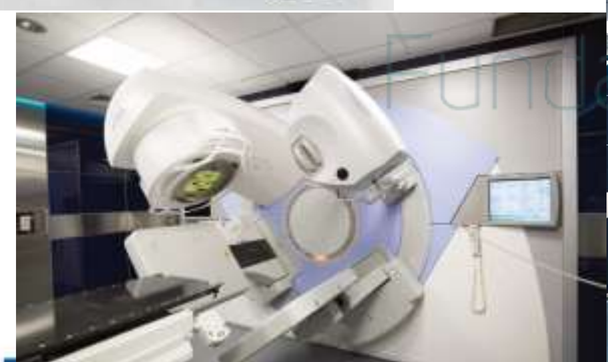
TOMOTHERAPY Y CYBERKNIFE: SISTEMAS DE IMAGENES

CELINE K. TORZSOK

FUNDACION ARTURO LOPEZ PEREZ

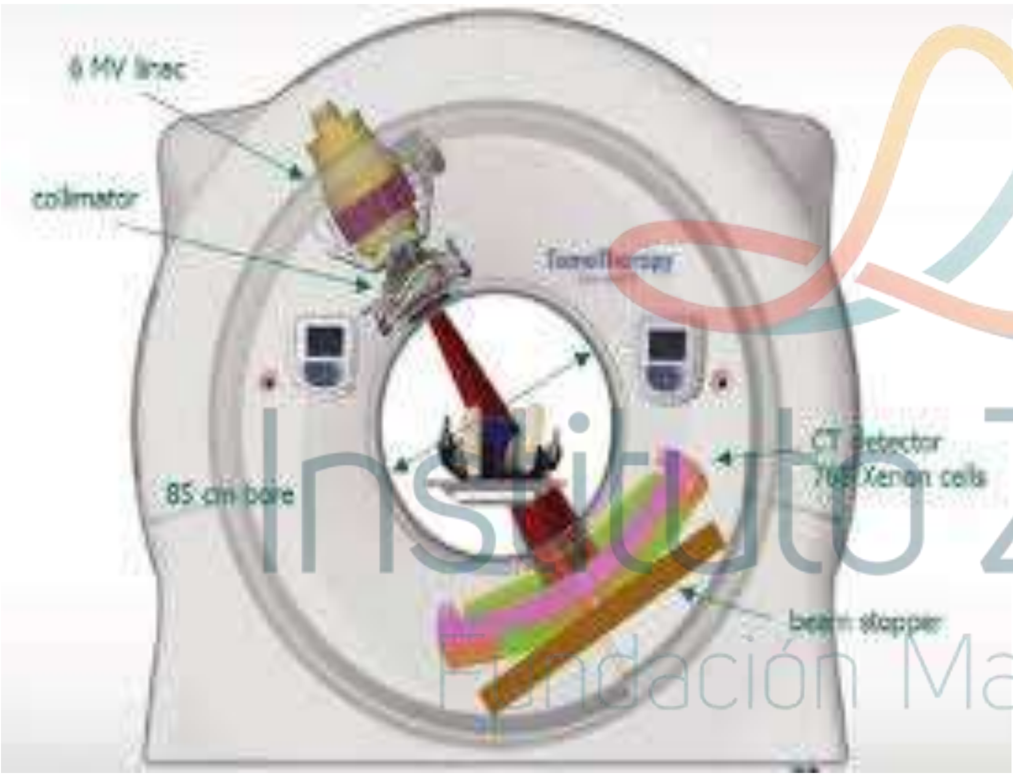
TORZSOK@FALP.ORG

- CYBERKNIFE M6-FI MLC
- TOMOTHERAPY HD
- ELEKTA VMAT
- LIAC (IORT)
- BIG BORE PET CT
- IMRT BRACHY HDR ^{60}Co
- MOSAIQ PAPERLESS
- IBA MYQA SOLUTION

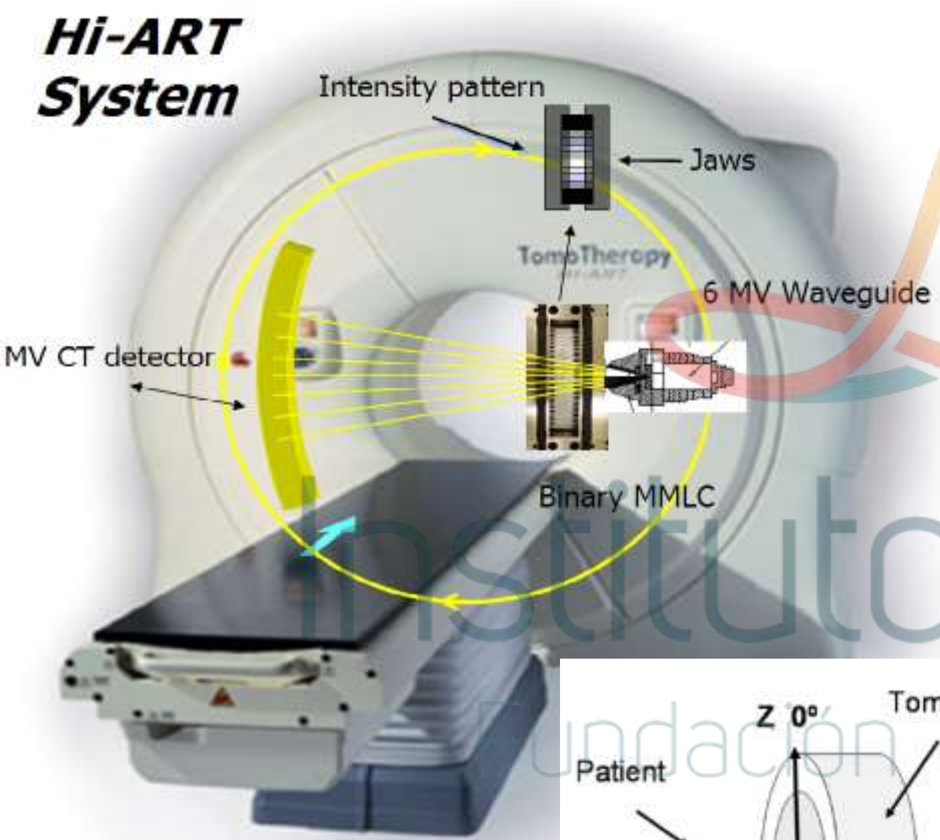


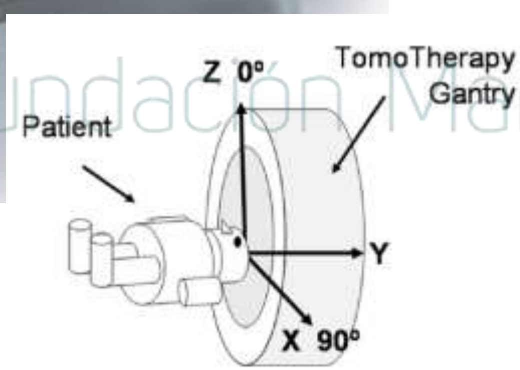
falp
Juntos contra el cáncer

IMAGING systems



TOMOTHERAPY





1) Accelerator 6 MV

2) 64-leaf binary MLC

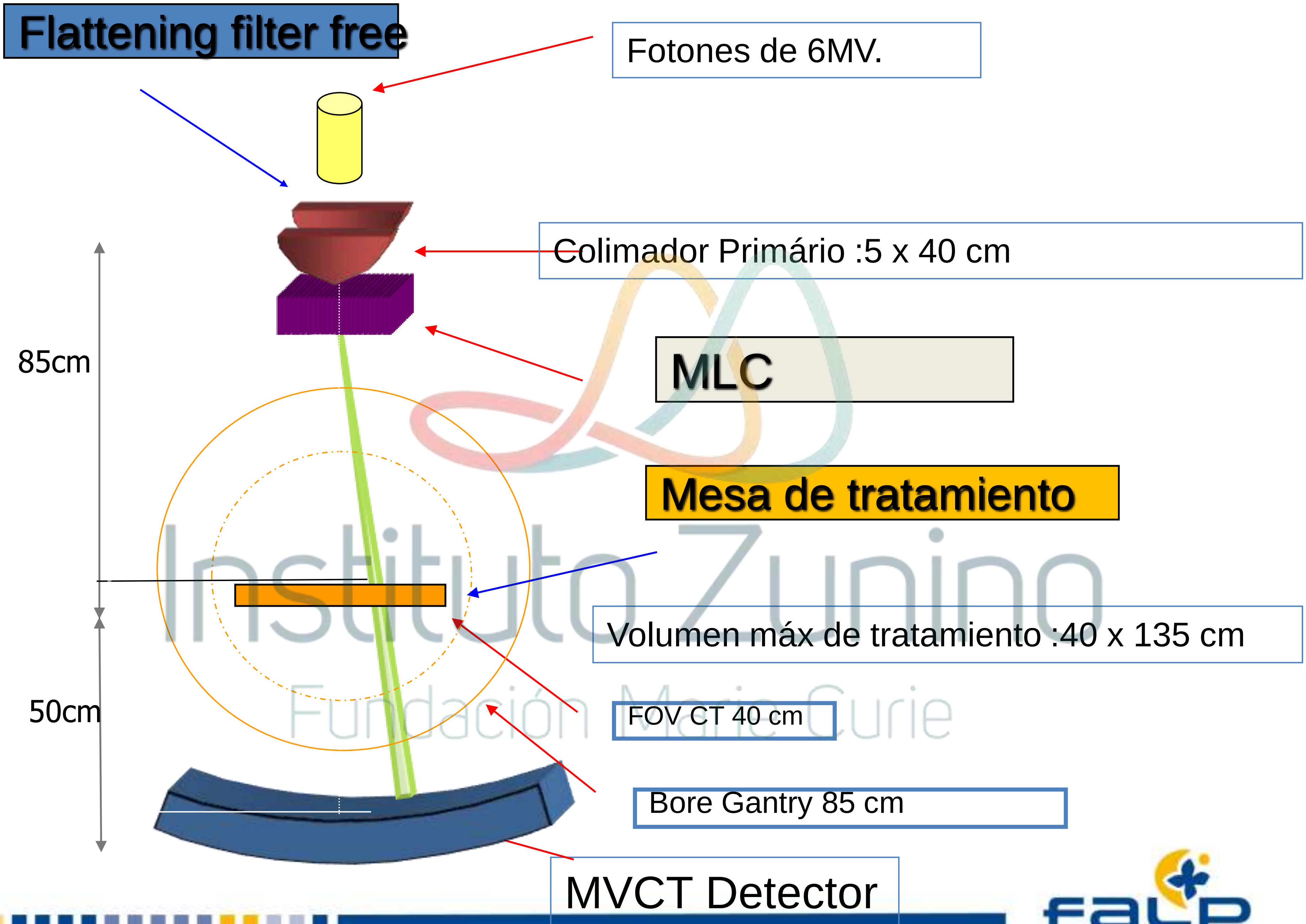
3) fan beam created by the collimator and jaws produces a maximum of 40 × 5 cm^2 field size at the isocenter

4) There is no flattening filter and the beam is cone shaped in the transverse direction. This produces an increased dose rate of about 850 cGy/min at the isocenter

5) SSD: 85 cm (also the bore diameter)

6) Robotic couch: The gantry and hence the fan beam rotates at a constant speed while the couch moves linearly into the gantry bore, thus producing a helical delivery

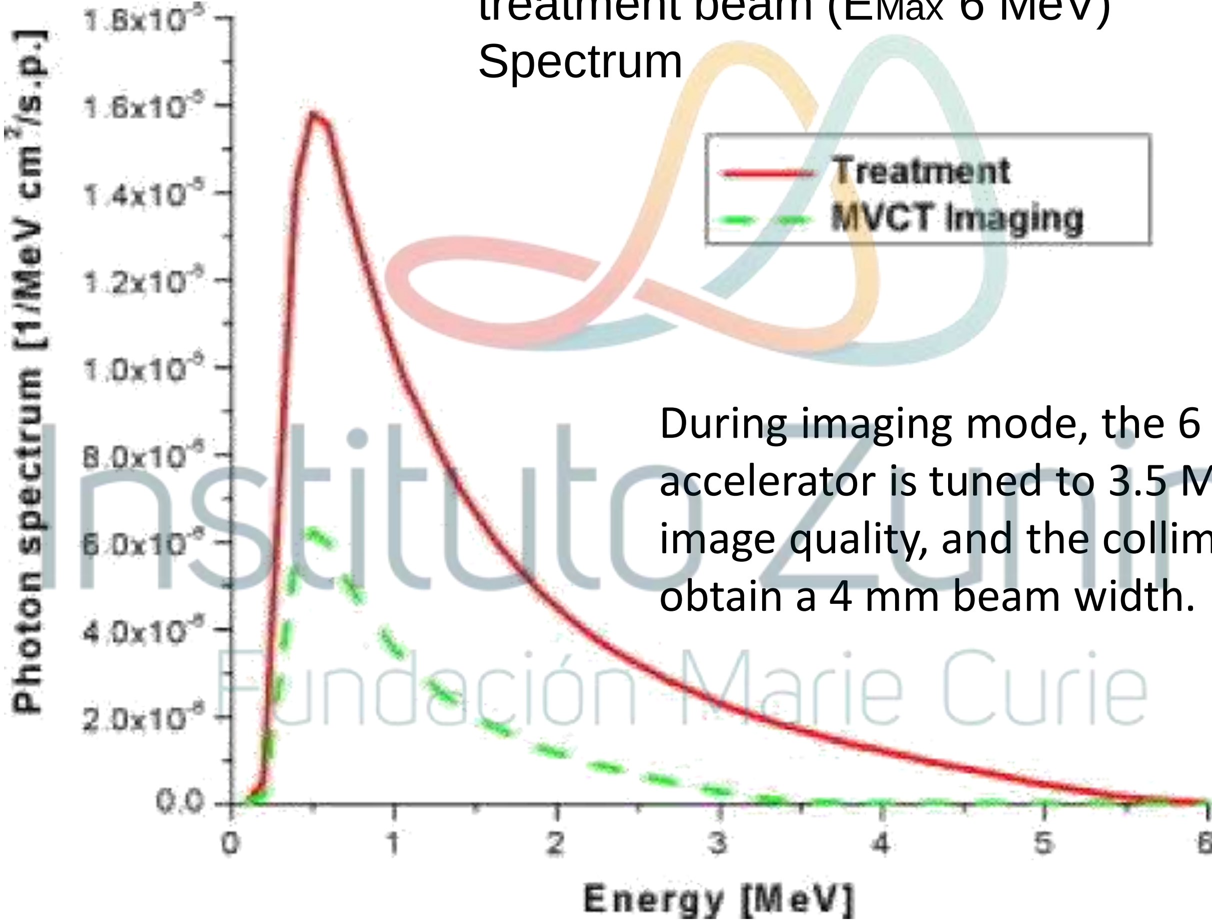
7) The linac can be operated at a lower voltage (3.5 MV) and dose rate to produce megavoltage CT images for patient setup



Flattening filter free
Fotones de 6MV.
Colimador Primário :5 x 40 cm
MLC
85cm
Mesa de tratamiento
Volumen máx de tratamiento :40 x 135 cm
FOV CT 40 cm
50cm
Bore Gantry 85 cm
MVCT Detector

MVCT Theory

MVCT (E_{Max} 3.5 MeV) and treatment beam (E_{Max} 6 MeV) Spectrum



During imaging mode, the 6 MV linear accelerator is tuned to 3.5 MeV to improve image quality, and the collimator is set to obtain a 4 mm beam width.

