate in R/h at a point 1 cm from a 1-mCi point source. In the case of radium, the source strength is specified in terms of milligrams of radium instead of mCi.

The ICRU defines the exposure rate constant as:

$$\Gamma_\delta = \frac{l^2}{A}\left(\frac{dx}{dt}\right)_\delta \quad (2.2)$$

where $\left(\frac{dx}{dt}\right)_\delta$ is the exposure rate due to photon of energy greater than δ, at a distance l from a point source of activity A. Special units of Γ_δ are $Rm^2h^{-1}Ci^{-1}$ or any convenient multiple of these.

The quantity replaces, but is not identical to, the specific γ-ray constant. The latter applied to γ-rays only and did not include the exposure rate of emitted x-rays such as characteristic x-rays and internal bremsstrahlung.

A further change has been made by the ICRU. A new quantity, called air kerma rate constant, has been recommended to the exposure rate constant. This quantity is still named Γ_δ, but is now defined as:

$$\Gamma_\delta = \frac{l^2}{A}\left(\frac{dk_{air}}{dt}\right)_\delta \quad (2.3)$$

where k_{air} is the air kerma. The SI unit for this quantity is $m^2Jkg^{-1}h^{-1}Ci^{-1}$. When the special names gray (Gy) and Becquerel (Bq) are used, the unit becomes $m^2GyBq^{-1}sec^{-1}$[13].

2.1.3 Dosimetry in brachytherapy[5]

Several parameters affect to the dose rate at a point near a given radioactive source. The distance to the source, the Reference Air Kerma Rate of the source (RAKR), the source shape, the composition of thickness of its metallic sheath, and the composition of the medium between the source and the point are all these parameters. The one-dimensional (1D) method of the calculation of the dose rate to tissue, D_{tissue}, at a

point P, as shown in figure 2.2, can be deduced from the reference air kerma rate, K_{ref}, when point P is surrounded by tissue at the distance d in tissue from point source. The RAKR is described as the source strength such as the air kerma rate in air at a distance of 1 m.

According to the inverse square law, the kerma rate to air at point P, embraced by air at a distance d (in m) as followed,

$$K_{air}(\text{in air}) = K_{ref} \cdot \frac{1}{d^2} \tag{2.4}$$

Therefore, the tissue kerma rate in a small volume (mass) of tissue at point P, can be defined by

$$K_{tissue}(\text{in air}) = K_{air}(\text{in air}) \cdot \left[\frac{\mu_{tr}}{\rho}\right]^{\text{tissue}}_{\text{air}} \tag{2.5}$$

in which $\left[\frac{\mu_{tr}}{\rho}\right]^{\text{tissue}}_{\text{air}}$ is the quotient of the mean mass energy transfer coefficients in tissue and in air.

The γ-rays, emitted by Ir-192, is almost identical ratio value of 1.10. Under conditions of electric equilibrium, the absorbed dose can be expressed as followed

$$D_{tissue}(\text{in air}) = K_{tissue}(\text{in air}) \cdot (1 - g) \tag{2.6}$$

where g is the fraction of the energy of the electrons, which is lost because of bremsstrahlung occurring in the mass. This radiation is not absorbed locally. The g is not considered for the energy of γ-rays in brachytherapy. Therefore, the mean mass energy absorption coefficient equals the mean mass energy transfer coefficient.

$$\frac{\mu_{tr}}{\rho} = \frac{\mu_{en}}{\rho} \tag{2.7}$$

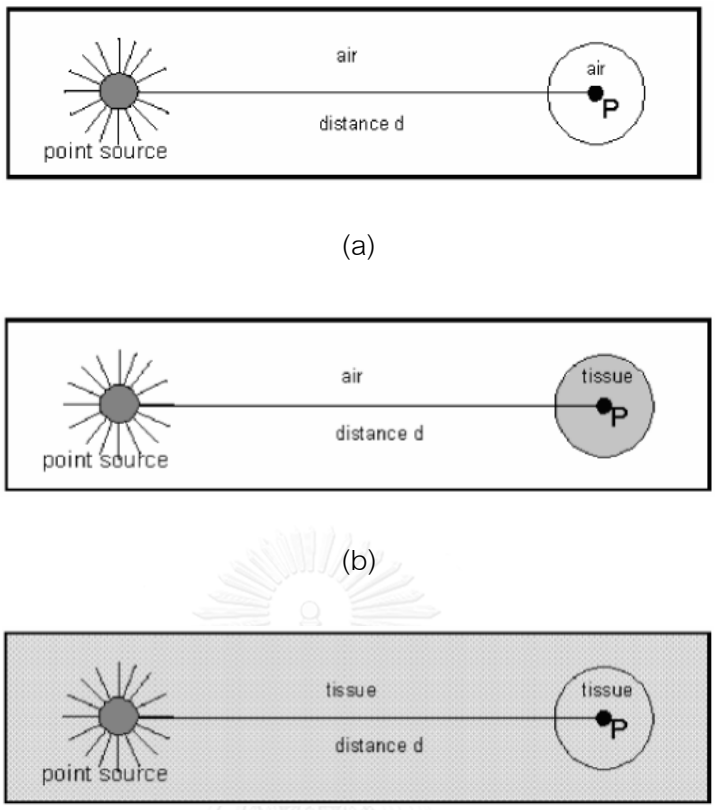


Figure 2.2 The calculation of the dose to tissue with the different conditions. (a) point P in air surrounded by air, (b) point P in tissue surrounded by air and (c) point P in tissue surrounded by tissue[5].

In figure 2.2, the calculation of the dose to tissue at point P at a distance d from a point source with a reference air kerma strength of K_{ref}, at 1 m with a unit $\mu Gy \cdot h^{-1}$ by A is point P in air encompassed by air, B is point P in tissue encompassed by air, and C is point P in tissue encompassed by tissue.

The dose to small volume of tissue, which is surrounded by air, equals the kerma to the small volume of tissue because all the energy is transferred to tissue is absorbed locally in tissue as followed by,

$$D_{tissue}(\text{in air}) = K_{ref} \cdot \left[\frac{\mu_{tr}}{\rho}\right]_{air}^{tissue} \cdot \frac{1}{d^2} \quad (2.8)$$

As it was mentioned that the small volume of tissue at point P and the source by tissue (see figure 2.2), the attenuation (absorption and scatter) in tissue should be considered. The absorbed dose in tissue that surrounded by tissue can be expressed by

$$D_{tissue}(\text{in tissue}) = D_{tissue}(\text{in air}) \cdot \varphi(d) \quad (2.9)$$

where $\varphi(d)$ represents the attenuation correction factor.

Finally, the dose to small volume of tissue is

$$D_{tissue} = K_{ref}\left[\frac{\mu_{en}}{\rho}\right]_{air}^{tissue} \cdot \frac{1}{d^2} \cdot \varphi(d) \quad (2.10)$$

where K_{ref} is the Reference Air Kerma Rate (RAKR),

$\left[\frac{\mu_{en}}{\rho}\right]_{air}^{tissue}$ is the ratio of the mean mass energy absorption coefficients for tissue and for air,

$\frac{1}{d^2}$ is the distance factor (inverse square law),

$\varphi(d)$ is the effective transmission through tissue.

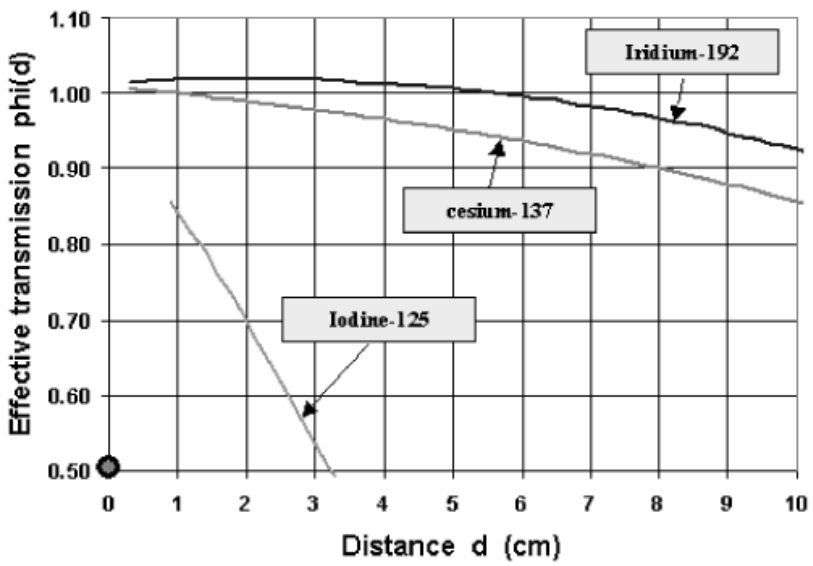


Figure 2.3 Effective transmission factors in water as a function of distance, $\varphi(d)$ for point source followed by Meisberger[14].

The effective transmission in iridium-192 dose not differ much from 1.00 over the first 5 cm as illustrated in figure 2.3. The absorption is mostly compensated by the scatter. The majority is an inverse square law effect.

The use of the RAKR for the specification of the strength of a brachytherapy source has the following advantages. Firstly, the source strength is directly traceable to a national standard. Secondly, the dose rate in a tissue is closely related to the RAKR as can be seen for a point source (see equation 2.10). Finally, it is easy to estimate hazards around an application. However, many of the sources used in brachytherapy are not point sources. The dose rate from sources of a particularly geometry can be calculated by considering the source to be made of many point sources. In this way the geometry of the source is taken into account.

The total dose at point P in figure 2.2 can be obtained by summation of the contribution of each of the point sources, into which the wire or linear source has been subdivided.

Attenuation by the source and its encapsulation and screening effect are influence to the dose distribution around the radiation source. The characteristic of this dose distribution is usually not isotropic so that an anisotropic function is accounted for the absorption and scatter effect in tissue. Because of self-filtration, oblique filtration of primary photons passing the encapsulating material, and scattering of photons in tissue, affect anisotropy function to have an angular variation of dose rate surrounding the source at each distance.

2.1.4 Dose calculation algorithm[11]

As followed by AAPM TG 43 since 1995[11], the two-dimensional (2D) dose rate calculation algorithm (cylindrical source) defined as

$$D(r,\theta) = S_k \cdot \Lambda \cdot \frac{G(r,\theta)}{G(r_0,\theta_0)} \cdot g(r) \cdot F(r,\theta) \qquad (2.11)$$

In this formula, θ will be defined as the polar angle between the longitudinal axis of the source and the ray from the active source center to the calculation point, P(r,θ) and r represents the distance from the source center to P(r,θ) with unit of cm so r_0 is the reference distance, which is 1 cm for this protocol. P(r,θ) is the point of interest, which positioned at distance r and angle θ from the geometric center of the radionuclide distribution as followed figure 2.4.

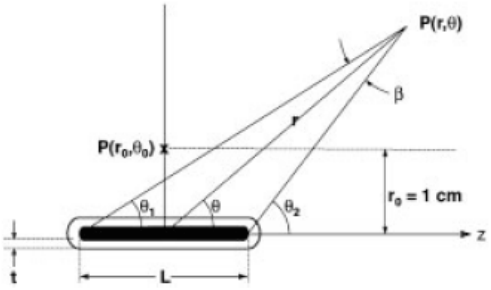


Figure 2.4 Brachytherapy dosimetry calculation coordinate system[11].

2.1.4.1 Dose rate

$D(r,\theta)$ is the dose rate in water at $P(r,\theta)$ with units of cGy/h and the reference dose rate $D(r_0,\theta_0)$ is defined at $P(r_0,\theta_0)$ with the same unit.

2.1.4.2 Air-kerma strength (S_k)

$$S_k = k_\delta(d) \cdot d^2 \tag{2.12}$$

where d represents the distance from the source center to the point of $k_\delta(d)$ specification on the transverse plane of the source.

2.1.4.3 Dose rate constant

Dose rate constant is defined at 1 cm along transverse axis of the source per unit air kerma strength in a water phantom.

$$\Lambda = \frac{D(r_0,\theta_0)}{S_k} \tag{2.13}$$

The quotient of the dose rate at the reference position, $P(r_0,\theta_0)$, and S_k. Also, the unit of Λ is $cGyh^{-1}U^{-1}$.

The factors of the dose rate constant are the source internal design of the radionuclide and source model and the experiment method.

2.1.4.4 Geometry function

Geometry function is the correction of spatial distribution of radioactivity within the source and the slump of photon fluence with the distance from the source.

$$G_p(r,\theta) = r^{-2} \quad \text{point– source approximation} \quad (2.14)$$

$$G_L(r,\theta) = \frac{\beta}{Lr\sin\theta} \quad \text{line – source approximation} \quad (2.15)$$

$$\text{or} = (r^2 - \frac{L^2}{4})^{-1} \text{ , if } \theta = 0^\circ \quad (2.16)$$

Where β is an angle in radians, the tips of the hypothetical line source subtended with the calculation point, P(r,θ).

Approximating the influence of the radionuclide physical distribution on the dose distribution.

2.1.4.5 Radial dose function

$$g_x(r) = \frac{D(r,\theta_0)G_x(r_0,\theta_0)}{D(r_0,\theta_0)G_x(r,\theta_0)} \quad (2.17)$$

The radial dose function accounts for dose fall-off on the transverse plane because of photon scattering and attenuation.

Describing the dose rate at distance r from the source relative to the dose rate at r_0 = 1 cm.

2.1.4.6 2D Anisotropy function

The 2D anisotropy function is the correction of angular variation of photon absorption and scattering in the encapsulation and the medium. Exposure distribution around a brachytherapy source is not isotropic due to attenuation of photons by the encapsulation of source and dose distribution of radioactivity within the source followed by

$$F(r,\theta) = \frac{D(r,\theta)G_L(r,\theta_0)}{D(r,\theta_0)G_L(r,\theta)} \quad (2.18)$$

The 2D anisotropy function defined as the variation in the dose as a function of polar angle relative to the transverse plane.

2.1.5 Calibration using well type ionization chamber[15-17]

The brachytherapy source calibration is necessary in order to check stated vendor calibration and ensure traceability to internationally accepted standards. The source calibration techniques have three main methods, those are calibration using well type ionization chamber, handling in phantom and performing in air.

The measurement with well type ionization chamber is usually performed in KCMH's institute because of its easy setup and the uncertainty minimization.

Measurement techniques are approached at the room center and the same position of source and chamber. It should be done with the chamber at least 1 m from the wall or floor with a minimum scatter ambient environment. Before the calibration is started, the chamber should be at equilibrium with its surroundings.

Calibration point inside the well type chamber must be stated on the chamber's calibration certificate. However, the calibration point is with the source at the position of

maximum response according to the IAEA standard well type chamber[16]. Moreover, the uncertainty in the reference air kerma rate is determined because of the minimization of the position uncertainty. The different position of the source along the axis of the chamber is measured by inserting of known length of the bottom.

The current measurement should be accumulated with a minimum of 4 significant digits for the charge, so it should be collected for a set time depending on the activity of the source. These measurements should be within 0.3% of the average reading and the average of two sets of readings should be within 0.5% for HDR sources. Measurements with beta-particle sources should be done at various orientation of the source in the cylindrical axis and averaging the results. The polarity effect for the beta particles, the calibration factor is only suitable for the polarity stated in calibration certificate.

The air kerma rate is followed by an equation 2.19 with several measurement corrections.

$$K_{air} = M_u \cdot N_{K_R} \cdot K_{TP} \cdot K_s \cdot N_{elec} \quad (2.19)$$

2.1.5.1 Charge reading (M_u)

When position of the maximum response is discovered, the average charge meter reading with the voltage at +300 V and the time of 300 seconds will be measured as shown in equation 2.20.

$$M_u = \text{Avg. reading} \cdot \left(\frac{3600}{\text{measured time}+\text{timer error}}\right) \quad (2.20)$$

The correction for timer error involves with the charge reading (M_u). The formula for timer error correction is shown in equation 2.21.

$$\text{Timer error} = \frac{M_B t_A - M_A t_B}{n M_A - M_B} \quad (2.21)$$

where t_A represents the measurement reading with 180 seconds, t_B is the measurement reading with 90 seconds, M_A is the average charge reading in t_A time and M_B is the average charge reading in two exposure times of t_B.

2.1.5.2 Reference air kerma rate calibration factor (N_{K_R})

$$N_{K_R} = \frac{K_R}{M_U K_{TP} K_s N_{elec}} \quad (2.22)$$

where K_R is the reference air kerma rate of the source, M_u is charge reading, K_{TP} is the correction for temperature and pressure, K_s is the correction for the recombination losses, and N_{elec} is the electrometer calibration factor.

2.1.5.3 Temperature and pressure correction (K_{TP})

The slow leakage of the gas will appear when using sealed chamber and the pressure of gas is higher than the ambient atmospheric pressure. Therefore, this event makes a change in the calibration factor. Normally, the standard ambient condition is usually 20°c and 101.3 kPa. A correction for temperature and pressure is determined since chamber opens to the atmosphere. Air density correction or temperature and pressure are calculated as the following,

$$K_{TP} = \frac{(273.15+T)\cdot}{(273.15+T_0)} \frac{P_0}{P} \quad (2.23)$$

where T is the temperature in Celsius and P is the pressure in kPa

(normally 101.3 kPa), also T_o is the temperature at calibration (generally 20°).

2.1.5.4 Recombination correction (K_s)

The recombination correction should be considered by using two-voltage technique. When the ratio of the voltage employed in this technique is equal two, so the recombination correction can be determined from an equation 2.24.

$$K_S = \frac{\left(\frac{V_1}{V_2}\right)^2 - 1}{\left(\frac{V_1}{V_2}\right)^2 - \left(\frac{M_1}{M_2}\right)} \tag{2.24}$$

where V_1 is the charge accumulated at the higher voltage, V_2 is at the lower voltage, M_1 is the average charge reading at V_1 and M_2 is the average charge reading at V_2.

The recombination correction of the good quality chambers is negligible for the brachytherapy source.

