Controles de Calidad de IMRT.

Dr. Eduardo Francisco Larrinaga Cortina

Créditos:

Dr. Rodolfo Alfonso Laguardia

Curso Nacional Introducción IMRT.

HHA Cuba 2008

Maestría en Física Médica

Dosimetría Clínica en Radioterapia

Curso 2011-2012

Créditos

https://www.youtube.com/watch?v=cSKhST4B_cI

Intensity Modulated Radiation Therapy: Dosimetric Aspects & Commissioning Strategies

ICTP School on Medical Physics for Radiation Therapy

Justus Adamson PhD

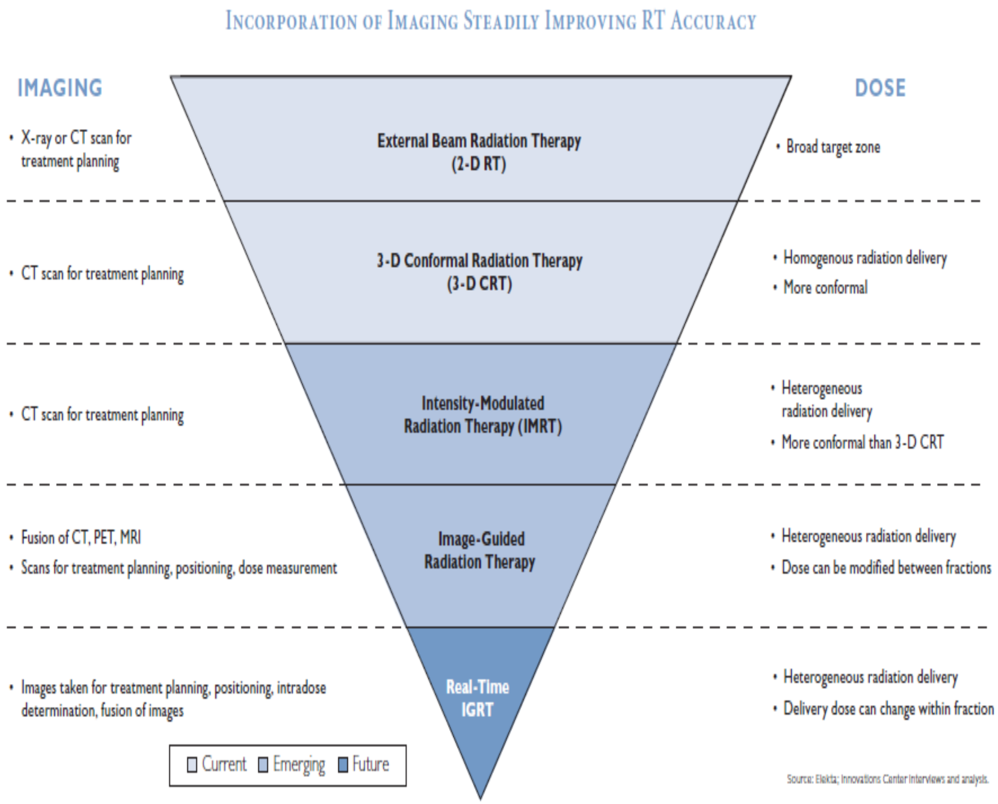
Assistant Professor

Department of Radiation Oncology

Duke University Medical Center

DukeMedicine

IMRT QA – Quo Vadis ?



J. Battista

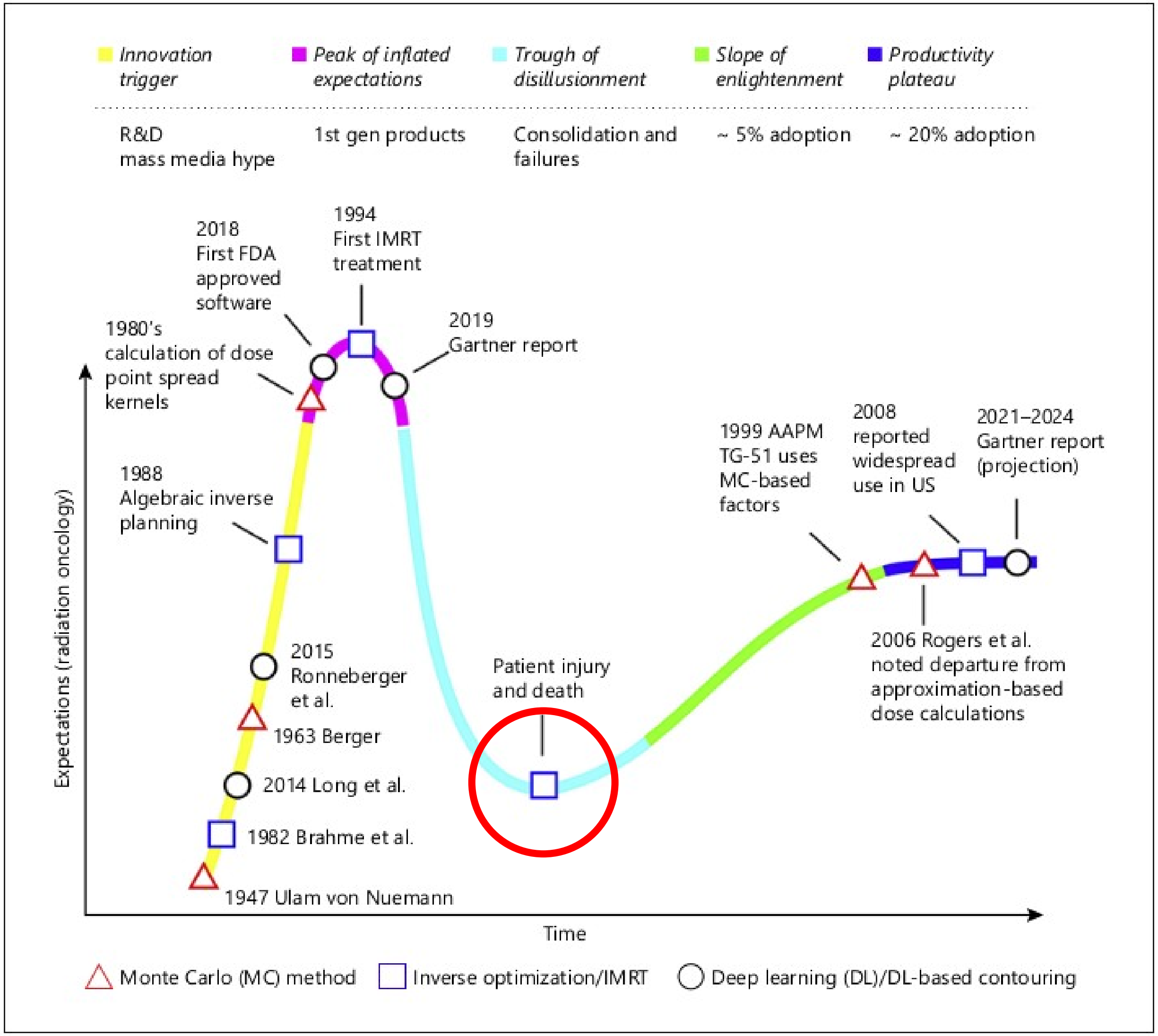
R. Barnett

December 14, 2011

Contenidos

- Controles de calidad a la unidad de tratamiento
- Controles de calidad paciente específicos de tratamientos de IMRT
  - Equipamiento disponible
  - Pruebas de principio a fin (end-to-end).
  - Inteligencia artificial
  - Evaluación de resultados

Principales Innovaciones en Radioterapia



The Emergence of Artificial Intelligence within Radiation Oncology Treatment Planning. Netherton T, Oncology 2021.

The New York Times FRONT PAGE

THE RADIATION BOOM

Radiation Offers New Cures, and Ways to Do Harm

BY WALT BOGDANICH
JANUARY 24, 2010

As Scott Jerome-Parks lay dying, he clung to this wish: that his fatal radiation overdose — which left him deaf, struggling to see, unable to swallow, burned, with his teeth falling out, with ulcers in his mouth and throat, nauseated, in severe pain and finally unable to breathe — be studied and talked about publicly so that others might not have to live his nightmare.

1 of 4

Scott Jerome-Parks, with his wife, Carmen, was 43 when he died in 2007 from a radiation overdose.

New York Incident

A Plan Goes Wrong
On a brisk day in March 2005, Mr. Jerome-Parks prepared for his fifth radiation **session** at St. Vincent's. The first four had been delivered as prescribed. Now Dr. Berson wanted the plan reworked to give more protection to Mr. Jerome-Parks' teeth.

...physicist was trying to save her work, the computer began seizing up, displaying an error message. The hospital would later say that similar system crashes "are not uncommon with the Varian software..."

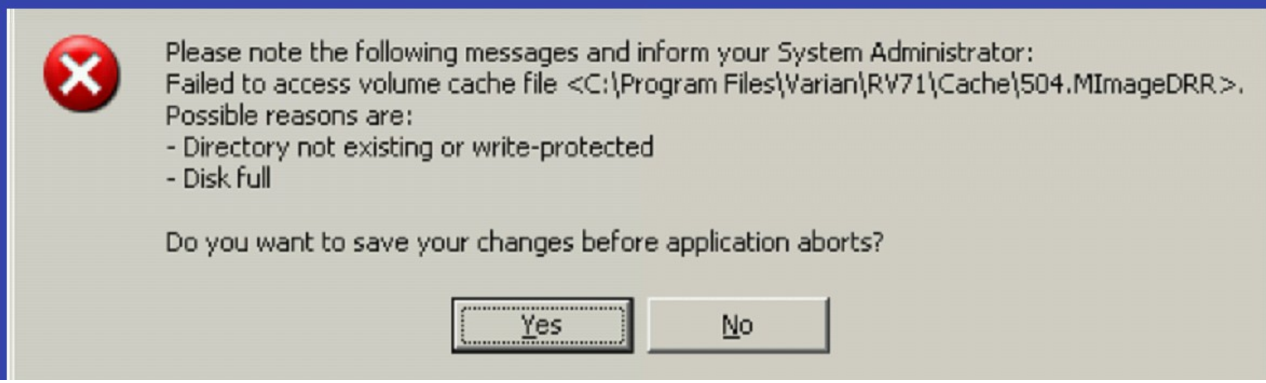
So at 6:29 p.m., she ran a test to verify that the treatment plan was carried out as prescribed. What she saw was horrifying: the multi-leaf collimator, which was supposed to focus the beam precisely on his tumor, was wide open.

- **March 11:** Physician wants **modified dose distribution** (reducing dose to teeth) "1AOropharyn" is copied and saved to the DB as "1BOropharyn"

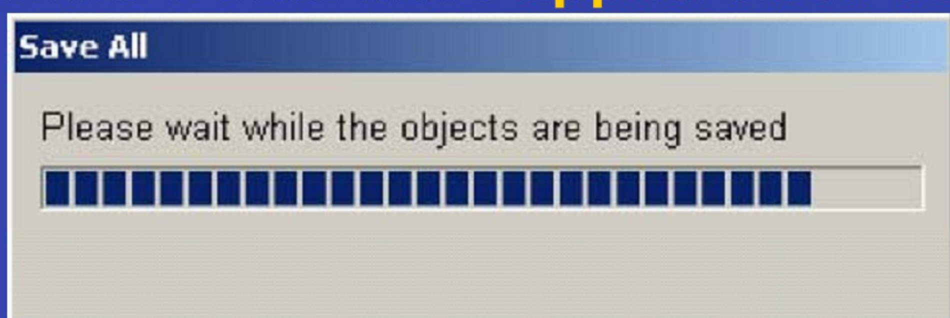
- **March 14:** Re-optimization for "1B Oropharyn".
  - New optimal fluences saved to DB.
  - MLC motion control points for IMRT generated. Normal completion.

- **March 14**
  - "Save all" is started. All new and modified data should be saved to the DB.
  - In this process, data is sent to a **holding area** on the server, and **not saved permanently until ALL data elements have been received.**
  - Data to be saved included: (1) fluence data, (2) DRRs and (3) MLC control points

- **March 14, 11 a.m.**
  - An error message is displayed.
  - The user presses "Yes", which begins a second, separate, save transaction.
  - MLC control point data is moved to the holding area.

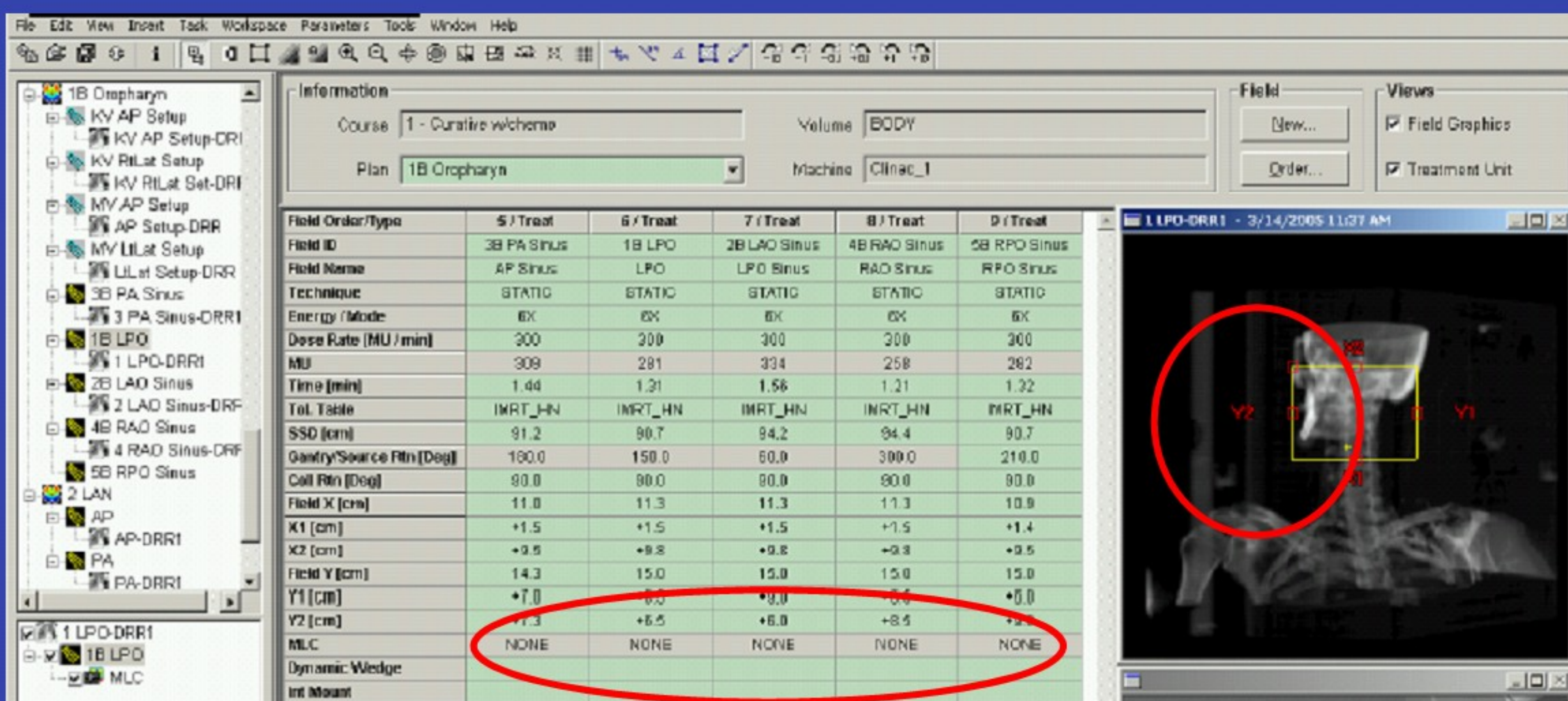


- The software would have **appeared to be frozen.**



- March 14, 11 a.m.
  - No verification plan, no pre-treatment dosimetry, no review by 2nd physicist
  - Several computer crashes ignored and over-ridden.
  - Plan approved by physician