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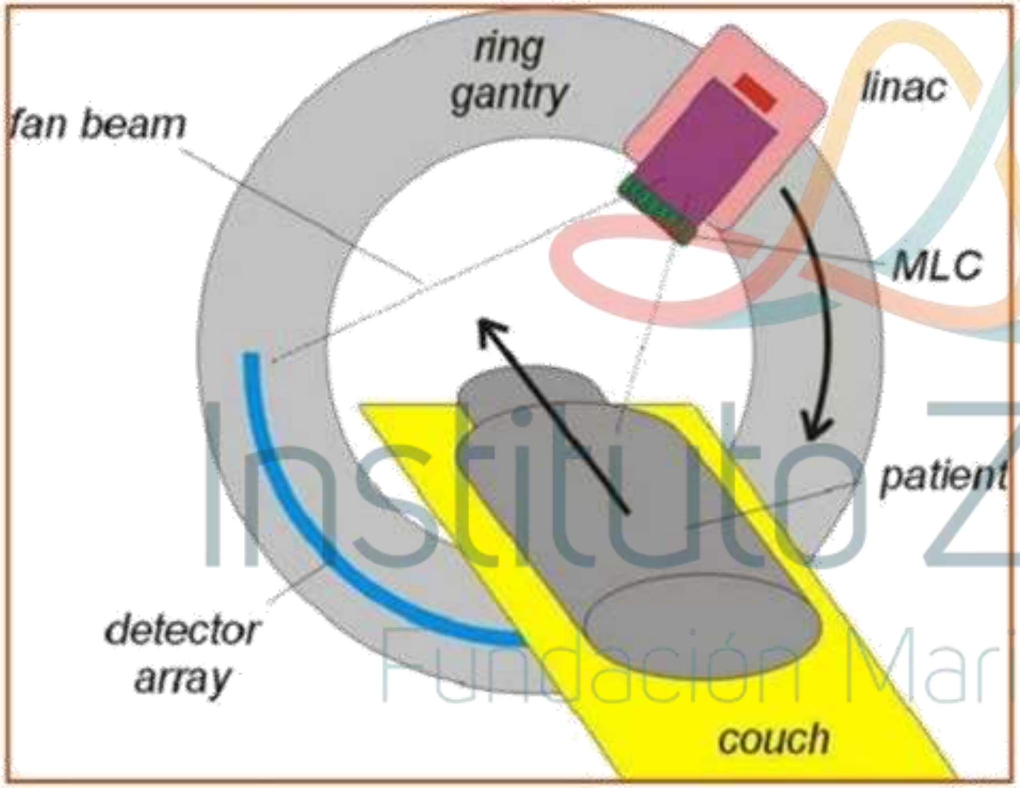
MVCT Theory

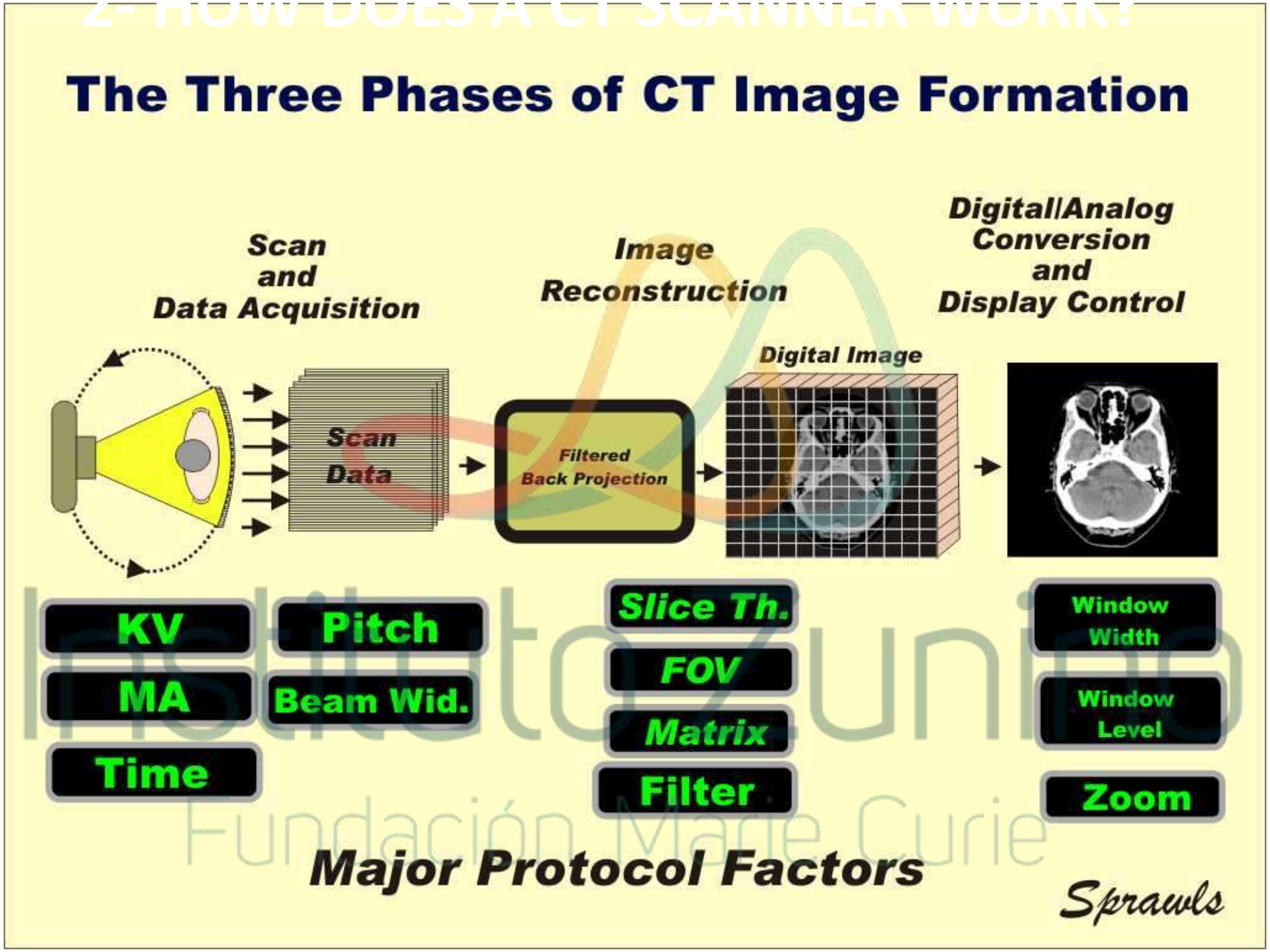
Acquiring an MVCT (Helical CT)



MVCT (E_{Max} 3.5 MeV) and treatment beam (E_{Max} 6 MeV) Spectrum

- Couch speed:
  - **Fine** = 4 mm/rotation
  - **Normal** = 8 mm/rotation
  - **Coarse** = 12 mm/rotation
- Reconstruction intervals:
  - **Fine** = 1 or 2 mm
  - **Normal** = 2 or 4 mm
  - **Coarse** = 3 or 6 mm

2- HOW DOES A CT SCANNER WORK?



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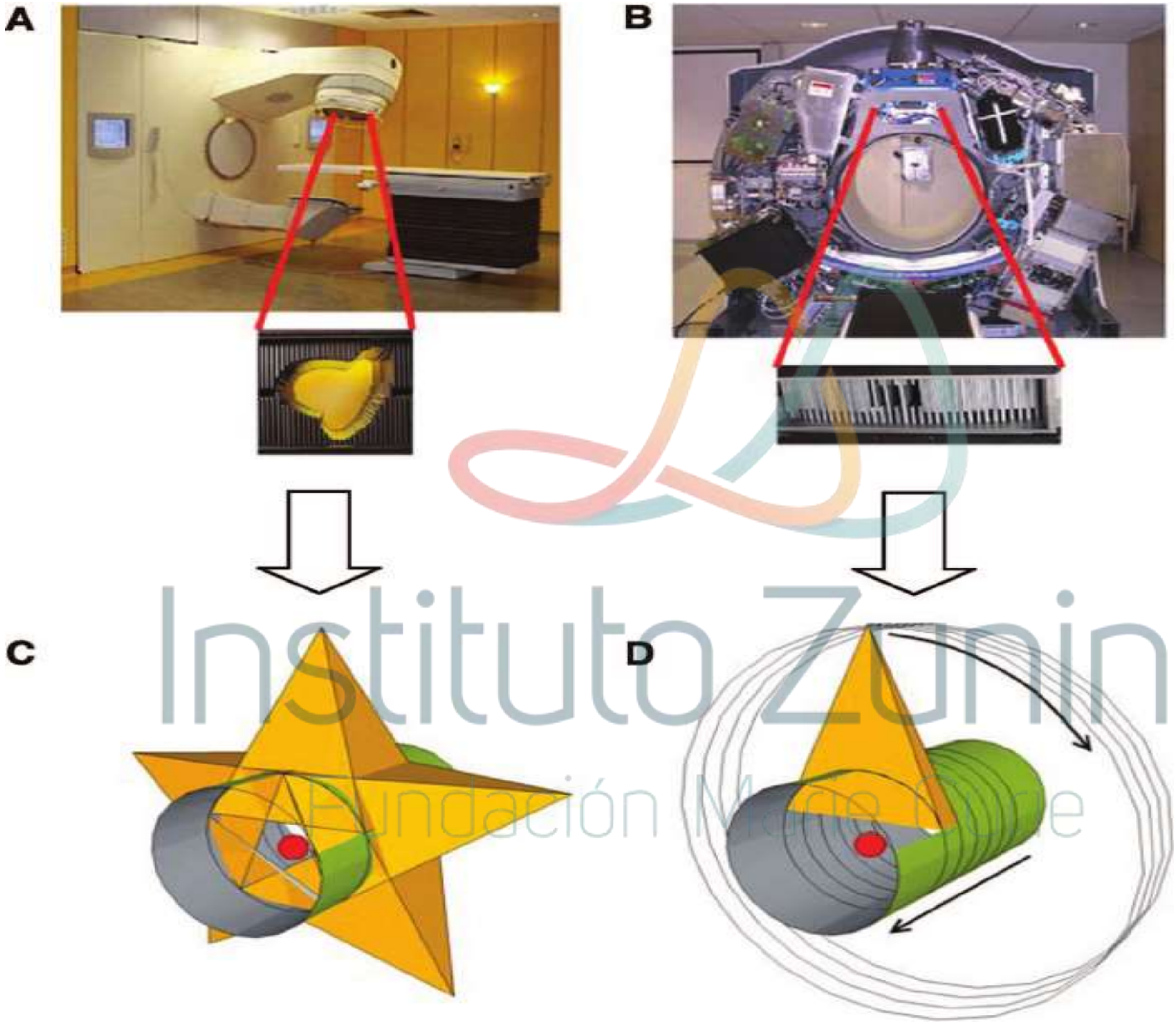

A
B
C
D

2- ANALYTIC METHODS

Used in almost all CT today.

Differ from iterative methods in that exact formulas are utilized for the analytical reconstructions.