2.1.5.5 Calibration factor of the electrometer (N_{elec})

The calibration factor of the electrometer must be handled, when the electrometer has been calibrated separately. Normally, it equals to 1.

Finally, the percentage difference between the air kerma rate from well chamber and source certification is obtained. The accepted tolerance from the source certification establishes less than ±5%.

2.1.6 Software programs for brachytherapy

The principal software programs for brachytherapy in KCMH contain treatment planning software and independent software. The routine software is mainly Oncentra treatment planning system with the calculation of TG-43 algorithm. Not only Oncentra but also MuCheck is implemented by TG-43 formalism.

2.1.6.1 Oncentra treatment planning system[7]

The treatment planning system in brachytherapy is based on Oncentra software. It can employ with the film for 2D or CT/ MR for volume calculation. Oncentra is performed by the DICOM image on the Windows system that contains the suitable and modern treatment plan process because of treatment plan's efficiency. The calculation algorithm is employed by TG-43 formalism[11], the table of all parameters are provided.

Brachy planning activity in Oncentra allows physicist to create the treatment plan which can be executed by a Nucletron remote afterloading system with a specific radioactive source for HDR brachytherapy.

The catheters are placed in the patient. Patient images are acquired with an imaging device. In Oncentra the acquired images are imported and attached to the patient data. Using the Anatomy Modeling activity, regions of interest (target, organs at risk) can be defined on the images. In the Brachy planning activity the brachytherapy treatment plan is made. The catheters are reconstructed on the image data set (s). The treatment plan is made using a specific set of tools (for example, activation of source dwell positions, dose optimization, and plan evaluation). The final treatment plan is approved by an authorized person and exported to the remote afterloading system.

Brachy planning includes the following functions. First, source definition is to select a Nucletron remote afterloading system with a specific calibrated radioactive

source for HDR brachytherapy. Second, catheter reconstruction is to reconstruct the catheters using the acquired images. If the required applicator model is available in the applicator library, physicist can use the applicator model for catheter reconstruction (requires a separate license). Physicist can apply shields to the following gynecological applicators: Fletcher Williamson Applicator Set, Standard Applicator Set and Shielded Cylindrical Applicator Set. Third, activation of source dwell positions is to define which source dwell positions in the catheters should be activated for treatment. Fourth, defining points is done for dose reporting and normalization on patient, applicator or dose points. Fifth, dose normalization is to set the reference isodose line with a selected dose normalization method. Sixth, dose optimization is to optimize the homogeneity and shape of the target dose distribution while sparing normal tissue. Seventh, dose prescription is to assign an absolute dose (cGy) to a relative dose (%), typically 100%. Eighth, plan evaluation is to calculate and evaluate the DVH, including the DVH table with markers. View the dose range display, live dose, and dose profile. Ninth, plan reporting is the treatment printout. Then, plan exporting is the treatment plan which can be exported to another treatment planning system (for evaluation, comparison and approval), or to the afterloader (for treatment). Figure 2.5 shows the screenshot of Oncentra brachytherapy planning system with vaginal cylinder applicator.

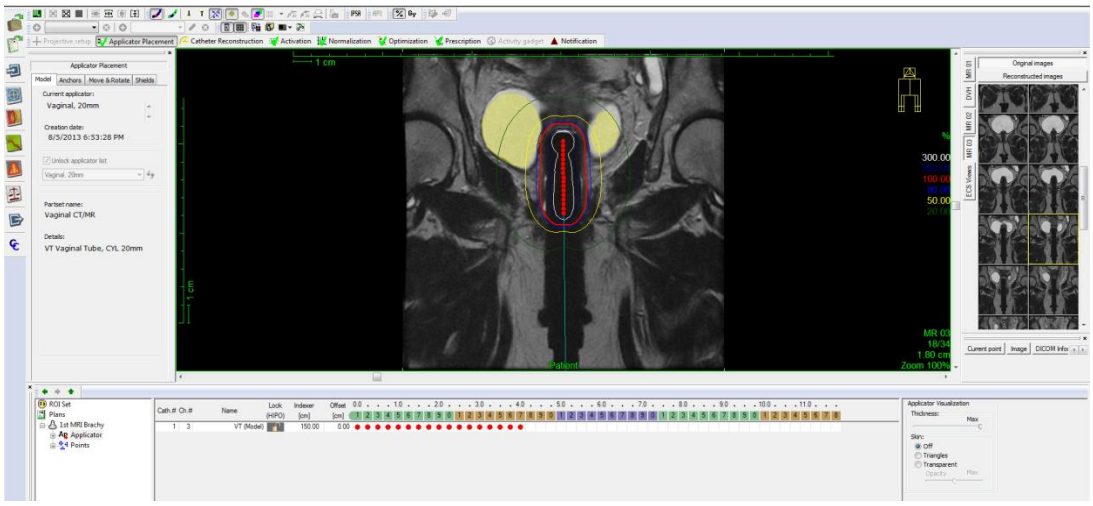


Figure 2.5 A screenshot of Oncentra software.

2.1.6.2 MuCheck independent software[10]

MuCheck software is an independent secondary tool for verifying the accuracy of treatment planning calculation, however, this software is capable of calculation module for brachytherapy treatment planning. It uses the same algorithm with Oncentra for brachytherapy dose calculation with the point source encapsulation contained 3.6 mm of the source length (figure 2.6). It includes the same factors i.e. radial dose function, geometry function, dose rate constant $\left(\Lambda = 1.108\ \frac{\mathrm{cGy}}{\mathrm{h}} \cdot \mathrm{U}\right)$and anisotropy function.

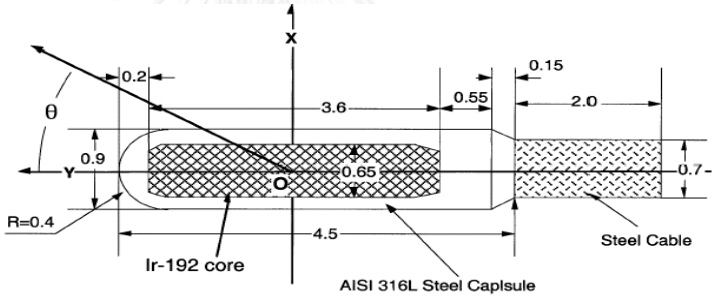


Figure 2.6 The structure of the source encapsulation (mm distance).

MuCheck can be conducted jauntily by a variety of the plan type i.e. DICOM plan, Plato plan, VariSeed plan, Prowess plan. All parameters from independent software are the same as treatment planning software, except the values from anisotropy function because the Oncentra software is more elaborate than MuCheck software.

When the quality assurance in MuCheck is begun, the source informations are implemented as shown in figure 2.7. It requires source type, manufacturer of the source selected, model factor from (e.g. microSelectron) , source

serial number from the source certificate, source of factors, specific calibration date, dose rate constant $(cGy/h \cdot U)$, calibrated air kerma strength ($cGy/h \cdot cm^2$), air kerma constant (U/mCi), half life (days), active source length (mm).

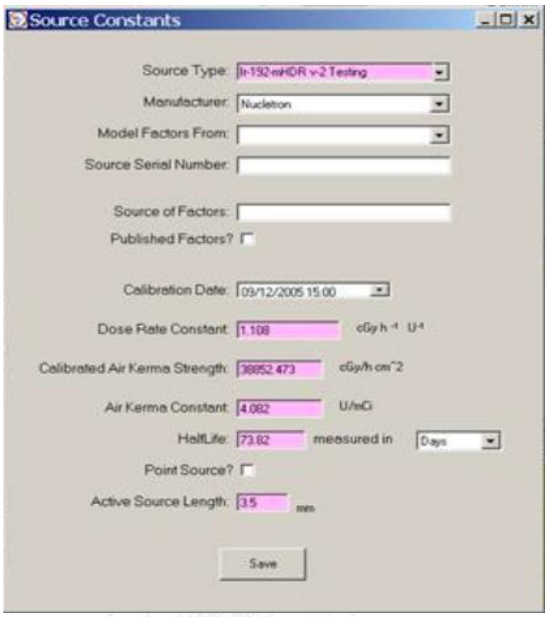


Figure 2.7 Source informations.

The performing of MuCheck software is convenient to assess due to fulfill only 4-source information i.e. source serial number, source of factors, calibration date and calibrated air kerma strength. The dose difference of MuCheck compared with TPS immediately calculates since DICOM plan is imported and the source information is corrected but a distance warning will be appeared when a dose point is closer than 1 cm from any dwell positions due to the constraints in TG-43 formalism.

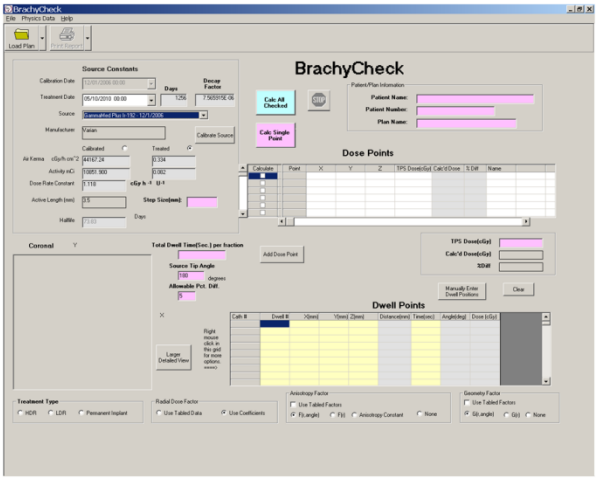


Figure 2.8 Screenshot of main MuCheck window.

The main window of MuCheck software is composed of source information, calculation defaults, patient/plan information, dwells and dose points and graphical display (figure 2.8). For graphics display, the lower right hand corner of the screen has a box in order to indicate a graphical representation of the Dwell points in the coronal view with (X,Z) coordinates, the sagittal view (Y,Z) and the transverse view (X,Y). The different colors of the catheter will be shown when catheter information is provided by the TPS. After a calculation has been handled and mouse-over Dwell positions allowance, BrachyCheck will show the anisotropy, geometry and radial dose factors which were used to calculate the dose contributed by the selected dwell position.

2.2 Review of related literatures

Many researchers have been studied about the way to verify the treatment planning system (TPS) for gynecological cancer.

Hariri S et al[18] demonstrated an algorithm, which was used in the dose calculation composed of AAPM TG-43. Three sources in GZP6 system have been studied using MCNP4C Monte Carlo (MC) code and the results were compared with others available Co-60 HDR sources. Generally, Co-60 source was available on HDR afterloading equipment for gynecological treatment. The AAPM TG-43 parameters of three GZP6 (Nuclear Power Institute of China) Co-60 HDR sources with two different designs were calculated by Monte Carlo method. The parameters were consisted of air kerma strength, dose rate constant, radial dose function and anisotropy function. In addition, the along-away table of dose rate for these sources was presented for data validation purpose. The obtained AAPM TG-43 dosimetric parameters were consistent with other Co-60 HDR system dataset and they had an uncertainty less than 1%. As a result, they can be used to validate the current TPS as well as to develop a complementary TPS. The existing GZP6 HDR system was utilized a treatment planning software which had some deficiencies including lack of a comprehensive treatment planning software for non-predefined treatments and uncommon anatomies, lack of ability to adapt the gradually changeable dosimetric variables and using the point source estimation in dose calculation. The overcome can be done by introduction of a complementary TPS using the obtained dosimetric parameters to enhance the system performance in gynecological treatments.

Kumar R et al[19] performed dose verification, which was the pretreatment patient specific QA for high dose rate brachytherapy treatment plan by a software tool in VC++

code using AAPM TG-43 algorithm. The different type of clinical cases using Varisource HDR unit was verified by compared with the treatment planning system (TPS). The geometrical information, which consisted of dwell time (s), Cartesian coordinates (cm) of dwell position, and calculation point coordinates (cm) from TPS and air kerma strength followed that treatment date were exported to this code. The good agreement was 3% dose difference for most of the dose calculation points. It can be performed to assure the given dose to patient promptly and expediently.

Lachaine M et al[20] provided a fast independent verification of the dose verification by using the in-house software. Their study had the procedure of verification code that started with this code by using the treatment file to compute to dose. Next, the code converted the source to the Cartesian coordinates. Many inputs were required to the verification code such as source strength, reference date, and treatment date. Also, AAPM TG-43 protocol was performed for the calculation of dose rate. Finally, the time was required 1-3 minutes, regardless of the complexity of the plan or the number of applicators. In the part of code evaluation, the BrachyVision planning system was compared these calculations to a single dwell position and validated the calculation with geometries. The result of this study demonstrated that a good agreement was found for the clinical plans. For the plans based on orthogonal films, all of the dose points were well within 1% of the planned dose. For two CT based implants, all dose points were also within 1% of the planned dose except for two points, which were within 2%. Also, All dose points were within 4% and that 14 out of 20 fall within 1%. Moreover, the percent deviation of the dose calculated by the verification code was compared to the planned dose for a total of 20 dose points from the complex nonclinical plans, 1% deviation in 14 dose points of 20 dose verifications, 2% deviation in 4 dose points of 20 dose verifications, 3% and 4% deviation in each 1 dose point of the total dose verification.

Saw C et al[21] evaluated an independent technique (LDR algorithm) for verifying HDR brachytherapy treatment plans, which have been formulated and validated clinically. Dwell times at dwell positions were computed by handle an optimization algorithm. Low-dose-rate (LDR) algorithm was used to compute the doses at defined distances based on dwell times, which were obtained from the HDR treatment plans. A histogram declared the number of the procedures with the associated percent deviation of doses computed at crosscheck points using the HDR and LDR algorithms. The deviation was within 5% for about 80% of HDR procedures were indicated. The deviation was within 10% for all the HDR procedures performed. Even though these percent deviations may be seen as large, but it was within 20% that was the criteria set forth by the US Nuclear Regulatory Commission (NRC) as a brachytherapy misadministration[22]. An independent technique was validated based on the clinical data and it was universal in its applications and not limited to either a particular implant applicator, implant site, or implant type. According to the table, the doses computed using the LDR and HDR algorithms as a function of the distance from an Ir-192 source were shown. In the distance of less than 5 mm, they used very high dose in both of HDR and LDR algorithms. In contrast, if the distance was more than 5 mm the dose will decrease.

CHAPTER III

METHODOLOGY

3.1 Research Design

This research is designed as a retrospective descriptive study, the differences of the dose at the reference points between Oncentra treatment planning system and MuCheck independent software are approached for verification.

3.2 Research Design Model

Research design model is obviously demonstrated in figure 3.1.

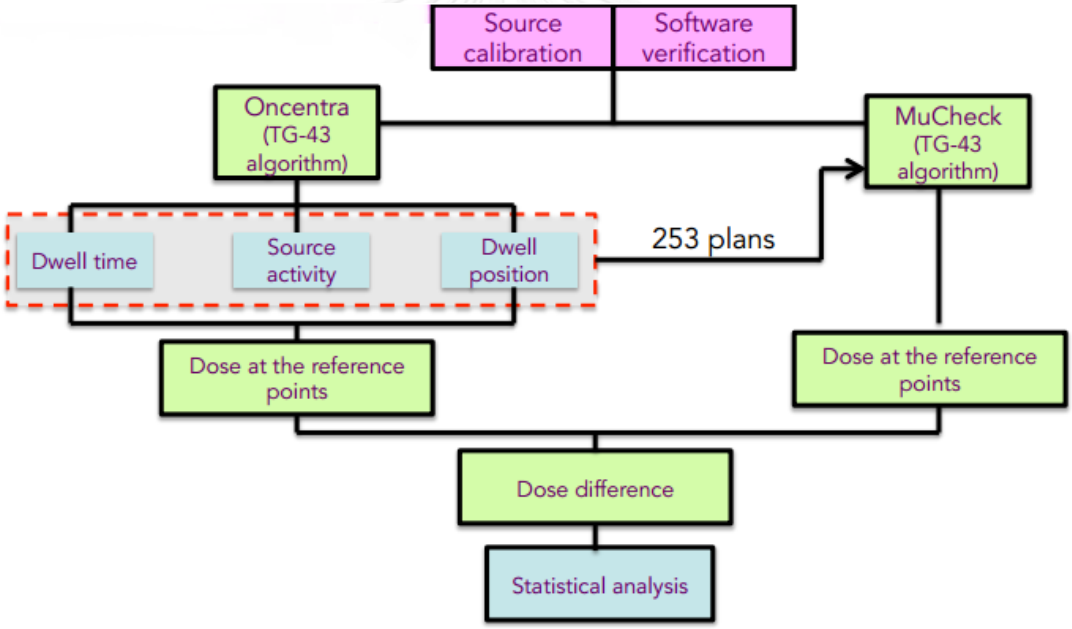


Figure 3.1 Research design model.

3.3 Conceptual framework

The dose differences at the reference points in the 253 cervical cancer brachytherapy treatment plans between Oncentra treatment planning and MuCheck

software are affected by various factors i.e. an error of the reference points location, dwell position and dwell time of an Ir-192 source, source strength, and software. Conceptual framework is shown in figure 3.2.

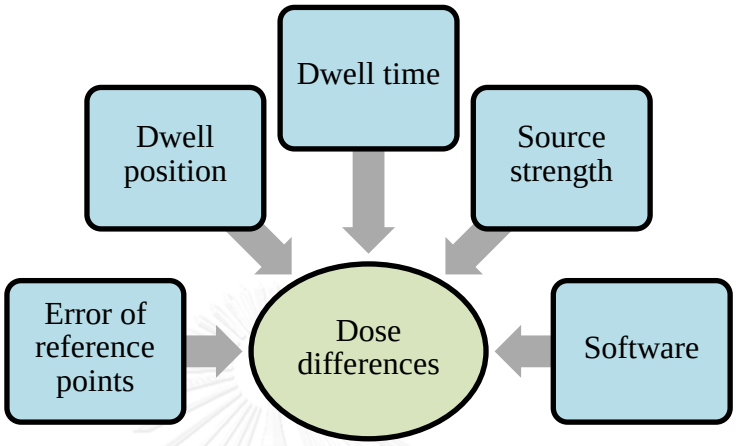


Figure 3.2 Conceptual framework.

