

### 3. Equipment and Methodology

#### 3.1 Equipment:

##### 3.1.1 Clinac Medical Linear Accelerator:

The Clinac® 2100C linear accelerator was installed in the National Cancer Institute in Wad Medani since 2007(*Figure3.1*). This system has two photon beam energies 6MV and 16MV and five electron energies 4,6,9,12 and 15 MeV, the maximum dose rate is up to 600 MU/min , the Choice of electron energies to meet clinical needs with electron applicators included Tight isocenter alignment of the gantry, couch, collimator, and other components Reproducible, stable, and accurate machine positioning, Exact® couch for accurate reproducible patient positioning, and Modes for special clinical procedures, e.g. high dose total skin electron mode and total body X-ray mode.

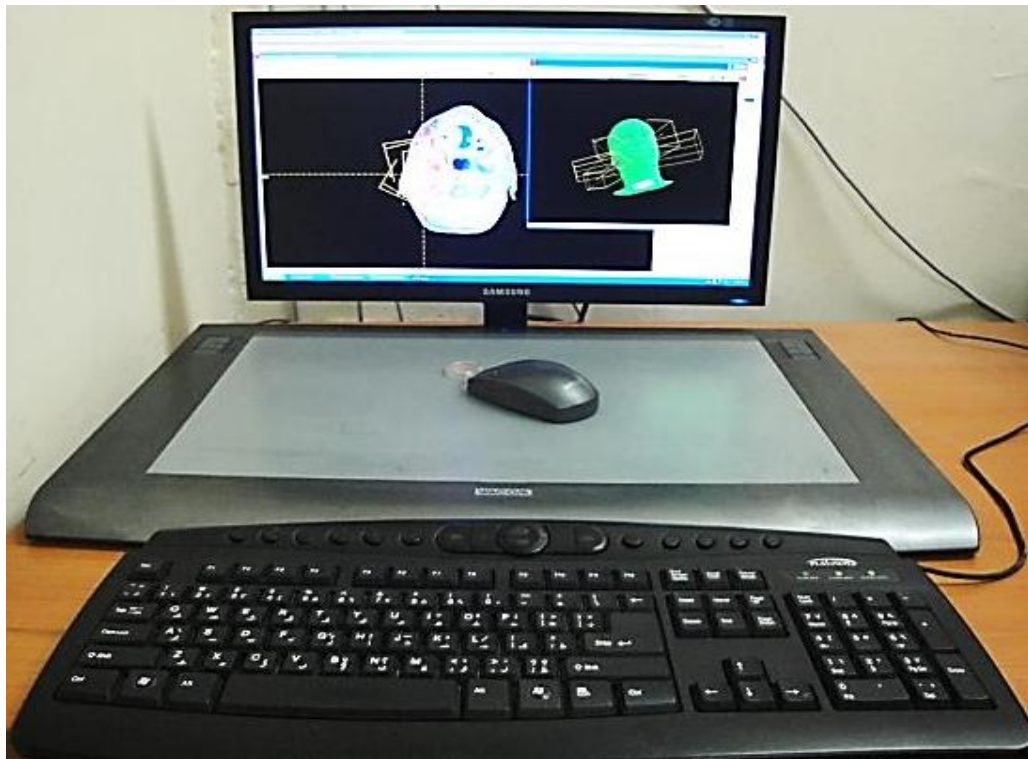


*Figure 3.1: The Varian Clinac® 2100C linear accelerator*

The machine has different wedge angles ( $15^\circ$ ,  $30^\circ$ ,  $45^\circ$ , and  $60^\circ$ ) which can be inserted in four different positions (IN, OUT, LEFT, and RIGHT). The machine also supported with an Enhanced dynamic wedge for Auto field sequencing, automate field delivery for maximum efficiency, and Laser guard collision detection system.

### **3.1.2 Treatment Planning System:**

The TPS used for treatment data calculation and beam data evaluation is PlanW2000 (UJP 2012), this TPS is based on IEC 1217 conventions (Alam R, et.al, 1997) for specifying gantry angle, collimator angle, table angle, wedge orientation and patient orientation. The TPS software operates in a Linux environment.