1. Two-Dimensional Fourier Analysis:

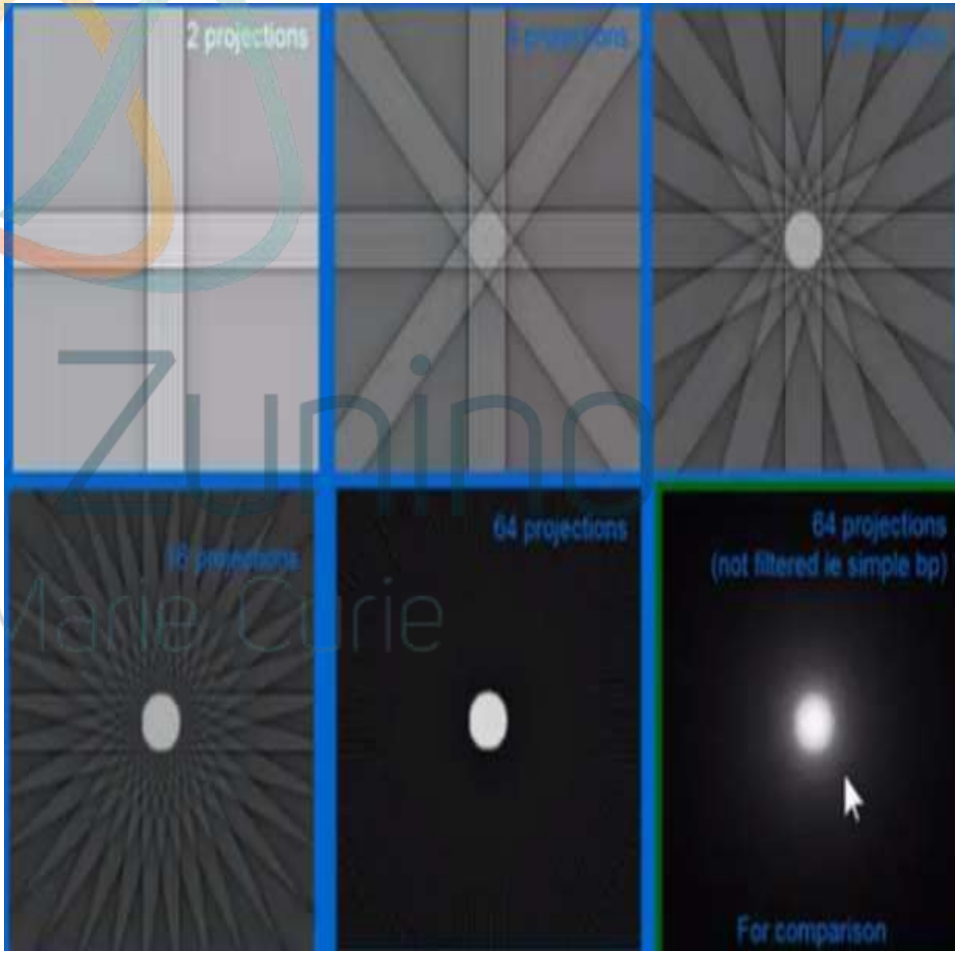
Basis any function of time or space can be represented by the sum of various frequencies and amplitudes of sine and cosine waves.
Ray projections with squared edges, are the most difficult to reproduce.

2. Filtered Back projection:

Is similar to back-projection except that the image is filtered, or modified to exactly counterbalance the effect of sudden density changes, which caused blurring (the star pattern) in simple back-projection.

Those frequencies responsible for blurring are eliminated to enhance more desirable frequencies.

Inside margins of dense areas are enhanced while the centres and immediately adjacent areas are repressed.



7. CTrue™ Imaging

ESPECIFICACIONES	DESEMPEÑO
Geometría	Haz en abanico
Dosis por imagen MVCT (típica)	0.5 – 3 cGy dependiendo de la resolución y del grosor del cuerpo
Configuración del detector	528 canales, matriz de cámaras de iones de fila única de xenón usadas para la adquisición de imagen
Resolución de imagen (xy)	512 x 512 (0.78 mm pixels)
Ancho entre cortes	2 mm, 4 mm, 6 mm
Tiempo de escaneo	Típicamente 2 minutos para 10 cm de longitud con 4 mm de ancho de corte
Campo de visión (FOV)	145 cm
Distancia del detector al isocentro	60 cm
Ruido de la imagen	2% - 4%
Uniformidad de la imagen	Dentro del 2.5%
Resolución espacial	0.5 lp/mm a 10% MTF (nominal)
Resolución de contraste	Densidad del 2% para un objeto de 2 cm (típicamente)
Algoritmo de reconstrucción de imagen	Retroproyección filtrada
Tiempo de reconstrucción de imagen	Tiempo real, corte a corte en tiempo de adquisición
Herramientas de registro de imagen	Superposición de imagen MVCT/kVCT con damero ajustable; registro manual y automático (maximización de información mutua) usando hueso o tejido blando; traslaciones y determinación de cabeceo/rotación/giro
Aplicación de ajustes obtenidos vía registro de imagen	Traslaciones aplicadas a través de la camilla. Rotación aplicado a través del gantry
Frecuencia de corrección para modo de guiado por imagen de flexión de geometría	No requerido; plataforma anular de gantry rígida
Modo de guiado por imagen	Daily 3D MVCT comparación con 3D kVCT

Estas técnicas se aplicaron radioterapia, manteniendo las mismas tolerancia del diagnóstico.

TAC

Parametro	Tolerancia
Slice thickness	±20% o 1 mm
MTF	±20% en respecto a la referencia
Numero CT	±20 HU u ±5%
Uniformidad	±20%
Posición de la camilla	±2mm en 20cm de desplazamiento

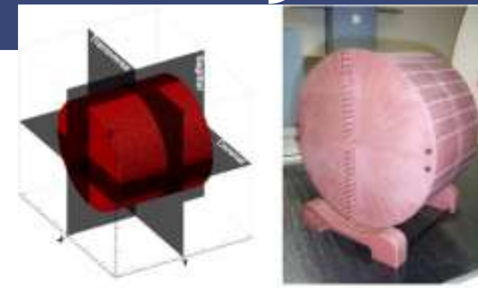
Protocolo Europeo de control de calidad en radiología

RMN

Parametro	Tolerancia
Slice thickness	±20% del valor nominal
MTF	±20% o 1 mm en respecto a la referencia
Uniformidad	±20%
Posición de la camilla	±2mm en 20cm de desplazamiento

AAPM REPORT NO. 28

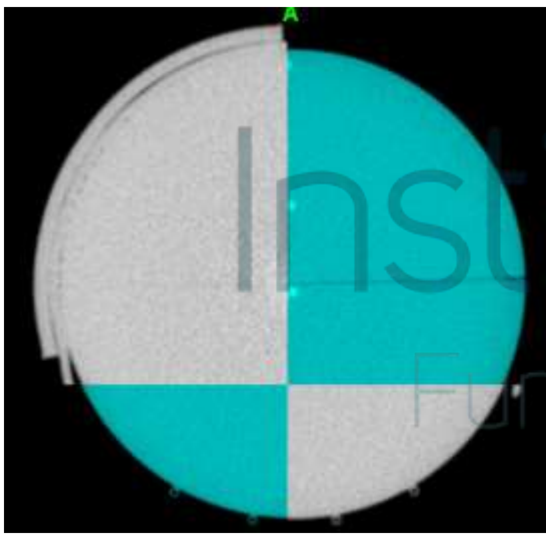
TOMO IGRT: MVCT Theory



(a) (b)

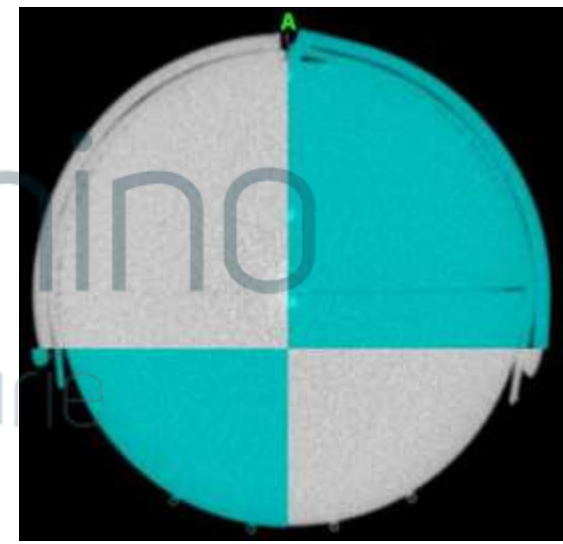
Using a simple phantom:
Cheese phantom® (Standard Imaging, Madison, WI)

Initial position of the phantom in the bore

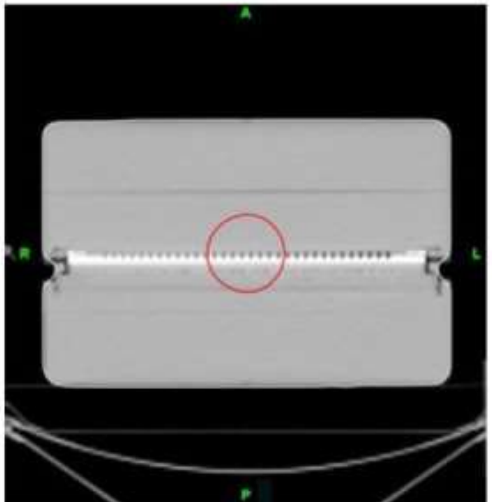


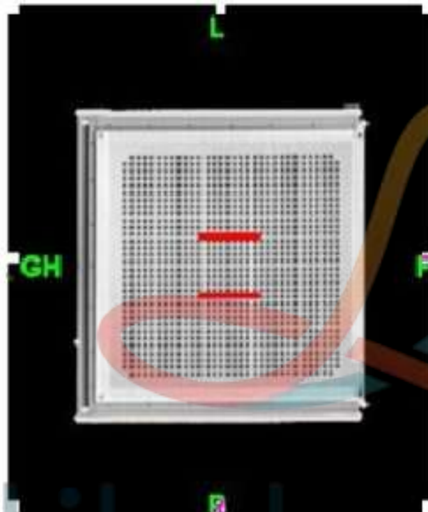
During the process of the phantom allignment

Ideal position of the phantom in the bore

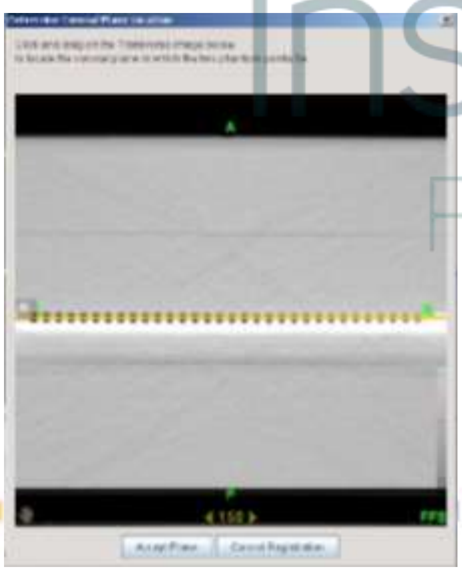


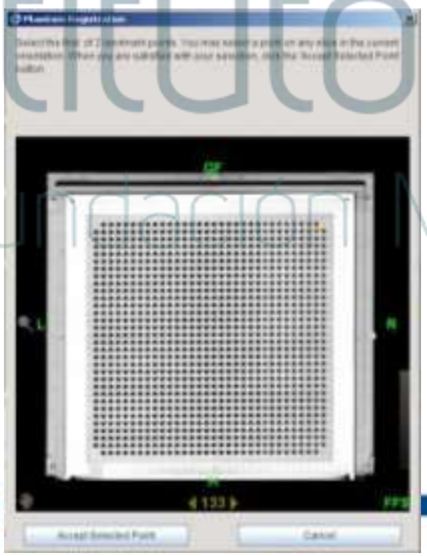
DQA Calculation



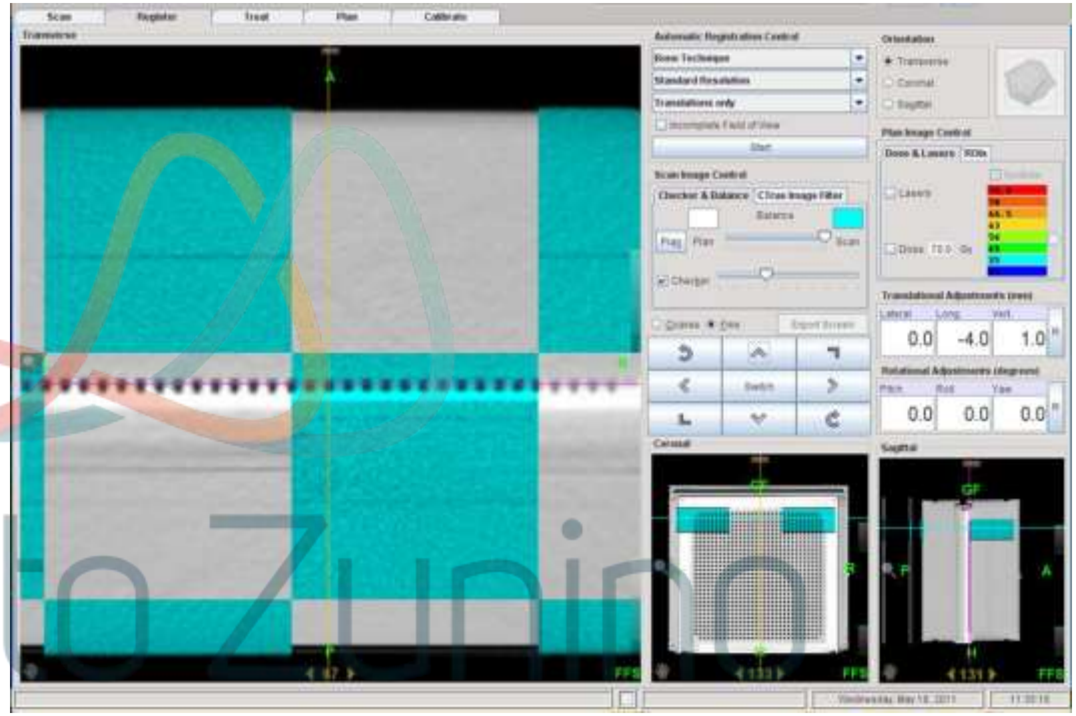


The plan, calculated on the patient, is recalculated on the phantom where we can extract the fluence to be compared with the measured with the MatriXX Evolution® (IBA Dosimetry).