What they didn't notice:



Impact of accident

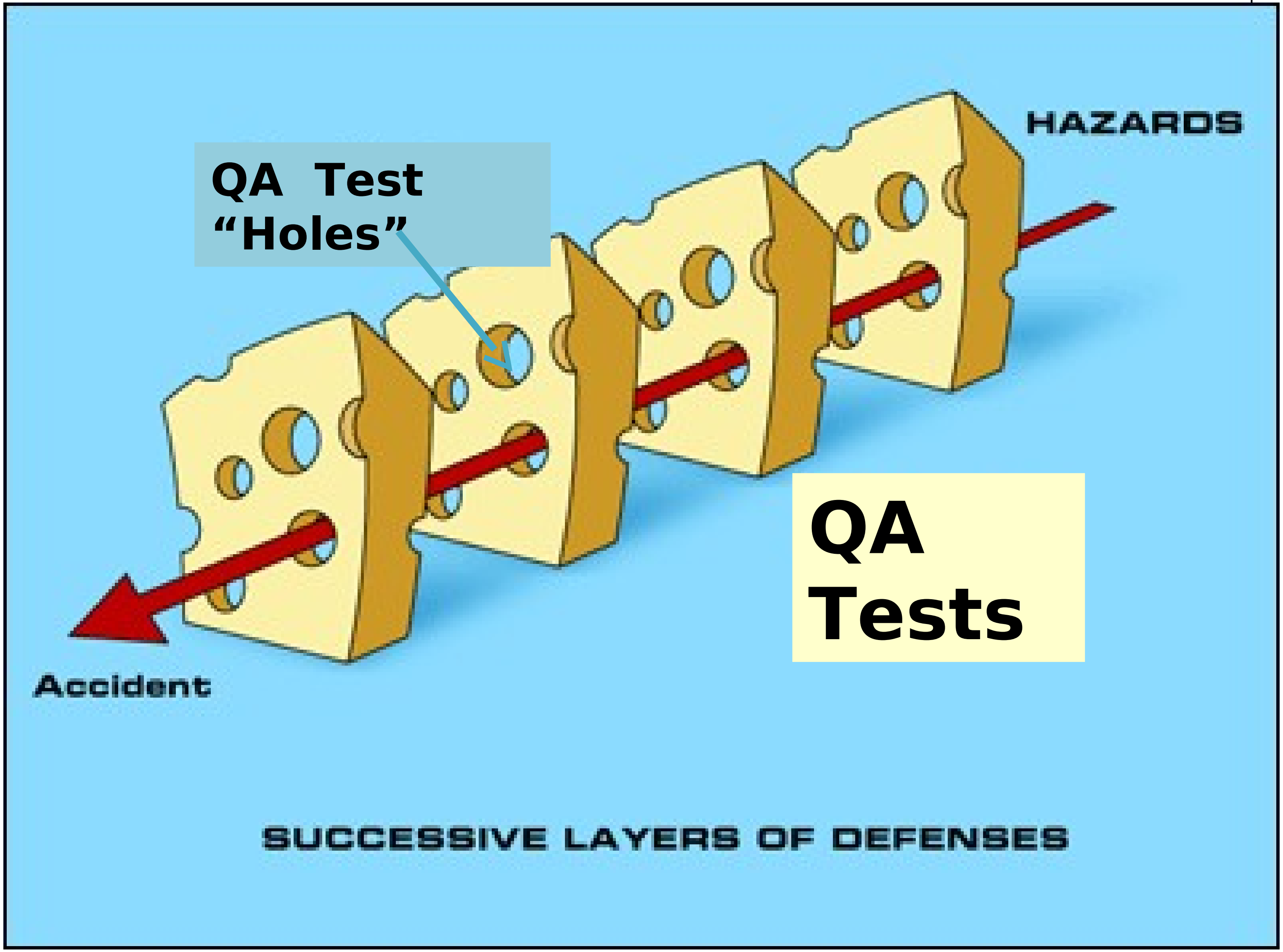
- The patient received 13 Gy per fraction for three fractions, i.e. 39 Gy in 3 fractions

Was there a bug in the Varian software:

Of course, but the software had a lot of help:

1. Error messages ignored and not investigated
2. Treatment plan QA not performed
3. No 2nd physics check
4. MD rushed the plan modification
5. Therapists weren't watching MLC display

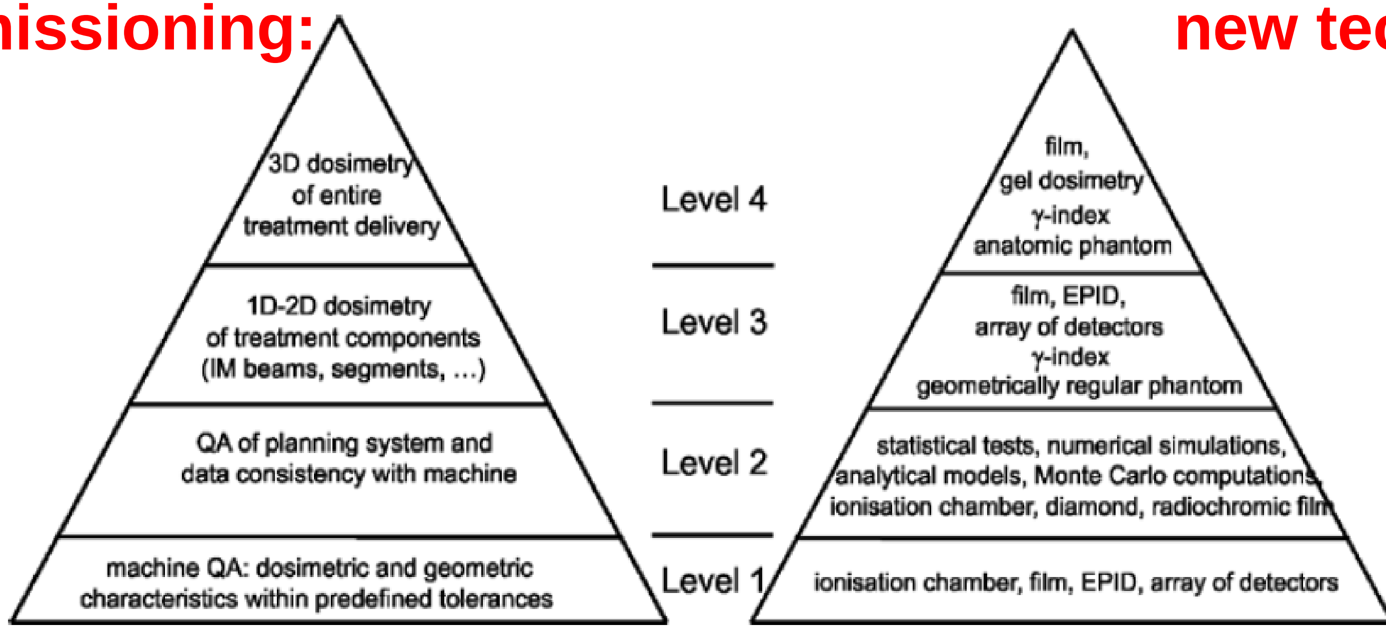
Accident Prevention



Suggested Layers of Quality Assurance:

initial commissioning: ↑

introducing a new technique: ↓



(a) (b)

Figure 3.1 (a) Conceptual pyramid that correlates the various levels of dosimetric QA in IMRT. Like the situation for a real pyramid, each level is based on the stability of the underlying levels. The two lower levels can be part of the periodic QA procedures of equipment used for IMRT planning and delivery. For QA of a new clinical IMRT solution, one may start at the top by applying a 3D dosimetric verification of an entire treatment. One descends the pyramid to the lower levels if the 3D dosimetric verification reveals unacceptable discrepancies with treatment planning. (b) Methodology and tools appropriate for each of the levels. (Courtesy Carlos De Wagter, Ghent University Hospital, Ghent, Belgium, and the Institute of Physics).

ESTRO Guidebook 9: GUIDELINES FOR THE VERIFICATION OF IMRT (2008)

Puesta en servicio clínico IMRT

- Unidad de tratamiento
  - Pruebas mecánicas
  - Pruebas dosimétricas
  - Pruebas específicas de IMRT
- Sistema de Planeación de Tratamiento (TPS)
  - Pruebas 3DCRT
  - Pruebas IMRT
- Verificación dosimétrica por plan.
- Verificación independiente redundante/Acreditación
- Control de calidad paciente-específico.

Control de Calidad IMRT

Unidad de Tratamiento

- **Pruebas 3DCRT**
- **Pruebas IMRT**
  - **Dosimétricas**
  - **Desempeño del MLC**

Puesta en servicio clínico IMRT

Unidad de tratamiento, Tolerancias

TABLE II. Monthly.

Procedure	Machine-type tolerance Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray output constancy			
Electron output constancy		2%	
Backup monitor chamber constancy			
Typical dose rate[a] output constancy	NA	2% (@ IMRT dose rate)	2% (@ stereo dose rate, MU)
Photon beam profile constancy		1%	
Electron beam profile constancy		1%	
Electron beam energy constancy		2%/2 mm	
Mechanical			
Light/radiation field coincidence[b]		2 mm or 1% on a side	
Light/radiation field coincidence[b] (asymmetric)		1 mm or 1% on a side	
Distance check device for lasers compared with front pointer		1mm	
Gantry/collimator angle indicators (@ cardinal angles) (digital only)		1.0°	
Accessory trays (i.e., port film graticle tray)		2 mm	
Jaw position indicators (symmetric)[c]		2 mm	
Jaw position indicators (asymmetric)[d]		1 mm	
Cross-hair centering (walkout)		1 mm	
Treatment couch position indicators[e]	2 mm/1°	2 mm/1°	1 mm/0.5°
Wedge placement accuracy		2 mm	
Compensator placement accuracy[f]		1 mm	
Latching of wedges, blocking tray[g]		Functional	
Localizing lasers	±2 mm	±1 mm	<±1 mm
Safety			
Laser guard-interlock test		Functional	
Respiratory gating			
Beam output constancy		2%	
Phase, amplitude beam control		Functional	
In-room respiratory monitoring system		Functional	
Gating interlock		Functional	

Task Group 142 report: Quality assurance of medical accelerators. Klein E et al. MP, 2009.

Received: 9 February 2021 | Revised: 16 March 2021 | Accepted: 28 April 2021
DOI: 10.1002/mp.14992

MEDICAL PHYSICS

AAPM SCIENTIFIC REPORT

AAPM Task Group 198 Report: An implementation guide for TG 142 quality assurance of medical accelerators

Joseph Hanley[1] | Sean Dresser[2] | William Simon[3] | Ryan Flynn[4] | Eric E. Klein[5] | Daniel Letourneau[6] | Chihray Liu[7] | Fang-Fang Yin[8] | Bijan Arjomandy[9] | Lijun Ma[10] | Francisco Aguirre[11] | Jimmy Jones[12] | John Bayouth[13] | Todd Holmes[14]

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Abstract

The charges on this task group (TG) were as follows: (a) provide specific procedural guidelines for performing the tests recommended in TG 142; (b) provide estimate of the range of time, appropriate personnel, and qualifications necessary to complete the tests in TG 142; and (c) provide sample daily, weekly, monthly, or annual quality assurance (QA) forms. Many of the guidelines in this report are

1 | INTRODUCTION

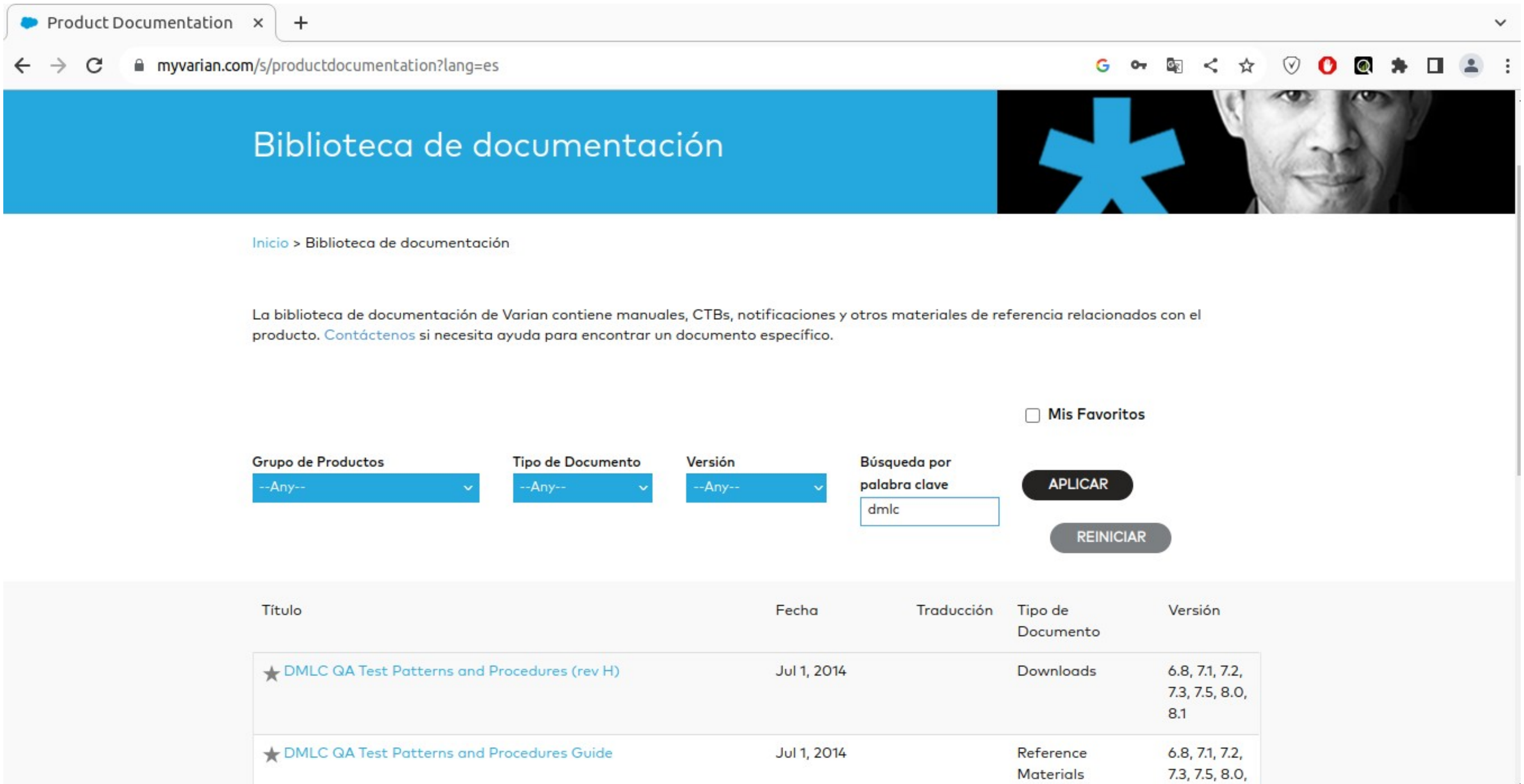
1.A | Purpose

The American Association of Physicists in Medicine (AAPM) Task Group (TG) 142 report,[1] "Quality Assurance of Medical Accelerators," published in 2009, updated table II of TG 40[2] with respect to frequency and tolerances of existing procedures. It also added recommendations for quality assurance (QA) of ancillary devices [asymmetric jaws, multileaf collimators (MLCs), dynamic or virtual wedges] that were not covered in TG 40. The recommendations made in TG 142 were dependent on the types of procedures performed on the linear accelerator (linac). Separate tests and tolerances were recommended based on whether spe-