*Figure 3.2: the treatment planning system (PlanW2000).*

The photon beam dose calculation algorithm employed by PlanW2000 TPS comprises a convolution based approach where the energy fluence distribution is convolved with a dose pencil beam (Bortfeld T, Schlegel W, Rhein B. 1993).

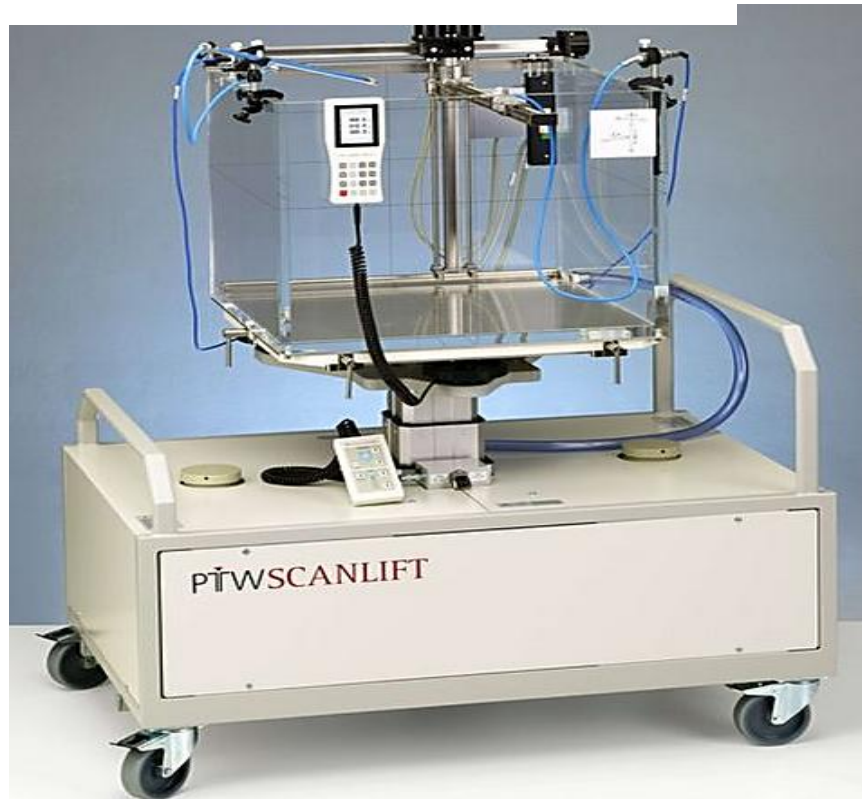
The dose pencil beam consists of depth independent width and depth dependent relative weight. Thus the dose calculation at any arbitrary depth in a homogeneous water phantom involves only one single convolution step for each of the three components. For other depths, the pencil beam components are added using the depth dependent relative weights.

Convolution of the energy fluence distribution with a Gaussian source distribution kernel allows for optimization of the fit between the measured and the calculated edge of the field. Inhomogeneities are taken into account by applying the equivalent tissue air ratio (ETAR) method . (Sontag M, Cunningham JR.1978)

### **3.1.3 Water Phantom System:**

A motorized PTW 3D water phantom was used for automatic dose distribution measurement of radiation therapy beams . The Features of this Integrated system is the most demanding relative and absolute dosimetry tasks in a wide variety of applications Robust (*Figure3.3*), fully automatic 3D water phantom for 50 cm ×50 cm ×40 cm scans, equipped with reinforced tank walls to prevent deformation or leaking calibration, high-speed stepper motor drives offering superior positioning accuracy (0.1 mm, 50 m/s), with easily maneuverable lift table and built in water reservoir for convenient and quick setup Routable positioning device for precise horizontal and vertical tank alignment, Quick and easy detector positioning using TRUFIX Powerful MEPHYSTO mc2 software platform.