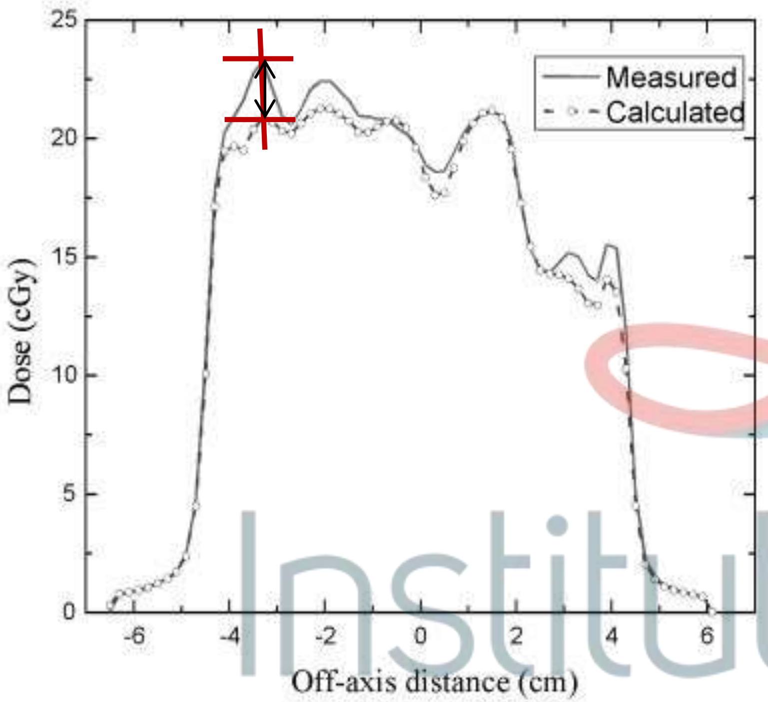




MVCT application to DQA



Gamma Analysis Principles (spatial and dose)



$$\Gamma = \sqrt{\left(\frac{DTA}{C_{DTA}}\right)^2 + \left(\frac{DD}{C_{DD}}\right)^2}$$

The idea is:
We fix a circular area around a point in the image (radius = 3mm) and we are looking for a dose difference between planned and measured fluence map lesser than our criteria (3% dose difference)
When we find a point that achive the dose criteria we put the distance value in the equation to calculate the Gamma value.

$$Gamma = \sqrt{\left(\frac{2.5mm}{3mm}\right)^2 + \left(\frac{1.5\%}{3\%}\right)^2} = 0.97$$

$$Gamma = \sqrt{\left(\frac{2.5mm}{3mm}\right)^2 + \left(\frac{2\%}{3\%}\right)^2} = 1.07$$

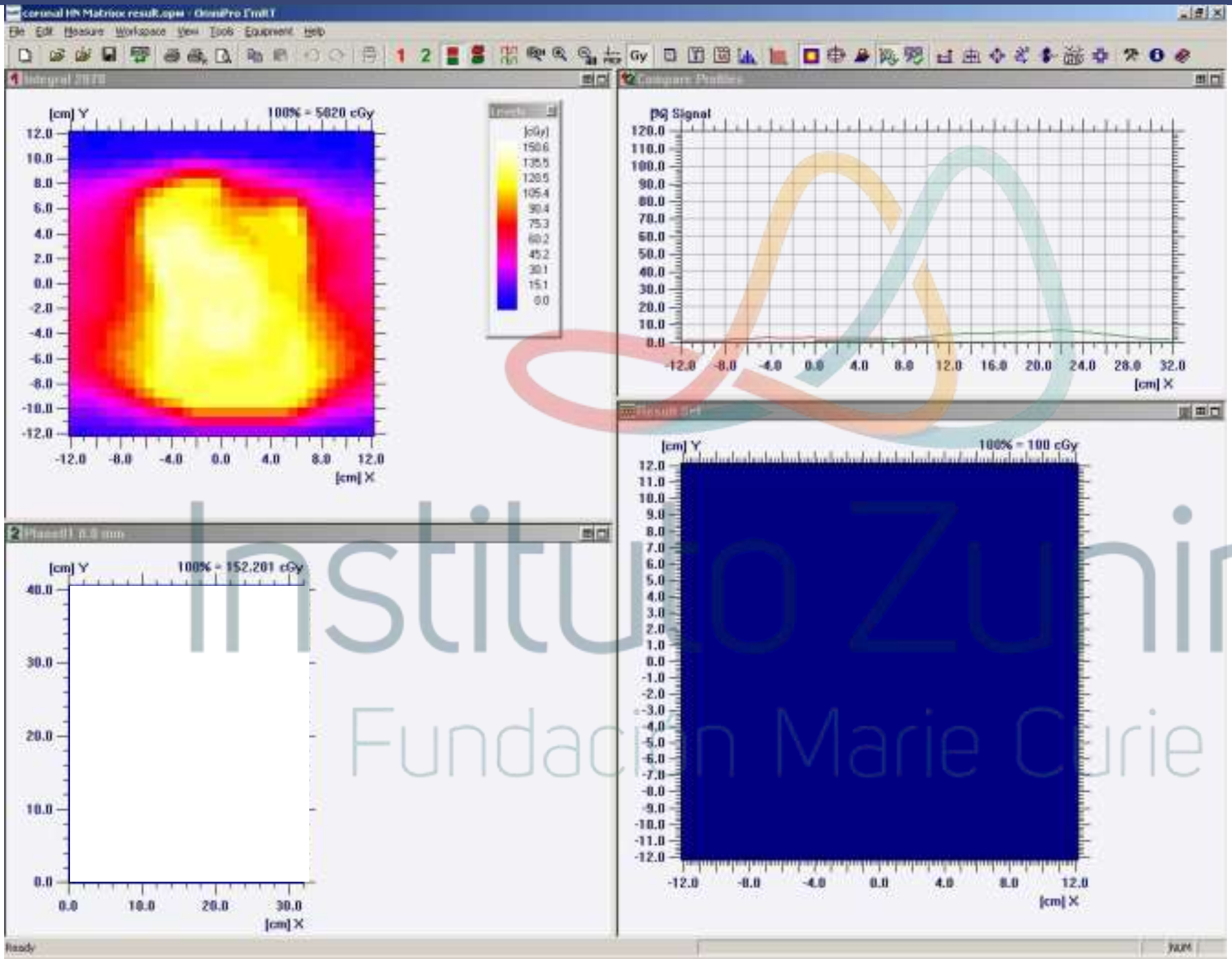
Low et al.(1) defined experimentally that we may acept the gamma values <1.

And we will acept at maximum of 5% of the points out of that criteria.

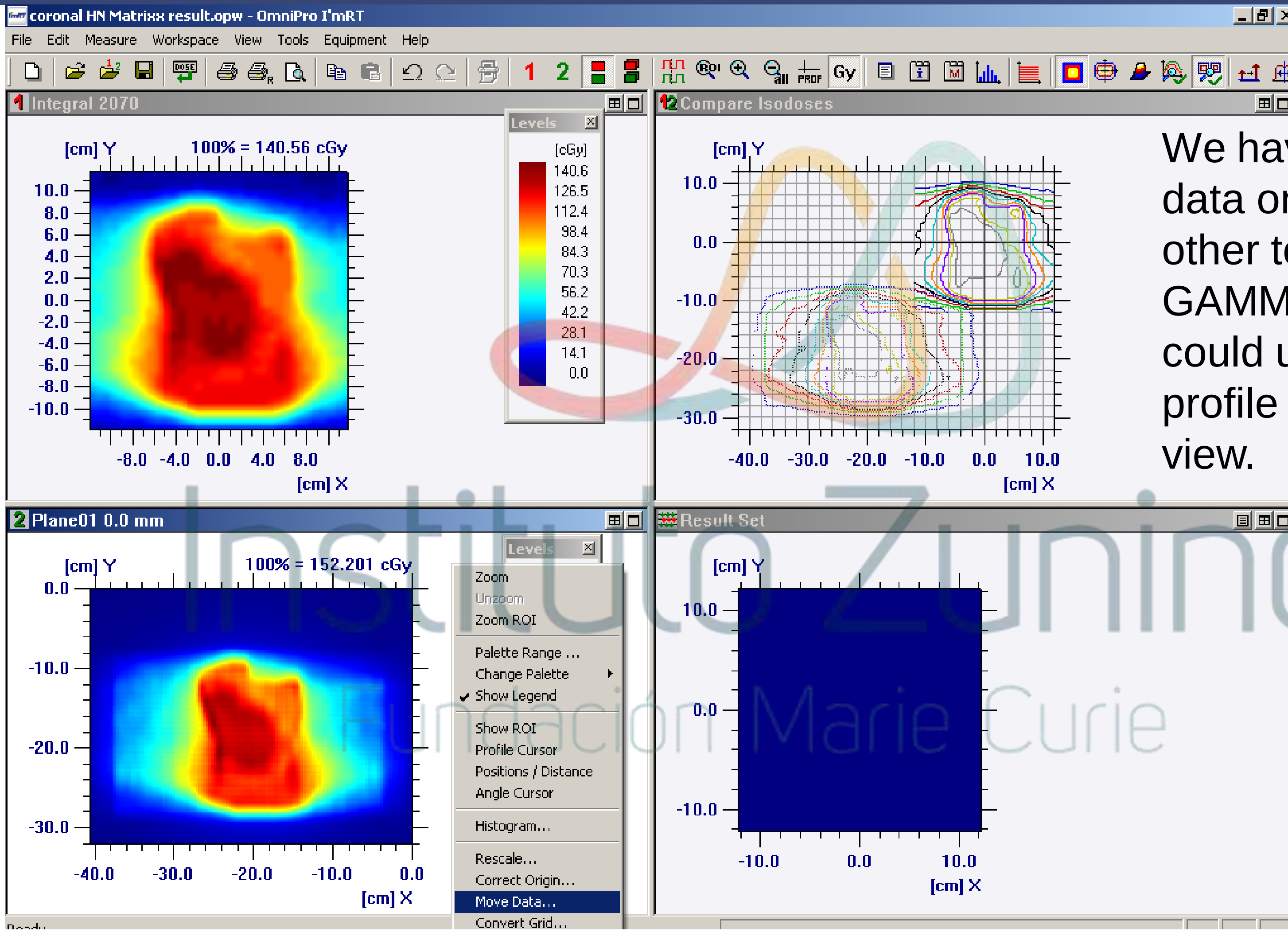
falp
Juntos contra el cáncer

(1) **A technique for the quantitative evaluation of dose distributions**, Daniel A. Low,a) William B. Harms, Sasa Mutic, and James A. Purdy

DQA Measurement

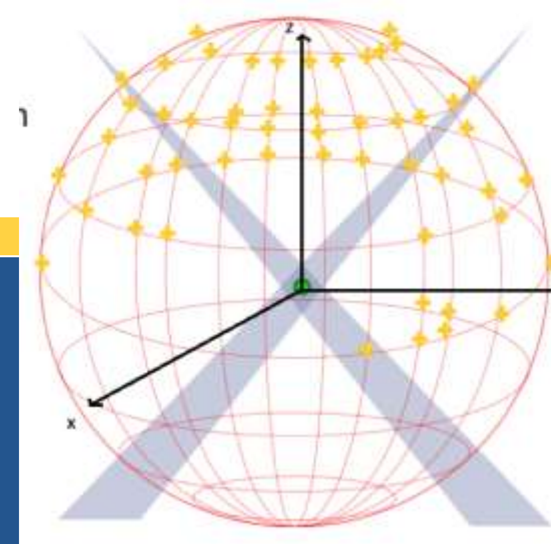


Analyzing the Measurements



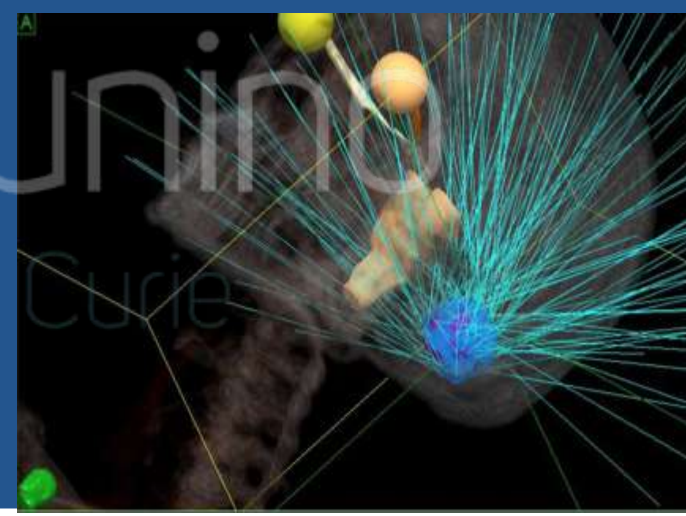
We have to move the data one over the other to calculate the GAMMA value. We could use the dose profile or the Isodose view.

1. CYBERKNIFE M6/ INTRODUCCION



- Equipo de Radiocirugía Robotizada desarrollado para administrar tratamientos con precisión sub-milimétrica y sin necesidad de marcos estereotáxicos.