Control de Calidad IMRT

Unidad de Tratamiento. Desempeño MLC

- **Suite de pruebas suministradas por el fabricante**
  - **Ejemplo Varian: DMLC QA Test Patterns**



Control de Calidad IMRT
Unidad de Tratamiento. Desempeño MLC

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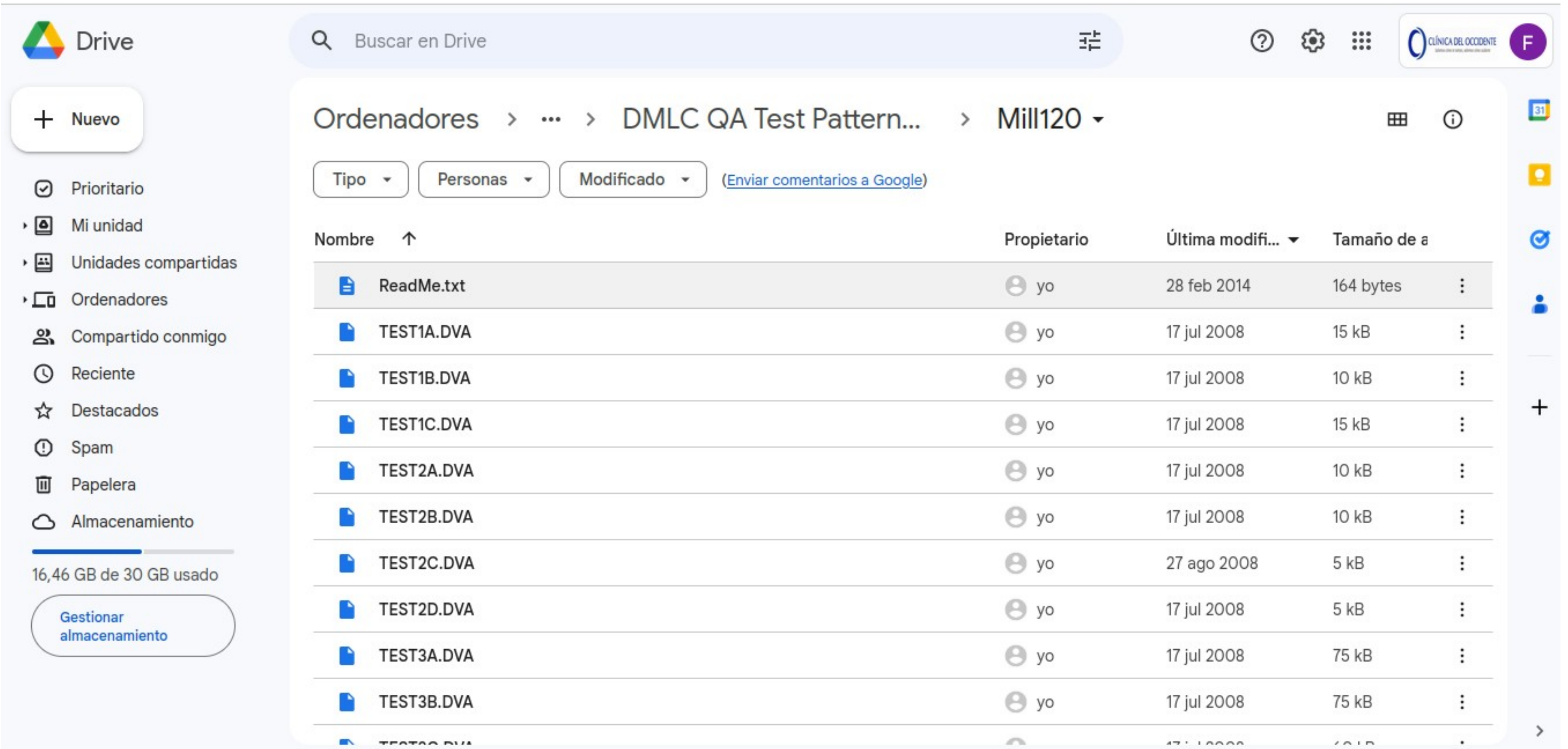

Control de Calidad IMRT

Unidad de Tratamiento. Desempeño MLC

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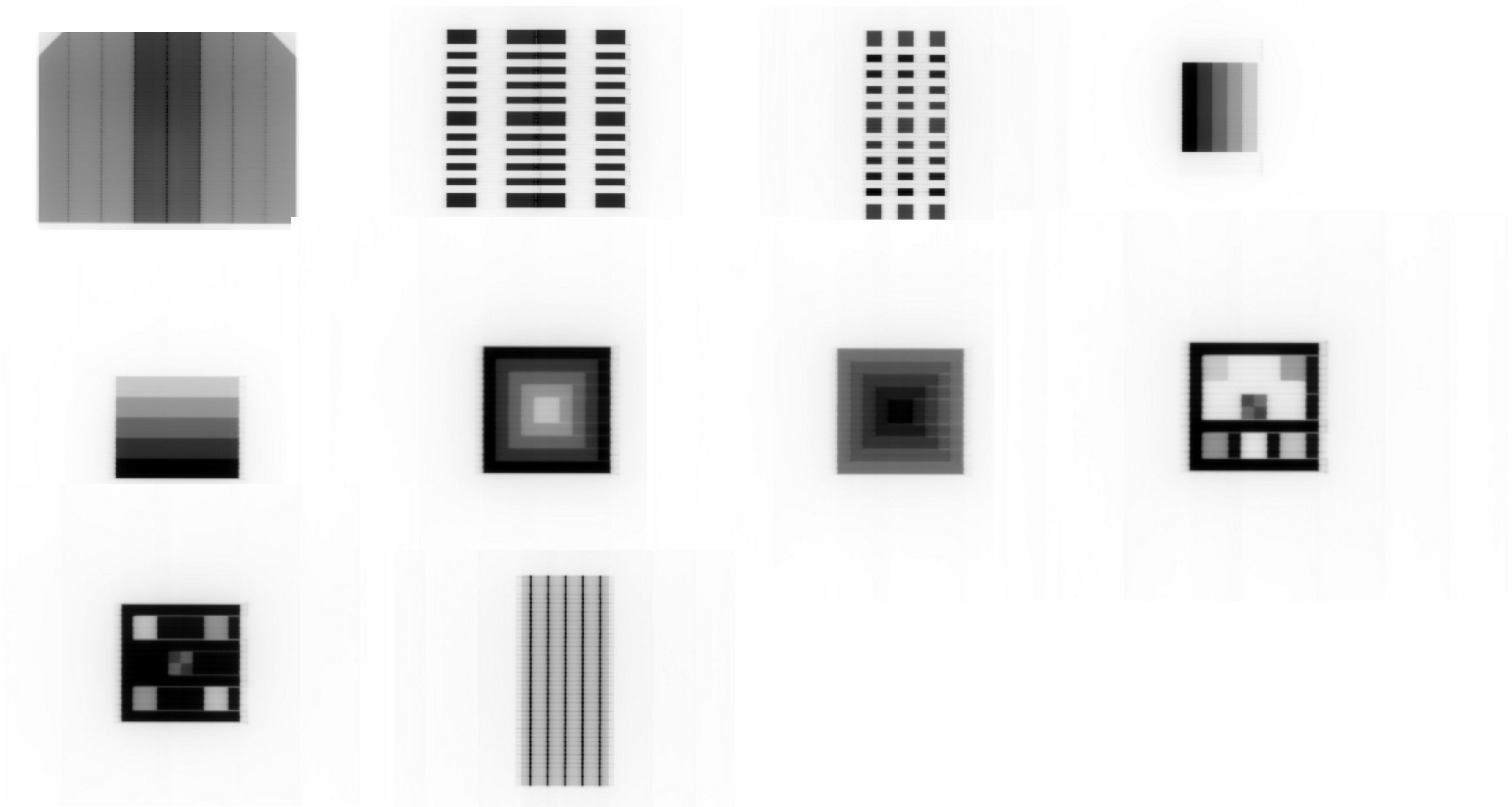

Control de Calidad IMRT

Unidad de Tratamiento. Desempeño MLC

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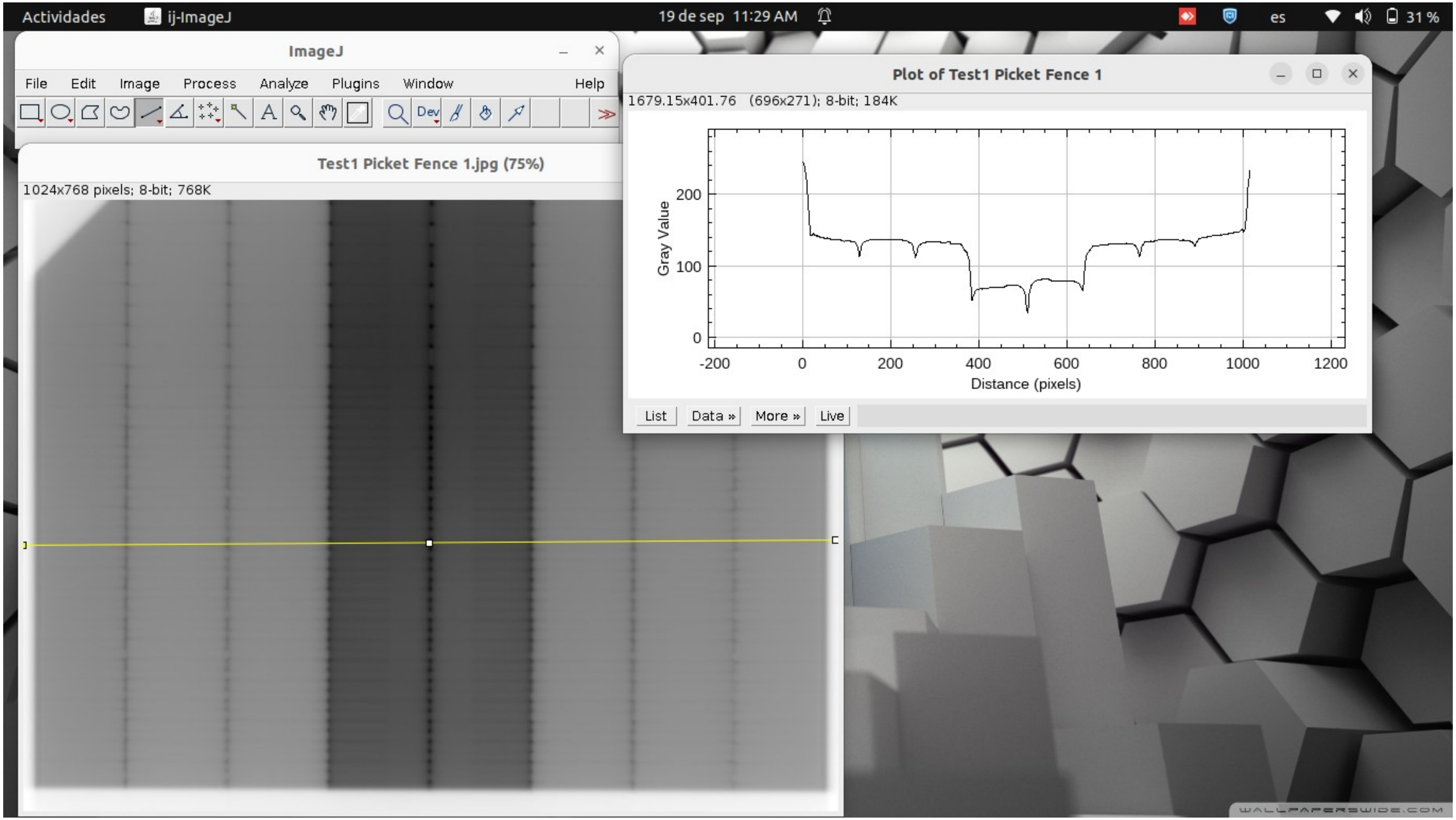

Control de Calidad IMRT

Unidad de Tratamiento. Desempeño MLC

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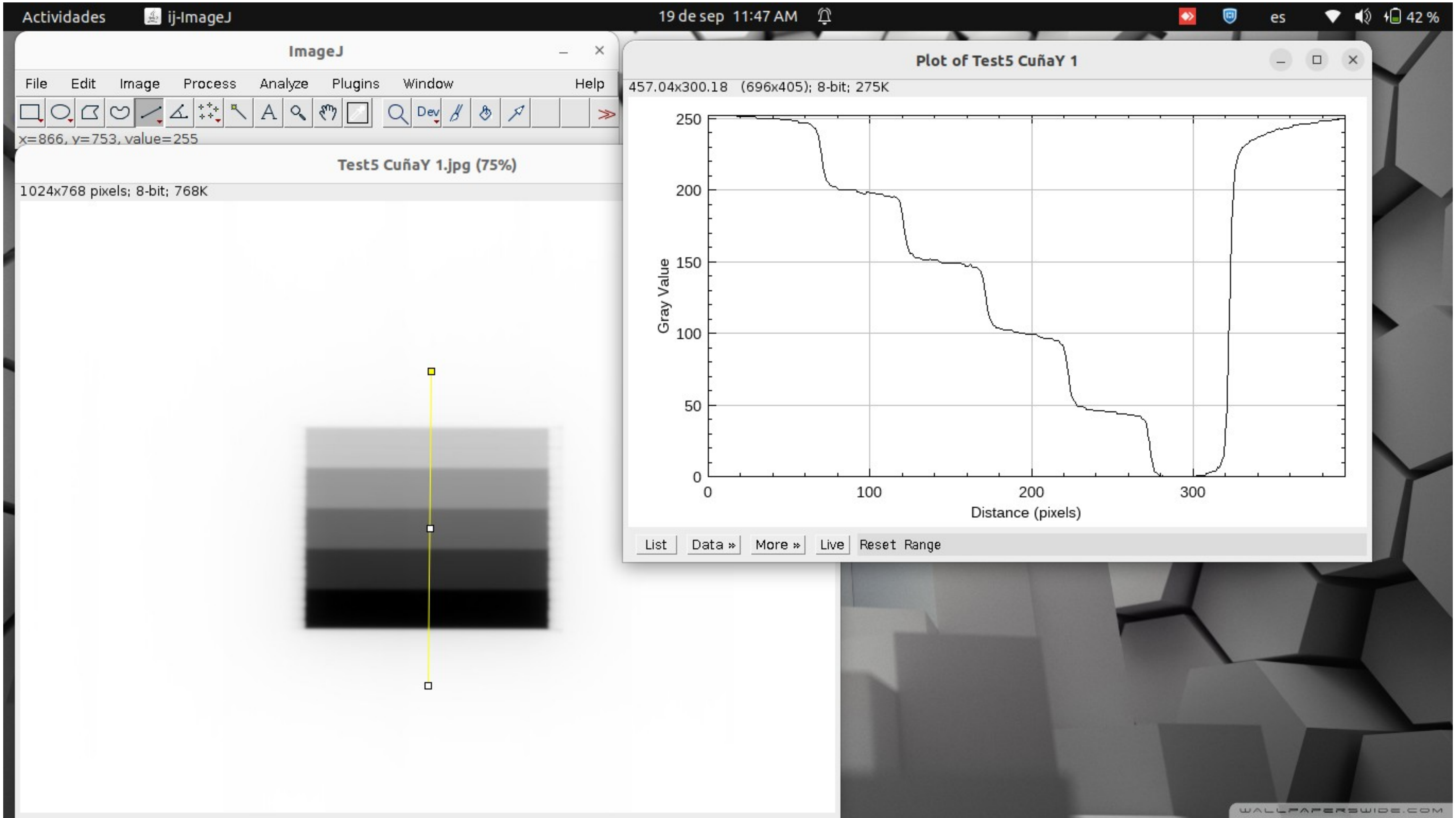