The MP3-M system is based on the MP3-M water tank, a medium-size, remote controlled 3D acrylic water tank with 20 mm thick walls and a scanning range of 50 x 50 x 40.8 cm<sup>3</sup>. It comes with a routable positioning device and a 3D stainless steel moving mechanism driven by three calibration-free. The water tank is controlled by the TBA Control Unit . (PTW.,2014)



*Figure3.3: MP3-M PTW Medium size motorized 3D water phantoms.*

A removable control pendant with TFT display and menu-controlled interface allows a manual control of the water tank moving mechanism. The SCANLIFT is a specially designed, high-precision electromechanical lift table/carriage on wheels, with 500 mm range of movement to allow for height adjustment of the MP3-M water tank. It includes a 190 water reservoir with PC-controlled pump for TPR measurements. (PTW.,2014)

The patented TRUFIX Detector Positioning System (*figure 3.4*), TRUFIX is patented detector positioning system, designed for convenient installation and superior positioning accuracy of PTW detectors in a PTW water phantom. PTW ionization chambers and solid state detectors can be quickly installed in the water phantom and their effective point of measurement quickly positioned to the water surface.



*Figure 3.4: TRUFIX® Detector Positioning System.*

### **3.1.4 Dual Channel Electrometer:**

The TANDEM Dual channel electrometer is for absolute dosimetry with TanSoft software and for relative dosimetry with TBA system (*Figure 3.5*). The TANDEM electrometer is calibrated in electrical current (*A*). It can be operated by a PC as an absolute therapy dosimeter.



*Figure 3.5: TANDEM Dual channel electrometer.*

The TanSoft software provides calibration and correction factors for various detectors and displays the measurement results. The chamber voltage for both channels is individually programmable in 50V increments up to 400V with reversible polarity. The TANDEM is very fast and makes it possible to set minimum measuring intervals of 10ms. It features auto range and offset compensation.

TANDEM is also designed to perform radiation field measurements referenced to an ionization chamber. In conjunction with a TBA therapy beam analyzer, MEPHYSTO software controls TANDEM for fast and accurate beam data acquisition. A trigger input synchronizes measurements with external signals.

The measurements were performed with the TANDEM Dual-Channel Electrometer with user selectable measurement times. The TANDEM is designed for fast and precise beam data acquisition in PTW water phantoms and absolute dose measurements. (PTW.,2014)

### **3.1.5 Detector Extension Cables:**

The low noise extension cables (*Figure 3.3*) for the connection of radiation detectors to dosimeters and electrometers are of high quality for precise current measurements. When irradiated, the cable leakage is less than 10-12 C/ (Gy·cm).



*Figure 3.6: High quality triax extension cables PTW-M connectors.*



### 3.1.6 Waterproof thimble chamber:

The Waterproof thimble chamber we used is a 0.6 cm<sup>3</sup> PTW Farmer chamber type 31013 is a waterproof standard chamber for absolute photon and electron dosimetry with therapy dosimeters to be used in water or in solid-state material. The nominal photon energy range is from 30 kV to 50 MV, the electron energy range is from 6 MeV to 50 MeV (*figure 3.7*).



*Figure 3.7: Waterproof thimble chamber PTW Farmer chamber type 31013.*

This chamber type is of rugged construction, since the wall material is graphite with a protective acrylic cover and the electrode is made of aluminum. The guard ring is designed up to the measuring volume.

The chamber is supplied with a cable of 1m length. A calibration certificate for calibration in absorbed dose to water or air kerma is included with each chamber. Air density correction is required for each measurement. (PTW.,2014)

### 3.1.7 Semiflex Ionization Chambers:

The Semiflex chambers are designed for therapy dosimetry, mainly for dose distribution measurements in motorized water phantoms. They have a short stem for mounting and a flexible connection cable (*figure 3.8*).



*Figure 3.8: Semiflex PTW 31010 Ionization Chambers.*

The nominal useful energy range is from 30 kV to 50 MV photons and 6 MeV to 50 MeV electrons. The wall material is graphite with a protective acrylic cover. The guard rings are designed up to the measuring volume. An acrylic build-up cap for in-air measurement in  $^{60}\text{Co}$  beams is included with each chamber, as well as a calibration certificate for calibration in absorbed dose to water or in air kerma.