- Seguimiento por imagen durante todo el tratamiento.
- El sistema es capaz de seguir, detectar y corregir los movimientos del tumor y/o paciente
- Extensa movilidad del robot : x,y,z,r,p,w
- Permite tratar tumores desde casi cualquier dirección
- Aplicaciones:
  - Intracraneales (sin marco estereotáxico)
  - Extracraneales: columna, pulmón, hígado, pancreas, prostata, etc
- Sistema no-coplanar y no-isocéntrico.
- Tratamientos isocéntricos & no-isocéntricos



1. PORQUE ES DIFERENTE?

- Espacio virtual alrededor del paciente
- Esfera para Intracraneales
- Elipsoide para Extracraneales

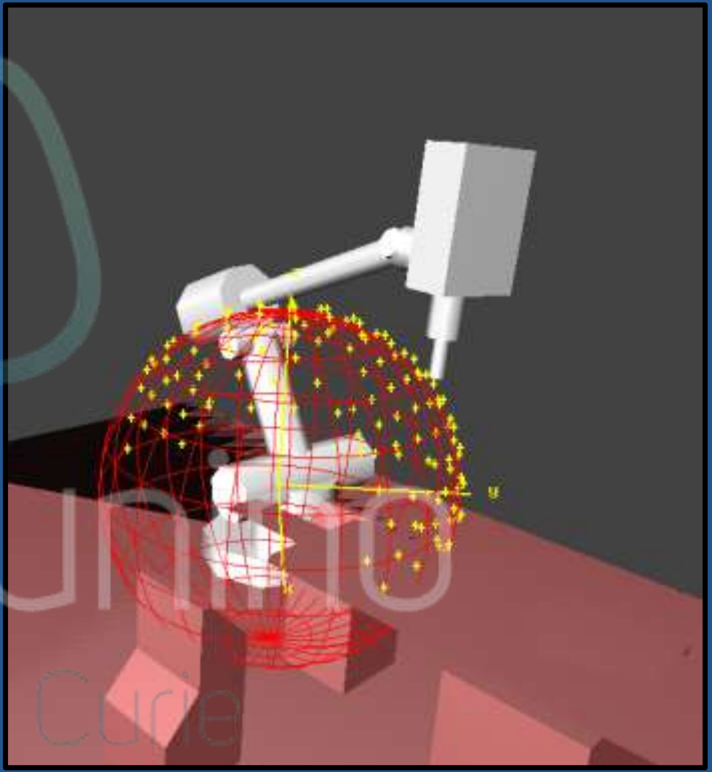
~ 110 posiciones LINAC (nodos)

X

> 12 direcciones del haz por nodo

=

> 1200 entradas de haz

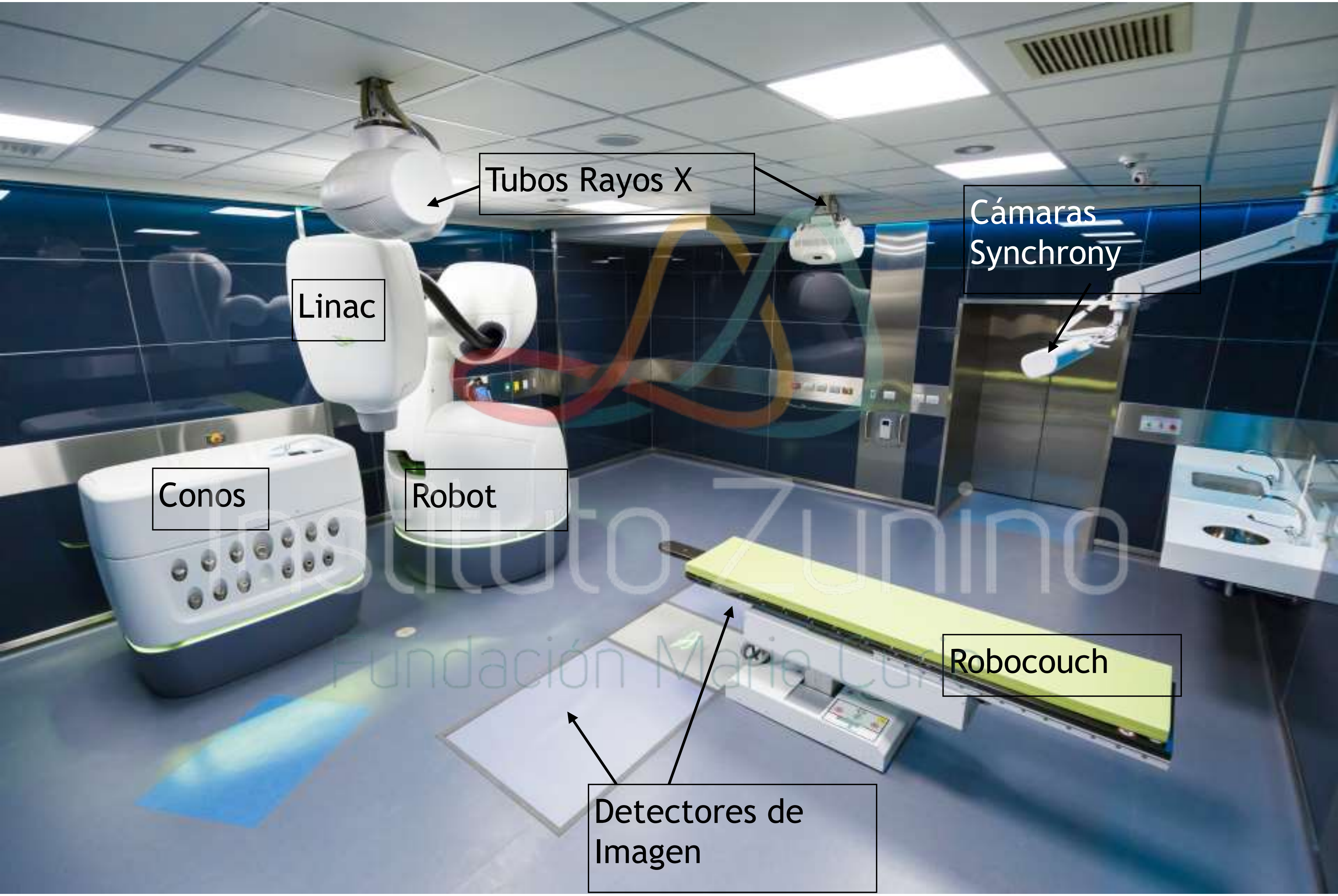


⇨ Tratamientos altamente conformados

⇨ Dosis mas altas al tumor preservando órganos críticos

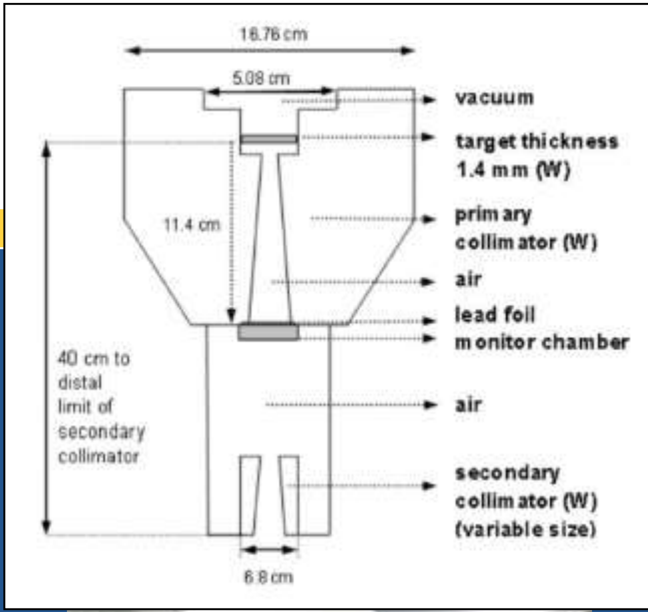
⇨ Posibilidad de reducción significativa del PTV

⇨ Disminución de puntos calientes fuera del blanco


Tubos Rayos X
Cámaras Synchrony
Linac
Conos
Robot
Robocouch
Detectores de Imagen
Instituto Zunino
Fundación Marie Cur

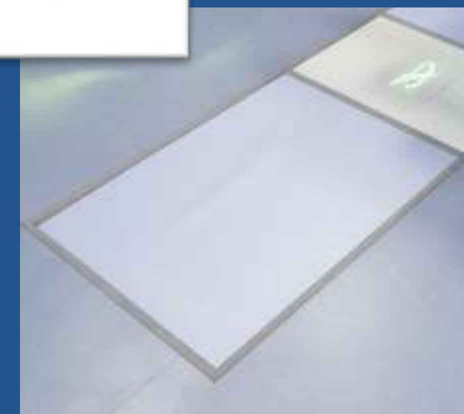
1. CK EL ACELERADOR LINEAL

- LINAC 6 MV , FFF, compacto montado en brazo robotizado.
- Permite diversificar las trayectorias y entradas de haces
- Reduce el riesgo de toxicidad



- Los aceleradores están calibrados a una energía de manera que 1UM da una dosis absorbida de 1cGy para un campo de 10cm x 10cm a una SAD/SSD = 100 cm.
- Campo de Referencia en CK: circular de 6 cm diámetro
- Profundidad Dosis máx. = 1.5 cm
- Cyberknife SAD 80 cm
- Tasa de Dosis: 1000 MU/min (actual.)

1. CK SISTEMAS DE LOCALIZACION DE BLANC



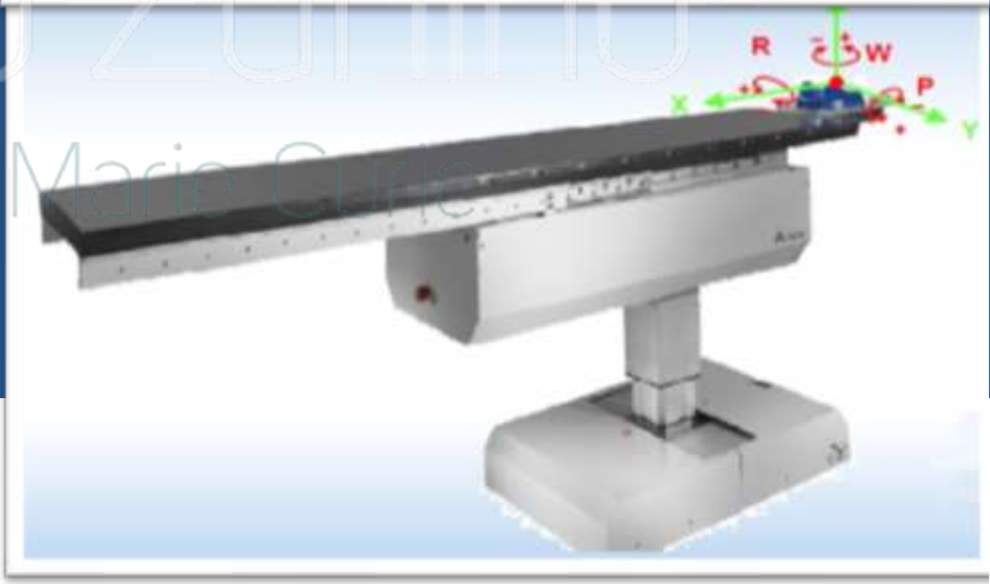
- 2 tubos de rayos X en el techo.
- Distancia tubo-detector ~ 3.7 m
- Parámetros de rayos X:
  - KV: 40 - 150
  - mA: 10 – 640
  - Ex: 1 - 500 ms
- 2 Detectores de Silicio amorfo (1024x1024 pixels) en suelo.
- Reconstrucción de la imagen a 45º
- Distorsión de la imagen corregida por Software
- Seguimiento del paciente/tumor durante todo el tratamiento.
- Imágenes adquiridas antes y durante toda la irradiación
- El robot corrige en tiempo-real el movimiento del paciente/tumor.

1. CK SISTEMAS DE POSICIONAMIENTO DEL PACIENTE

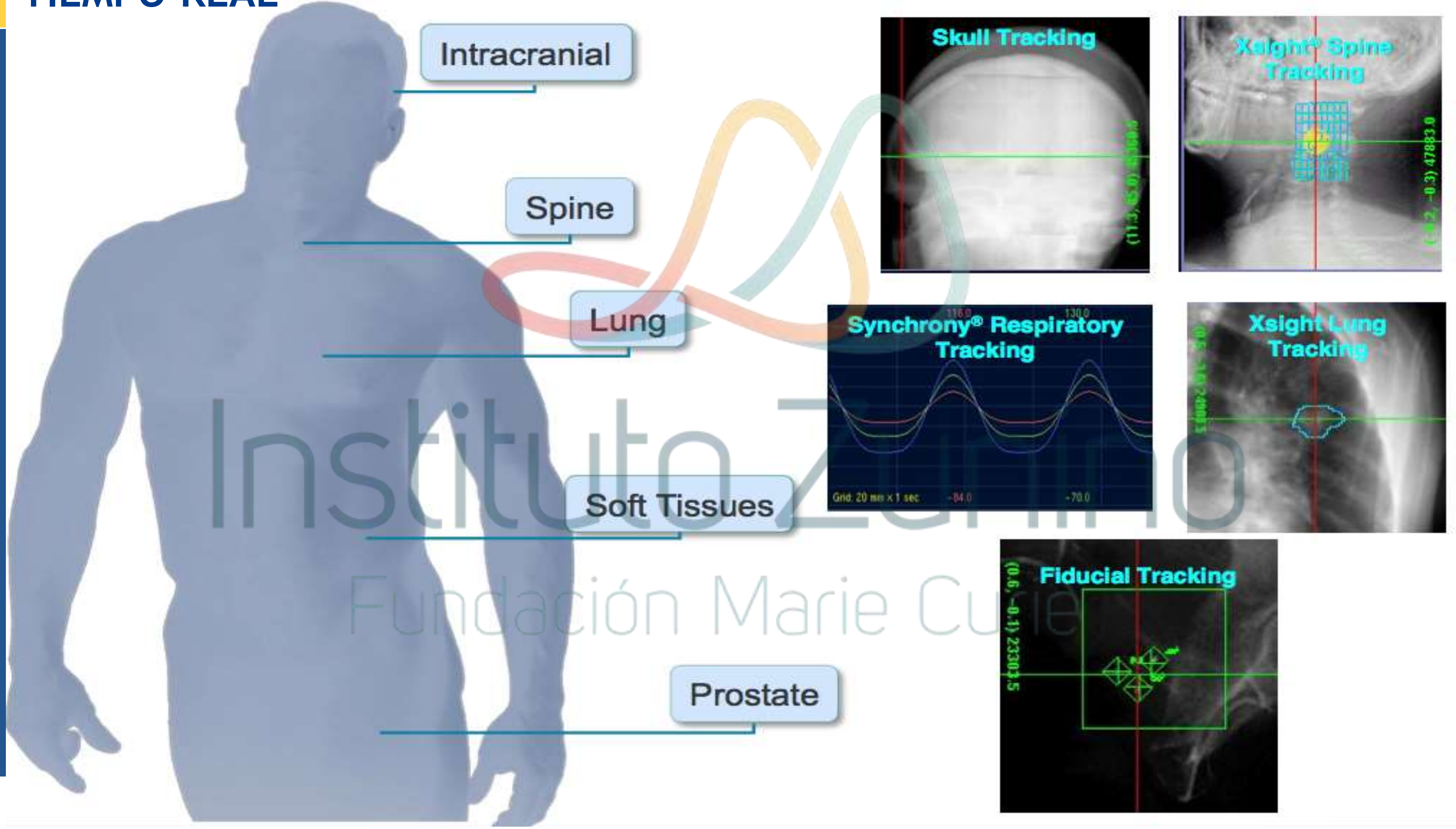
- Posicionamiento automático del paciente
- A traves de los varios algoritmos de correcion de desplazamiento por localizacion
- Tablero de fibra de carbono