Control de Calidad IMRT

Unidad de Tratamiento. Desempeño MLC

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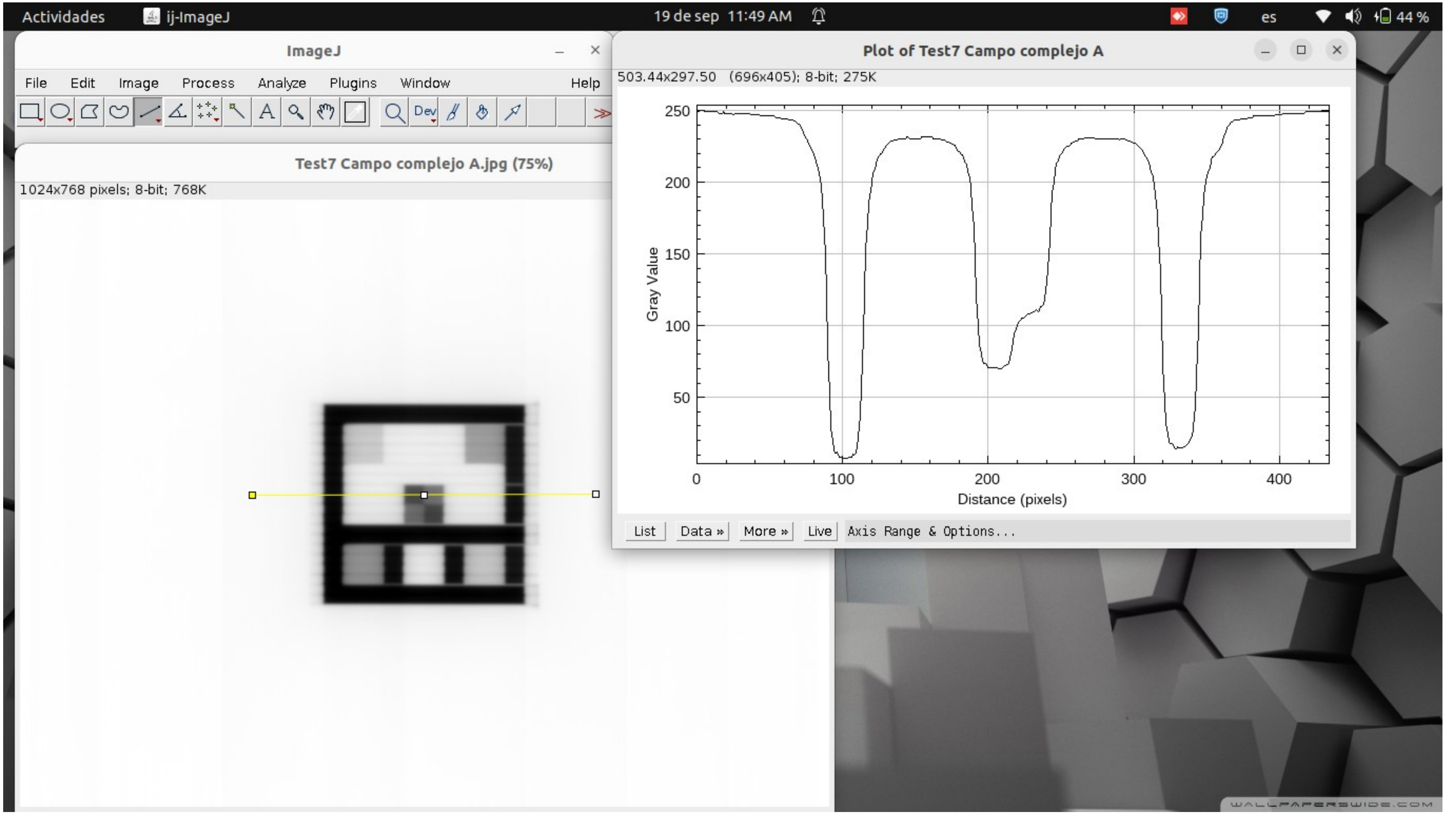
  - **Ejemplo Varian: DMLC QA Test Patterns**



Control de Calidad IMRT

Unidad de Tratamiento. Desempeño MLC

- **Suite de pruebas suministradas por el fabricante**
  - **Ejemplo ELEKTA: iComCAT/ ELEKTA MACHINE QA**

(a) (b)

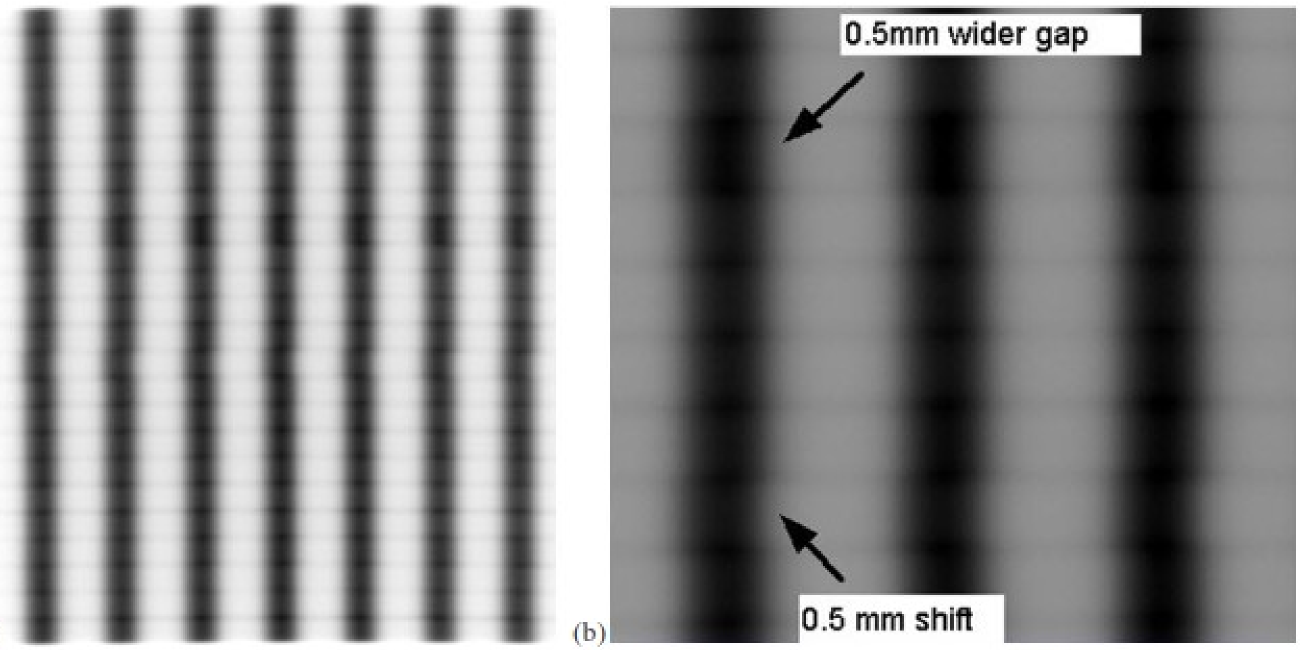


FIG. 7. Picket Fence with intentional errors of 0.5 mm wider gap and 0.5 mm horizontal shift shown for: a) 25 cm by 25 cm field, and b) magnified portion.

VMAT testing for an Elekta accelerator. Kurin D et al. JACMP, 2012

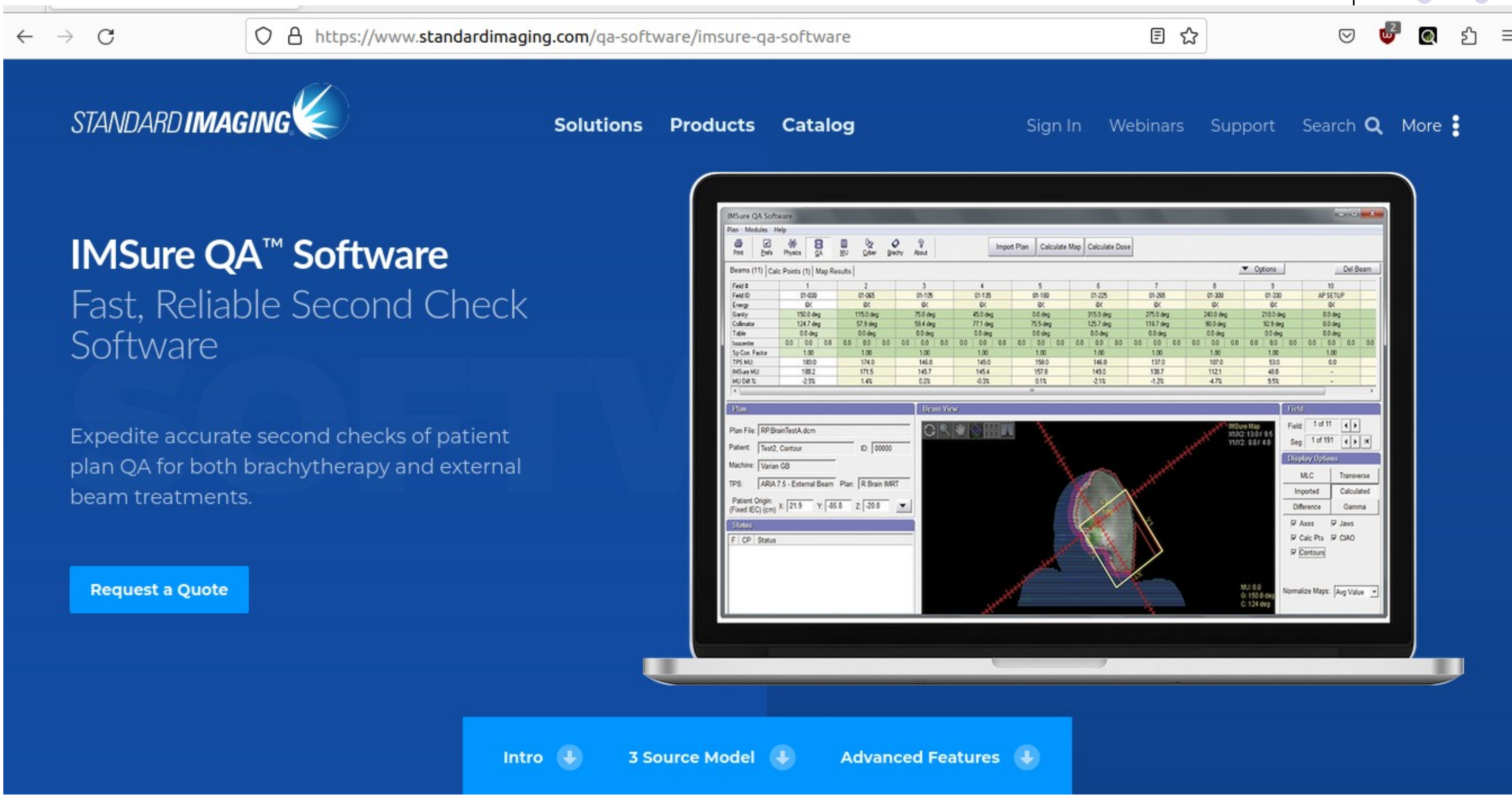
https://www.elekta.com/focus/austrian-physicists-save-time-and-increase-efficiency-with-elekta-qa-solutions/

Control de Calidad IMRT
Paciente-Específico

- **IMRT Planificaciones complejas**
  - **Difíciles de calcular los aportes de dosis manualmente**
  - **Pueden ser utilizados paquetes informáticos alternativos para el cálculo de los dosis (no tiene en cuenta la administración)**
  - **Pueden ser medidos las dosis (fluencias) impartidas por la unidad de tratamiento (prueba principio-fin)**
  - **Puede estimarse el desempeño y resultado de la administración del tratamiento del análisis de los ficheros de registro del MLC (log files)**
  - **Pueden estimarse los resultados del CC paciente-específico desde la planeación del tratamiento, Inteligencia Artificial**