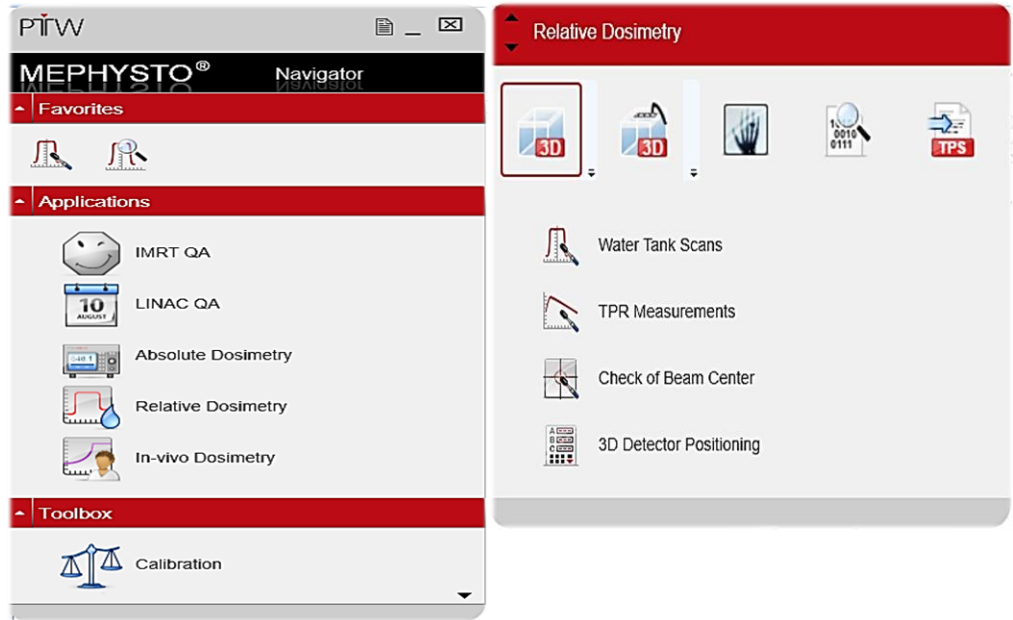
Air density correction was required for each measurement, and a radioactive check device is available as an option. Both chambers were shaped cylindrically with an inner diameter of 5.5 mm; they differ only in the length of the measuring volume. The PTW 31010 chamber is ideal for 3D dosimetry in a water phantom, since the measuring volume is approximately spherical resulting in a flat angular response over an angle of  $\pm 160^\circ$  and a uniform spatial resolution along all three axes of a water phantom. (PTW.,2014)

### **3.1.8 Beam Analysis Software:**

MEPHYSTO is the advanced software platform for beam data acquisition and analysis with a PTW Water scanning system. Equipped with all essential tools, this feature-packed software allows users to perform any dosimetry task related to accelerator commissioning and beam QA.



The MEPHYSTO TBA software with the MEPHYSTO Navigator is the most advanced, comprehensive and self-explaining user interface for TBA control and data evaluation. Solutions of all important dosimetry tasks in radiotherapy are implemented in modules with optimized workflows (*Figure3.9*).



*Figure 3.9: MEPHYSTO® mc<sup>2</sup> Navigator Software*

Predefined measurement programs for PDDs, profiles, matrices for isodose, Axis definition for each defined radiation device with name and direction is possible.

Beam data collection for LINAC commissioning and TPS beam data collection can be structured due to an implemented Task List with multiple energies, applicators, wedges, blocks, field sizes, SSDs, depths and even multiple queues. The ability for optimized batch conversion module for each established TPS. All established international protocols including the LINAC vendor specifications are available. User specific protocols can be generated. Curve comparison with percentage difference.

Besides many other operations, ion depth curves can be converted into dose depth curves according to all established international protocols. Matrix operations allow adding treatment fields. Isodose and rotational 3D Display in color wash or lines. Dual cross hairs zoom and various normalization functions are available. A deconvolution algorithm allows the correction of volume effect of ionization chambers (PTW.,2014).