- Mesa “Robocouch”.
- 6 grados de libertad
- Máx. carga ~ 190 Kg

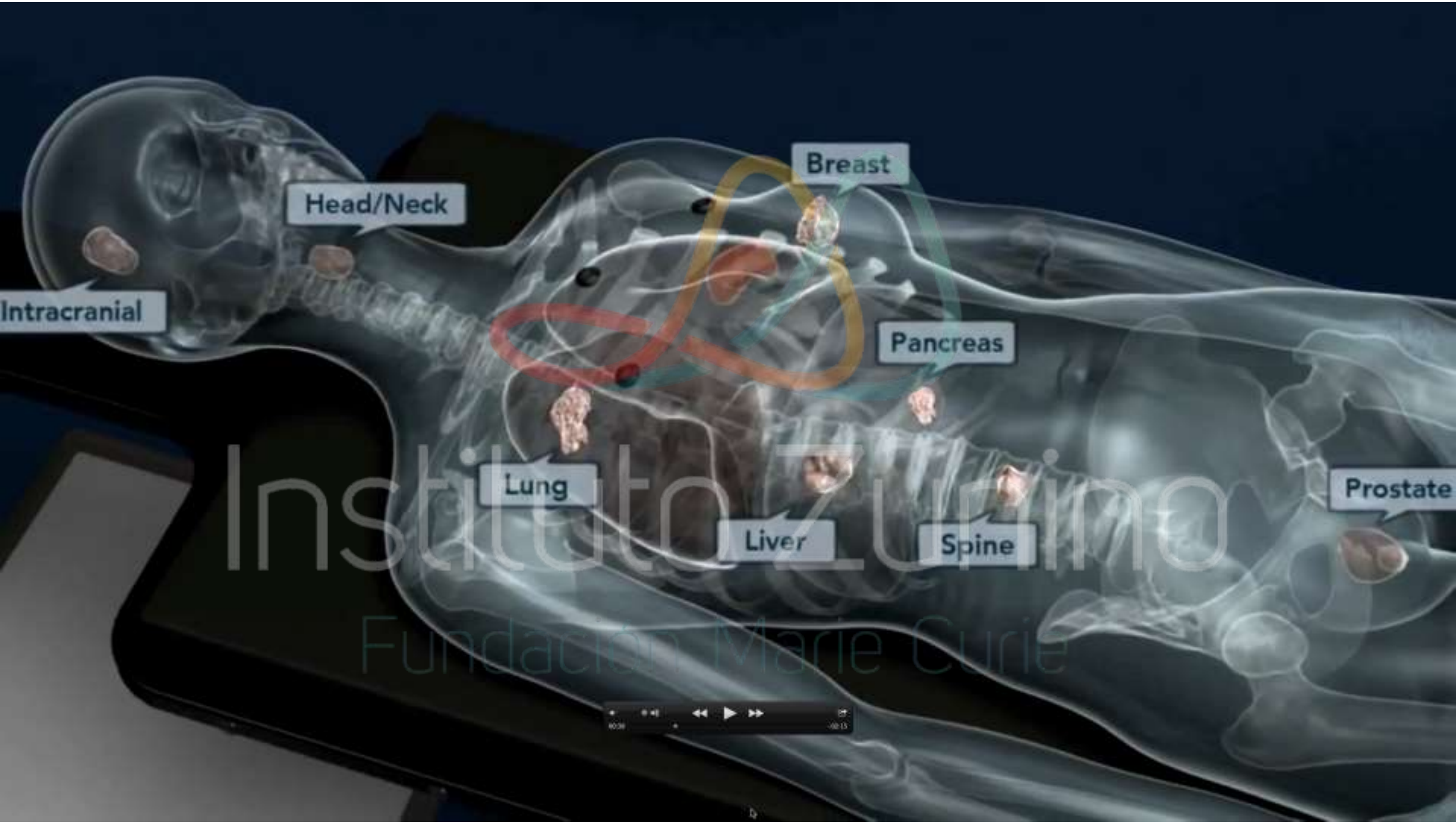
- Mesa “Standard”
- 5 grados de libertad
- Máx. carga ~ 150 Kg



1. TLS :TARGET LOCATING SYSTEM
ALGORITMO POR LOCALIZACION ANATOMICA
CALCULA LOS DESPLAZAMIENTOS BASADO EN DRR E IMÁGENES EN TIEMPO REAL



CK TRATAMIENTO de 1 A 5 FRACCIONES



Scope

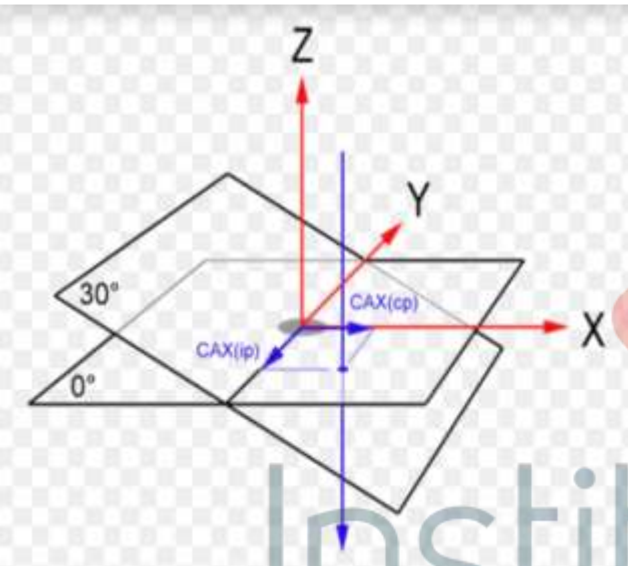
1. Why are we thinking in stereotactic QA ?
2. What is Winston-Lutz test ?
3. What is AQA ?
4. AQA general procedure
5. Alternative AQA (PANDA)
6. What is E2E ?
7. Registration methods
8. Conclusion

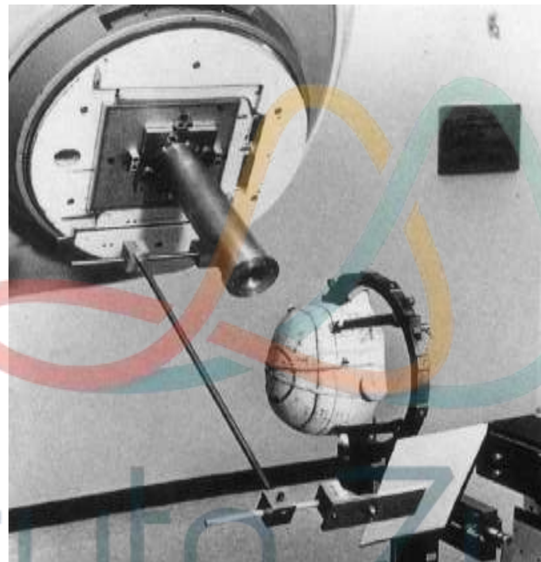
Connecting ideas: Why are we thinking in stereotactic QA?

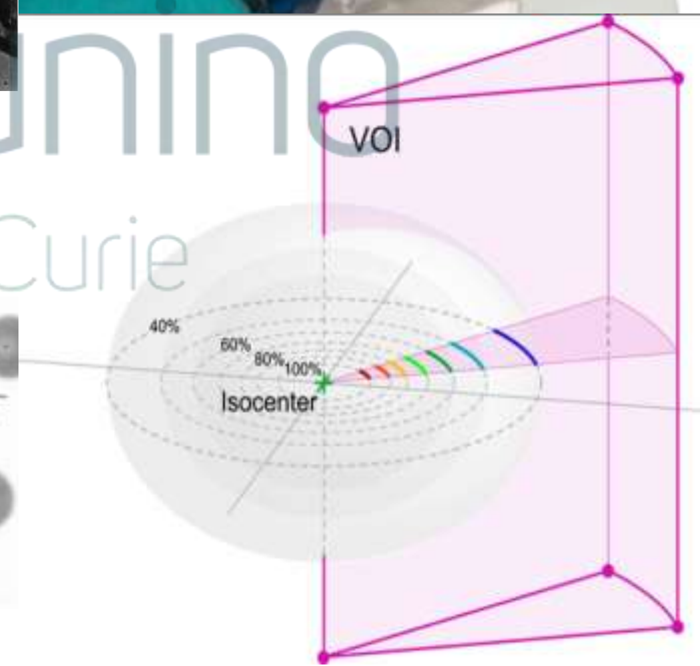
- It verifies the accuracy of your lasers.
- The mechanical isocenter can shift over time.
- Tolerance within 1 mm.
- The couch positioning can fail (mechanical isocenter).
- The cone mount may not be repositioned perfectly after service.
- As long as the patient does not move during treatments (frames), matching mechanical and radiation isocenter **will** guarantee treatment accuracy.
- No images are being taken in real time (**intrafraction motions**), **now motion management/compensation** does exist: WL can be little representative of the real challenges (all manual interventions).

Connecting ideas: Why are we thinking in stereotactic QA?

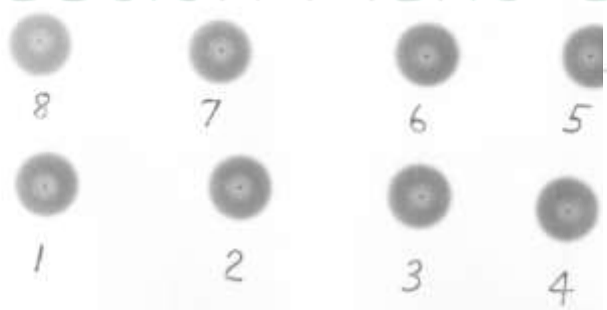
•Use of mm paper.







Radiation center sphere



Connecting ideas: What is Winston-Lutz ?

Gantry LINAC Stereotactic QA technique

Winston-Lutz History

Back to the past, 1988…

A SYSTEM FOR STEREOTACTIC RADIOSURGERY WITH A LINEAR ACCELERATOR

WENDELL LUTZ, PH.D., KEN R. WINSTON, M.D. AND NASSER MALEKI, PH.D.

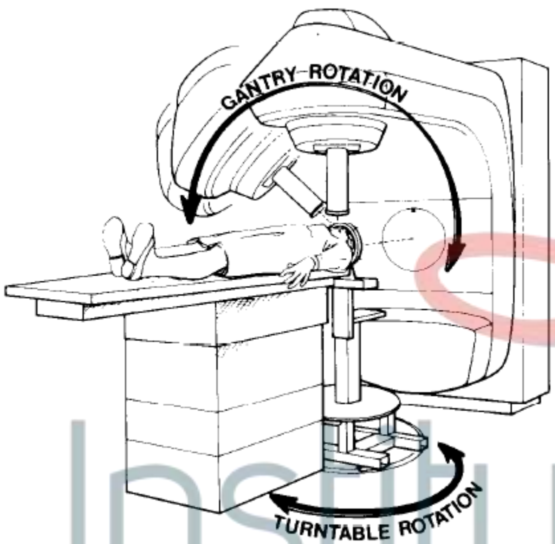
The Joint Center for Radiation Therapy, The Department of Surgery (Neurosurgery) of the Brigham and Women's Hospital, The Department of Neurosurgery of The Children's Hospital, Harvard Medical School, Boston, Massachusetts

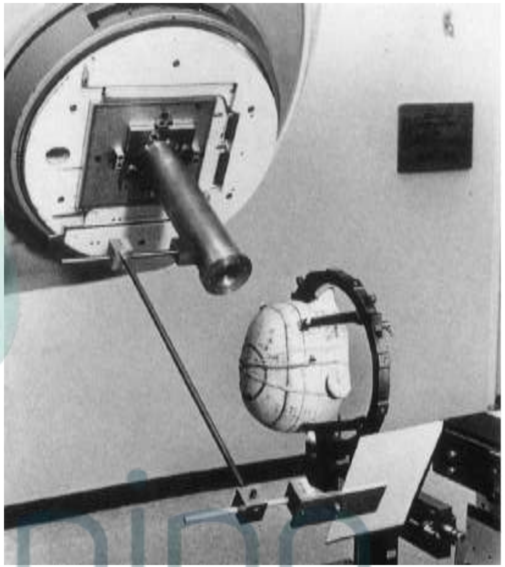
Verification of the accuracy between mechanical and radiation **isocenters**.
Also Taking into account different gantry and table positions that could be used during treatment.

Connecting ideas: What is Winston-Lutz ?

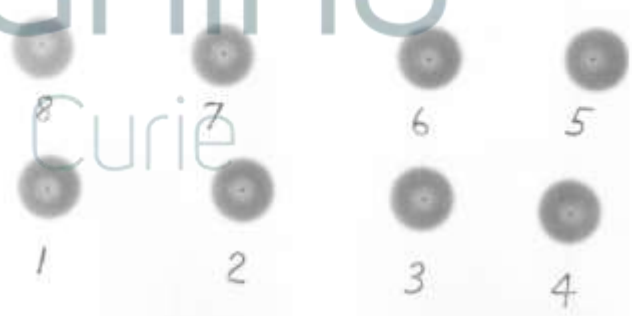
Gantry LINAC Stereotactic QA technique

Winston-Lutz History





Exposure	Gantry	Couch
1	50°	Normal as in Fig. 1
2	130°	Normal as in Fig. 1
3	230°	Normal as in Fig. 1
4	310°	Normal as in Fig. 1
5	310°	−90°, rotated CCW
6	230°	−90°, rotated CCW
7	130°	+90°, rotated CW
8	50°	+90°, rotated CW



Connecting ideas: What is Winston-Lutz ?