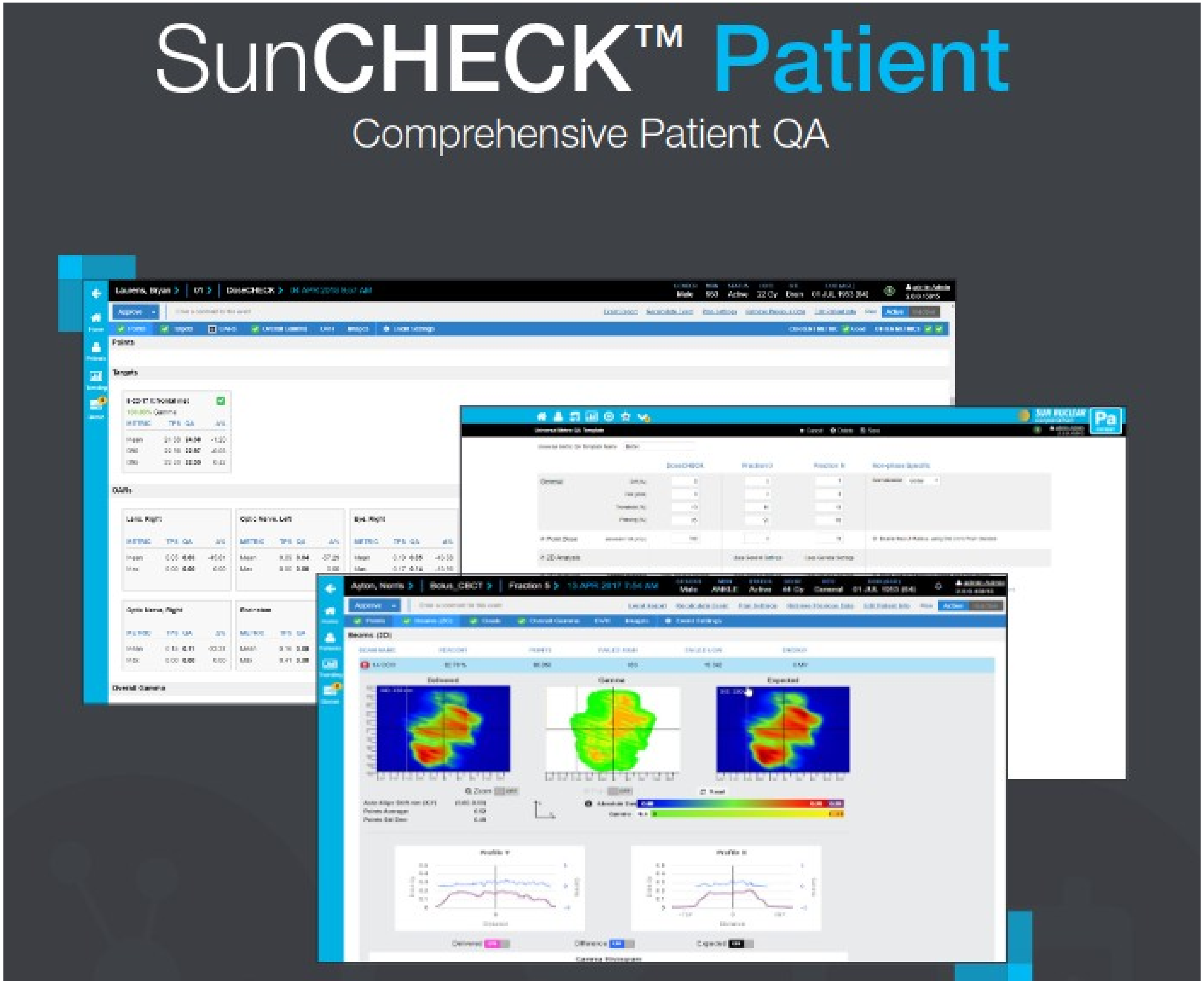
Control de Calidad IMRT

Paciente-Específico. Programas independientes



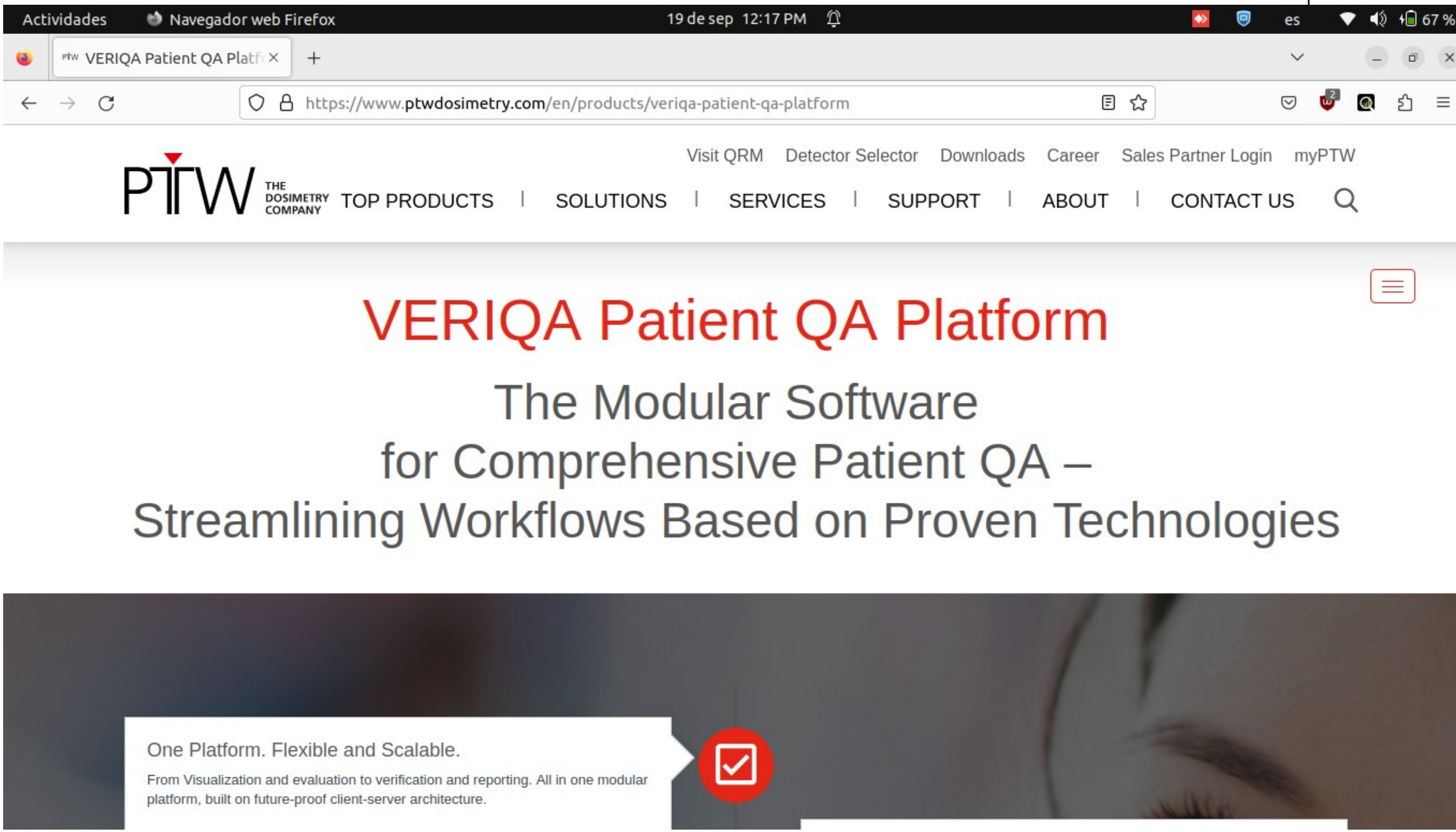
Control de Calidad IMRT

Paciente-Específico. Programas independientes



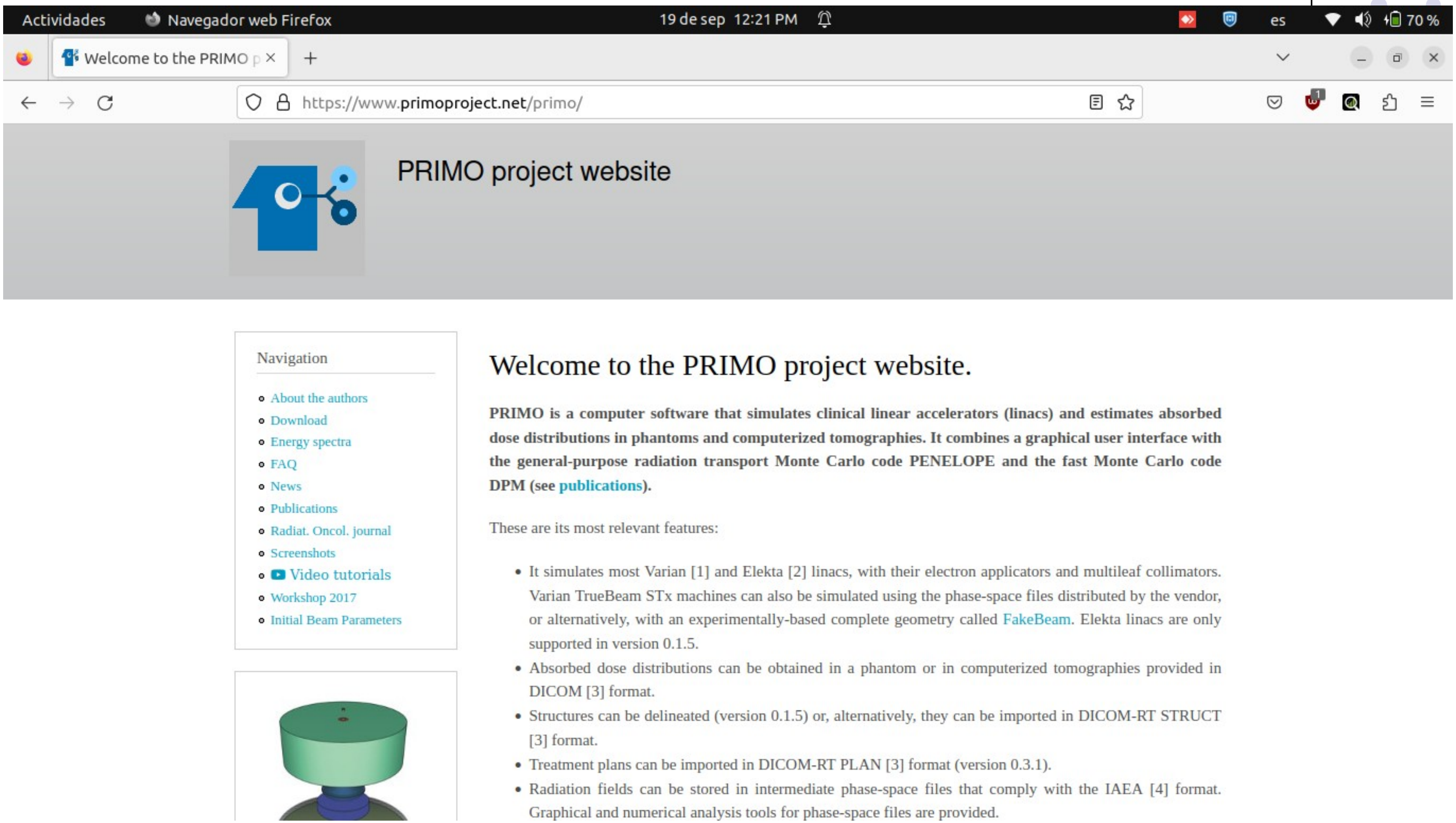
Control de Calidad IMRT

Paciente-Específico. Programas independientes



Control de Calidad IMRT

Paciente-Específico. Programas independientes



Actividades Navegador web Firefox 19 de sep 12:21 PM es 70 %

Welcome to the PRIMO p

https://www.primoproject.net/primo/

PRIMO project website

Navigation

- About the authors
- Download
- Energy spectra
- FAQ
- News
- Publications
- Radiat. Oncol. journal
- Screenshots
- Video tutorials
- Workshop 2017
- Initial Beam Parameters

Welcome to the PRIMO project website.

PRIMO is a computer software that simulates clinical linear accelerators (linacs) and estimates absorbed dose distributions in phantoms and computerized tomographies. It combines a graphical user interface with the general-purpose radiation transport Monte Carlo code PENELOPE and the fast Monte Carlo code DPM (see publications).

These are its most relevant features:

- It simulates most Varian [1] and Elekta [2] linacs, with their electron applicators and multileaf collimators. Varian TrueBeam STx machines can also be simulated using the phase-space files distributed by the vendor, or alternatively, with an experimentally-based complete geometry called FakeBeam. Elekta linacs are only supported in version 0.1.5.
- Absorbed dose distributions can be obtained in a phantom or in computerized tomographies provided in DICOM [3] format.
- Structures can be delineated (version 0.1.5) or, alternatively, they can be imported in DICOM-RT STRUCT [3] format.
- Treatment plans can be imported in DICOM-RT PLAN [3] format (version 0.3.1).
- Radiation fields can be stored in intermediate phase-space files that comply with the IAEA [4] format. Graphical and numerical analysis tools for phase-space files are provided.

Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

- **Pruebas (principio-fin)**
  - **Mediciones en un punto**
    - **C.I./diodo/otros detectores**
  - **Mediciones en un plano**
    - **películas radiográficas/radiocrómicas**
    - **arreglos de C.I./diodos**
    - **EPID**
  - **Mediciones Compuestas**
  - **Mediciones volumétricas**
    - **Gels**
    - **Fricke**

Dosimetry tools and techniques for IMRT. Low, D. Med Phys 2011

Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

- **TC (True Composite), Compuesto**
- **PFF (Perpendicular Field by Field), Campo a campo perpendicular o colapsado**
- **PC (Perpendicular Composite), Compuesto perpendicular o colapsado**

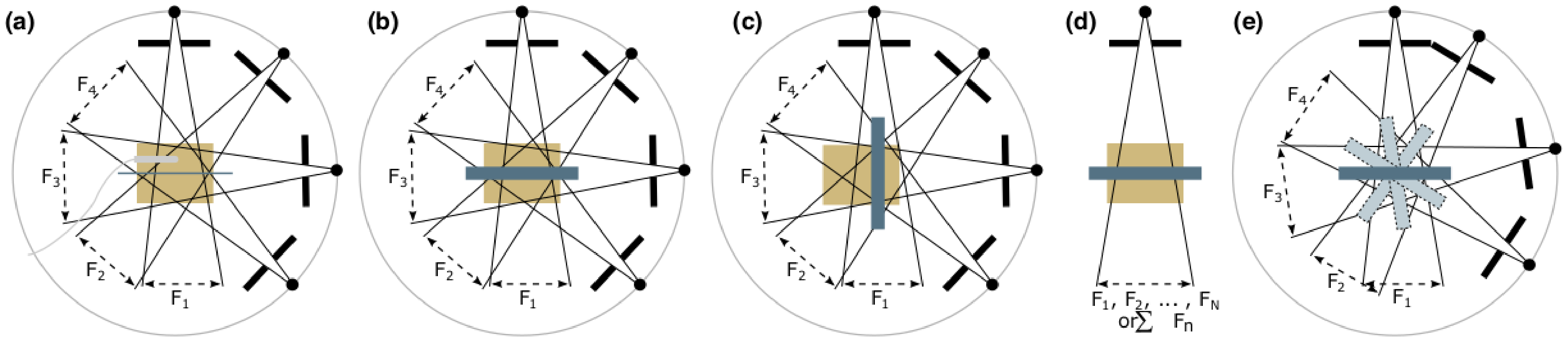
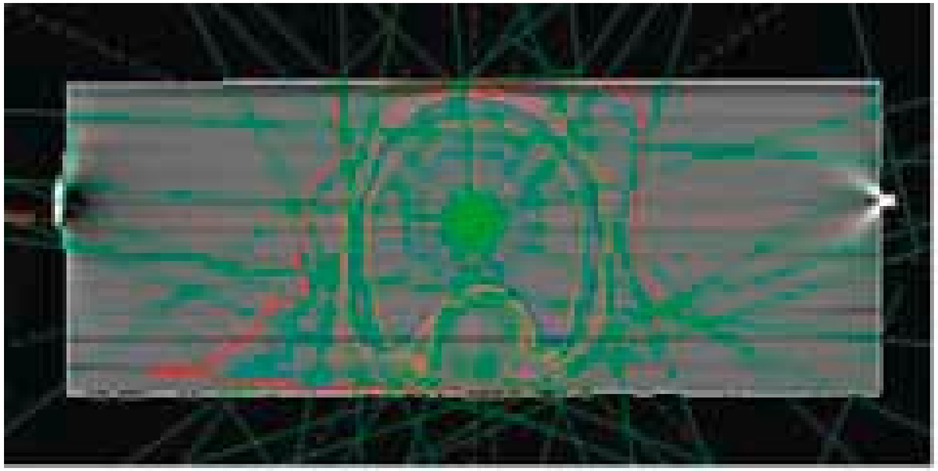


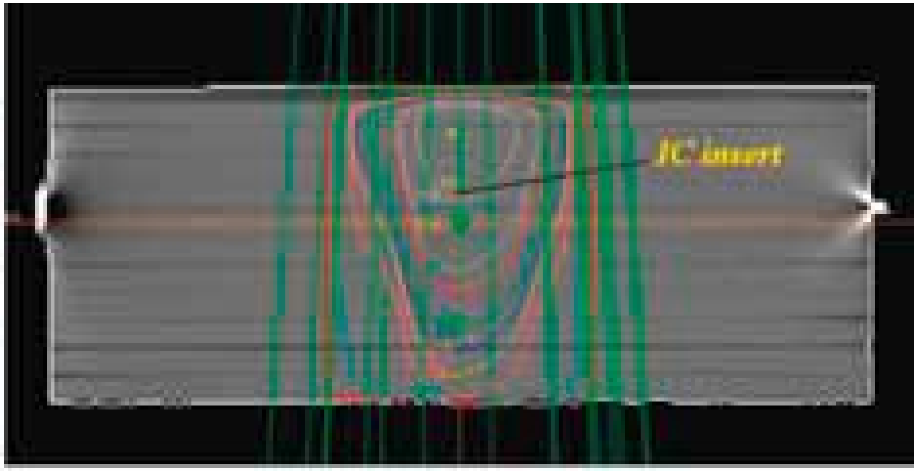
Fig. 6. (a) True composite (TC) delivery on a phantom with an IC placed at a specific depth and a radiographic film at a coronal orientation. (b) TC delivery on a stationary 2D array device placed in the coronal direction on the treatment table. (c) TC delivery on a stationary 2D array device placed in the sagittal direction on the treatment table. (d) Perpendicular field-by-field (PFF) or perpendicular composite (PC) delivery on a stationary 2D array device placed in the coronal direction on the treatment table. (e) PFF or PC delivery on 2D array device mounted on the treatment head.