### **3.2 Methodology:**

Every Treatment Planning System has its own set of data and their own way of data entering; these sets of data are normally specified by the manufacturer. The validation of dose calculation algorithms in the (PlanW2000-TPS) were performed by a comparison between the measured data using the computerized PTW 3D water phantom with calculated data using PlanW2000 TPS system. These measurements were conducted at National Cancer Institute of Gezira University during April 2014 until June 2014, Department of Medical Physics.

The reliability of measured data sets is dependent on the stability of the accelerator, e.g. energy, output, flatness, and symmetry which may vary in time and can only partly be controlled. Other possible limitations on measurements are related to the choice of detector and experimental setup, which may restrict the number of comparison points and introduce dosimetric problems.

Before machine dataset collected, a number of necessary beam data acceptance tests were measured and checked with the data provided by machine manufacturer, these test included the following:

- Clinical Mechanical isocenter Check for (Collimator, Couch, and Gantry).
- Mechanical Tests:
  - Front Point distance Alignment verification.
  - Field light alignment.
  - Crosshair alignment and jaw parallelism.
  - Jaw position readout.

- Couch motion (rotation, longitudinal, lateral, and vertical).
  - Collimator rotation.
  - Optical distance indicator.
- Accessory System test:
  - Accessory communications and switches.
  - Wedge communication.
  - Special procedures accessories.
- Gantry Rotation Spoke Shot.
- Beam Quality checks
  - Quality index
  - Flatness
  - Symmetry

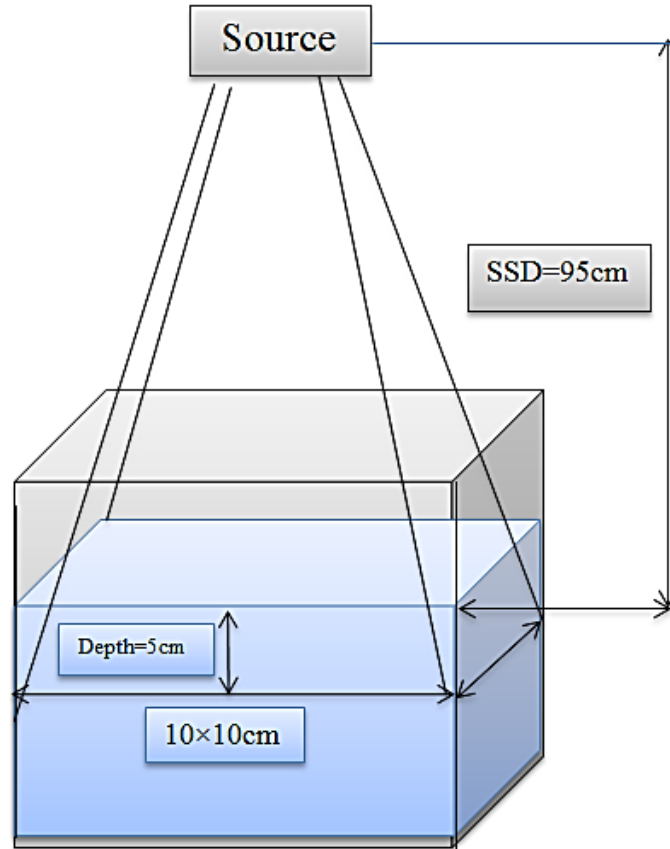
### **3.2.1 Datasets for PlanW2000 for 6MV Photon beam:**

The datasets included the required input data for the PlanW2000 TPS and a series of test cases covering the clinical range. The Data entered into the PlanW2000 were measured from the Varian Clinac 2100 included the following:

- Absolute Dose at standard condition (standard SSD, depth, and field size)
- PDD curves for square fields ,
- Profiles with and without the wedges
- Wedge Factors.
- Spectral distribution Data.
- Back scatter Factors.
- Output Factors.

### 3.2.2. Experimental measurements:

All measurements presented were acquired in a  $50\text{ cm} \times 50\text{ cm} \times 40.8\text{ cm}^3$  PTW water tank. Two Semiflex PTW 31010 Ionization Chambers were used for relative dosimetry measurements. For absolute dosimetry measurements, a Waterproof thimble chamber PTW Farmer chamber type 30013 was used following the IAEA 398 protocol.