3.4 Keywords

- Brachytherapy
- Independent software
- Cervical cancer
- Dose verification
- MuCheck

3.5 Research Question

What are the dose differences at reference points for cervical cancer in HDR brachytherapy calculated by Oncentra treatment planning system compared with independent software?

3.6 Materials

The research implemented the materials and machines from Division of Therapeutic Radiology and Oncology, King Chulalongkorn Memorial Hospital, Bangkok, Thailand.

3.6.1 Brachytherapy Machine

High dose rate (HDR) brachytherapy treatment machine (Elekta, microselectron version V3; figure 3.3) with Iridium-192 (Ir-192) source, which has 73.84 days of half-life come along with 18 channels configuration was used in this study.

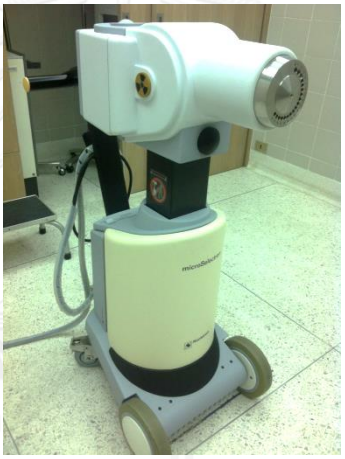
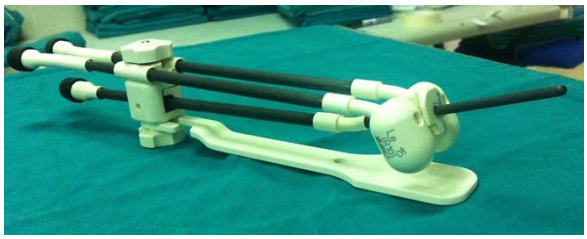


Figure 3.3 High dose rate Brachytherapy machine.

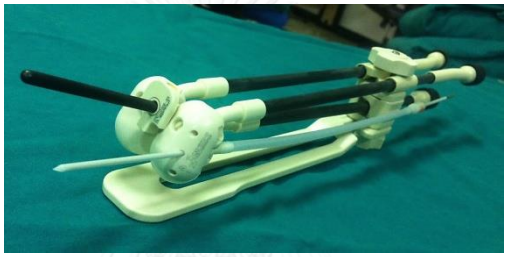
3.6.2 Applicators

Delivering the dose to the treatment site requires applicator. The different body site for applicators has a wide range. First, the Fletcher applicator with MR compatible can be used as a standard intracavitary applicator as illustrated in figure 3.4a. Second, Utrecht applicator with CT/MR compatible is usually employed for MRI based brachytherapy (see figure 3.4b). Additionally, it can perform with needles to allow for dose shaping in case of unfavorable topography, where standard dose distribution

leads to high exposure for organs at risk (bladder and rectum). The last type is the vaginal cylinder applicator (see figure 3.4c) that is suitable for hysterectomy patients.



(a)



(b)

(c)

Figure 3.4 (a) Fletcher applicator for ovoids, (b) Utrecht applicator with needles and (c) Vaginal cylinder applicator.

3.6.3 Magnetic Resonance Imaging (MRI) simulator

MRI scanner becomes the imaging modality of choice because it contributes the good image resolution, no ionizing radiation[23] and better soft tissue contrast compared with conventional CT imaging. Currently, brachytherapy plan is based on MRI in this

institute. The 1.5 HDxt MRI scanner (GE healthcare, Waukesha, WI, USA) is displayed in figure 3.5. A MRI protocol for cervical cancer patient is T2-fast spin echo sequence selected from T2-weighted sequences with small FOV (18X18 cm) for para-axial, para-coronal, and para-sagittal planes. In addition, the 3 mm slice thickness and 0.3 mm gap are required. Body coil is used to increase signal-to-noise ratio and high-resolution body imaging as shown in figure 3.6.

Figure 3.5 MRI machine.

Figure 3.6 Body coil for cervical cancer patients.

3.6.4 Treatment planning system

Oncentra treatment planning system version 4.3 (Nucletron B.V., Veenendaal, The Netherlands) can calculate an accurate dose distribution and provide the applicator modeling to choose for the fast reconstruction. The optimization is automatically by IPSA and HIPO modules but graphical optimization was used in this research. The plans are evaluated by DVH for the quick plan analysis[7] (see figure 3.7).

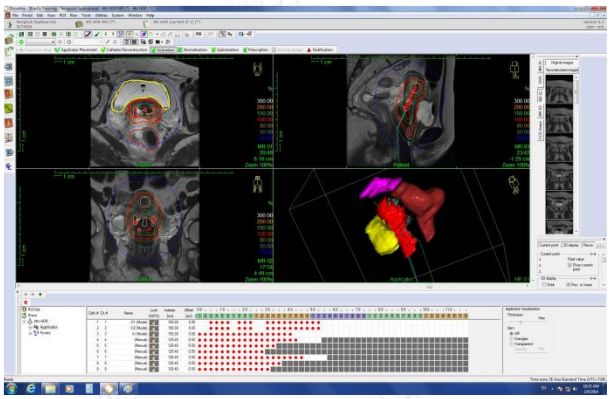


Figure 3.7 Oncentra treatment planning system.

3.6.5 MuCheck independent software

Brachytherapy MuCheck (Oncology Data Systems Inc.) is also known as BrachyCheck, it provides a fast and reliable way to verify the dose calculated by Oncentra treatment planning system. BrachyCheck (version 8.2.0) follows the AAPM TG-43 formalism to calculate the dose applying data imported from TPS system. The window of BrachyCheck of MuCheck software is shown in figure 3.8.

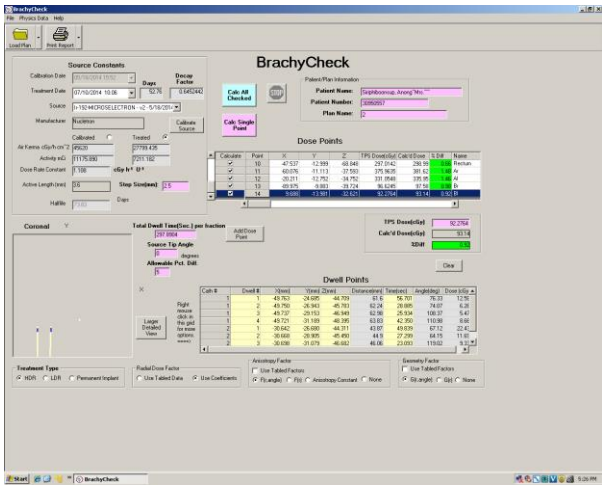


Figure 3.8 MuCheck independent software.

3.6.6 Well type chamber (Nucletron source dosimetry system)

The well type chamber (model 077.091, serial no. 25095, certificate no. 94-3951, Nucletron, The Netherlands) is applied for source calibration in brachytherapy (see figure 3.9) according to AAPM TG-56. The well chamber accommodates a 10-nA current from a 370 GBq (10.0 Ci) Ir source.

Figure 3.9 Well type ionization chamber.

3.6.7 Electrometer

Using electrometer is depended on the type of ionization chamber. The range of measured current should be considered. The Dose 1 dosimeter (Scanditronix Wellhofer, SN 04-9570) is shown in figure 3.10. It employs by connecting with the well type chamber in this study for source calibration. The capable of measuring current is up to 200 nA for the high dose rate source and 0.1% signal resolution. A high accuracy and a good resolution are the characteristic of the Dose 1 dosimeter.

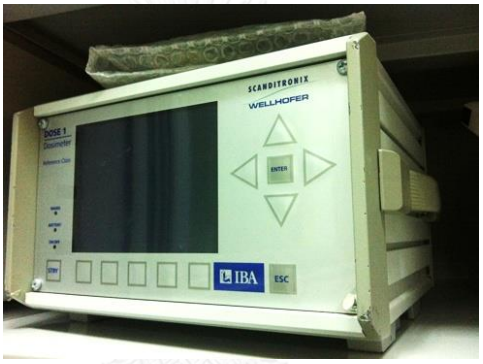


Figure 3.10 The Dose 1 dosimeter.

3.6.8 Afterloading calibration phantom

Afterloading calibration phantom is made from an acrylic cylinder with a diameter of 20 cm and a height of 12 cm (Nucletron, The Netherlands). It is used for the dose calibration. The source is placed at the central tube inside the phantom. The other tube is inserted 8 cm apart from central tube for ion chamber but it is adapted to contain the water and film strip that are changed for 7 different setting times (see figure 3.11).

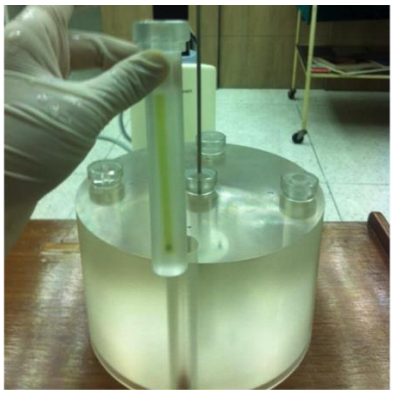


Figure 3.11 Solid phantom for the film calibration.

3.6.9 Water equivalent phantom

An in-house water equivalent phantom is shown in figure 3.12. The dimension is 30×30×30 cm^3. It consists of 2 pieces of bolus, solid water phantoms and many bags of tapioca perl as the water equivalent material. Fletcher applicator which is attached with the rectangular film is placed between tapioca perl bags and solid water phantoms to perform the software verification.

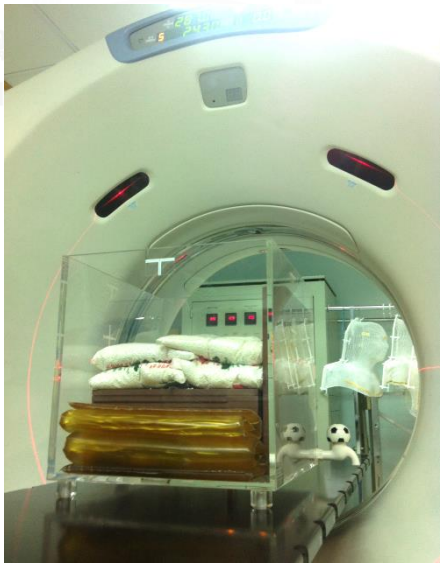


Figure 3.12 CT scanning of water equivalent phantom.

3.6.10 Gafchromic EBT 2 film

The advantage of Gafchromic EBT 2 (Ashland Inc., KY, USA) film (illustrate in figure 3.13) is high spatial resolution and 2-dimensional dose measurement which is better than 1-dimensional detector i.e. ionization chamber, thermoluminescent detectors (TLD), and semiconductor detector. Recently, Gafchromic EBT 2 film are widely utilized in radiation dosimetry due to no film developing, energy independence dose response, reduce scattered radiation, near tissue equivalent, and wide dose range (1 cGy to 40 Gy)[12].

Figure 3.13 Gafchromic EBT 2 film.

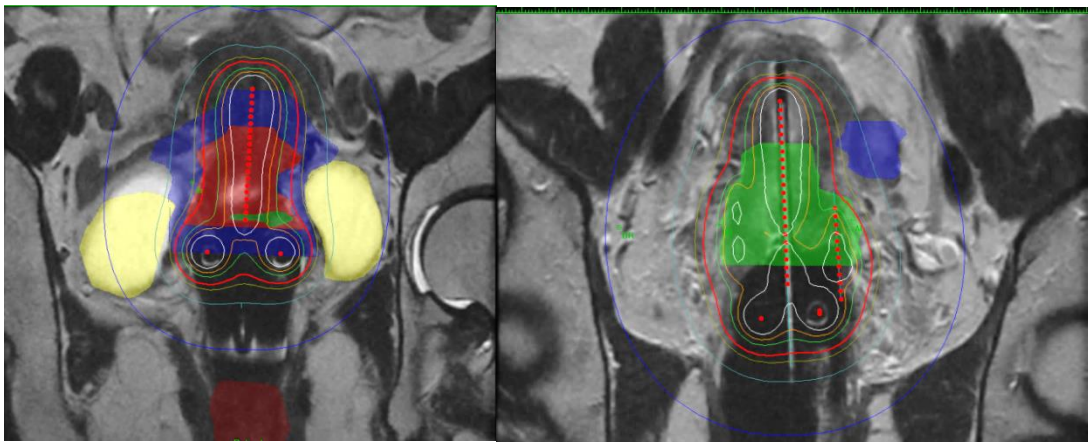
3.6.11 Scanner

The photo scanner (Perfection V700 photo scanner Epson Seiko Corp., Nagano, Japan) is applied for EBT2 film scanning (see figure 3.14). The 4800 dpi and 6400 dpi of resolutions (Epson Dual Lens System) consistently deliver precision color and detail. The excellent detail of image is obtained.

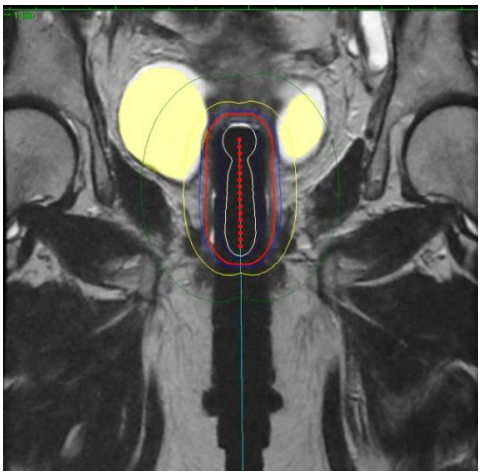
Figure 3.14 Scanner.

3.6.12 Clinical treatment plan

The 253 retrospective treatment plans of cervical cancer are collected from April to August 2014 and are divided into 3 groups those were 107 tandem and ovoids plans (Fletcher applicator), and 75 tandem, ovoids with needle plans (Utrecht applicator) and 71 Tandem plans (Cylinder applicator). The tandem and ovoid (figure 3.15a) are used for standard CA cervix case, the tandem and ovoid with needles (figure 3.15b) are recommended for irregular tumor shape and the tandem plan (figure 3.15c) is normally used in CA corpus.



(a) (b)



(c)

Figure 3.15 (a) Tandem and ovoids plan, (b) Tandem, ovoids, with needle plan, and (c) Tandem plan.

3.7 Methods

The methods were divided into 3 parts. The source calibration was the first process to check the reference air kerma strength. Next, the verification of Oncentra treatment planning and MuCheck independent software was taken into account by comparing with the film measurement. The last step was the clinical application that was the determination of the dose difference between calculated by Oncentra and MuCheck at the reference points.

3.7.1 Source calibration

At every interval of 4 months of new source installation, source calibration was necessary in order to investigate the source strength of Ir-192 from manufacturer. The entire process comprised the steps below.

A. The calibration was performed according to the recommendation of IAEA-TECDOC-1274[16]. Air kerma rate was the significant source strength for dose calculation and the well type chamber was used to measure air kerma rate.

B. The efficiency of DOSE1 dosimeter (Scanditronix Wellhofer, Germany) and the battery status were checked. An electrometer was set to be 0.00 nA so that the monitor displayed no counts.

C. The well chamber and electrometer were placed at least 30 minutes before performing of the measurement in order to equilibrate ambient temperature and pressure. HDR microselectron machine was connected with the transfer tube for the movement of the source to applicator tube inserted inside the well chamber. Also, the well chamber was connected with an electrometer outside the treatment room via cable.

E. The HDR unit and electrometer were warmed up approximately 10 minutes before Ir-192 source calibration was started.

F. The scatter radiation occurred and leaded to scatter back to well chamber so that the HDR unit and well chamber should be located far from walls at least 1 m.

G. The temperature and pressure inside the treatment room were considered using equation 3.1.

$$K_{TP} = \frac{(273.15+T)\cdot}{(273.15+T_0)}\frac{P_0}{P} \qquad (3.1)$$

where T was the room temperature in degree Celsius and P was the room pressure in kPa, P_o was the standard pressure at the SSDL calibration (normally 101.3 kPa) , also T_o is the standard temperature (generally 20^{o}).

H. The maximum current was explored for the exact source position before performing of the measurement and must be determined prior to the brachytherapy source calibration; the maximum current's usually was at the 17-20 source position.

I. The correction of timer error was significantly considered for absorbed dose rate[24]. Assumed time was corrected for on/off effect as followed by equation 3.2.

$$\text{Timer error} = \frac{M_B t_A - M_A t_B}{n M_A - M_B} \quad (3.2)$$

where t_A represented the measurement reading with 180 seconds, t_B was the measurement reading with 90 seconds, M_A was the average charge reading in t_A time and M_B was the average charge reading in two exposure times of t_B.

J. The exponential decay factor was corrected by equation; $I = I_0 \times e^{-\lambda t}$, which I represented by the dose at the time, I_0 was the initial dose, λ was ln 2 divided by the half-life of the brachytherapy source (73.83 days for Ir-192) and t was the duration time between the initial date of company's source calibration to user's source calibration date.

K. The average charge from the measurement of the voltage +300 and +150 volts were collected and calculated according to an equation 2.8 for the recombination correction (K_s). Finally, an equation (3.3) was the formula to calculate the air kerma rate.

$$K_R = M_U N_K K_{TP} K_s \quad (3.3)$$

where K_R was the reference air kerma rate of the source, M_u was the scale unit reading corrected for timer error, N_k, k_{Tp}, and K_s were calibration factor, corrections factor for temperature and pressure, and recombination factor, respectively.

3.7.2 Dose verification between measurement and calculation

The Oncentra and MuCheck software must be checked before the experiment begins for the accuracy and precision performing. The film was an appropriate tool to verify the software. There were the several steps for dose verification between measurement and calculation.

A. Dose verification was employed by Gafchromic EBT2 film (International Specialty Products, Wayne, NJ).

B. The film was calibrated by dividing into 8 small strips (figure 3.16) and was placed in the water phantom irradiated with Ir-192 source.