Gantry LINAC Stereotactic QA technique

Winston-Lutz History

Verification of the accuracy between mechanical and radiation **isocenters**.

Table 2. Treatment and localization errors in patient coordinate system

Target no.	$\lvert\vec{E}_T\rvert$	$\lvert\vec{E}_A\rvert$	$\lvert\vec{E}_L\rvert = \lvert\vec{E}_T - \vec{E}_A\rvert$
1	1.8	0.5	1.3
2	1.1	0.7	1.6

... was based on angiographically determined coordinates.

$\lvert\vec{E}_T\rvert$ is the displacement of the center of the radiation distribution from the center of the target.

$\lvert\vec{E}_A\rvert$ is the error generated solely by the treatment apparatus.

$\lvert\vec{E}_L\rvert$ is the error introduced by the localization procedure. It is determined from measurements of $\vec{E}_T$ and $\vec{E}_A$.

Winston-Lutz ideology

- More uncertainties.
- Too much non integrated parameters and more user dependence not recommendable nowadays for SRS.
- New LINACS with imaging system are still using Winston-Lutz test as a way to determine SRS error but the image system is not really integrated in the test and results.

AQA ideology

- integrated test that gives you a general result of the entire system: images and mechanical errors.

Conecting ideas: What is Winston-Lutz ?

Gantry LINAC Stereotactic QA technique

What about Cyberknife?

- laserless system (non dependent of)
- Crosshairless system
- Non isocentric machine
- Robot arm is used for **motion compensation**, not the couch.
- **Frameless system**. Images are being acquired in real time during treatment. Robot is in charge of patient motion compensation.
- **AQA was born to better represent the new CK SRS philosophy.**

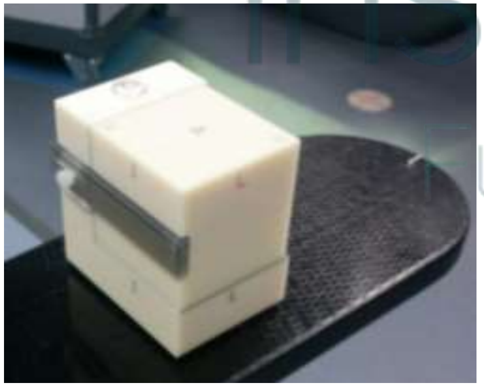
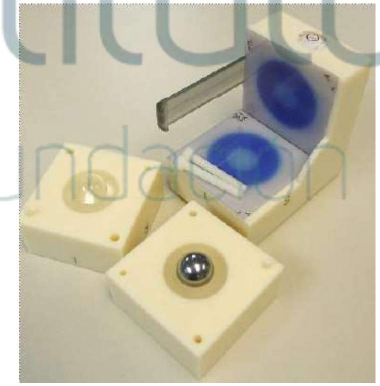
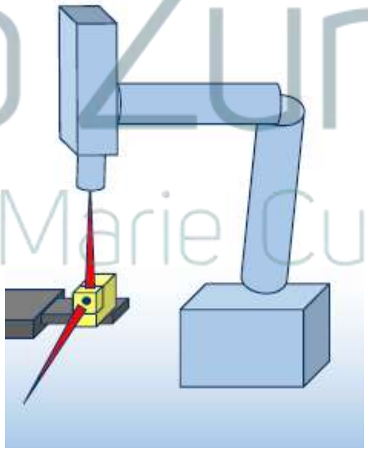
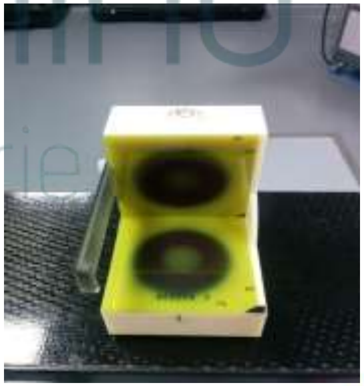
So, What is AQA ?

AQA means: Automatic Quality Assurance

Non-isocentric image-guided system

- AQA is a **daily test** used to determine the behavior and precision of the dual system: **imaging** and the **mechanical robotic arm**.

- **How is it done ? by delivering a plan** with **1 metal target** and **2 orthogonal radiation beams** where the position of the target is given to the system through the imaging system.

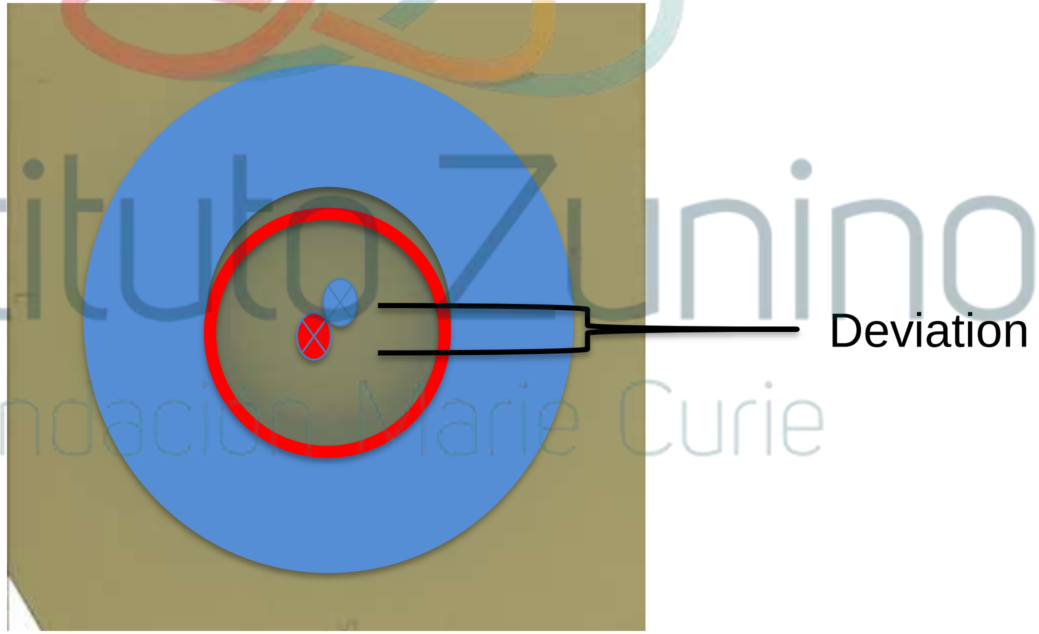





What is AQA ?

AQA means: Automatic Quality Assurance

Non-isocentric image-guided system

What to measure ? deviation of **radiation center** and **center of the steel sphere** could be detected on 2 orthogonal films.

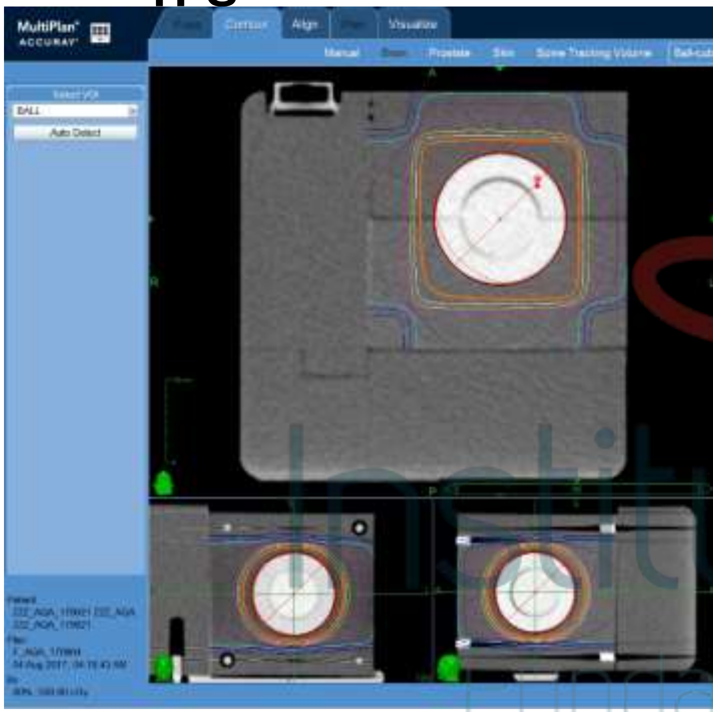


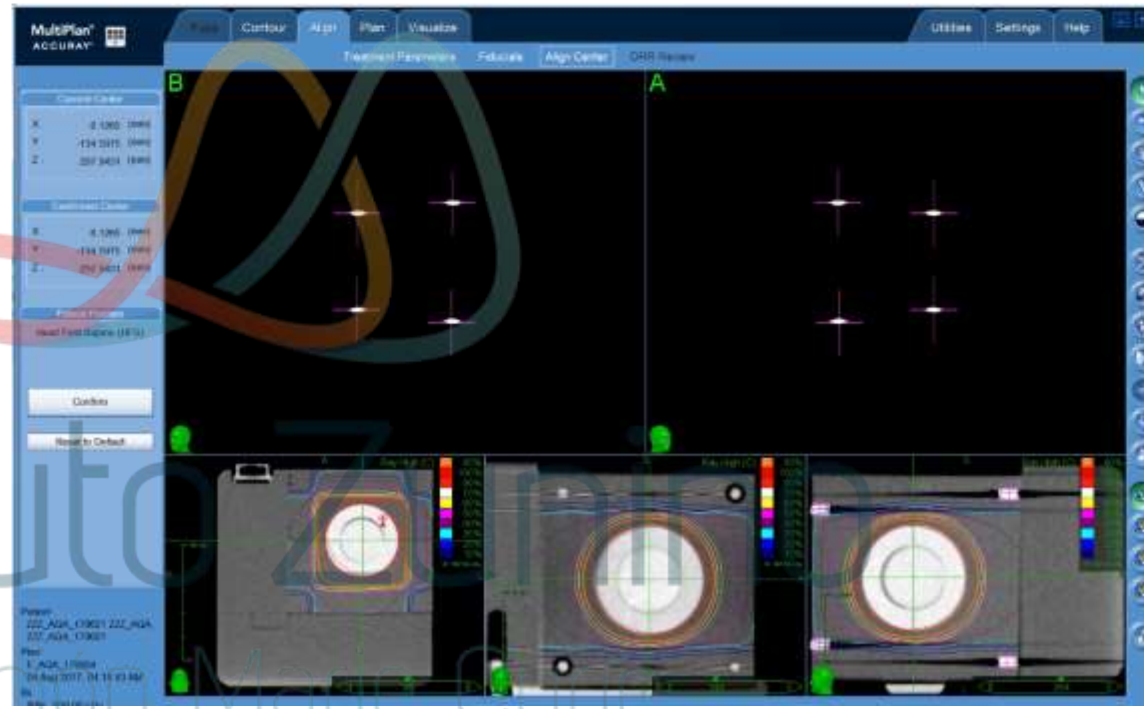
AQA general procedure

1. CT Scan of AQA phantom.
2. AQA procedure on CK TPS: The center of radiation is placed in the center of the AQA phantom sphere when creating the delivery plan of 2 orthogonal beams:
    - User defined.
    - User dependent.
3. The AQA phantom is loaded with 2 orthogonal films.
4. The ball is loaded into the AQA phantom.
5. Position the phantom on the couch. The target ball is not mechanically placed precisely at the room isocenter.
6. Deliver radiation in 4 general steps
    - Overview.
    - Alignment.
    - Readiness.
    - Delivery.
7. Scan the films:
    - Scan AS film.
    - Scan LS film.
8. Analyze films using AQA software evaluation.
9. Result: radial error, which is a **combination of tracking and delivery error.**
10. Register and check trend analysis in MyQA DB and Cockpit.