*Figure 3.10: Setup for field definition adjustment.*

#### 3.2.2.1 Spectral distribution Data:

Energy Distribution across the beam (Figure 3.11) for 6 MV Photon beam was measured to correct for different energy distribution across the beam due to cone and wedge inserts, the following parameter HD (ratio of  $R_{150}$  to  $R_{\max}$ ) were measured to be load into TPS.

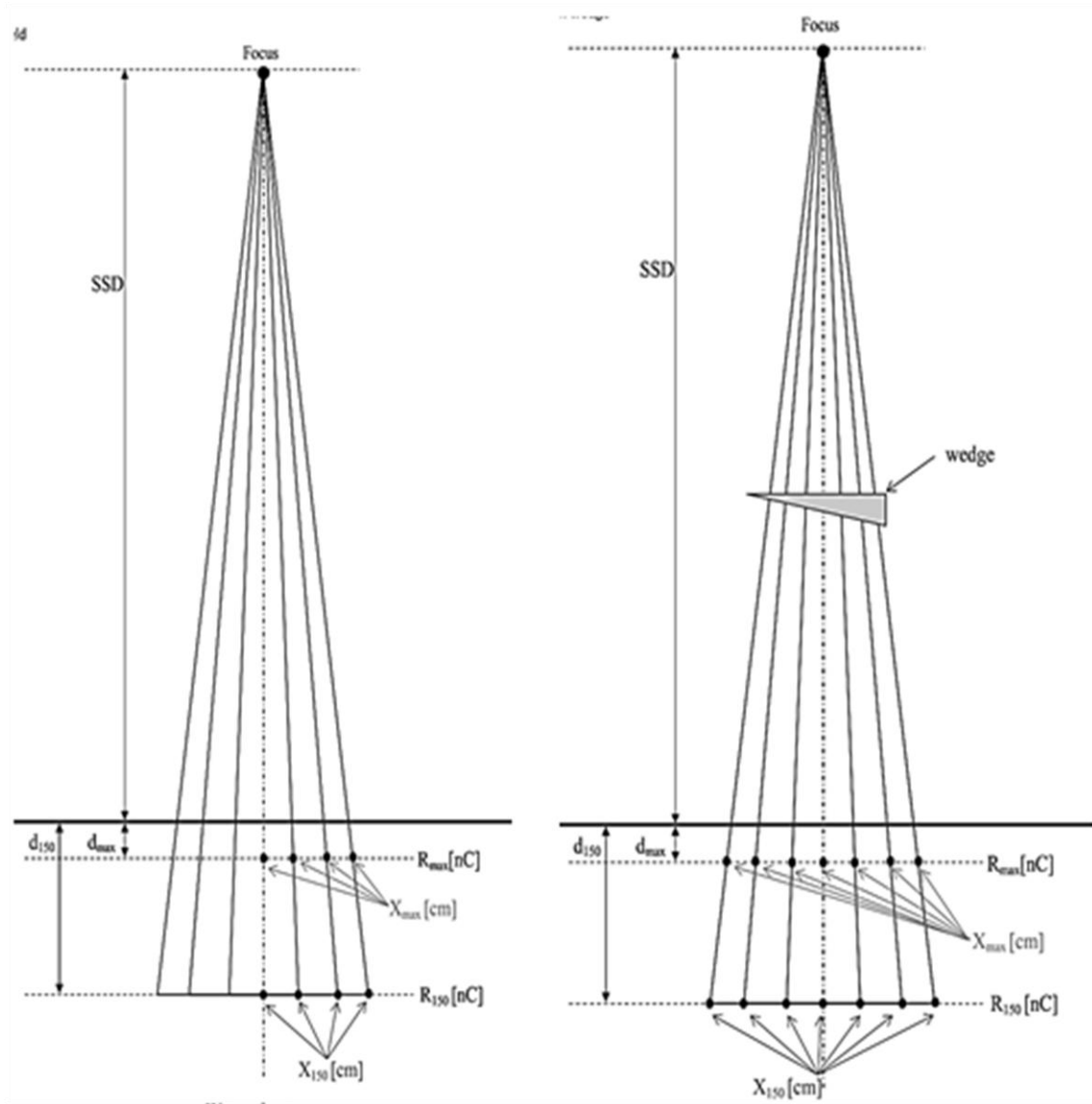


Figure 3.11: setup for measuring Energy Distribution across the beam.