Figure 3.16 The 8 irradiated film strips with the different dwell time for different doses.

C. The source was driven into the phantom of 300, 600, 900, 1500, 3000, 4500, 6000 seconds and one strip for background with the dose varying from 43 to 863 cGy (table 3.1) calculated from air kerma strength corrected for decay time.

Table 3.1 The dose of each time varying from 0 to 6000 seconds.

Time (sec)	0	300	600	900	1500	3000	4500	6000
Dose (cGy)	0	43.17	86.35	129.53	215.88	431.77	647.65	863.54

D. After irradiation of 24 hours, the film was read by the Epson scanner (Perfection V700 photo scanner Epson Seiko Corp., Nagano, Japan).

E. The graph between the dose ranged from 43 to 863 cGy and the scanner response or optical density (OD) values were constructed.

F. For the verification, the CT scan was undertaken to get the images of the solid phantom with the Fletcher applicator as shown in figure 3.17.

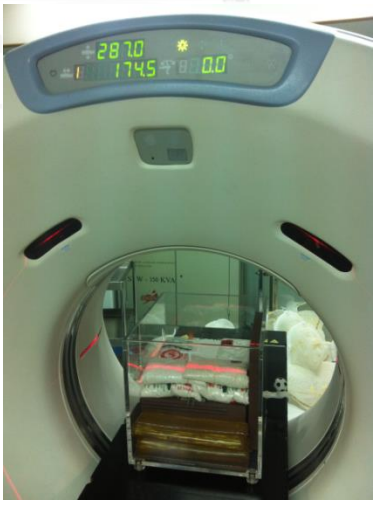


Figure 3.17 CT scanning of the solid phantom.

G. The 3-dimensional images were imported into Oncentra (version 4.3) in order to acquire the dose distribution with the source position and dwell time weight according to the routine used. The total dose at point A was 300 cGy.

H. The radiochromic film was inserted below the Fletcher applicator in the phantom. Then, the film was irradiated by iridium-192 in Brachytherapy machine (Elekta MicroSelectron V2, Veenendaal, The Netherlands) with the source position, dwell time weight and total dose according to G.

J. After 1 day, the exposed film was interpreted with the film calibration curve.

K. All the parameters of source strength, dwell time dwell position, and the geometry of the applicator were exported to MuCheck independent software to calculate the dose points.

L. Dose measurements from the films were compared to calculated dose from Oncentra treatment planning and MuCheck independent software.

3.7.3 Clinical application

In this study, 253 treatment plans were divided into 3 batches of insertions, one was the brachytherapy plan, the plan without needle (Fletcher applicator), the plan with needle (Utrecht applicator), and finally was one tandem (Vaginal cylinder applicator). The plan with needle was more clinical complicate than others in order to tailor the dose of irradiation to the anatomy of the patient with a better target volume coverage[25]. The percent dose difference in both techniques was analyzed for all reference points. The step by step of procedure was described below.

A. Each patient was treated by 3-4 times with the tumor dose of 750-800 cGy at target volume. The patient images were reconstructed using MRI machine (GE Signa 1.5

Tesla, USA) with T2-fast spin echo sequence, small FOV for para-axial, para-coronal, and para-sagittal planes.

B. After that, images were exported to Oncentra treatment plan for applicator reconstruction employing library applicator and the planning was performed using graphical optimization according to tumor and organs.

C. The prescribed dose and tolerance dose of normal tissues were stated for optimization according to the GEC-ESTRO protocol[26].

D. The reference points of A, B, bladder and rectum were recorded. Then, the uncertainty data in the dose reference points was checked by MuCheck software (version 8.2.0).

E. The positions of an applicator source, activity, and dwell time were exported to MuCheck software.

F. The dose between Oncentra and MuCheck independent software was compared. The percent dose difference can be calculated from equation (3.5).

$$\%\ \text{dose difference} = \frac{(\text{MuCheck} - \text{Oncentra})}{\text{Oncentra}}\ \text{x}\ 100 \tag{3.5}$$

The following equation (3.6), which was from AAPM TG-43, was used in Oncentra and MuCheck software for dose calculation.

$$D(r,\theta) = S_k \cdot \Lambda \cdot \frac{G(r,\theta)}{G(r_0,\theta_0)} \cdot g(r) \cdot F(r,\theta) \tag{3.6}$$

where $D(r,\theta)$ is a dose rate to water at point P(r,θ) in unit cGy, S_k is an air kerma strength in unit $\mu Gy \cdot m^2 h^{-1}$, Λ is the dose rate constant in unit $cGy \cdot h^{-1} U^{-1}$, g(r) is a

radial dose function, $G(r,\theta)$ is a geometry function and $F(r,\theta)$ is a 2D anisotropy function.

3.8 Outcome measurement

3.8.1 The dose difference between Oncentra system and MuCheck software at point A, point B, bladder and rectum.

3.8.2 The dose difference between Oncentra and MuCheck at the reference points in needle, no needle and tandem applicator.

3.9 Data collection

Eventually, the 253 cervical cancer plans with the specification of point A, point B, bladder, and rectum from TPS were exported and calculated by MuCheck software. The dose difference at the reference point A, point B, bladder, and rectum on MuCheck program were recorded.

3.10 Data analysis

The dose differences at the reference point were accounted from Oncentra treatment planning system and MuCheck independent software by the equation 3.5. The collected data was analyzed from the average and the standard deviation as followed in the equation 3.7 and 3.8, respectively. Evaluation for the data was done by Microsoft Excel version 2011.

$$\overline{X} = \frac{\sum_i^n x_i}{n} \tag{3.7}$$

$$SD = \left[\frac{\sum_i^n (x_i - \bar{x})}{n-1}\right] \tag{3.8}$$

3.11 Benefit of this study

Dose verification in TPS was evaluated by independent software, called MuCheck. The patient doses at the reference points in cervical cancer treatment plan were determined accurately by MuCheck software.

3.12 Ethical consideration

Although this study was done by planning from the patients, but a retrospective data collection was performed. Consequently, the Ethic Committee of Faculty of Medicine Chulalongkorn University approved the proposal.

CHAPTER IV

RESULTS

4.1 Source calibration using well type ionization

Before the performing of the source calibration, the daily quality control of the brachytherapy unit as listed in appendix A was undertaken. The position of the source can be obtained from the maximum current reading by surveying the source position. Maximum current was observed at position 19th with the irradiated time of 30 seconds as shown in table 4.1. With this position, the source calibration was performed.

Table 4.1 The current (A) in each source position.

Position	Current (x 10^{10} A)
17	2.290
18	2.294
19	2.296
20	2.295

For source calibration process, the given time was 300 seconds, temperature was 26.5 degree Celsius, and pressure was 101.5 kPa, so air density correction was 1.020. The average charged readings for two voltages are shown in the table 4.2, while the timer error is resulted in the table 4.3.

Table 4.2 The average charge (Coulomb) from the measurement in the voltage of +300 and +150 volts.

Voltage (Volt)	Reading	Charge (Coulomb)	Average Charge (Coulomb)
+300	1	6.901×10^{-6}	6.901×10^{-6}
	2	6.900×10^{-6}	
+150	1	6.871×10^{-6}	6.876×10^{-6}
	2	6.876×10^{-6}	
	3	6.881×10^{-6}	

Table 4.3 The measurement reading with 180 seconds in 1 time and 90 seconds in 2 times.

Reading	180 seconds 1 time (M_A) (Coulomb)	90 seconds 2 time (M_B) (Coulomb)
1	4.131×10^{-6}	4.161×10^{-6}
2	4.148×10^{-6}	4.161×10^{-6}
Average	4.149×10^{-6}	4.161×10^{-6}

Timer error was 0.5 seconds (equation 4.2) from IAEA-TRS-398[24] with equation of 4.1.

$$\text{Timer error} = \frac{M_B t_A - M_A t_B}{n M_A - M_B} \tag{4.1}$$

$$\text{Timer error} = \frac{(4.161\times10^{-6})(180)-(4.149\times10^{-6})(90)}{(2)(4.149\times10^{-6})-(4.161\times10^{-6})} = 0.5 \text{ s} \tag{4.2}$$

In order to find the recombination correction, the below equation (4.3) was used

$$K_S = \frac{\left(\frac{V_1}{V_2}\right)^2 - 1}{\left(\frac{V_1}{V_2}\right)^2 - \left(\frac{M_1}{M_2}\right)} \tag{4.3}$$

$$K_S = \frac{\left(\frac{300}{150}\right)^2 - 1}{\left(\frac{300}{150}\right)^2 - \left(\frac{6.901\times10^{-6}}{6.876\times10^{-6}}\right)} = 1.0012 \quad (4.4)$$

so that the recombination correction was equal to 1.0012 as shown in equation 4.4.

From the source strength formula was shown in equation 4.5.

$$K_{\text{air in well}} = M_U \cdot N_K \cdot K_{TP} \cdot K_s \quad (4.5)$$

$$K_{\text{air in well}} = \left(6.901 \times 10^{-6} \times \frac{3600}{(300 + 0.5)}\right)\frac{C}{h} \cdot \left(2.546 \times \frac{10^2 Gy}{C}\right) \cdot 1.020 \cdot 1.0012$$
$$= 21.502 \ \text{mGy} \cdot \text{m} \cdot \text{h}^{-1} \quad (4.6)$$

Thus, Air kerma strength for Ir-192 from our measurement was 21.502 mGy/h/m (equation 4.6). From date 25 July 2013 of dose calibration from company certificate to 28 October 2013 of our dose measurement, the total time was 25 days and the half-life for Ir-192 source was 73.83 days. From the source decay equation; $I = I_0 \times e^{-\lambda t}$, the source strength of certificate at the measurement date was 21.545 mGy/h/m and the ratio of air kerma strength in our measurement and in certificate was 0.998 (<±5%) which was very close agreement.

4.2 Software verification performed by the films measurement

As a previous mentioned, before performing the experiment, the verification of the software should be revealed in order to assure about the accuracy of the planning software.

The Oncentra TPS was verified using radiochromic film (Gafchromic EBT 2 film). The calibration curve became an exponential trend line as seen in figure 4.1. The

average dose difference between measurement in solid phantom at the reference points and calculation was -2.69 ± 4.45% (-10.81 to 4.81%) for Oncentra treatment planning as shown in table 4.4, and -2.37 ± 4.65% (-10.24 to 5.46%) for MuCheck software as displayed in table 4.5. The percent dose difference between Oncentra and the films was calculated by an equation below.

$$\%\ \text{dose difference} = \frac{(\text{Oncentra}-\text{film})}{\text{film}} \text{x}100 \tag{4.4}$$

$$\%\ \text{dose difference} = \frac{(\text{MuCheck}-\text{film})}{\text{film}} \text{x}100 \tag{4.5}$$

The results also showed that the dose in the films were higher than the point dose in Oncentra because most of values was tended to be a minus. Both of the software programs (Oncentra and MuCheck) demonstrated the average percent dose difference that was within 10% dose discrepancy[9] so that the software programs were reliable to be used.

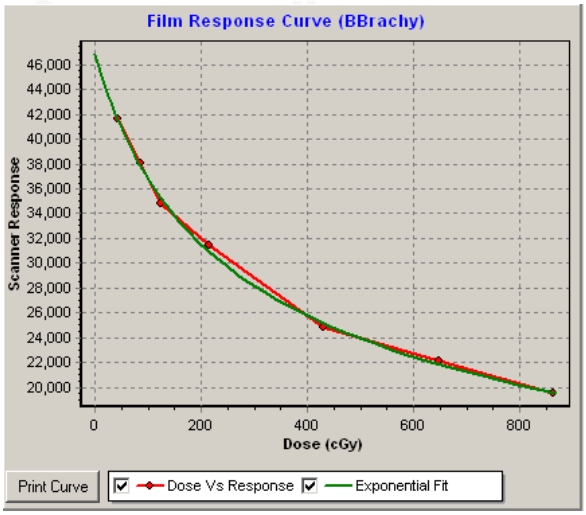


Figure 4.1 Film calibration curve.

Table 4.4 Oncentra software verification using Gafchromic EBT 2 films.

Position	Oncentra (cGy)	Film (cGy)	Dose difference (%)
(2,2)	331.25	338.82	-2.23
(-2,2)	268.75	288.94	-6.99
(0,2)	318.25	331.88	-4.11
(0,5)	131.61	133.93	-1.73
(2,5)	108.44	111.60	-0.03
(-2,5)	101.28	100.83	0.00
(5,2)	81.12	83.80	-3.20
(-5,2)	48.18	45.97	4.81
(-5,5)	52.17	58.49	-10.81
	Average		*-2.69*
	Standard deviation		*4.45*

Table 4.5 MuCheck software verification using Gafchromic EBT 2 films.

Position	Film (cGy)	MuCheck (cGy)	Dose difference (%)
(2,2)	330.49	338.82	-2.46
(0,2)	320.80	331.88	-3.34
(0,5)	133.11	133.93	-0.61
(2,5)	109.88	111.60	-1.54
(-2,5)	102.64	100.83	1.80
(5,2)	81.48	83.80	-2.77
(-5,2)	48.48	45.97	5.46
(-5,5)	52.50	58.49	-10.24
	Average		*-2.37*
	Standard deviation		*4.65*

4.3 Clinical application

For all clinical cases which the dose and percent dose difference data between Oncentra TPS and MuCheck independent software are recorded in appendix B, the result showed good agreement between two treatment planning systems. Figure 4.2 represents the dose difference between MuCheck and Oncentra at the reference points that most of the data were within 1% for point A, point B, bladder, and rectum points, those were 81.82%, 87.74%, 90.12%, and 82.21% of the percent frequency, respectively, as shown in figure 4.2.

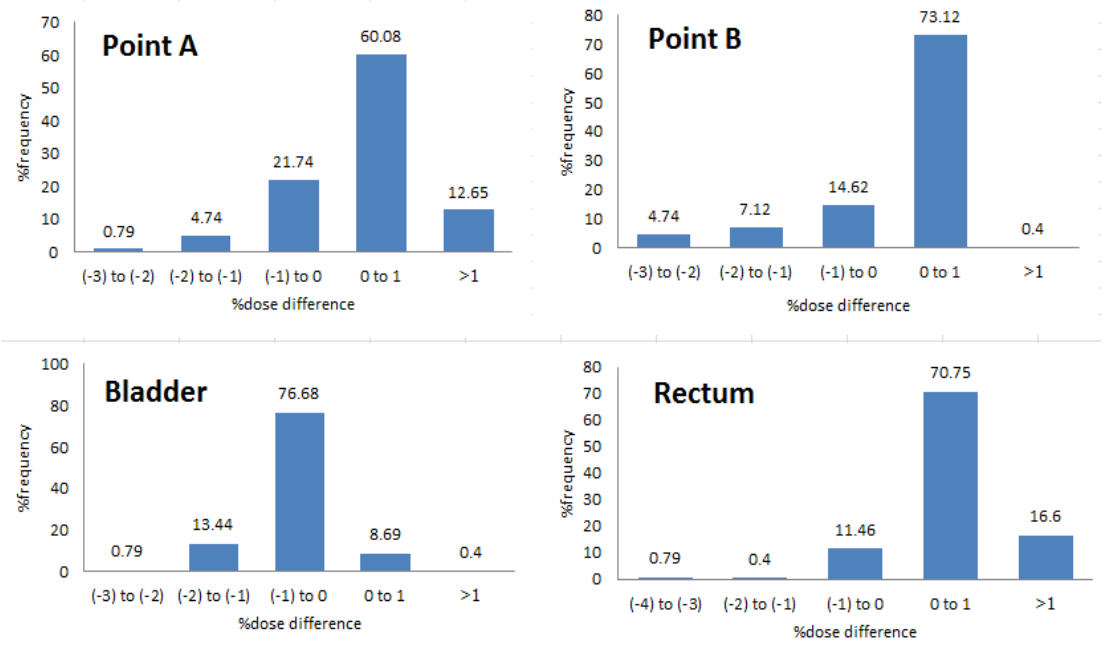


Figure 4.2 The dose differences at the reference points between MuCheck independent software and Oncentra treatment planning software.

Table 4.6 illustrates the dose difference at the reference points in all Tandem and ovoids without needle insertion plans. The average percent dose difference was

0.18±0.91% (-2.27 to 1.42%), -0.24±0.97% (-2.41 to 1.01%), 0.49±0.52% (-1.45 to 1.90%), and 0.44±0.86% (-3.88 to 2.55%) in point A, point B, bladder, and rectum, respectively.

Table 4.6 The dose difference at the reference points in No needle plans.