Tolerance limits and methodologies for IMRT measurement-based verification QA: Recommendations of AAPM Task Group No. 218. Miften M et al. Med Phys, 2018

Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

- **Mediciones en un punto**





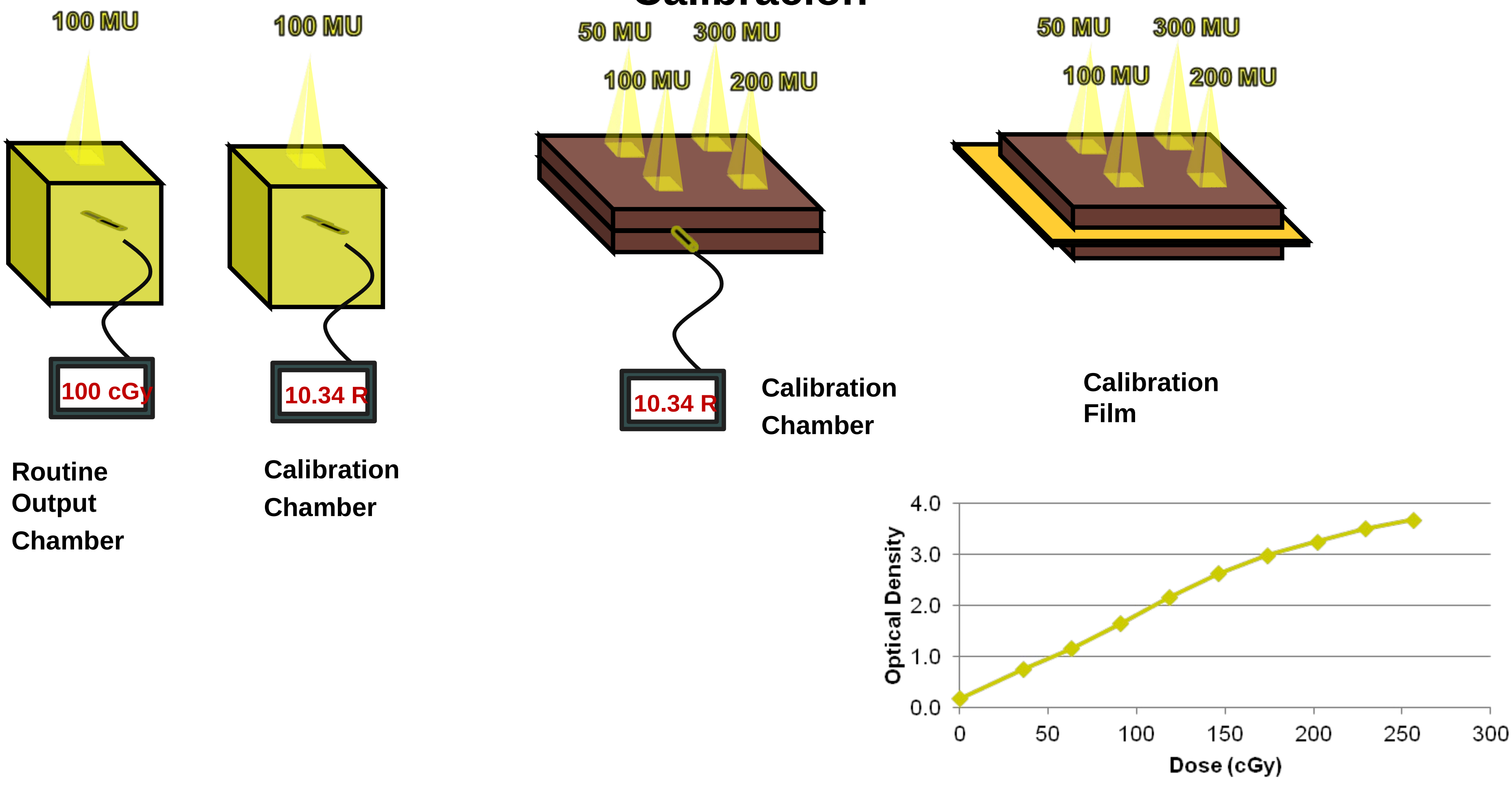
EXPERIMENTAL EVALUATION OF REFERENCE DOSIMETRY FOR NON-STANDARD FIELDS IN AN APERTURE-BASED IMRT SYSTEM.
R. ALFONSO-LAGUARDIA et al. STANDARDS, APPLICATIONS AND QUALITY ASSURANCE IN
MEDICAL RADIATION DOSIMETRY (IDOS) IAEA Proceedings Vienna 2010.

Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

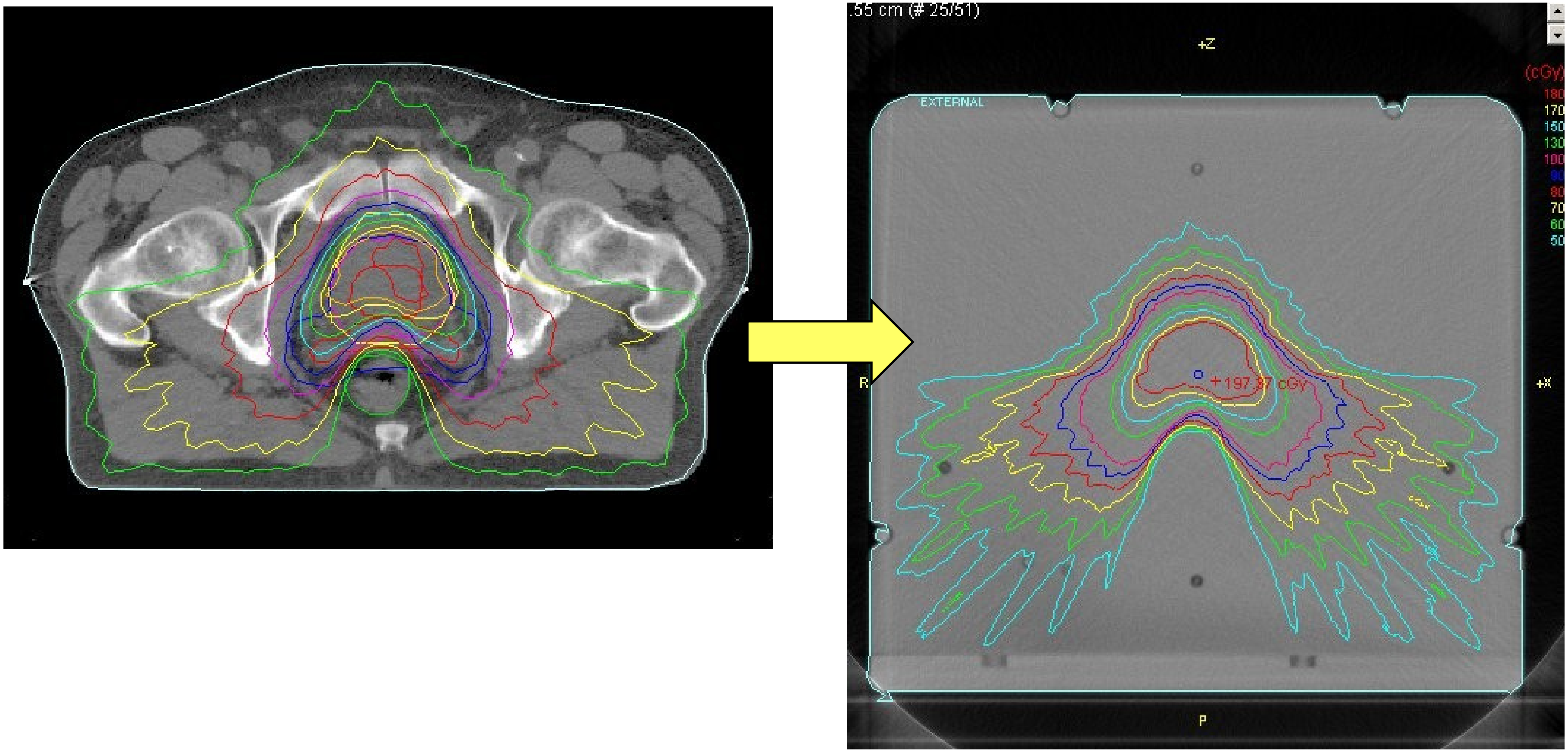
- **Mediciones en un plano. Películas radiográficas**

Calibración



Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Películas radiográficas**



Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Películas radiográficas**

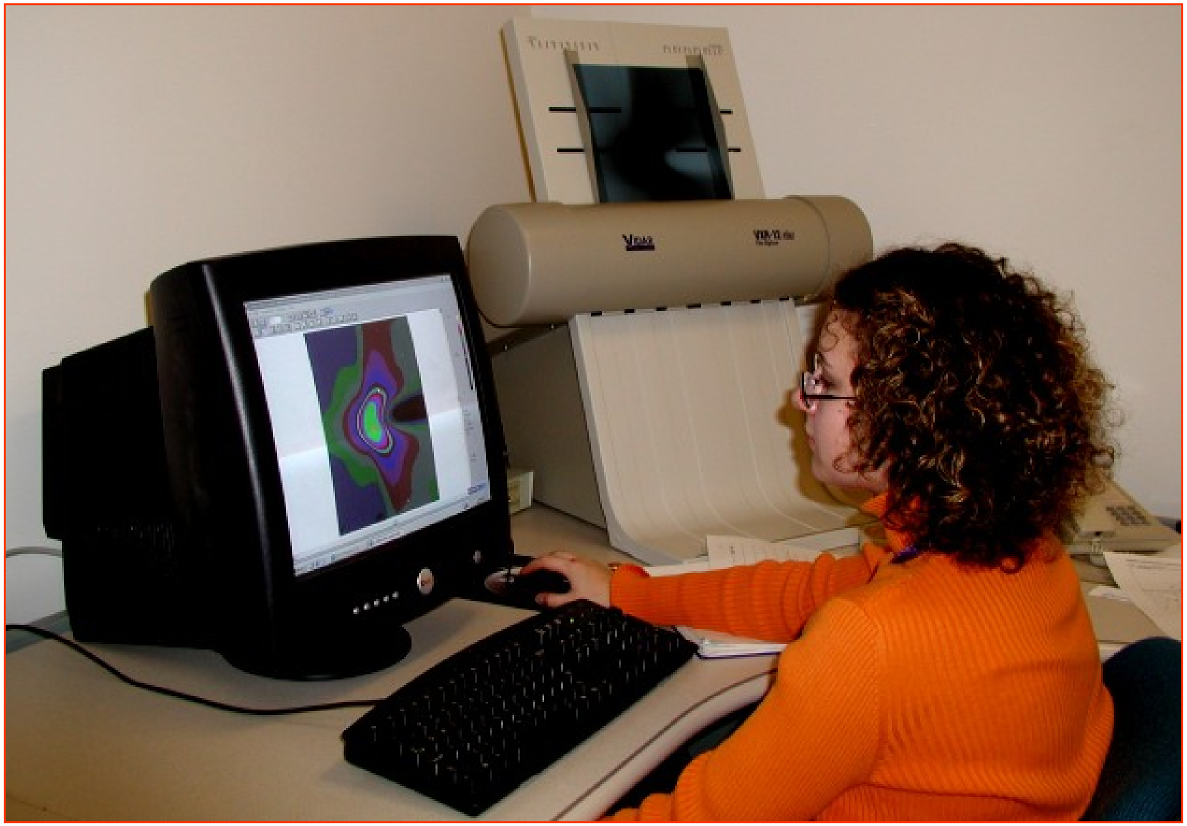
  Kodak Enhanced Dose Range (EDR) Film

Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Películas radiográficas**

  Procesamiento (Digitalización)

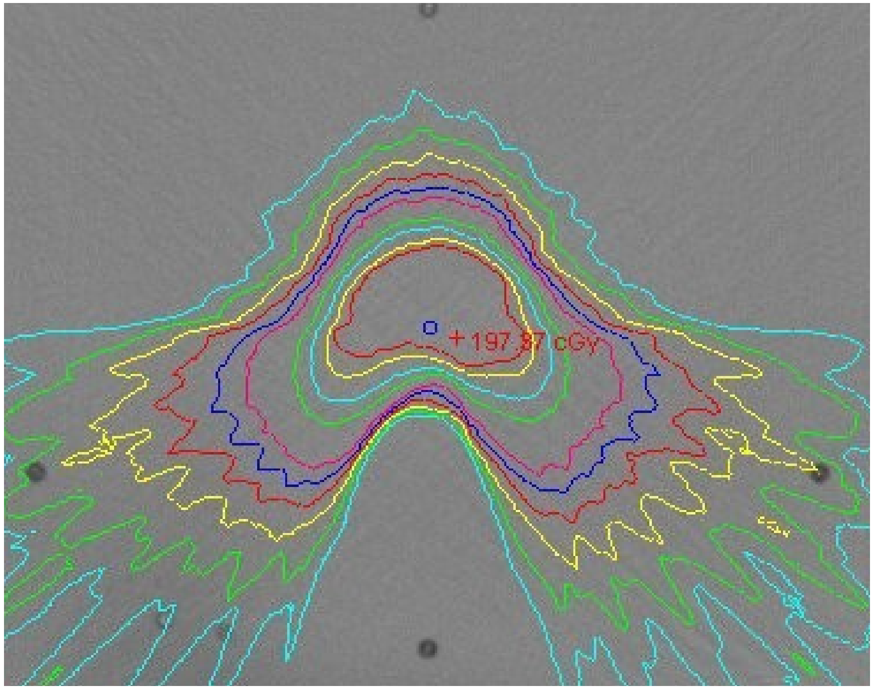


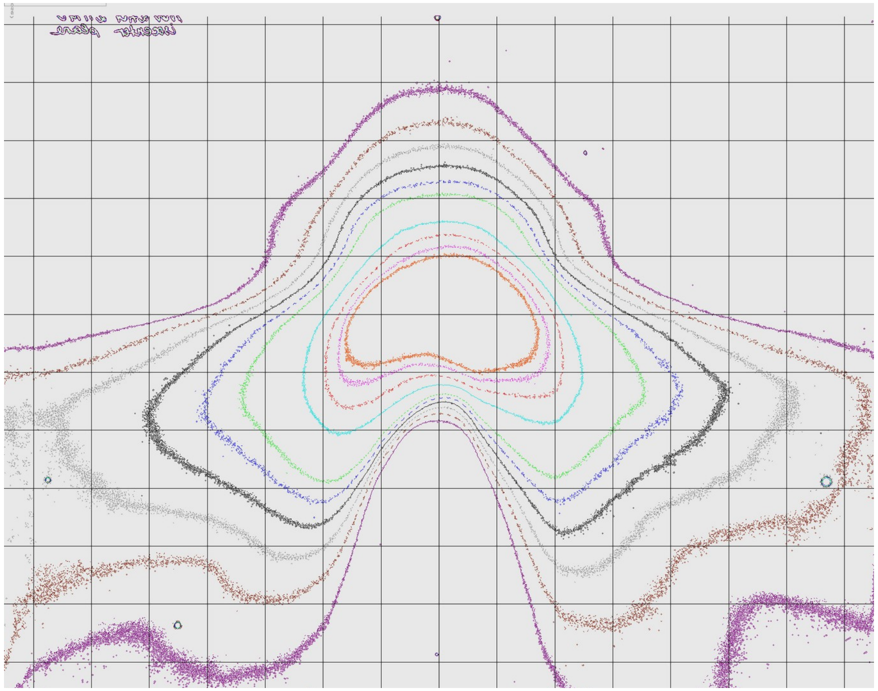
Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Películas radiográficas**