AQA general procedure

1. **CT scan of AQA phantom.**
2. ***Create the plan* in the CK TPS**

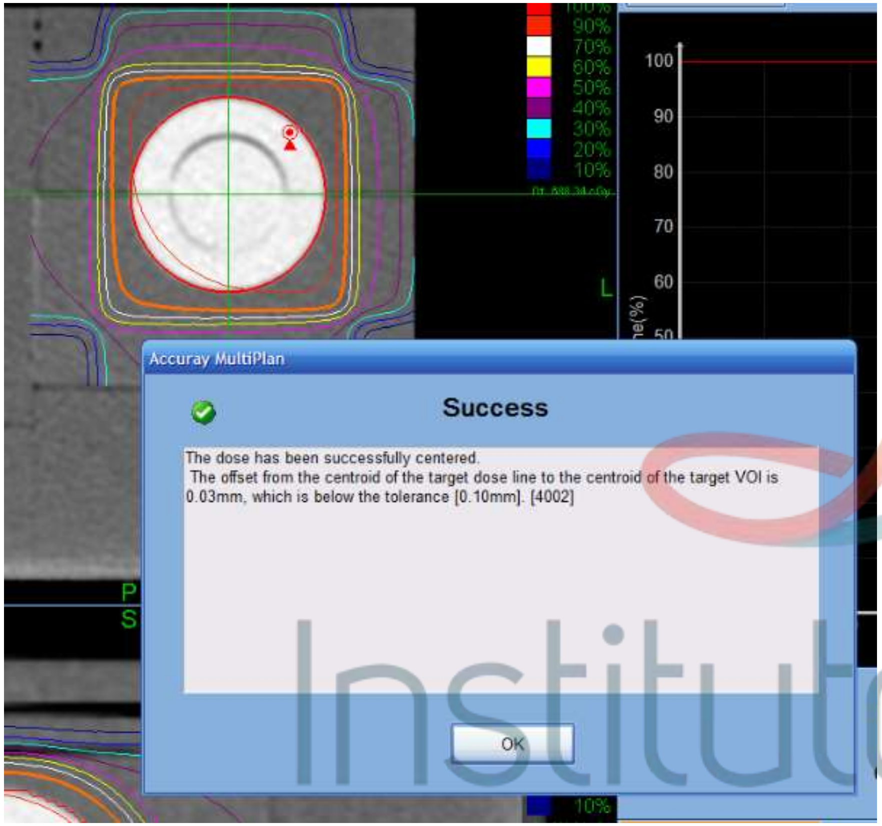




2,1. Define sphere steel center,

2,2. Define align center,

AQA general procedure

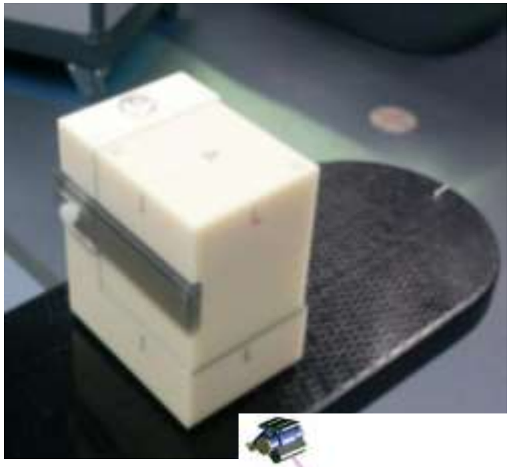


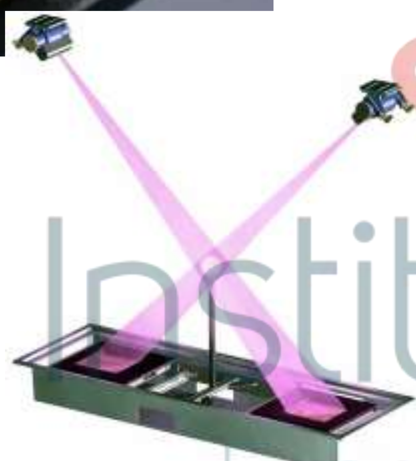
2,3. Center 70% isodose **to steel ball VOI**

3. Load the phantom with films,

Juntos contra el cáncer

AQA general procedure



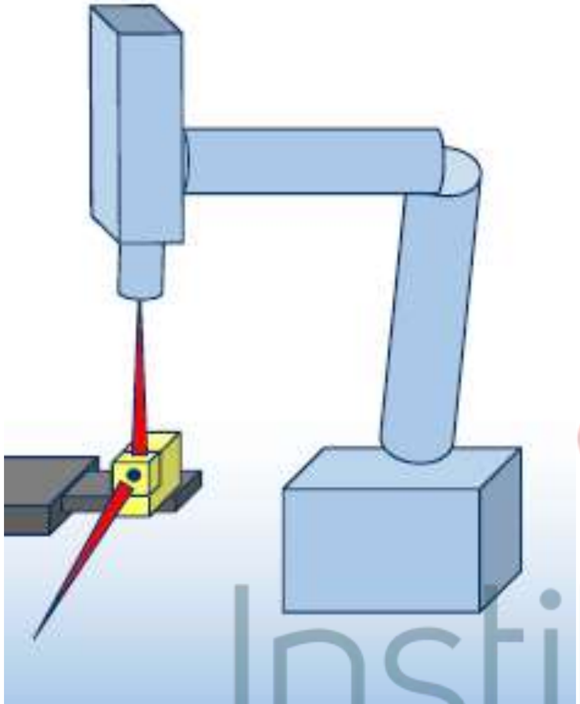


***4.* Position de phantom near the imaging center,**

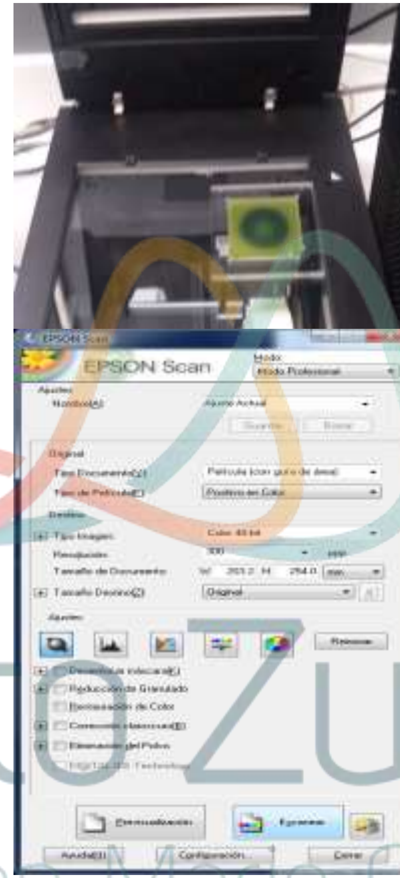
5. Take images, evaluate image parameters and apply corrections,

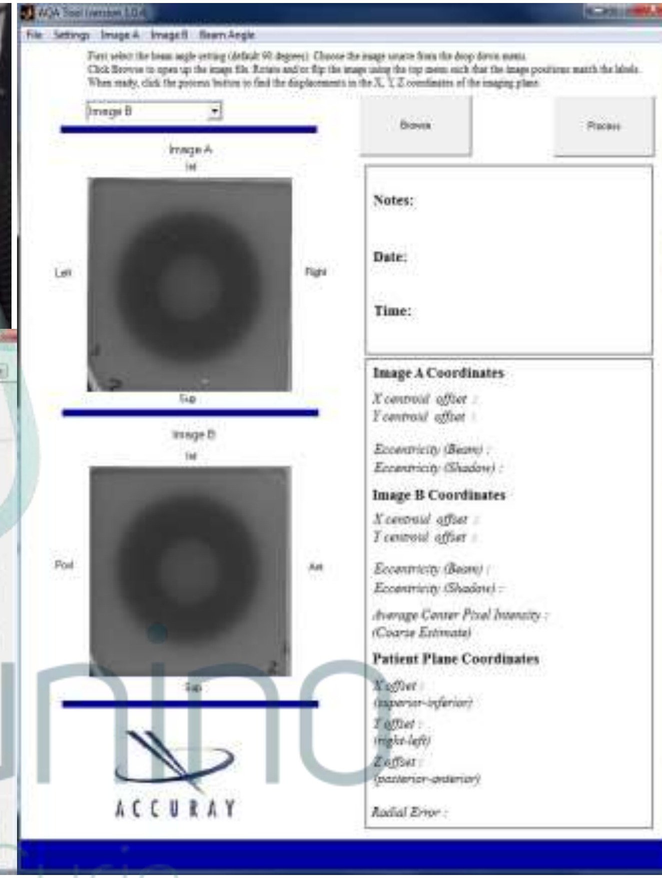
Juntos contra el cáncer

AQA general procedure



6. **Deliver radiation perpendicularly to the films,**





7. **Scan the films (OFF) :**
   - **Scan AS film.**
   - **Scan LS film.**
8. **Analyze films using the AQA software,**

Alternative AQA (PANDA)

PANDA: Position And Delivery Analysis

Non-isocentric image-guided system

Why PANDA test is **similar** to AQA test?

Principal reason:

- Both, PANDA and AQA, have the capability to get a combined error from the **Image System and the robotic arm.**

Why AQA test is not the same to PANDA test?

Principal reason:

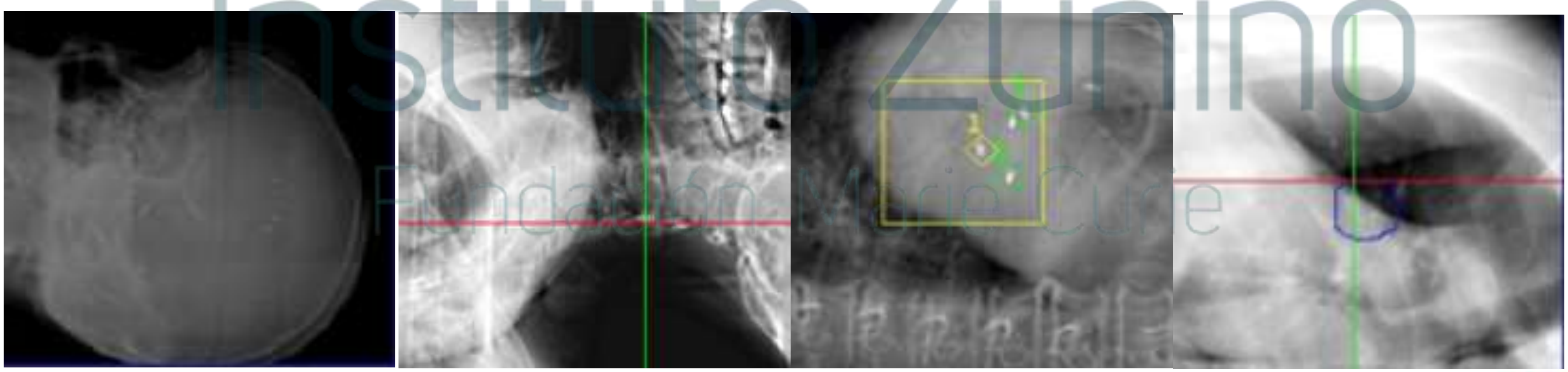
- PANDA compares a baseline everyday and AQA gives a new raw data everyday.
- **PANDA is Filmless and more clinically relevant robot**

What is E2E ?

An E2E is a test that embraces all the steps in the process of radiosurgery (from the scan to delivery)

TARGET TRACKING METHODS
SKULL
SPINE
FIDUCIAL
SYNCHRONY (Synchrony Fiducial)
LUNG

- There is one E2E test for each tracking mode and they use to be delivered in a monthly frequency.
- This is a more complete and rigorous test than the AQA daily test.
- So, this 5 E2E tests evaluate the precision of the robotic arm and the image system with all tracking methods.



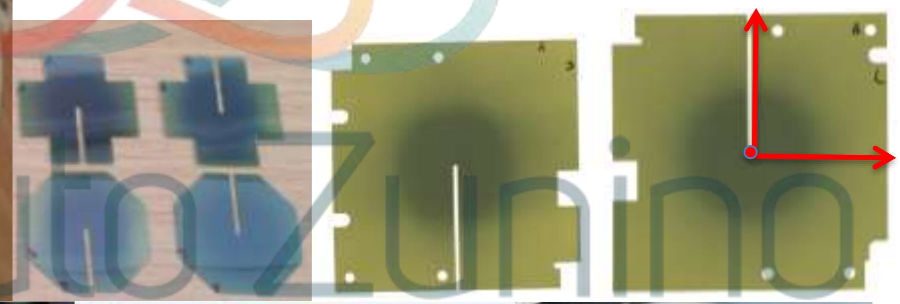
What is E2E ?
What do we need ?

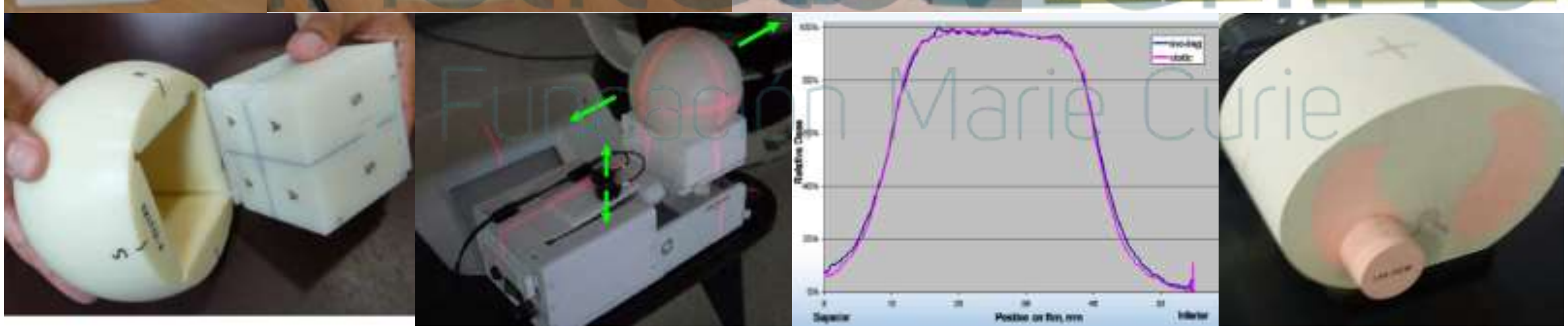
Software:

- Converting pixels to mm
- Distance from the radiation center to the edge – nominal distance (31.75 mm).

Total targeting error:

- Square root of the sum of the square errors





falp
Juntos contra el cáncer

Registration methods in AQA,E2E and treatments

Based on

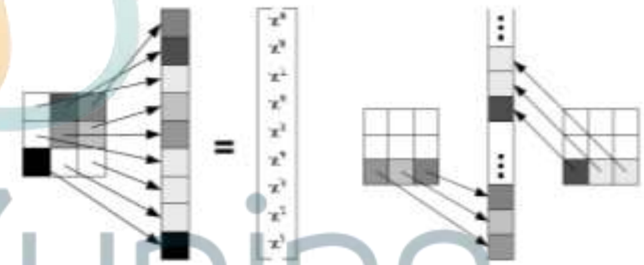
image features

- Anatomical edges
- Image gradients
- Contours
- Object surfaces or segmented objects

Fast computation (Advantage)

Low accuracy (Disadvantage)

image intensity



High accuracy (Advantage)

Larger computation cost (Disadvantag

CONCLUSIONS

- Most of the evolution of treatment in radiotherapy are consequences of the evolution of the acquisition and processing imaging techniques.
- In the long run, image processing development will be absolutely necessary for new advanced techniques for treatment delivery including intrafraction corrections.
- In terms of time the tests must be more efficient.
- QASC with PANDA is the beginning for the integration of the tests.

CONCLUSIONS

- Quality Assurance with a high level of precision is possible because of the imaging processing software and devices.
- Despite of this, the complexity of the tests must be reduced.