No needle plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
1	0.65	0.02	1.10	1.01
2	0.87	0.48	0.61	0.71
3	0.57	0.16	1.61	1.33
4	-0.33	0.37	0.05	1.20
5	-0.69	0.37	0.21	1.00
6	-0.05	0.30	0.47	1.02
7	0.84	0.37	0.54	2.55
8	0.26	0.41	0.69	0.59
9	-1.20	0.44	0.86	0.77
10	0.15	0.49	0.68	0.09
11	1.42	0.51	0.60	0.62
12	0.88	0.85	0.82	0.65
13	0.81	0.67	0.63	0.69
14	0.42	0.35	0.92	0.71
15	-0.75	0.42	0.61	0.59
16	0.67	0.45	0.57	0.72

No needle plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
17	0.72	0.36	-0.04	1.16
18	0.43	0.34	-1.01	0.80
19	0.57	0.08	1.29	1.08
20	0.78	0.35	1.69	0.61
21	0.70	0.30	0.63	1.67
22	0.68	0.36	0.57	1.15
23	0.78	0.39	0.48	0.73
24	0.63	0.21	0.55	1.07
25	0.62	0.23	1.36	0.20
26	0.69	0.33	0.81	0.26
27	0.67	0.35	0.72	1.22
28	0.63	0.17	0.66	0.75
29	0.78	0.35	0.60	1.01
30	0.78	0.43	0.71	0.65
31	1.00	0.62	0.72	0.36
32	0.53	0.45	0.56	0.93
33	-0.36	0.30	1.37	0.69
34	0.12	0.38	0.73	0.88
35	0.73	0.50	0.65	0.82
36	0.71	0.47	0.48	0.65
37	-0.75	0.22	0.57	0.56

No needle plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
38	0.23	0.04	1.11	1.48
39	1.08	1.01	0.54	0.63
40	0.15	0.40	0.85	-0.53
41	-0.03	0.18	0.76	1.88
42	-1.58	0.46	0.60	1.12
43	-0.43	0.09	0.45	0.37
44	0.56	0.49	0.66	0.93
45	-0.29	0.34	0.93	0.79
46	-0.12	0.43	0.78	0.75
47	0.39	0.56	0.71	0.21
48	0.26	0.10	0.49	1.15
49	0.66	0.36	0.95	1.42
50	0.75	0.31	0.64	0.82
51	-0.80	0.43	0.62	0.56
52	0.79	0.65	0.60	0.55
53	-1.38	0.29	-0.07	-0.34
54	-0.36	0.37	0.60	0.71
55	-0.33	0.37	0.61	1.06
56	-0.46	0.55	0.50	0.21
57	-0.56	0.22	-0.13	0.83
58	0.81	0.01	0.69	0.52

No needle plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
59	0.73	0.36	0.77	0.56
60	0.30	0.10	0.80	0.78
61	0.30	0.69	0.62	0.68
62	0.48	0.36	0.61	0.76
63	0.44	0.66	0.61	0.72
64	0.50	0.54	0.83	0.91
65	-0.10	0.36	0.57	0.02
66	1.29	0.78	0.52	0.86
67	0.74	0.48	0.89	0.66
68	-0.30	-2.38	-0.42	-0.44
69	-0.36	-2.37	-0.56	-0.49
70	-0.33	-2.41	-0.43	-0.68
71	-0.47	-2.14	-0.52	-0.48
72	-1.17	-2.12	-0.22	-0.40
73	-0.99	-1.77	-0.45	-0.38
74	-1.25	-2.12	-0.44	-0.32
75	-0.33	-2.28	-0.36	-0.65
76	-0.39	-2.39	-0.34	-0.56
77	-1.00	-2.25	-0.60	-3.58
78	-0.49	-2.11	-0.41	-3.88
79	-0.36	-2.36	-0.36	-1.70

No needle plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
80	-0.35	-2.29	-1.45	-0.58
81	0.84	-1.20	0.56	0.69
82	0.63	-1.15	0.56	0.27
83	0.65	-1.28	0.59	0.18
84	0.27	-1.83	0.29	0.38
85	0.53	-1.54	0.42	-0.76
86	0.76	-1.28	0.58	0.73
87	-0.79	-0.98	0.56	0.91
88	-1.42	-0.78	0.51	0.54
89	-2.27	-1.06	0.55	0.50
90	-0.10	-0.73	0.56	0.44
91	0.11	-1.24	0.69	0.52
92	0.07	-1.27	0.37	0.64
93	0.71	-1.23	0.41	0.57
94	-0.02	-1.05	0.72	0.62
95	-0.43	-1.00	0.35	0.42
96	-0.20	-1.09	0.36	0.34
97	-0.30	-1.03	0.41	-0.47
98	-0.17	-1.60	1.90	-0.77
99	-0.20	-1.10	-0.07	-0.30
100	-0.40	0.23	0.62	-0.94

No needle plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
101	0.97	-0.04	0.79	0.95
102	0.76	0.09	0.70	1.36
103	0.71	0.29	0.54	0.74
104	0.63	0.22	0.73	0.61
105	0.38	-0.29	0.38	0.32
106	0.08	-0.35	0.25	0.08
107	0.17	-0.26	0.11	0.23
Average	*0.13*	*-0.24*	*0.49*	*0.44*
SD	*0.69*	*0.97*	*0.52*	*0.86*

Table 4.7 demonstrated the dose difference at the reference points in Tandem and ovoids with needles insertion plans. The average percent dose difference was 0.34±0.58% (-1.66 to 1.21%), 0.37±0.25% (-0.39 to 0.83%), 0.62±0.54% (-0.21 to 4.66%), and 0.75±0.91% (-0.85 to 7.70%) in point A, point B, bladder, and rectum, respectively.

Table 4.7 The dose difference at the reference points in Needle plans.

Needles plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
1	-0.37	0.26	4.66	7.70
2	0.98	0.68	0.54	0.25

Needles plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
3	0.29	0.26	0.43	0.67
4	0.21	0.48	0.59	0.68
5	0.25	0.46	0.58	0.80
6	0.82	0.49	0.68	0.97
7	0.59	0.21	0.66	0.70
8	0.85	0.40	1.41	1.07
9	0.61	0.28	0.81	0.69
10	-0.08	0.24	0.61	-0.83
11	0.62	0.01	0.64	0.79
12	0.17	0.34	0.86	1.20
13	0.43	0.21	0.77	0.21
14	0.26	0.42	0.48	0.35
16	0.27	0.44	0.83	0.80
17	0.57	0.35	0.47	0.72
18	-0.06	0.66	0.55	0.72
19	0.43	0.58	0.55	0.79
20	-0.67	0.54	0.57	0.95
21	0.28	0.27	0.50	0.94
22	0.24	0.36	0.31	0.62
23	0.94	0.72	1.26	0.09
24	-0.67	0.38	0.36	0.85

Needles plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
25	0.27	0.38	0.61	1.01
26	0.28	0.51	0.59	0.86
27	0.20	0.21	0.66	0.98
28	0.91	0.50	0.52	1.13
29	0.71	0.35	0.56	0.82
30	0.16	0.53	0.45	0.78
31	0.73	0.26	0.67	1.97
32	0.68	0.25	0.32	0.36
33	0.95	0.83	0.23	0.69
34	0.04	-0.01	0.55	0.91
35	0.64	0.29	0.64	0.83
36	0.81	0.45	0.84	0.90
37	1.14	0.68	0.60	0.49
38	1.21	0.60	0.67	0.61
39	0.83	0.49	0.75	0.71
40	1.04	0.60	0.56	1.10
41	0.26	0.38	0.58	0.37
42	0.53	0.47	0.55	0.69
43	-0.33	0.38	0.60	1.01
44	0.25	0.28	0.67	1.24
45	0.47	0.36	0.68	0.74

Needles plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
46	0.56	0.19	0.75	0.95
47	0.64	0.18	0.59	0.89
48	0.66	0.14	0.64	0.55
49	1.01	0.55	0.62	0.51
50	0.61	0.58	0.70	0.90
51	0.87	0.64	0.65	0.65
52	-0.22	0.57	0.63	0.14
53	0.78	0.56	0.63	0.45
54	0.09	0.29	0.71	0.92
55	-0.02	0.53	0.71	0.61
56	0.98	0.67	0.59	0.53
57	0.68	0.35	0.67	1.26
58	1.10	0.63	0.32	0.78
59	0.22	0.48	0.59	0.68
60	1.00	0.69	0.67	0.83
61	0.12	0.55	0.69	0.65
62	0.30	0.26	0.57	0.74
63	0.96	0.51	0.76	0.84
64	-0.94	0.58	0.59	0.31
65	0.17	0.56	0.38	0.38
66	0.66	0.53	0.77	0.76

Needles plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
67	-0.52	0.36	0.56	0.86
68	-0.21	-0.29	-0.10	0.08
69	-1.66	-0.29	-0.07	-0.85
70	-0.71	-0.07	-0.11	0.03
71	-0.41	-0.06	-0.15	0.04
72	0.47	0.14	0.26	0.19
73	0.23	-0.39	0.24	0.44
74	0.16	-0.35	-0.21	-0.23
75	-1.50	0.47	0.59	0.90
Average	*0.34*	*0.37*	*0.62*	*0.75*
SD	*0.58*	*0.25*	*0.54*	*0.91*

If the Tandem plans were sorted out, the dose difference at the reference points in all Tandem plans was presented in Table 4.8. The average percent dose difference was 0.52±0.76% (-2.20 to 1.58%), 0.25±0.51% (-1.90 to 0.98%), 0.55±0.43% (-0.18 to 1.21%), and 0.58±0.44% (-0.76 to 1.31%) in point A, point B, bladder, and rectum, respectively.

Table 4.8 The dose difference at the reference points in Tandem plans.

Tandem plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
1	0.44	0.26	0.43	0.72
2	0.21	0.21	0.71	1.04
3	-2.20	-1.90	0.88	1.00
4	0.75	-0.50	0.82	0.86
5	0.57	0.34	0.72	0.79
6	0.50	0.26	0.73	0.61
7	0.83	0.69	0.98	0.99
8	-1.33	-0.93	0.94	1.12
9	0.83	0.64	1.21	1.31
10	0.77	0.39	1.05	-0.76
11	1.58	0.98	1.00	0.91
12	1.24	0.72	0.56	0.60
13	0.96	0.57	0.58	0.76
14	1.09	0.67	0.84	0.84
15	0.85	0.64	0.62	0.58
16	1.13	0.63	0.46	0.38
17	1.22	0.67	0.91	0.89
18	1.31	0.78	0.63	0.67
19	1.25	0.71	0.85	0.90
20	1.29	0.76	0.56	0.54

Tandem plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
21	0.93	0.62	0.86	0.83
22	0.63	0.37	0.88	0.89
23	1.18	0.73	1.03	1.00
24	1.08	0.66	0.80	0.84
25	1.05	0.08	0.97	0.98
26	0.70	0.32	0.77	0.98
27	0.98	0.63	0.58	0.91
28	1.22	0.71	1.06	1.05
29	0.69	0.34	0.73	0.76
30	0.60	0.38	0.56	0.62
31	1.12	0.60	1.03	1.02
32	0.97	0.98	1.14	1.25
33	1.20	0.69	1.13	1.10
34	1.18	0.62	1.00	1.00
35	0.99	0.65	0.89	0.97
36	1.09	0.59	1.00	1.00
37	1.25	0.79	0.96	0.90
38	1.08	0.69	1.06	1.07
39	1.15	0.65	0.48	0.51
40	0.88	0.68	0.91	0.60
41	0.63	0.11	-0.12	-0.10

Tandem plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
42	0.16	-0.03	0.25	0.25
43	-0.09	-0.36	0.24	0.31
44	0.90	0.31	0.21	0.22
45	0.45	-0.01	0.84	0.45
46	0.97	0.28	0.23	0.28
47	0.04	-0.17	0.00	0.30
48	0.14	-0.06	0.04	0.25
49	0.46	0.12	0.18	0.60
50	0.27	0.24	0.51	0.20
51	0.10	-0.32	0.15	0.06
52	0.13	-0.27	0.08	0.07
53	-0.96	-0.30	-0.09	-0.33
54	-1.78	-0.18	-0.16	-0.15
55	-0.22	-0.03	-0.05	-0.18
56	-1.82	-0.24	-0.09	-0.09
57	-0.22	-0.16	-0.10	-0.30
58	0.06	-0.24	-0.13	0.17
59	-0.03	-0.56	-0.18	0.73
60	1.14	0.67	1.00	0.83
61	-0.51	-0.10	0.08	0.52
62	0.26	-0.08	0.05	0.26

Tandem plan no.	Dose Difference (%)			
	Point A	Point B	Bladder	Rectum
63	0.05	-0.30	-0.03	0.59
64	0.17	-0.21	-0.17	-0.05
65	-0.02	-0.46	-0.06	0.24
66	0.09	-0.31	-0.04	-0.37
67	0.19	-0.15	-0.04	0.39
68	1.02	0.59	0.78	0.82
69	0.86	0.50	0.74	0.83
70	0.75	0.47	0.98	0.98
71	0.64	0.85	0.76	0.67
Average	*0.52*	*0.25*	*0.55*	*0.58*
SD	*0.76*	*0.51*	*0.43*	*0.44*

CHAPTER V

DICUSSION AND CONCLUSION

5.1 Discussion

5.1.1 Source calibration

Source calibration is performed in each changing of the source for iridium-192, about every 4 months because of its short half-life (approximately 73.83 days). In order to ensure the reference air kerma strength from certificate of the company with the different value from hospital used is within the limitation of ±5%, the source calibration is necessary. The Reference Air Kerma Rate value from certificate is 21.545 mGy/hr/m, while our measurement in the well type chamber is 21.502 mGy/hr/m on the day of calibration. The dose difference is only -0.19%. A good agreement is obtained for the ±5% of tolerance from the source certification[15-17].

5.1.2 Dose verification in Oncentra and MuCheck using film

After finishing the source calibration in the well chamber, the reference air kerma strength from the certificate can be used with confidence as well. Subsequently, dose verification in software is also checked with the radiochromic EBT2 film for evaluation in the accuracy of Oncentra and MuCheck software. Also, the results show the good agreement that is within 10% dose difference[9]. The difference of both treatment plans from the measurement are similar, these are -2.69±4.45% (-10.81 to 4.81%) and -2.37±4.65% (-10.24 to 5.46%) for Oncentra and MuCheck, respectively. However, the dose differences in some points are high due to the error in defined point location while performing the experiment. Also, the film calibration curve is the steep dose gradient in the low dose region so if the measure position is small shifted, the large dose deviation will occur.

5.1.3 Clinical verification of Oncentra using MuCheck software

Figure 5.1 shows the average percent dose difference at reference points within 3% that was comparable with Lachaine M studied[20] who showed the maximum dose difference of 4%. In our study, the maximum percent dose difference is within 4% except at bladder and rectum point, they are 1.21% at point A, 0.83% at point B, 4.66% at bladder point and 7.70% at rectum point.

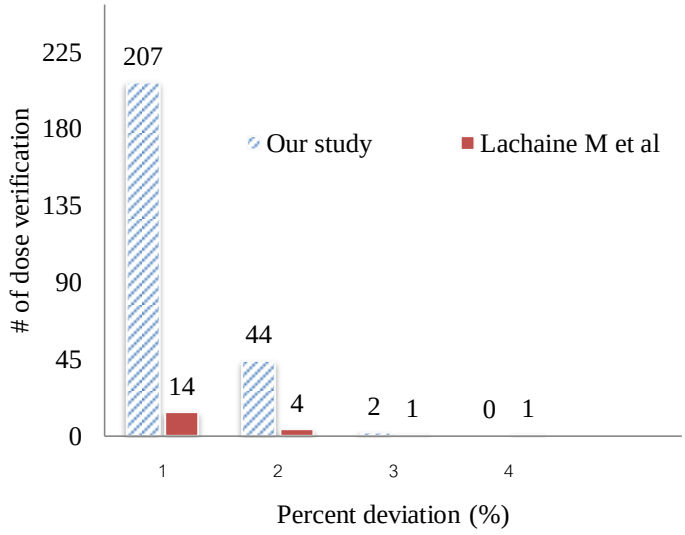


Figure 5.1 The percent dose difference between independent and planning software.

The average percent dose difference between Oncentra and MuCheck calculation at reference points in case of needle plans are slightly larger than without needle plans due to the complicate dose distribution plan excepted point B in needle plans that contributes lower than no needle plans. However, the dose difference is less than 1%. This is in good agreement with Kumar R et al[19] who reported that the point dose difference was within 3% by an independent way using TG-43 algorithm.

In case of the treatment plan without needle, the average dose difference at the reference point A, point B, bladder, and rectum are 0.18±0.91% (-2.27 to 1.42%), -

0.24±0.97% (-2.41 to 1.01%), 0.49±0.52% (-1.45 to 1.90%) and 0.44±0.86% (-3.88 to 2.55%), respectively. Conversely, treatment plan with needle, the average dose difference at the reference point A, point B, bladder, and rectum are 0.34 ±0.58% (-1.66 to 1.21%), 0.37±0.25% (-0.39 to 0.83%), 0.62±0.54% (-0.21 to 4.66%) and 0.75±0.91% (-0.85 to 7.70%), respectively. Also, the treatment plan using only tandem applicator shows the average dose difference at the reference point A, point B, bladder, and rectum are 0.52±0.76% (-2.20 to 1.58%), 0.25±0.51% (-1.90 to 0.98%), 0.55±0.43% (-0.18 to 1.21%), and 0.58±0.44% (-0.76 to 1.31%), respectively as shown in Table 5.1. The average dose differences of three type applicators are comparable, maximum dose difference are observed in the treatment plan with needle those are more complicate plans, especially in bladder and rectum point.

Table 5.1 The average percent dose difference of needle, no needle, and Tandem plans at the reference points.

Plan	Dose Difference (%)			
	point A	point B	Bladder	Rectum
No Needle	0.18 ±0.91	-0.24 ±0.97	0.49 ±0.52	0.44±0.86
Needle	0.34 ±0.58	0.37 ±0.25	0.62 ±0.54	0.75±0.91
Tandem	0.52±0.76	0.25±0.51	0.55±0.43	0.58±0.44

The variations of an applicator type are the cause of dose varying in brachytherapy. In order to get the suitable comform dose for cervical plan, the applicator should be appropiate selected. The general gynecological cancer plans which have the standard paired shape dose distribution used the Fletcher applicator.

For the treatment plans which are not along or protude with the paired shape, the needles are the proper choice to acquire due to coverage the dose shaping. Nevertheless, the prescribed dose (high dose) is located at the isodose line and the needles will be weighted for source travelling to CTV. The dose difference at some collected point is high because the quite different of anisotropy function that is the factor from AAPM TG-43 formula compare between MuCheck and Oncentra software. According to table 5.2 and table 5.3, anisotropy function in MuCheck is more elaborate than the value from Oncentra software so the dose difference between MuCheck and Oncentra will appear.

Table 5.2 Anisotropy function in MuCheck software.