  Procesamiento (Comparación)





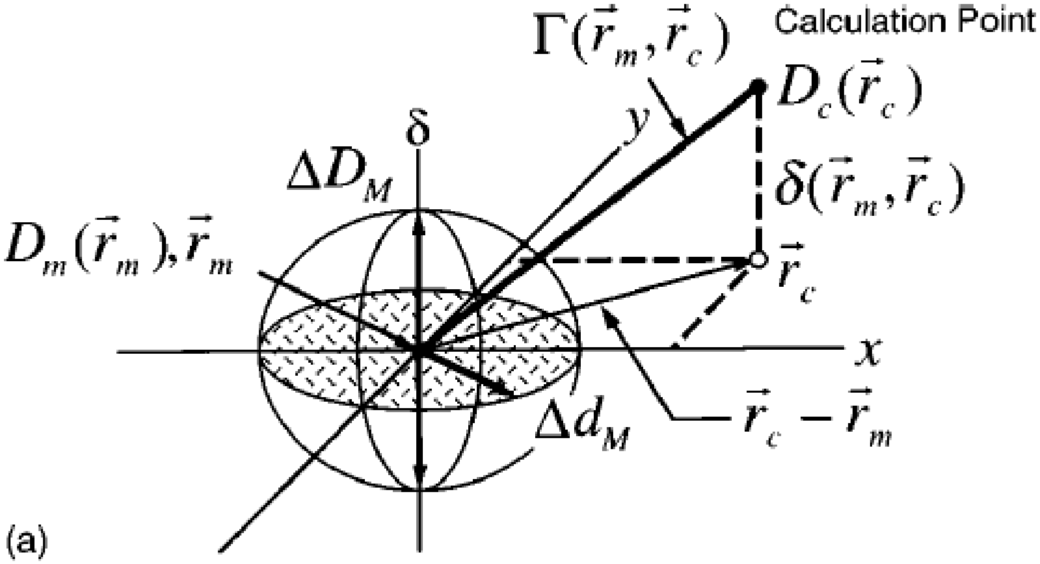
Calculada **Medida**

Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Películas radiográficas**

  Procesamiento (Métrica Gamma)



$$\Gamma(\mathbf{r}_m,\mathbf{r}_c)=\sqrt{\frac{r^2(\mathbf{r}_m,\mathbf{r}_c)}{\Delta d_M^2}+\frac{\delta^2(\mathbf{r}_m,\mathbf{r}_c)}{\Delta D_M^2}},$$

$$\gamma(\mathbf{r}_m)=\min\{\Gamma(\mathbf{r}_m,\mathbf{r}_c)\}\forall\{\mathbf{r}_c\}.$$

A technique for the quantitative evaluation of dose distributions. Low D., et al. Med. Phys. 25 .5., May 1998

Control de Calidad IMRT

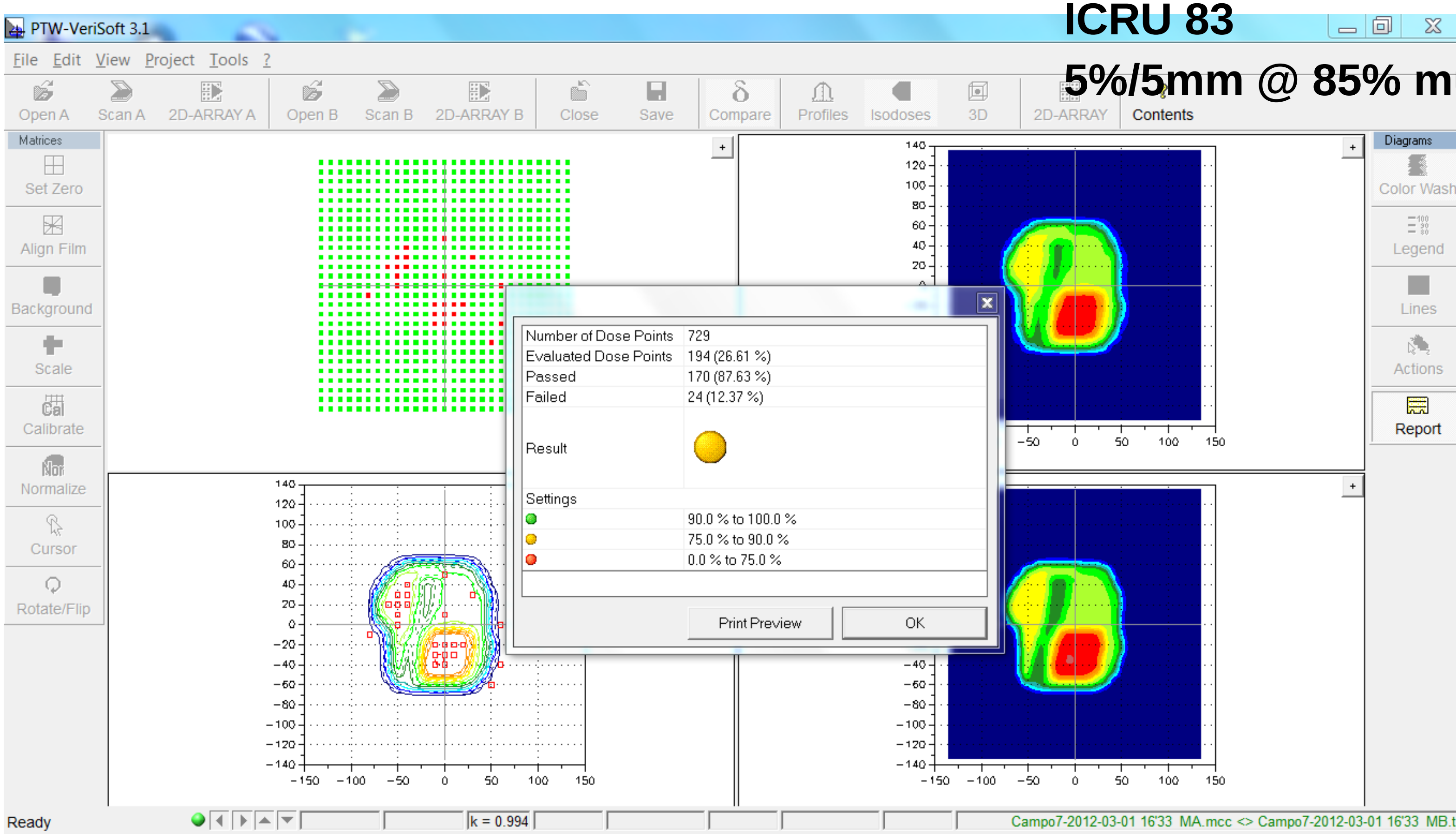
Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Películas radiográficas**

  Procesamiento (Comparación)

ICRU 83

5%/5mm @ 85% muestra



Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano.**

Películas radiocrómicas vs radiográficas

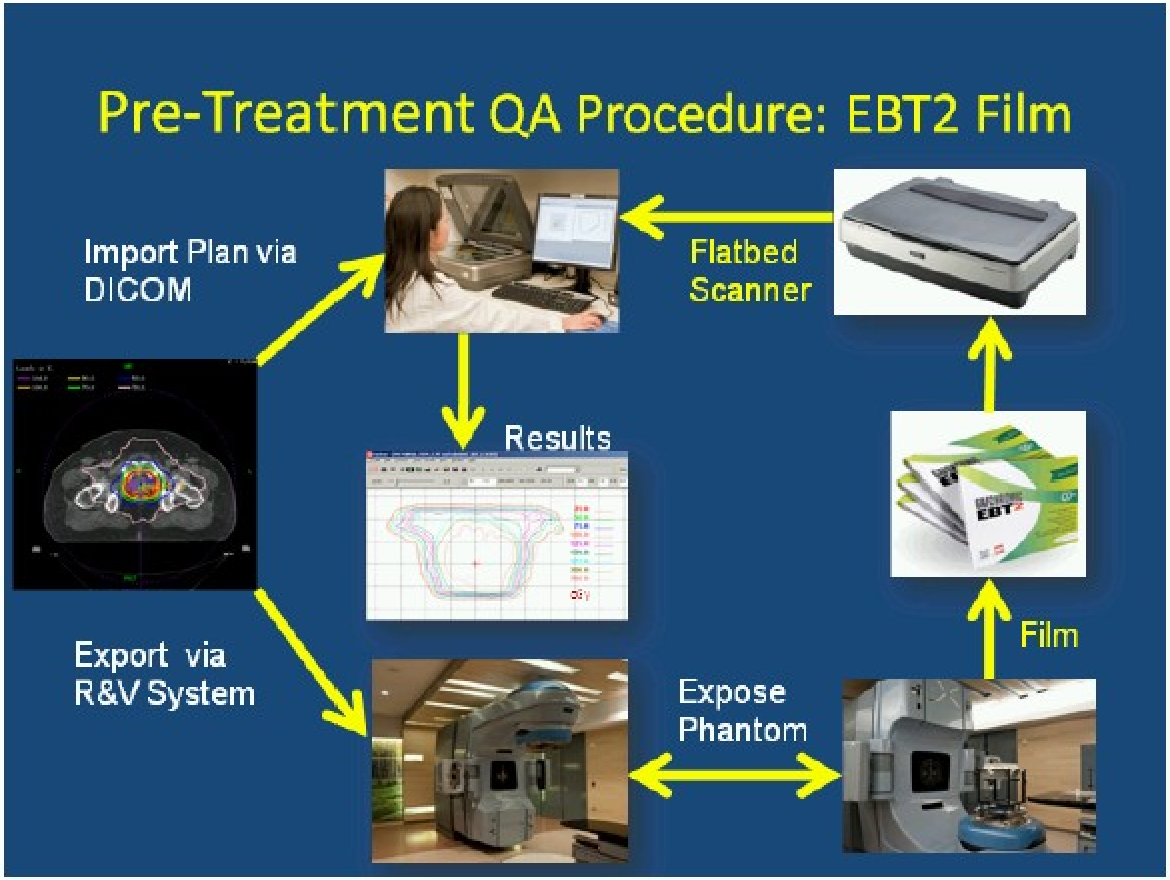
Radiochromic Film	Radiographic Film
Polymer-based	AgBr-based
Tissue equivalent	Not tissue equivalent
Not sensitive to light	Very sensitive to light
Handle in room light	Require dark room
Easy to position accurately	Difficult to position accurately
Self developing	Require processing
Instant color change	Grey shades develop with processing
Store in dark envelope	Fixed after processing
Watch temperature and humidity effect	Not affected by temperature and humidity post processing

Radiochromic Film Radiographic Film

Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano.**

Películas radiocrómicas (procedimiento similar)



Pre-Treatment QA Procedure: EBT2 Film

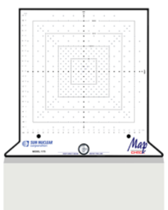
Computed Radiography Film

- **Active layer: photostimulable phosphor (BaSrFBr:Eu)**
- **Inserted in light tight envelope to avoid signal decay from room light exposure**
- **semi-logarithmic dose response up to 150cGy**
- **energy dependent leads to over-response of low energy scatter**

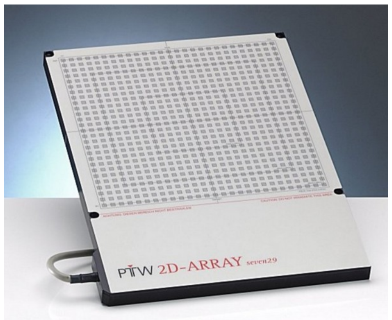
Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Arreglos bidimensionales de detectores**