### 3.2.2.2 Percentage Depth Dose Data:

For 6 MV Photon the Preferable chambers is a Cylindrical chamber, a waterproof Semiflex PTW 31010 Ionization Chamber was used as a reference chamber, the Effective point of measurement is the center of the chamber as recommended by IAEA protocol. the Scanning direction upwards starting from the Max (35cm) to Min (0cm) depth were used, with 100cm SSD, for the field sizes of : 4×4, 5×5, 6×6, 8×8, 10×10, 12×12, 15×15, 18×18, 20×20, 25×25, 30×30, 35×35, 40×40cm<sup>2</sup>.

### **3.2.2.3 Photon beam Profile data:**

For the same 6 MV photon beam energy the Preferable chambers is the Diode chamber - absorbed dose and Small Cylindrical chamber, a waterproof Semiflex PTW 31010 cylindrical Ionization Chamber were used.

The Effective point of measurement is the center of the chamber as recommend by IAEA protocol, and the Scanning direction in the Open profiles for photon at the reference depths (5cm) is in the X, Y directions; with the following FS = 4×4, 5×5, 6×6, 8×8, 10×10, 12×12, 15×15, 18×18, 20×20, 25×25, 30×30, 35×35, diagonal profile for the largest field size 40x40cm<sup>2</sup>.

On the other hand, for Wedge profiles at the reference depths (5cm), if wedge gradient is in direction Y the profiles were measured for each wedge, the wedge was inserted in the basic positions starting with the 15° Wedge with the field sizes (X×Y): (4×20, 5×20, 6×20, 8×20, 10×20, 15×20, 20×20, 25×20, 30×20, and 40×20 ), the 30° Wedge with the field sizes (X×Y): (4×20, 5×20, 6×20, 8×20, 10×20, 15×20, 20×20, 25×20, 30×20, and 40 × 20), and 45° Wedge with the field sizes (X×Y): (4×20, 5×20, 6×20, 8×20, 10×20, 15×20, 20×20, 25×20, 30×20, and 40×20).

### **3.2.2.4 Absolute dose rate, Output and Wedge factors:**

The absolute dose rate was measured for the field 10x10 cm<sup>2</sup> at the reference depth ( $D_{ref}$ ), SAD 100cm, SSD 95cm. The output factor for 6MV photon measured for all field sizes and normalized to Field size 10x10 cm<sup>2</sup> at the reference depth ( $D_{ref}$ ), SAD 100cm, SSD 95cm. Wedge factors were measured for the square field size and the square equivalent for the maximum field size at the reference depth ( $D_{ref}$ ), SAD 100cm, SSD 95cm.

### **3.2.3 Comparison between the Calculated and Measured Data:**

After all the required datasets were entered into the PlanW2000 TPS, a set of data were measured for commissioning and verification of beam data and absolute dose measurements with calculated data From PlanW2000 TPS.



System tests included several checks for the consistency of reported doses by various modules of the software. These included the Doses reported by physics tools or modeling routines; Point doses, Isodose plots, and Dose matrix export (DICOM, RTOG, proprietary).

There were basically two categories to taken into account, Basic water scans (characterization set) and phantom tests (verification set), and how these were implemented depends on the type of algorithm. The characterization set is either the set of basic data needed for input to a system (measured beam algorithm) or the basic scans needed to verify the input parameters for the pencil beam modeled system. These consist of water scans for basic beam configurations (square fields, standard SSD, open and wedge fields).

There were some basic principles implemented when acquiring these measurements. Data set of reference scans were taken throughout the measurement period to ensure the stability of the beam. Such as reference sets of depth dose and profiles at  $d_{\max}$  for a 10x10 field, 100 SSD and 40x40 profiles at  $d_{\max}$ , 100 SSD were measured.