Radius	Angle (degree)									
(cm)	0	1	2	3	4	5	6	7	8	10
0.25	0.729	0.73	0.729	0.73	0.731	0.733	0.735	0.734	0.739	0.756
0.5	0.667	0.662	0.662	0.663	0.664	0.671	0.68	0.691	0.702	0.727
1	0.631	0.631	0.632	0.64	0.65	0.661	0.674	0.687	0.7	0.727
2	0.645	0.645	0.652	0.662	0.673	0.684	0.696	0.708	0.72	0.745
3	0.66	0.661	0.67	0.679	0.69	0.7	0.711	0.723	0.734	0.758
5	0.696	0.701	0.709	0.718	0.726	0.735	0.743	0.753	0.763	0.782

Table 5.3 Anisotropy function in Oncentra software.

Radius	Angle (degree)									
(cm)	0	5	10	15	20	25	30	35	40	45
0	0.791	0.795	0.785	0.837	0.876	0.9083	0.936	0.9442	0.9589	0.9694
0.5	0.667	0.671	0.727	0.7863	0.836	0.8749	0.904	0.9262	0.9433	0.9564
1	0.631	0.661	0.727	0.7893	0.839	0.8752	0.902	0.925	0.9429	0.9575
1.5	0.6339	0.6751	0.7378	0.7981	0.8449	0.8796	0.9058	0.9264	0.946	0.9601

Radius	Angle (degree)									
(cm)	0	5	10	15	20	25	30	35	40	45
2	0.645	0.684	0.745	0.8017	0.846	0.8803	0.907	0.927	0.9481	0.9612
2.5	0.6535	0.692	0.7516	0.8065	0.8492	0.8809	0.9066	0.9282	0.9492	0.9624
3	0.66	0.7	0.758	0.8122	0.854	0.882	0.906	0.9296	0.9497	0.9634

However, the dose difference of 3% is accepted which is within 10% dose difference between Oncentra treatment planning system and MuCheck independent software according to the tolerance from AAPM TG-59[9] that mentioned about the quality assurance in brachytherapy.

5.2 Conclusion

MuCheck independent software is a quick tool to verify the point dose in brachytherapy for each treatment plan. A few minutes are required for this method so that it provides less time consuming for patient waiting time. Most of the dose points are within 1% (207 out of 253) in dose difference between TPS and MuCheck software so that is a good agreement satisafactorily. However, we should bare in mind that both MuCheck and Oncentra using TG-43 still have the deficiency to get the accurate dose in brachytherapy adequately such as the differences in homogenity between TG-43 data and patient organ.

The source calibration plays an important role before dose verification in order to check an accuracy of the source strength from the certificate and the result shows the 1% agreement with the certificate. The latter precedure is the performing of the software verfication for both Oncentra and MuCheck due to an accuracy of the dose calculation is a fundamental. The software is verified by the Gafchromic EBT 2 films and the dose

difference is less than 10% between the film and the software. Thus, the result is met the criteria absolutely.

MuCheck is used to verify 253 clinical plans, using 3 types of applicator (Fletcher, Utrecht and Vaginal cylinder applicator). The dose difference at the reference points is also within 1% in total patients. Additionally, the dose difference of bladder point shows the maximum frequency but point A is the lowest percent frequency that has the 1% dose difference. This is because point is located in the high dose gradient area and the difference anisotropy function between both of software programs.

The types of the applicator are one of the causes of the dose difference because the applicators give the different dose distribution. Utrecth applicator, treated with needles provided the dose conformation. Needle plan gives the highest dose difference at bladder and rectum point. In the case without needle, all of the reference points is lowest dose difference.

According to all the results, it shows that MuCheck software is fast and convenient way of independent checking dosimetry which provides the mandatory quality assurance program for HDR brachytherapy completely in order to irradiate the cancer patient by extremely safety application.

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APPENDICES

Appendix A

Routine quality control

The basis of routine daily, monthly and less frequent measurements is made from many of the checks at commissioning form. Performing of daily checks before brachytherapy treatment is essential.

Facility testing is important, the check list which can be reviewed at the beginning of each treatment session is helpful. The detail to be included will depend upon the type of equipment being used. The following item are used for daily QC:

Lists	usual	unusual
1.CCTV camera function/patient intercom		
2.Warning light function - Radiation at door entrance, at control console - Machine indicator status - Printer status		
3. Door interlock checks		
4. Emergency stop (soft test)		
5. Interrupt button function		
6. Radiation event monitor function		
7. Source position		
8. Source activity at planning, at treatment console		
9. Transfer tube status		

The next part of routine daily QC is the source position accuracy checking. It is essential for accuracy treatment that the source goes to the correct location for the programmed dwell position and additionally that this position corresponds to that used in the treatment plan. In a stepping source device the controller usually requires the distance along the catheter corresponding to a specific dwell position, often the first, to be able to send the source to the correct location. The distance may refer to the length from some part of the unit or from a fictitious point. The dwell positions will then be relative to this absolute position and therefore the precise localization of this position is important. To locate this position the unit is equipped with radio-opaque markers, which can be inserted into the catheter in well-defined positions. The markers may consist of 75 of a long wire with nubs attached, which correspond to one or more specific point(s) in an applicator. There are two methods to perform the source position verifying.

1. One of the methods to verify the correct source position uses an especially designed ruler that replaces a catheter, marked directly with 'distance'. Attaching the ruler and focusing a camera on the scale allows the position of the tip of the source to be verified during a source run.

2. Another method utilizes autoradiographs. Tape a transparent catheter to a film and indicate by pinholes on both sides of the catheter the position of the marker corresponding to the reference position (usually the first dwell position). Program the source to stop at the marked position and execute the run. On the film the dark 'blot' indicates the effective center of the source and this should fall on the line between the two pinholes. A jig, which can accommodate different types of applicators, equipped with a permanently fixed array of diode detectors, can be used for quality control of the source positioning. If this device is calibrated with a radiograph where X-ray markers are

inserted in the catheter it is possible to evaluate the source position relative to the markers.

Appendix B: Dose and percent dose difference data between Oncentra TPS and MuCheck independent software.

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
1	431.29	433.31	0.47	480.71	482.70	0.41	104.09	104.30	0.19	107.54	107.88	0.32	741.76	744.96	0.43	671.89	676.74	0.72
2	270.91	272.62	0.63	1079.58	1077.37	-0.21	82.09	82.01	-0.09	147.33	148.07	0.5	457.59	460.87	0.71	680.95	688.1	1.04
3	551.83	540.24	-2.15	551.83	539.67	-2.25	118.88	116.83	-1.75	118.88	116.49	-2.05	543.57	548.38	0.88	629.49	635.83	1
4	107.93	108.58	0.60	121.49	122.59	0.89	60.31	59.81	-0.83	71.81	71.7	-0.16	565.57	570.24	0.82	595.82	601.01	0.86
5	461.95	464.64	0.58	473.50	476.18	0.56	106.33	106.66	0.31	107.49	107.89	0.36	577.35	581.55	0.72	684.11	689.59	0.79
6	433.16	435.03	0.43	421.70	424.10	0.57	113.84	114.15	0.28	112.32	112.58	0.23	488.22	491.82	0.73	620.55	624.36	0.61
7	478.34	482.30	0.82	484.29	488.38	0.84	106.67	107.35	0.63	108.23	109.05	0.75	583.12	588.88	0.98	629.16	635.46	0.99
8	418.77	412.19	-1.60	359.69	355.93	-1.06	84.42	83.71	-0.85	79.18	78.39	-1.01	392.07	395.78	0.94	627.43	634.52	1.12
9	569.66	569.18	-0.08	626.01	621.92	-0.66	127.54	127.85	0.25	156.54	156.97	0.27	516.19	541.43	4.66	278.94	302.2	7.7
10	551.02	556.56	0.99	535.94	541.16	0.97	133.90	134.93	0.76	127.04	127.78	0.59	718.62	722.49	0.54	157.32	157.71	0.25
11	1309.33	1311.76	0.19	967.93	971.73	0.39	228.99	229.93	0.41	191.79	192.01	0.11	951.72	955.83	0.43	718.61	723.48	0.67
12	1323.92	1322.38	-0.12	722.68	726.62	0.54	189.48	190.64	0.61	167.89	168.48	0.35	1036.5	1042.63	0.59	412.47	415.29	0.68
13	502.56	506.81	0.84	510.22	514.43	0.82	104.90	105.57	0.64	105.74	106.43	0.64	543.39	550.07	1.21	442.34	448.23	1.31
14	720.94	725.40	0.62	748.01	753.07	0.67	162.13	161.66	-0.29	216.74	217.46	0.33	653.35	660.65	1.1	442.53	447.05	1.01
15	847.12	853.93	0.80	622.03	627.87	0.93	198.85	199.84	0.500	170.85	171.62	0.45	644.99	648.93	0.61	371.59	374.24	0.71
16	787.45	791.65	0.53	628.43	632.26	0.61	195.51	195.76	0.13	200.33	200.69	0.18	448.22	455.53	1.61	746.62	756.71	1.33
17	385.96	388.79	0.73	365.82	368.77	0.80	90.09	90.44	0.38	89.57	89.91	0.39	526.87	532.48	1.05	560.33	556.09	-0.76
18	244.75	248.59	1.55	267.62	271.98	1.60	76.98	77.65	0.86	80.79	81.68	1.09	516.81	567.48	1	656.36	662.41	0.91
19	1407.96	1404.55	-0.24	938.70	934.88	-0.41	164.71	165.29	0.35	162.12	162.73	0.38	738.04	738.44	0.05	593.94	601.13	1.2
20	1851.7	1842.65	-0.49	1081.84	1072.37	-0.88	166.45	167.20	0.45	149.74	150.16	0.28	788.69	790.34	0.21	713.66	720.83	1

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
21	924.52	926.11	0.17	676.03	674.26	-0.26	203.09	204.25	0.57	123.75	123.77	0.02	595.72	598.55	0.47	630.84	637.34	1.02
22	634.39	640.66	0.98	630.45	634.89	0.70	183.87	184.76	0.49	149.59	149.94	0.24	662.73	666.36	0.54	460.29	472.33	2.55
23	904.49	905.29	0.090	691.53	694.50	0.43	147.65	148.24	0.400	142.21	142.79	0.41	417.85	420.73	0.69	403.75	406.17	0.59
24	8696.36	8469.47	-2.68	1636.67	1641.36	0.29	304.99	306.54	0.51	204.47	205.2	0.36	772.5	779.24	0.86	690.61	695.96	0.77
25	1419.55	1421.5	0.14	1555.46	1557.95	0.16	209.26	210.28	0.49	227.64	228.76	0.49	825.55	831.21	0.68	549.7	550.18	0.09
26	7602.99	7448.65	2.07	1285.58	1295.41	0.76	275.09	276.35	0.46	243.67	245.02	0.55	661.79	665.81	0.6	605	608.75	0.62
27	606.30	612.94	1.08	630.20	634.49	0.68	181.10	182.31	0.66	206.25	208.39	1.03	604.86	609.88	0.82	559.54	563.2	0.65
28	385.48	390.27	1.23	398.27	403.29	1.24	93.05	93.7	0.7	93.32	94.02	0.74	392.19	394.4	0.56	690.3	694.44	0.6
29	464.09	468.56	0.96	490.23	495	0.96	98.13	98.67	0.54	100.38	100.98	0.6	413.98	416.38	0.58	668.66	673.75	0.76
30	1611.71	1613.5	0.11	776.12	779.16	0.39	244.64	246.43	0.73	142.06	142.32	0.19	581.74	585.16	0.58	648.23	653.45	0.8
31	392.76	397.08	1.09	392.76	397.08	1.09	91.14	91.75	0.67	91.14	91.75	0.67	661.67	667.29	0.84	607.39	612.53	0.84
32	808.57	815.3	0.83	827.74	834.53	0.81	214.59	215.78	0.55	205.25	206.13	0.43	461.91	465.09	0.68	288.54	291.38	0.97
33	1019.79	1025.88	0.59	1080.22	1086.67	0.59	299.18	299.8	0.21	279.64	280.19	0.2	279.34	281.2	0.66	552.86	556.78	0.7
34	500.21	504.44	0.84	455.02	458.99	0.86	95.2	95.84	0.67	91.03	91.59	0.61	228.77	230.2	0.62	583.61	587.03	0.58
35	485.77	491.27	1.12	478.05	483.58	1.14	112.49	113.21	0.63	112.06	112.76	0.62	693.88	697.12	0.46	798.93	801.94	0.38
36	496	502.09	1.21	490.73	496.79	1.22	118.82	119.62	0.67	118.46	119.25	0.66	675.04	681.21	0.91	647.31	653.13	0.89
37	390.69	395.88	1.31	408.22	413.59	1.3	98.77	99.54	0.77	101.44	102.24	0.78	254.53	256.15	0.63	690.34	695.01	0.67
38	882.49	888.76	0.71	715.8	722.33	0.9	216.91	218.2	0.59	190.24	191.66	0.74	640.09	644.14	0.63	412.54	415.41	0.69
39	1756.05	1758.47	0.14	763.06	768.38	0.69	253.6	254.91	0.52	171.15	171.44	0.17	442.36	446.47	0.92	573.39	577.48	0.71
40	1656.46	1648.39	-0.49	1552.58	1537.28	-1	213.63	214.49	0.4	212.65	213.56	0.43	574.19	577.69	0.61	431.34	433.88	0.59

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
41	505.7	509.9	0.82	546.22	551	0.87	146.11	146.62	0.35	156.65	157.34	0.44	382.5	387.96	1.41	526.83	532.55	1.07
42	549.68	553.02	0.6	658.42	662.47	0.61	134.68	134.96	0.2	154.32	154.87	0.35	135.35	136.46	0.81	253.87	255.65	0.69
43	622.14	621.75	-0.06	579.69	579.14	-0.09	150.73	151.13	0.25	143.58	143.9	0.22	113.66	114.36	0.61	195.49	193.89	-0.83
44	460.68	466.48	1.24	443.6	449.24	1.26	111.64	112.49	0.76	111.1	111.83	0.66	524.85	529.33	0.85	619.82	625.46	0.9
45	472.94	479.1	1.28	461.58	467.62	1.29	115.74	116.64	0.77	114.47	115.32	0.74	567.29	570.48	0.56	593.75	596.96	0.54
46	677.19	681.41	0.62	665.59	669.68	0.61	188.75	188.83	0.04	185.95	185.9	-0.03	893.18	898.97	0.64	578.23	582.85	0.79
47	1444.41	1438.13	-0.44	483.58	487.39	0.78	182.65	183.42	0.42	138.59	138.94	0.25	668.65	674.46	0.86	551.13	557.83	1.2
48	608.98	614.72	0.93	615.35	621.06	0.92	124.25	125.01	0.61	125.96	126.74	0.62	564.99	569.91	0.86	642.8	648.16	0.83
49	781.81	787.06	0.67	510.32	513.27	0.58	144.07	144.79	0.5	116.57	116.84	0.23	465.52	469.67	0.88	676.31	682.39	0.89
50	898.01	904.01	0.66	926.33	932.65	0.68	250.16	251.34	0.47	254.48	255.55	0.42	758.33	762.71	0.57	571.91	576.03	0.72
51	679.77	684.94	0.76	613.89	618.11	0.68	194.31	195.33	0.52	177.79	178.13	0.19	351.37	351.22	-0.04	449.2	454.46	1.16
52	772.24	775.48	0.42	745.52	748.78	0.43	184.07	184.71	0.35	183.06	183.66	0.33	637.87	631.48	-1.01	528.6	532.87	0.8
53	770.35	774.72	0.56	774.89	749.13	0.57	224.35	224.49	0.06	222.17	222.38	0.1	403.29	408.56	1.29	657.27	664.48	1.08
54	1015.57	1019.26	0.36	954.52	959.26	0.49	191.94	192.34	0.21	191.75	192.14	0.2	524.99	529.05	0.77	413.29	414.16	0.21
55	1146.11	1145.98	-0.01	964.54	969.61	0.52	198.09	198.94	0.42	199.53	200.36	0.42	549.79	552.42	0.48	410.54	411.98	0.35
56	700.4	705.34	0.7	935.51	943.51	0.85	209.44	209.88	0.21	231.04	232.17	0.49	306.16	311.42	1.69	436.37	439.03	0.61
57	685.58	690.43	0.7	656.35	660.81	0.7	191.12	191.8	0.36	177.79	178.22	0.24	413.16	415.78	0.63	223.11	226.89	1.67
58	625.81	630.08	0.68	664.45	669.02	0.68	154.72	155.25	0.34	159.2	159.79	0.37	405.37	407.68	0.57	393.73	398.31	1.15
59	725.97	731.78	0.79	618.29	623.03	0.76	167.45	168.2	0.44	156.45	156.97	0.34	485.77	488.09	0.48	420.02	423.12	0.73
60	703.33	707.88	0.64	651.66	655.66	0.61	186.49	187.08	0.31	172.91	173.08	0.1	652.65	656.27	0.55	524.79	530.47	1.07

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
61	460.8	465.83	1.08	891.35	900.75	1.04	144.24	144.52	0.19	222.86	225.07	0.98	737.74	741.71	0.54	381.58	383.91	0.61
62	2126.45	2119.24	-0.34	1334.44	1346.32	0.88	253.17	254.1	0.37	373.31	375.23	0.51	930.93	938.76	0.83	748.64	754.71	0.8
63	1238.63	1245.36	0.54	1307.29	1315	0.59	257.27	258.2	0.36	262.32	263.18	0.33	474.77	477.02	0.47	396.96	399.82	0.72
64	621.86	625.66	0.61	633.63	637.55	0.62	167.55	167.91	0.22	168.94	169.35	0.24	391.22	396.61	1.36	415.05	415.9	0.2
65	707.34	712.22	0.69	704.26	709.07	0.68	197.05	197.7	0.33	196.04	196.68	0.32	599.13	604.05	0.81	493.55	494.85	0.26
66	602.14	606.36	0.7	592.1	595.89	0.64	180.6	181.38	0.43	178.65	179.13	0.27	702.33	707.45	0.72	778.59	788.25	1.22
67	801.54	804.64	0.39	1130.65	1124.97	-0.51	150.08	151.02	0.62	143.87	144.88	0.7	610.3	613.7	0.55	971.91	979	0.72
68	865.8	869.76	0.46	635.17	637.73	0.4	168.25	169.21	0.57	150.69	151.57	0.58	718.43	722.38	0.55	667.26	672.59	0.79
69	1717.8	1684.34	-1.99	620.54	624.62	0.65	144.74	145.53	0.54	126.59	127.28	0.54	747.91	752.19	0.57	553.71	559	0.95
70	355.68	357.69	0.56	940.51	940.52	0	76.04	76.01	-0.05	138.59	139.42	0.59	371.18	373.04	0.5	529.49	534.51	0.94
71	1055.92	1060.61	0.44	1478.75	1479.19	0.03	170.28	170.99	0.42	161.46	161.94	0.3	512.63	514.21	0.31	563.53	567.05	0.62
72	243.41	296.44	1.03	497.04	501.24	0.84	83.94	84.11	0.2	150.17	152.04	1.23	373.32	378.09	1.26	558.75	559.24	0.09
73	2469.56	2443.1	-1.08	1201.82	1198.7	-0.26	170.58	171.22	0.37	144.24	144.8	0.39	184.67	185.34	0.36	513.38	517.79	0.85
74	735.7	740.47	0.64	744.37	749.02	0.62	210.74	211.18	0.21	209.12	209.39	0.13	653.62	657.94	0.66	481.67	285.32	0.75
75	571.58	575.73	0.72	724.55	730.69	0.84	155.54	155.87	0.22	180.93	181.79	0.48	354.55	356.7	0.6	541.81	547.36	1.01
76	1052.64	1055.49	0.27	832.97	835.11	0.26	162.77	163.35	0.35	157.16	157.79	0.4	615.08	618.86	0.61	559.59	565.27	1.01
77	842.99	845.22	0.26	810.54	813.01	0.3	144.24	145.04	0.55	139.46	140.11	0.46	631.04	634.79	0.59	516.52	520.99	0.86
78	935.52	935.88	0.04	647.39	649.65	0.35	160.44	160.87	0.26	144.65	144.89	0.16	511.84	515.25	0.66	304.16	307.17	0.98
79	527.82	532.37	0.85	645.23	651.58	0.97	150.46	150.95	0.32	173.23	174.39	0.67	837.6	841.97	0.52	647.29	654.69	1.13
80	697.46	702.35	0.7	796.92	802.64	0.71	173.07	173.65	0.33	184.89	185.58	0.37	642.42	646.01	0.56	604.72	609.72	0.82

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	diff
81	665.43	670.32	0.73	754.83	751.75	-0.41	155.33	156.04	0.45	179.6	180.69	0.6	678.74	681.81	0.45	543.37	547.67	0.78
82	665.69	670.77	0.76	613.98	618.23	0.69	223.84	224.59	0.33	206.12	206.52	0.19	899.54	905.65	0.67	533.59	544.3	1.97
83	565.86	570.2	0.76	528.01	532.19	0.79	162.21	162.95	0.45	157.49	158.13	0.41	734.14	739.37	0.71	317.11	319.19	0.65
84	482.9	487.94	1.03	515.09	520.16	0.97	147.25	148.21	0.65	154.04	154.96	0.59	767.15	772.7	0.72	284.02	285.03	0.36
85	495.87	501.74	1.17	420.21	425.24	1.18	126.44	127.44	0.79	116.63	117.41	0.66	538.64	544.22	1.03	633.81	640.2	1
86	409.79	414.25	1.08	412.98	417.47	1.08	99.16	99.81	0.66	100.29	100.94	0.65	556.79	561.27	0.8	888.43	895.92	0.84
87	895.82	900.14	0.48	851.54	856.44	0.57	211.22	212.23	0.47	189.25	190.05	0.42	614.75	618.19	0.56	538.05	543.12	0.93
88	1607.85	1593.42	-0.91	1472.31	1475.24	0.2	230.54	231.34	0.34	223.05	223.64	0.26	326.29	330.83	1.37	429.1	432.07	0.69
89	1109.22	1113.31	0.37	1447.65	1445.58	-0.14	224.03	224.85	0.36	224.66	225.57	0.4	643.73	648.48	0.73	667.02	672.94	0.88
90	550	553.8	0.69	855.05	861.58	0.76	127.75	128.25	0.39	196.44	197.63	0.6	557.85	561.5	0.65	436.38	440	0.82
91	868.46	874.15	0.65	1212.15	1220.71	0.7	258.2	258.44	0.09	305.98	307.21	0.4	126.59	126.99	0.32	769.67	772.48	0.36
92	232.89	234.87	0.84	298.74	301.91	1.05	587.04	591.61	0.77	917.75	925.88	0.88	180.47	180.89	0.23	231.29	232.91	0.69
93	924.39	928.95	0.49	1392.71	1386.91	-0.42	226.85	226.77	-0.03	243.2	243.22	0.01	684.89	688.68	0.55	646.54	652.48	0.91
94	665.57	671.58	0.89	1957.37	1967.67	0.52	189.63	189.8	0.09	366.09	369.23	0.85	600.47	603.38	0.48	483.22	486.4	0.65
95	1312.25	1313.82	0.12	4115.5	4050.27	-1.61	279.39	279.22	-0.06	581.45	584.37	0.5	916.63	921.86	0.57	683.31	687.15	0.56
96	864.84	867.62	0.32	1208.85	1210.58	0.14	234.05	233.73	-0.14	990.52	992.56	0.21	452.49	458.06	1.11	541.07	549.23	1.48
97	618.73	626.38	1.22	823.7	831.51	0.94	226.85	228.3	0.64	367.2	372.34	1.38	691.58	695.33	0.54	639.63	643.72	0.63
98	1165.95	1164.13	-0.16	648.79	651.8	0.46	195.97	196.85	0.45	161.83	162.38	0.34	440.13	443.89	0.85	673.25	669.73	-0.53
99	582.13	580.16	-0.34	704.32	706.33	0.29	159.03	159.24	0.13	161.75	162.13	0.23	541.85	545.98	0.76	439.55	447.96	1.88
100	832.02	822.45	-1.16	1649.99	1617.67	-2	283.65	285.7	0.72	221.41	221.85	0.2	611.5	615.18	0.6	466.47	471.76	1.12

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
101	1146.64	1135.63	-0.97	619.22	619.98	0.12	226.47	226.62	0.07	201.59	201.82	0.11	584.34	586.96	0.45	504.19	506.09	0.37
102	1181.45	1185.63	0.35	841.9	848.39	0.76	205.79	207.07	0.61	183.61	184.29	0.37	632.05	636.26	0.66	804.03	811.58	0.93
103	1187.17	1184.64	-0.21	1380.65	1375.73	-0.36	188.62	189.18	0.3	224.23	225.09	0.38	539.12	544.17	0.93	667.59	672.94	0.79
104	1447.32	1447.73	0.03	1777.69	1773	-0.26	199.93	200.73	0.4	207.23	208.17	0.45	640.33	645.35	0.78	526.01	530.01	0.75
105	1225.39	1232.98	0.62	1224.68	1226.47	0.15	197.75	198.88	0.57	197.39	198.47	0.55	678.02	682.88	0.71	394.27	395.11	0.21
106	211.82	214.05	1.04	184.77	186.76	1.06	97.28	97.47	0.2	82.13	82.1	-0.04	516.38	521.43	0.97	454.11	458.6	0.98
107	475.76	478.7	0.61	443.34	446.83	0.78	115.53	115.9	0.32	112.15	112.5	0.31	556.22	560.56	0.77	671.48	678.11	0.98
108	672.28	678.92	0.98	688.92	695.7	0.97	145.41	146.32	0.62	146.22	147.14	0.63	662.62	666.46	0.58	1043.15	1052.71	0.91
109	465.67	471.32	1.2	464.95	470.75	1.23	113.89	114.72	0.72	114.21	115.01	0.69	767.43	775.67	1.06	790.83	799.2	1.05
110	1705.96	1709.69	0.22	1196.17	1199.64	0.29	227.24	227.79	0.24	193.24	193.15	-0.05	997.29	1002.23	0.49	504.95	510.83	1.15
111	514	517.58	0.69	520.36	523.66	0.63	147.21	147.95	0.5	146.63	146.95	0.22	847.01	855.09	0.95	717.55	727.86	1.42
112	393.78	396.78	0.76	401.31	404.25	0.73	120.74	121.04	0.25	123.98	124.43	0.36	1015.36	1021.95	0.64	734.39	740.44	0.82
113	3747.89	3676.6	-1.94	940.79	944.13	0.35	188.69	189.76	0.57	162	162.46	0.28	590.17	593.84	0.62	522.16	525.08	0.56
114	634.33	639.84	0.86	564.1	568.13	0.71	131.32	132.25	0.7	127.53	128.29	0.6	564.82	568.2	0.6	279.73	281.26	0.55
115	2059.99	2020	-1.98	2882.38	2860.19	-0.78	145.76	146.02	0.18	208.92	209.76	0.4	670.15	669.71	-0.07	323.58	322.49	-0.34
116	852.32	854.71	0.28	1694.49	1677.66	-1	137.91	138.49	0.42	136.78	137.21	0.32	636.36	640.21	0.6	199.82	201.24	0.71
117	1324.39	1312.7	-0.89	885.64	887.67	0.23	152.44	152.96	0.34	163.93	164.57	0.39	583.94	587.55	0.61	707.01	714.56	1.06
118	534.43	537.93	0.65	1728.96	1702.2	-1.57	122.96	123.41	0.36	141.48	142.53	0.74	432.82	435.01	0.5	317.88	318.55	0.21
119	564.77	563.79	-0.17	993.52	984.15	-0.95	124.33	124.3	-0.02	146.04	146.7	0.45	599.35	598.56	-0.13	729.66	735.76	0.83
120	354.99	357.5	0.7	390.37	393.95	0.91	165.79	165.63	-0.1	173.17	173.37	0.11	598.38	602.55	0.69	470.89	473.36	0.52

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
121	1458.66	1468.26	0.65	702.41	708.16	0.81	255.57	256.92	0.53	187.9	188.27	0.19	581.17	585.65	0.77	758.53	762.84	0.56
122	1223.31	1220.33	-0.24	710.07	716.11	0.84	251.94	252.08	0.06	234.06	234.37	0.13	733.74	739.64	0.8	570.24	574.72	0.78
123	1411.35	1409.92	-0.1	1577.55	1588.59	0.69	208.39	209.68	0.61	263.19	265.21	0.76	565.76	569.3	0.62	529.87	533.49	0.68
124	988.33	992.96	0.47	1530.31	1537.65	0.48	281.43	282.33	0.32	319.49	320.77	0.4	628.2	632.05	0.61	691.69	696.98	0.76
125	759.54	765.89	0.83	1904.08	1905.09	0.05	212.36	213.77	0.66	252.67	254.32	0.65	712.42	716.77	0.61	659.35	664.16	0.72
126	1150.37	1157.75	0.64	894.05	899.69	0.63	239.87	240.62	0.31	225.74	226.35	0.27	636.03	640.13	0.64	842.67	849.7	0.83
127	647.91	653.1	0.79	697.32	703.15	0.83	198.54	199.27	0.37	201.95	203	0.52	454.46	458.3	0.84	729.05	735.7	0.9
128	409.54	412.27	0.66	507.62	511.23	0.71	100.37	100.63	0.25	112.68	113.15	0.42	605.78	610.23	0.73	679.59	684.82	0.76
129	534.47	536.59	0.4	614.41	618.05	0.59	105.41	105.94	0.5	116.51	117.19	0.58	440.27	443.96	0.83	395.83	399.45	0.91
130	726.29	725.81	-0.07	929.47	928.38	-0.12	106.57	106.96	0.36	124.98	125.42	0.35	467.78	470.44	0.57	435.89	435.99	0.02
131	229.38	232.35	1.28	221.96	224.85	1.29	77.33	77.99	0.84	75.15	75.69	0.71	720.61	724.38	0.52	604.65	609.9	0.86
132	563.28	566.87	0.63	451.48	455.32	0.84	123.81	124.55	0.6	109.36	109.75	0.36	293.03	295.66	0.89	388.81	391.39	0.66
133	483.63	482.2	-0.3	510.67	509.17	-0.29	131.59	128.52	-2.39	130.22	127.21	-2.37	677.55	674.73	-0.42	622.72	620	-0.44
134	496.73	495.11	-0.33	469.67	467.34	-0.39	126.93	123.76	-2.56	142.54	139.51	-2.17	883.59	878.66	-0.56	783.28	779.47	-0.49
135	496.95	495.07	-0.38	535.85	534.4	-0.27	138.22	134.71	-2.6	148.22	145.01	-2.21	994.78	990.56	-0.43	879.45	873.48	-0.68
136	809.75	806.02	-0.46	797.38	793.6	-0.48	266.56	261.3	-2.01	242.61	237.25	-2.26	1351.58	1344.55	-0.52	750.24	746.62	-0.48
137	881.58	866.12	-1.78	760.02	755.89	-0.55	143.4	140.47	-2.09	139.33	136.42	-2.14	470.99	469.96	-0.22	784.26	781.17	-0.4
138	1377.05	1366.66	-0.76	893.17	882.47	-1.21	206.08	203.79	-1.12	125.41	122.44	-2.42	731.95	728.7	-0.45	496.19	494.32	-0.38
139	1624.86	1594.02	-1.93	1179.08	1167.84	-0.56	179.59	176.31	-1.86	149.4	145.93	-2.37	659.36	656.5	-0.44	636.57	634.56	-0.32
140	546.89	545.15	-0.32	541.44	539.66	-0.33	141.42	139.28	-2.27	140.71	137.56	-2.28	734.52	731.86	-0.36	658.58	654.31	-0.65

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
141	487.16	485.11	-0.42	484.11	482.41	-0.35	136.89	133.67	-2.42	136.61	133.46	-2.36	646.87	644.7	-0.34	856.29	851.5	-0.56
142	786.03	781.41	-0.59	886.4	874.12	-1.4	236.03	231.16	-2.11	220.31	215.17	-2.39	711.32	707.11	-0.6	213.84	206.45	-3.58
143	779.82	776.9	-0.37	828.97	823.93	-0.61	189.68	185.65	-2.17	201.31	197.29	-2.04	833.59	830.17	-0.41	170.59	164.22	-3.88
144	830.36	827.72	-0.32	624.44	621.99	-0.39	218.18	213.82	-2.04	177.41	172.79	-2.68	771.38	768.62	-0.36	373.97	367.74	-1.7
145	1075.75	1072.37	-0.32	817.79	814.77	-0.37	276.23	270.56	-2.1	238.82	233.04	-2.48	523.87	516.39	-1.45	763.59	759.16	-0.58
146	504.56	508.92	0.86	513.57	517.75	0.81	128.61	127.19	-1.11	123.21	121.64	-1.29	697.98	701.94	0.56	583.91	587.96	0.69
147	568.57	572.13	0.62	557.74	561.32	0.64	134.76	133.26	-1.13	133.01	131.49	-1.16	726.76	730.84	0.56	636.65	638.37	0.27
148	386.14	388.64	0.64	397.15	399.74	0.65	97.95	96.7	-1.29	98.08	96.85	-1.27	558.82	562.15	0.59	536.29	537.26	0.18
149	517.44	518.7	0.24	616.59	618.39	0.29	183.68	179.94	-2.08	206.42	203.22	-1.57	612.22	613.99	0.29	454.04	455.78	0.38
150	604.18	607.26	0.51	663.48	667.12	0.54	180.09	177.11	-1.68	190.4	187.78	-1.39	629.58	632.21	0.42	320.24	317.82	-0.76
151	514.6	518.45	0.74	538.47	542.7	0.78	139.19	137.27	-1.4	148.91	147.23	-1.15	633.92	637.65	0.58	387.73	390.59	0.73
152	758.26	762.17	0.51	2269.47	2223.01	-2.09	212.93	210.5	-1.16	243.21	241.27	-0.8	527.6	530.59	0.56	717.71	724.33	0.91
153	2644.3	2584.39	-2.32	2031.28	2020.88	-0.51	221.33	219.84	-0.68	205.11	203.33	-0.88	739.75	743.54	0.51	653.25	656.81	0.54
154	875.83	866.07	-1.13	910.12	880.09	-3.41	153.06	151.26	-1.19	170.35	168.8	-0.92	659	662.62	0.55	619.25	622.34	0.5
155	766.34	772.97	0.86	1533.65	1517.72	-1.05	220.08	218.93	-0.53	187.74	186.02	-0.92	623.34	626.86	0.56	676.88	679.85	0.44
156	424.61	427.07	0.58	1154.58	1150.34	-0.37	118.04	116.13	-1.64	154.21	152.94	-0.83	644.57	649.07	0.69	603.5	606.63	0.52
157	489.38	492.06	0.54	1381.25	1375.56	-0.41	140.04	137.89	-1.56	170.84	169.18	-0.98	765.22	768.03	0.37	697.24	701.7	0.64
158	685.27	690.13	0.7	668.1	672.96	0.72	167.18	165.15	-1.23	164.92	162.93	-1.22	942.62	946.54	0.41	848.71	853.57	0.57
159	771.26	775.4	0.53	946.24	940.86	-0.57	159.7	158.08	-1.02	151.52	149.91	-1.08	868.73	875.03	0.72	985.01	991.16	0.62
160	1845.37	1830.97	-0.79	994.29	993.66	-0.06	172.24	170.68	-0.91	159.99	158.28	-1.08	672.96	675.34	0.35	737.05	740.16	0.42