Also the pertinent beam parameters were recorded (bend magnet current, injection current, pulse height, rep rate, water temperature, etc.) during each scan to insure that, the differences were due to normal experimental error not the characterization of the beam itself.

The basic output for a radiotherapy machine is the dose rate for a point at a reference depth  $z_{\text{ref}}$  (often the depth of dose maximum  $z_{\max}$ ) in a water phantom for a nominal source surface distance (SSD) and a reference field size (often  $10 \times 10 \text{ cm}^2$ ).

### 3.2.3.1 Dose point verification:

Point dose verification data were evaluated using a set of selected central axis points and off axis points, the dose was measured using Water scanner system and compared with the calculated dose from PlanW2000 TPS, the experimental setup are shown in (Figure3.12) and (Figure3.13):

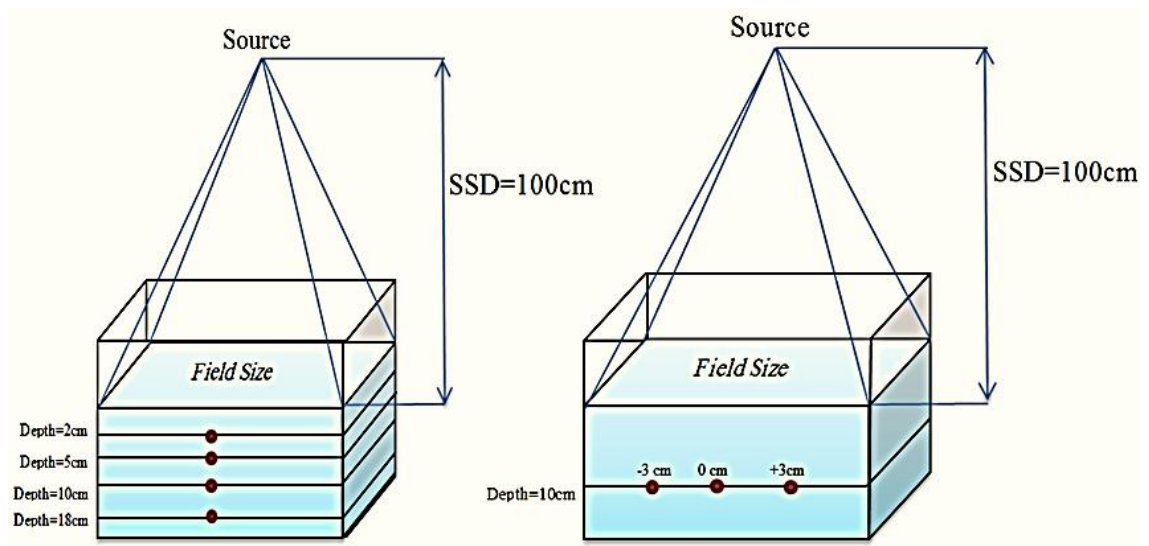


Figure 3.12: The setup of central axis and off axis dose Points Measurement for Comparison Test.

### 3.2.3.2 PDDs verification:

For PDD curve verification, a set of new PDDs were measured for different field sizes including;  $7 \times 7 \text{ cm}^2$ ,  $13 \times 13 \text{ cm}^2$ ,  $27 \times 27 \text{ cm}^2$ , and  $37 \times 37 \text{ cm}^2$ , these data were then compared with the calculated data from PlanW2000. For calculations a homogeneous water phantom was created in the PlanW2000 treatment planning system using reference conditions.

### **3.2.3.3 Beam Profile verification:**

The profile curves verification a set of new profiles was measured for different field sizes including;  $7 \times 7 \text{ cm}^2$ , and  $13 \times 13 \text{ cm}^2$ , And a diagonal profile was measured for  $17 \times 17 \text{ cm}^2$ , and  $27 \times 27 \text{ cm}^2$  for open field, all this measurement at 100 cm SSD and depth of 5 cm , these data were then compared with the calculated data from PlanW2000.