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
161	1343.32	1346.11	0.21	1275.74	1268.18	-0.6	254.94	252.96	-0.78	207.05	204.2	-1.39	861.66	864.78	0.36	779.7	782.39	0.34
162	1423.41	1421.34	-0.15	1262.39	1256.89	-0.44	246.41	244.42	-0.82	211.15	208.59	-1.23	550.83	553.07	0.41	559.58	556.95	-0.47
163	808.75	807.46	-0.16	505.28	504.4	-0.17	169.62	167.58	-1.21	135.6	132.97	-1.98	364.6	371.68	1.9	903.99	897.12	-0.77
164	817.51	817.13	-0.05	832.05	829.11	-0.35	156.29	154.8	-0.97	139	137.32	-1.22	699.62	699.15	-0.07	542.97	541.32	-0.3
165	689.18	697.19	1.15	554.28	560.59	1.13	162.6	163.8	0.73	147.69	148.62	0.63	717.18	720.73	0.6	208.8	210.06	0.49
166	469.83	475.64	1.22	353.99	358.3	1.2	136.36	137.35	0.72	115.02	115.57	0.48	647.77	652.15	0.67	288.51	290.27	0.61
167	581.89	586.64	0.81	608.93	614.16	0.85	140.7	141.35	0.45	140.92	141.65	0.52	298.59	300.86	0.75	354.23	356.77	0.71
168	643.91	651.47	1.16	757.92	764.89	0.91	154.69	155.51	0.52	185.26	186.52	0.68	471.49	474.13	0.56	629.85	636.86	1.1
169	667.46	672.03	0.58	838.5	844.97	0.61	140.74	141.28	0.32	158.48	159.5	0.43	469.12	471.58	0.56	549.14	552.04	0.62
170	620.42	627.48	1.13	613.98	620.85	1.11	138.36	139.21	0.61	137.64	138.46	0.59	633.15	639.77	1.03	605.49	611.75	1.02
171	375.96	381.62	1.23	331.06	335.95	0.71	96.63	97.58	1.2	92.28	93.14	0.76	620.05	623.89	1.14	297.01	298.99	1.25
172	941.56	943.1	0.16	906.59	909.91	0.36	167	167.65	0.39	171.61	172.23	0.36	539.9	543.06	0.58	325.63	326.85	0.37
173	642.17	645.59	0.53	917.26	922.14	0.53	168.64	169.45	0.47	187.75	188.63	0.47	749.91	754.03	0.55	666.58	671.21	0.69
174	1405.28	1395.97	-0.67	1255.67	1255.91	0.02	148.56	148.96	0.27	173.22	174.08	0.49	405.68	408.12	0.6	552.86	558.48	1.01
175	948.66	946.71	-0.21	905.17	911.56	0.7	165.02	165.37	0.21	189.72	190.37	0.34	574.06	577.95	0.67	183.04	185.33	1.24
176	720.53	725.85	0.73	1691.99	1695.37	0.2	210.9	211.52	0.29	258.36	259.48	0.43	570.61	574.54	0.68	527.91	531.83	0.74
177	633.84	637.47	0.57	2430.71	2443.79	0.54	159.13	158.8	-0.21	447.62	450.27	0.59	586.84	591.26	0.75	495.36	500.12	0.95
178	668.01	672.15	0.62	1007.51	1014.12	0.65	187.43	187.49	0.03	220.33	221.05	0.33	625.07	628.77	0.59	522.48	527.16	0.89
179	300.47	302.34	0.62	1546.33	1557.29	0.7	119.29	118.13	-0.98	549.53	556.49	1.25	534.31	537.74	0.64	440	442.43	0.55
180	587.63	583.84	-0.65	565.04	564.23	-0.14	155.66	156.03	0.23	146.57	146.89	0.22	644.38	648.41	0.62	298.22	295.46	-0.94

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
181	348.58	352.78	1.19	344.92	349.13	1.21	82.6	83.18	0.69	82.3	82.87	0.68	415.1	419.27	1.13	531.33	536.71	1.1
182	343.68	347.8	1.18	339.7	343.71	1.17	79.58	80.09	0.63	79.58	80.06	0.61	540.55	546.75	1	551.03	557.16	1
183	458.97	463.49	0.98	442.8	447.22	0.99	111.54	112.28	0.66	109.87	110.57	0.63	553.31	558.88	0.89	651.69	658.29	0.97
184	419.42	424.02	1.09	408.01	412.45	1.08	92.23	92.8	0.62	91.98	92.5	0.56	523.01	527.73	1	633.75	639.96	1
185	315.15	319.17	1.26	317.63	321.63	1.24	86.5	87.18	0.78	86.92	87.61	0.79	493.03	497.82	0.96	663.79	669.83	0.9
186	534.57	540.7	1.07	552.18	558.49	1.09	122.68	123.51	0.68	124.32	125.2	0.69	654.64	662.06	1.06	393.51	398.1	1.07
187	620.89	627.63	1.07	500.81	505.59	0.95	188.73	190.49	0.92	136.89	137.14	0.18	659.17	663.25	0.62	378.94	380.89	0.51
188	332.87	336.15	0.97	331.29	334.55	0.97	103.94	103.92	-0.02	103.82	103.76	-0.06	424.55	427.94	0.79	301.63	304.52	0.95
189	518.59	523.57	0.95	598.69	600.28	0.26	141.07	141.86	0.55	130.39	131.18	0.6	737.36	742.56	0.7	441.67	445.67	0.9
190	475.09	480.06	1.04	817.48	823.13	0.69	142.86	143.65	0.55	174.53	175.79	0.72	779.64	784.74	0.65	1056.32	1063.19	0.65
191	962.29	954.1	-0.86	830.14	833.77	0.43	121.45	122.07	0.5	136.61	137.48	0.64	843.83	849.22	0.63	360.52	361.03	0.14
192	698.43	704.14	0.81	663.48	668.47	0.75	149.09	149.91	0.55	141.64	142.44	0.56	769.16	774.04	0.63	745.37	748.71	0.45
193	2654.99	2650.97	-0.15	867.86	870.62	0.32	258.67	259.94	0.49	154.79	154.91	0.08	712.82	717.9	0.71	712.26	718.88	0.92
194	437.12	440.43	0.75	406.44	409.57	0.76	115.83	116	0.14	111.42	111.46	0.04	610.51	614.84	0.7	143.64	145.61	1.36
195	420.56	423.53	0.7	495.46	498.99	0.71	112.29	112.48	0.17	130.99	131.53	0.4	344.99	346.87	0.54	215.15	216.76	0.74
196	611.44	614.99	0.58	989.41	983.3	-0.62	137.35	138.17	0.59	138.24	138.9	0.47	713.52	718.61	0.71	433.97	436.63	0.61
197	524.89	529.59	0.89	628.78	635.61	1.07	161.49	162.6	0.68	161.23	162.29	0.65	714.45	718.67	0.59	390.83	392.93	0.53
198	868.11	873.98	0.67	772.73	778.02	0.68	173.89	174.7	0.47	155.17	155.51	0.22	682.63	687.26	0.67	654.81	663.16	1.26
199	406.02	410.85	1.18	408.24	412.43	1.02	117	117.79	0.67	113.07	113.74	0.59	669.29	671.44	0.32	615.87	620.69	0.78
200	1323.92	1322.39	-0.12	722.68	726.66	0.55	189.48	190.64	0.61	167.89	168.48	0.35	1036.5	1042.66	0.59	412.47	415.31	0.68

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
201	620.89	627.63	0.94	500.81	505.59	1.05	188.73	190.49	1.29	136.89	137.14	0.08	659.17	663.25	0.67	378.94	380.89	0.83
202	511.83	515.05	0.62	537.54	540.96	0.63	126.69	126.94	0.2	130.77	131.08	0.23	917.29	924.05	0.73	102.86	103.5	0.61
203	430.25	435.2	1.14	446.34	451.56	1.16	101.62	102.27	0.63	103.25	103.94	0.67	738.58	742.11	0.48	596.8	599.87	0.51
204	1512.69	1502.67	-0.67	431.83	435.79	0.91	180.07	181.42	0.74	136.81	137.31	0.36	644.39	648.85	0.69	541.87	545.42	0.65
205	1338.29	1340.66	0.18	1129.47	1134.24	0.42	239.13	239.87	0.31	217.18	217.63	0.21	755.59	759.95	0.57	128.94	129.9	0.74
206	641.97	647.77	0.9	749.71	757.42	1.02	165.17	165.55	0.23	222.59	224.34	0.78	1007.99	1015.73	0.76	532.42	536.96	0.84
207	3162.76	3105.35	-1.85	1252.64	1252.34	-0.02	200.73	201.82	0.54	181.95	183.07	0.61	778.29	782.88	0.59	553.27	554.96	0.31
208	1556.08	1552.55	-0.23	735.07	739.19	0.56	192.29	193.71	0.73	144.81	145.36	0.38	716.57	719.3	0.38	662.68	665.24	0.38
209	1064.54	1069.98	0.51	402.33	405.6	0.81	226.46	228.83	1.04	108.75	108.77	0.01	662.76	667.88	0.77	656.42	661.47	0.76
210	2036.77	2033.75	-0.15	1854.29	1837.92	-0.89	222.84	223.64	0.36	221.38	222.16	0.35	695.92	699.87	0.56	626.14	631.56	0.86
211	547.36	553.03	1.02	780.93	786.77	0.74	152.69	153.48	0.52	193.57	195.22	0.84	792.43	799.72	0.91	493.42	496.42	0.6
212	584.78	586.78	0.34	744.32	747.45	0.42	181.66	180.94	-0.4	209.92	209.55	-0.18	599.06	601.34	0.38	952.62	955.68	0.32
213	501.04	501.39	0.07	493.82	494.28	0.09	131.25	130.74	-0.4	129.48	129.1	-0.3	516.45	517.74	0.25	191.49	191.65	0.08
214	436.02	438.75	0.62	432.66	435.46	0.64	107.38	107.48	0.1	105.82	105.95	0.12	594.73	594.04	-0.12	683.55	682.86	-0.1
215	682.8	683.85	0.15	693.99	695.11	0.16	137.39	137.35	-0.04	138.42	138.39	-0.02	659.19	660.87	0.25	667.66	669.33	0.25
216	761.32	760.56	-0.1	621.82	621.32	-0.08	148.55	148.02	-0.35	136.55	136.66	-0.36	572.35	573.72	0.24	669.78	671.88	0.31
217	345.28	348.29	0.87	420.59	424.54	0.93	104.07	104.27	0.19	117.45	117.95	0.42	720.75	722.28	0.21	404.98	405.86	0.22
218	539.51	540.29	0.14	643.47	644.76	0.2	165.59	165.07	-0.32	177.07	176.73	-0.19	886.28	887.29	0.11	680.02	681.55	0.23
219	1132.23	1127.23	-0.44	517.68	517.84	0.03	178.83	178.67	-0.09	142.22	141.53	-0.49	648.97	648.31	-0.1	685.89	686.48	0.08
220	6805.81	6664.84	-2.12	2452.28	2423.55	-1.19	332.17	331.33	-0.25	255.27	254.44	-0.33	544.34	543.94	-0.07	517.34	512.95	-0.85

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
221	1871.52	1858.95	-0.68	1377.53	1367.39	-0.74	259.99	259.73	-0.1	239.03	238.94	-0.04	615.84	615.19	-0.11	660.29	660.47	0.03
222	493.14	495.36	0.45	495.74	497.93	0.44	109.62	109.62	0	110.13	110.11	-0.01	546.12	550.72	0.84	819.32	823.04	0.45
223	335.91	339.24	0.98	287.95	290.7	0.95	99.1	99.47	0.37	89.87	90.04	0.18	573.16	574.5	0.23	381.48	382.55	0.28
224	852.17	853.8	0.19	2839.79	2811.73	-1	208.92	208.52	-0.19	297.49	297.73	0.08	794.59	793.38	-0.15	660.48	660.76	0.04
225	383.59	383.78	0.05	377.79	377.92	0.03	80.76	80.64	-0.14	79.92	79.77	-0.19	660.21	660.21	0	665.05	667.03	0.3
226	440.88	441.45	0.13	461.42	462.1	0.15	93.82	93.76	-0.07	96.02	95.98	-0.05	738.33	738.63	0.04	685.17	686.91	0.25
227	488.26	490.53	0.46	492.07	494.45	0.48	140.94	141.04	0.07	141.58	141.87	0.2	561.86	563.34	0.26	575.89	576.97	0.19
228	601.34	602.77	0.24	546.82	548.04	0.22	168.43	168.03	-0.24	178.49	177.55	-0.53	585.59	587.02	0.24	528.1	530.43	0.44
229	502.34	504.6	0.45	515.52	517.92	0.46	113.97	114.08	0.1	114.96	115.12	0.13	949.52	951.22	0.18	647.74	651.64	0.6
230	340.85	341.56	0.21	772.37	774.91	0.33	84.74	84.5	0.28	128.5	128.75	0.19	474.47	476.9	0.51	768.51	770.06	0.2
231	629.06	630.16	0.17	613.56	614.46	0.15	159.73	159.17	-0.35	159.73	159.17	-0.35	221.83	221.37	-0.21	164.97	164.6	-0.23
232	584.34	584.9	0.1	567.19	567.74	0.1	162.78	162.3	-0.3	156.09	155.58	-0.33	503.62	504.37	0.15	516.03	516.33	0.06
233	551.64	552.32	0.12	509.12	509.84	0.14	131.77	131.48	-0.22	122.41	122.02	-0.32	369.99	370.29	0.08	406.46	406.74	0.07
234	7347.15	7231.29	-1.6	1261.04	1257.07	-0.32	338.21	337.89	-0.1	231.21	230.07	-0.49	723.39	722.73	-0.09	354.17	353.01	-0.33
235	6949.72	6765.4	-2.72	2756.31	2733.72	-0.83	311.93	311.71	-0.07	264.09	263.36	-0.28	714.45	713.35	-0.16	644.43	643.43	-0.15
236	7156.27	6881.06	-4	1688.69	1751.22	3.57	225.65	225.59	-0.03	226.33	226.26	-0.03	690.89	690.55	-0.05	712.05	710.75	-0.18
237	9423.39	9110.56	-3.43	1027.39	1025.24	-0.21	209.47	208.95	-0.25	194.82	194.37	-0.23	507.63	507.17	-0.09	689.94	689.33	-0.09
238	913.18	907.89	-0.58	494.25	494.94	0.14	126.65	126.59	-0.04	117.51	117.18	-0.28	595.84	595.24	-0.1	419.81	418.55	-0.3
239	521.74	522.23	0.09	619.49	619.63	0.02	110.29	110.09	-0.19	123.16	122.81	-0.28	629.21	628.39	-0.13	392.79	393.46	0.17
240	631.22	631.11	-0.02	611.41	611.22	-0.03	146.15	145.4	-0.52	142.43	141.58	-0.6	1026.49	1024.65	-0.18	440.93	444.19	0.73

No.	Ar			Al			Br			Bl			Bladder			Rectum		
	Oncentra	MuCheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff	Oncentra	Mucheck	% diff
241	398.77	403.36	1.14	387.11	391.57	1.14	90.68	91.3	0.68	89.73	90.32	0.65	538.24	543.68	1	748.16	754.4	0.83
242	1942.03	1931.61	-0.54	1681.99	1674.19	-0.47	317.24	316.88	-0.11	317.14	316.9	-0.08	587.6	588.08	0.08	600.88	604.01	0.52
243	615.37	616.98	0.26	535.98	537.36	0.26	164.71	164.91	0.12	144.03	143.65	-0.27	931.58	932.05	0.05	670.39	672.12	0.26
244	786.69	786.53	-0.02	586.08	586.72	0.11	179.74	179.19	-0.31	151.82	151.4	-0.28	592.62	592.45	-0.03	825.78	830.66	0.59
245	912.34	913.94	0.17	554.82	555.76	0.17	222.83	222.83	0	146.27	145.66	-0.42	627.81	626.75	-0.17	260.23	260.09	-0.05
246	695.55	695.39	-0.02	724.42	724.35	-0.01	180.09	179.12	-0.54	188.59	187.87	-0.38	699.52	699.1	-0.06	451.86	452.97	0.24
247	715.37	716.02	0.09	697.49	698.06	0.08	175.96	175.46	-0.29	167.92	167.36	-0.33	708	707.69	-0.04	219.15	218.34	-0.37
248	627.79	628.93	0.18	605.25	606.39	0.19	173.46	173.35	-0.07	161.55	161.17	-0.23	773.56	773.26	-0.04	404.66	406.23	0.39
249	511.29	516.3	0.97	456.78	461.65	1.06	119.19	119.95	0.63	114.46	115.1	0.55	360.89	363.72	0.78	501.32	505.46	0.82
250	371.73	375.29	0.95	1271.05	1280.9	0.77	109.67	109.78	0.11	200.38	202.18	0.89	432.33	435.56	0.74	596.61	601.6	0.83
251	759.25	765.58	0.83	346.66	348.96	0.66	126.39	127.3	0.71	84.95	85.14	0.22	601.99	607.98	0.98	753.99	761.48	0.98
252	826.13	834.28	0.98	925.74	928.4	0.29	205.89	207.11	0.58	240.55	243.28	1.12	841.34	847.8	0.76	485.04	488.3	0.67
253	3501.02	3394.12	-3.15	1658.79	1661.34	0.15	174.35	174.87	0.3	261.12	262.77	0.63	758.33	762.86	0.59	660.72	666.73	0.9
Avg	1010.21	1004.92	0.26	832.82	833.81	0.35	167.99	168.11	0.08	175.02	175.23	0.08	616.52	619.85	0.54	551.87	554.34	0.57
SD	1256.05	1221.7	0.89	511.8	507.06	0.74	60.28	60.38	0.75	96.44	97.03	0.78	175.74	175.74	0.5	177.62	179.33	0.79

VITA

NAME Miss Watcharaphawn Sanklaa

DATE OF BIRTH 19 April 1991

PLACE OF BIRTH Bangkok

EDUCATION Bachelor of Science
(Radiological Technology),
Faculty of Medical Technology, Mahidol University, 2013

HOME ADDRESS 220/586 Moo. 4, Suksawat Rd., Naikhlongbangplakot,
Phrasamutchedi, Samutprakan 10290
Tel. 087-125-3839

E-mail w_biu@hotmail.com

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