Sun Nuclear MapCHECK/3



PTW Seven29/ 1000 SRS / 1500/ 1600 SRS

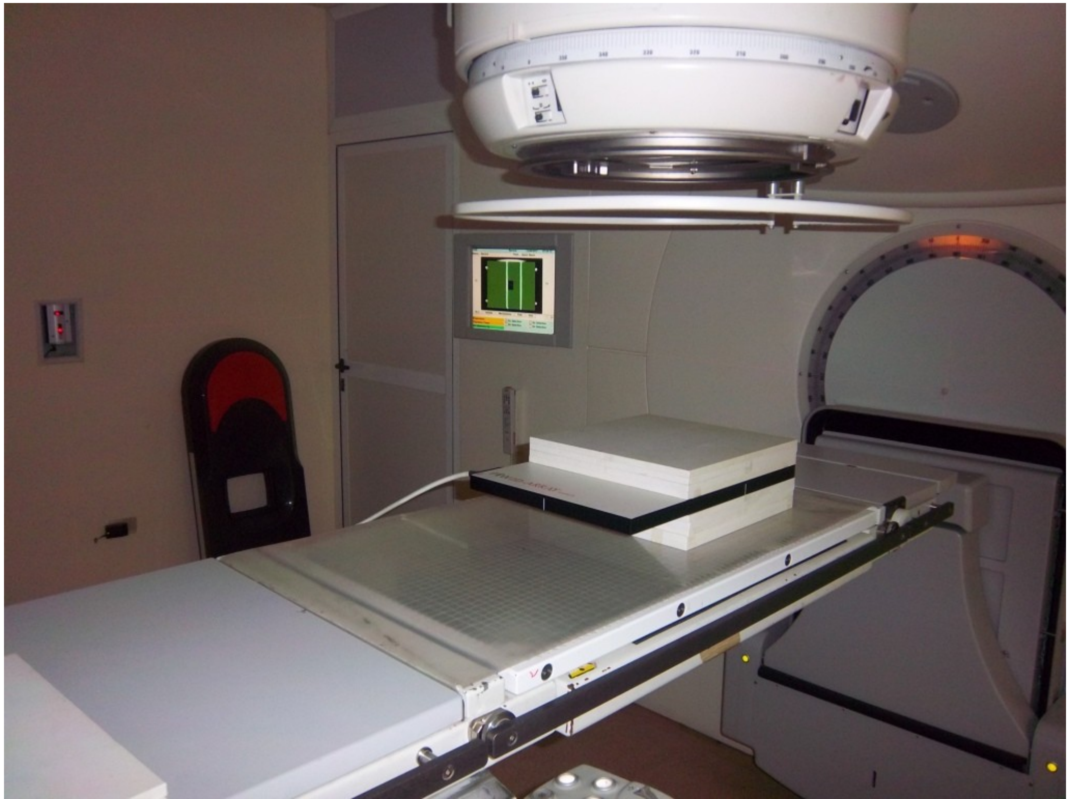
IBA Matrixx

Sun Nuclear StereoPhan+ SRS MapCHECK

IBA myQA SRS

Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

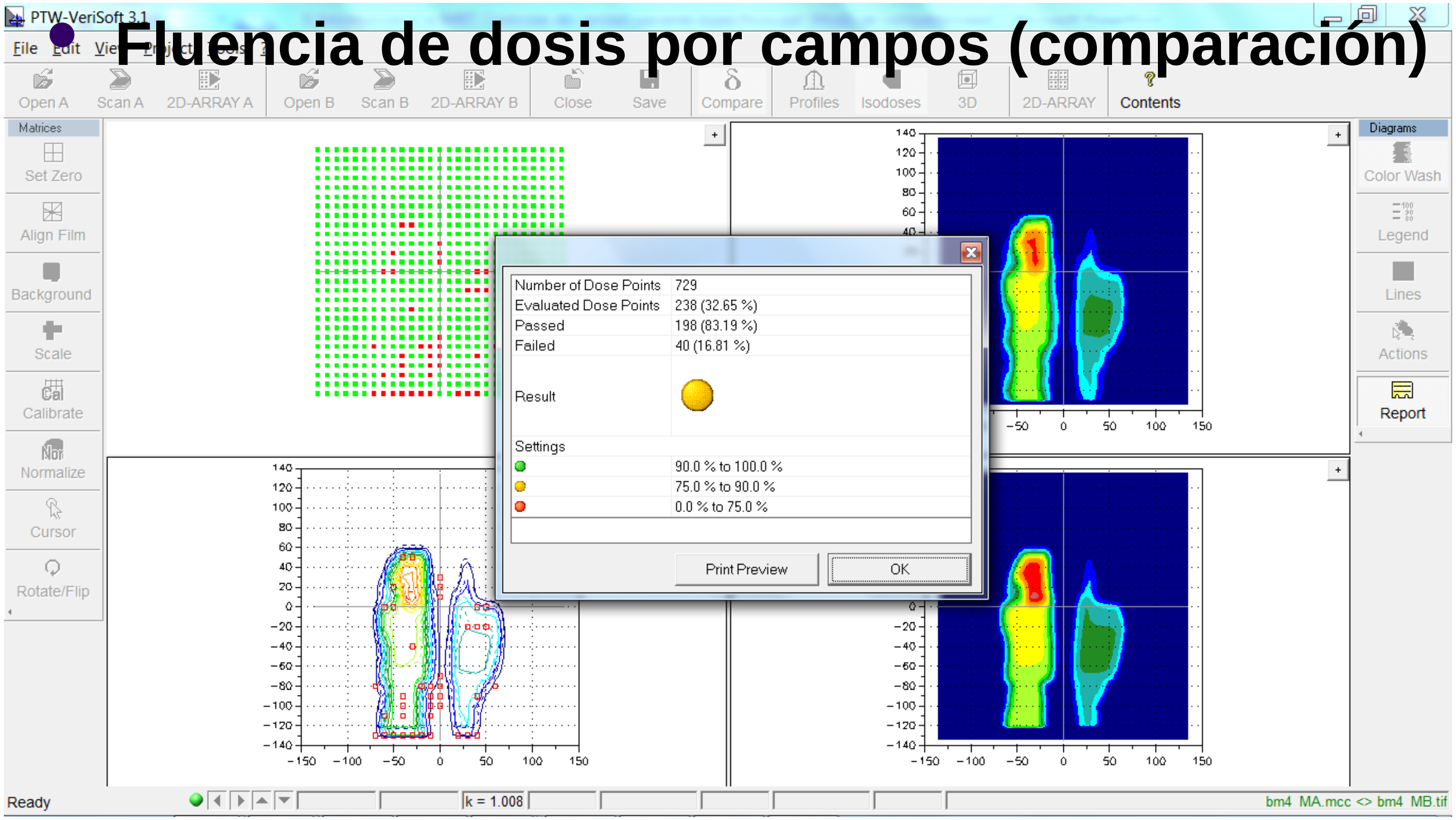
- **Mediciones en un plano. Arreglos bidimensionales de detectores.**
  - **Fluencia de dosis por campos**



Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

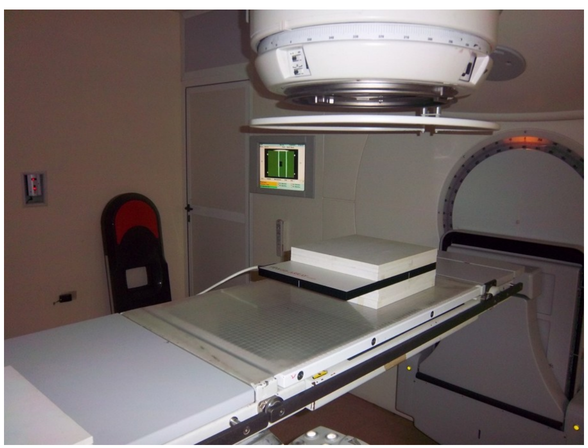
- **Mediciones en un plano. Arreglos bidimensionales de detectores.**
- **Fluencia de dosis por campos (comparación)**



Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Arreglos bidimensionales de detectores.**
  - **Fluencia de dosis compuesta (aporte de todos los campos de tratamientos). Precisa de correcciones por incidencia angular**



Address Rotational Beams

Use MapCHECK 3 with MapPHAN™, a water equivalent phantom, for RapidArc®, VMAT, and TomoTherapy®. Setup time is fast and measurement can occur in coronal and sagittal orientations.

Outstanding Accuracy

- ✓ 50% more data points compared to previous MatriXX detectors for highest IMRT & VMAT measurement resolution.
- ✓ Wireless Gantry Sensor+ enables precise QA of rotational cases and automated gantry angle correction.
- ✓ Confidence through independent QA.

Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

- **Mediciones compuestas**
  - **Fluencia de dosis compuesta (plan)**



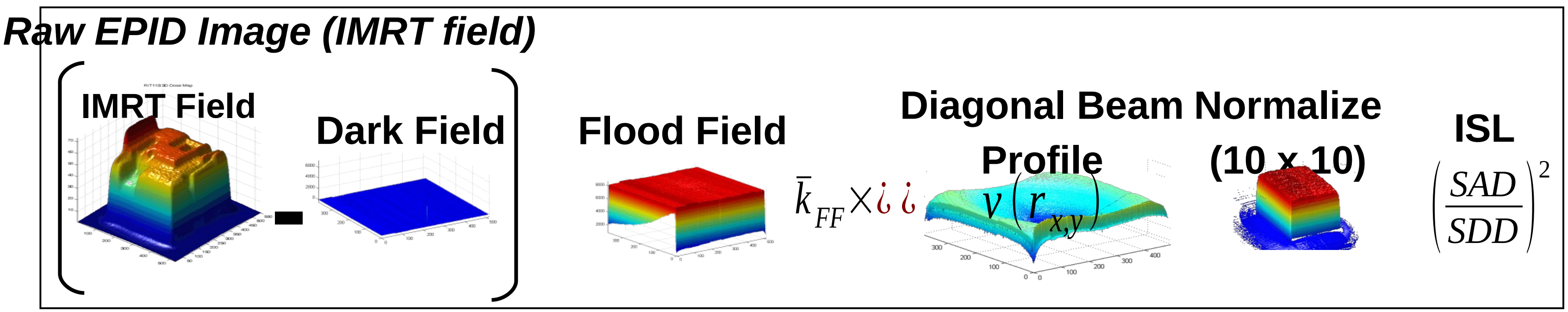

Sun Nuclear ArcCHECK **PTW OCTAVIUS 4D** **IBA myQA SRS** **ScandiDos DELTA4**

Sun Nuclear
StereoPhan+SRS MapCHECK

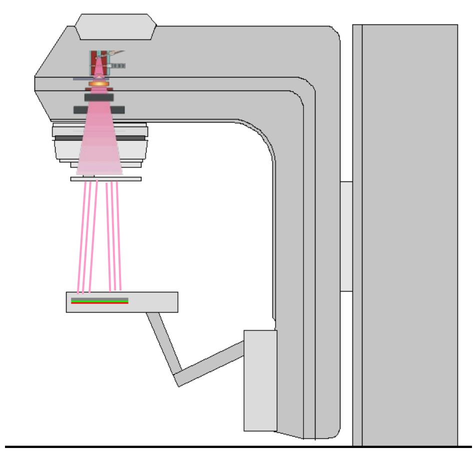
Control de Calidad IMRT

Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Electronic Portal Image Device**
  - **Fluencia de dosis por campos (adquisición)**



Comparison (in Matlab)
and/or
Clinical Vision Review Environment

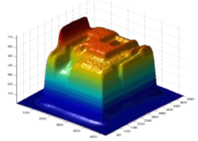


Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

- Mediciones en un plano. Electronic Portal Image Device
  - Fluencia de dosis por campos (predicción del portal)

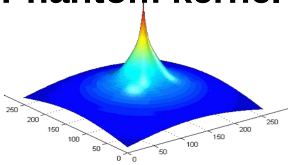
Pinnacle TPS planar dose map (IMRT field)

IMRT field



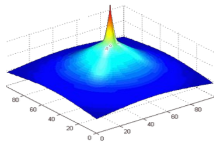
$$\left[\; MU \times \frac{OF(x,y)}{PSF(x,y)} \right] \otimes^{-1}$$

Phantom kernel

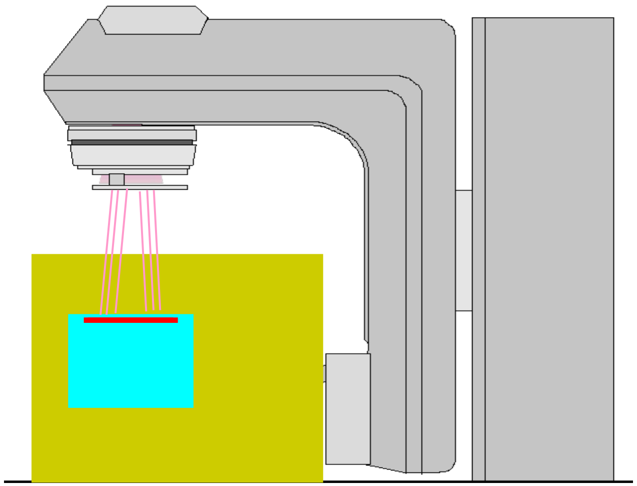


$$\otimes$$

Dose-glare kernel

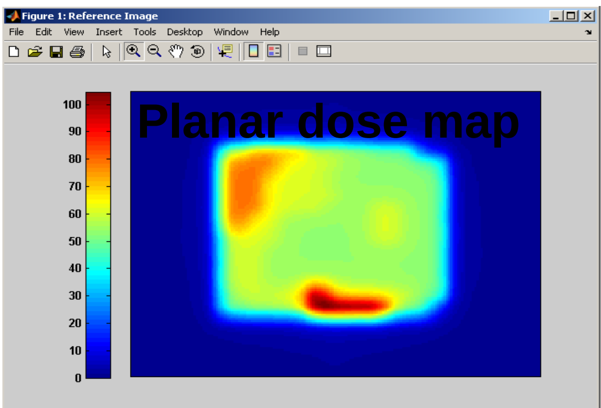


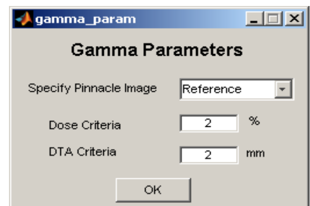
Comparison (in Matlab)
and/or
Clinical Vision Review Environment

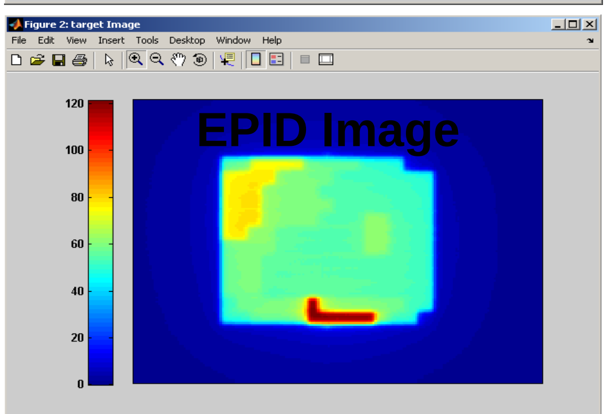


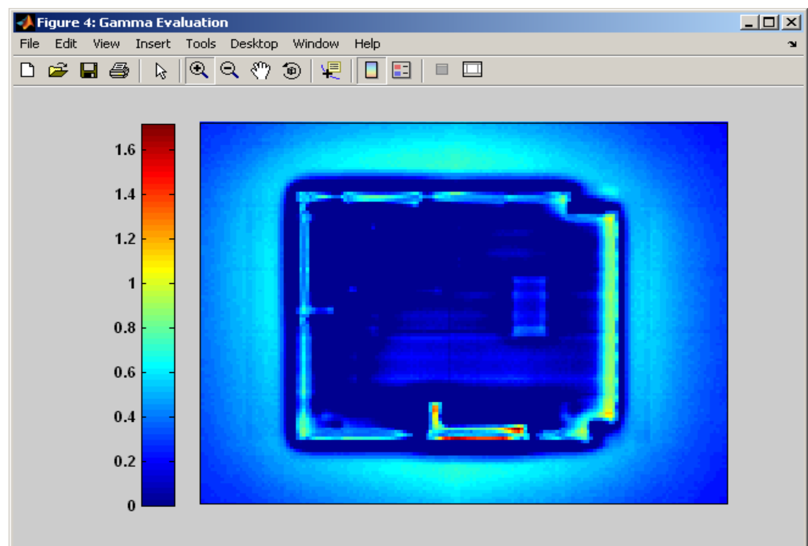
Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Electronic Portal Image Device**
  - **Fluencia de dosis por campos (comparación)**



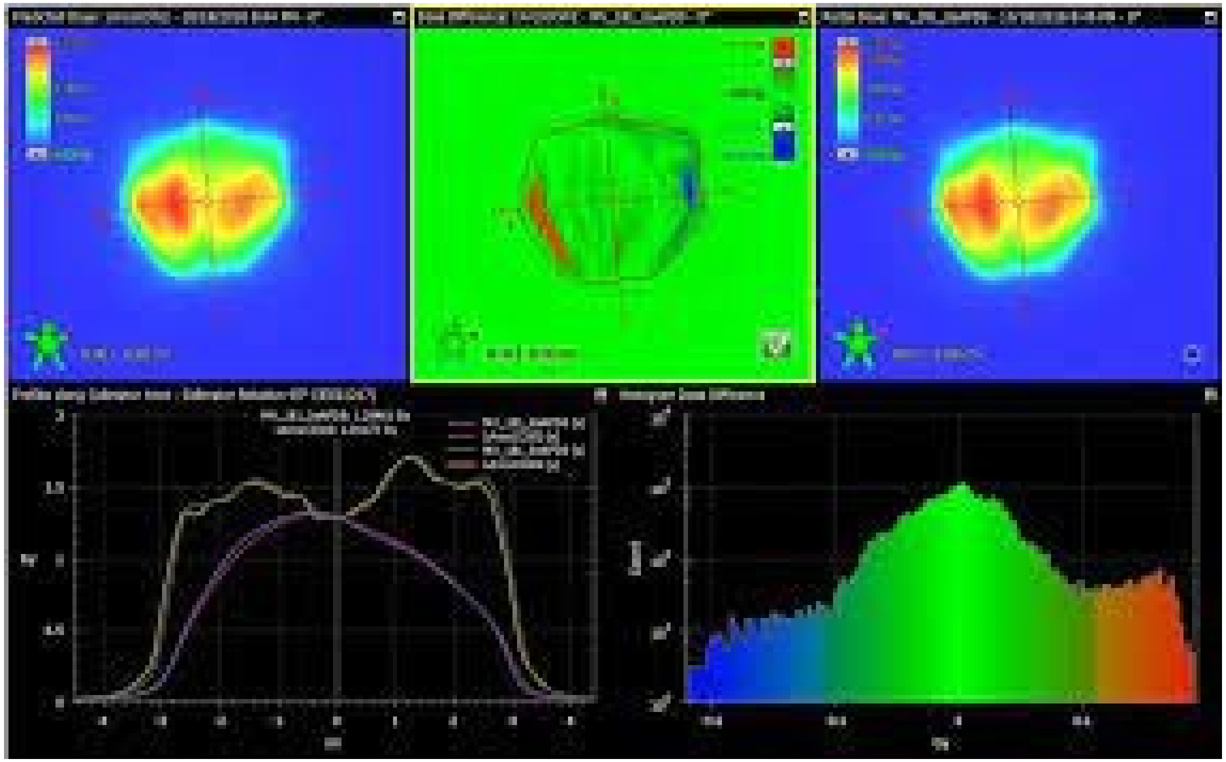






Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

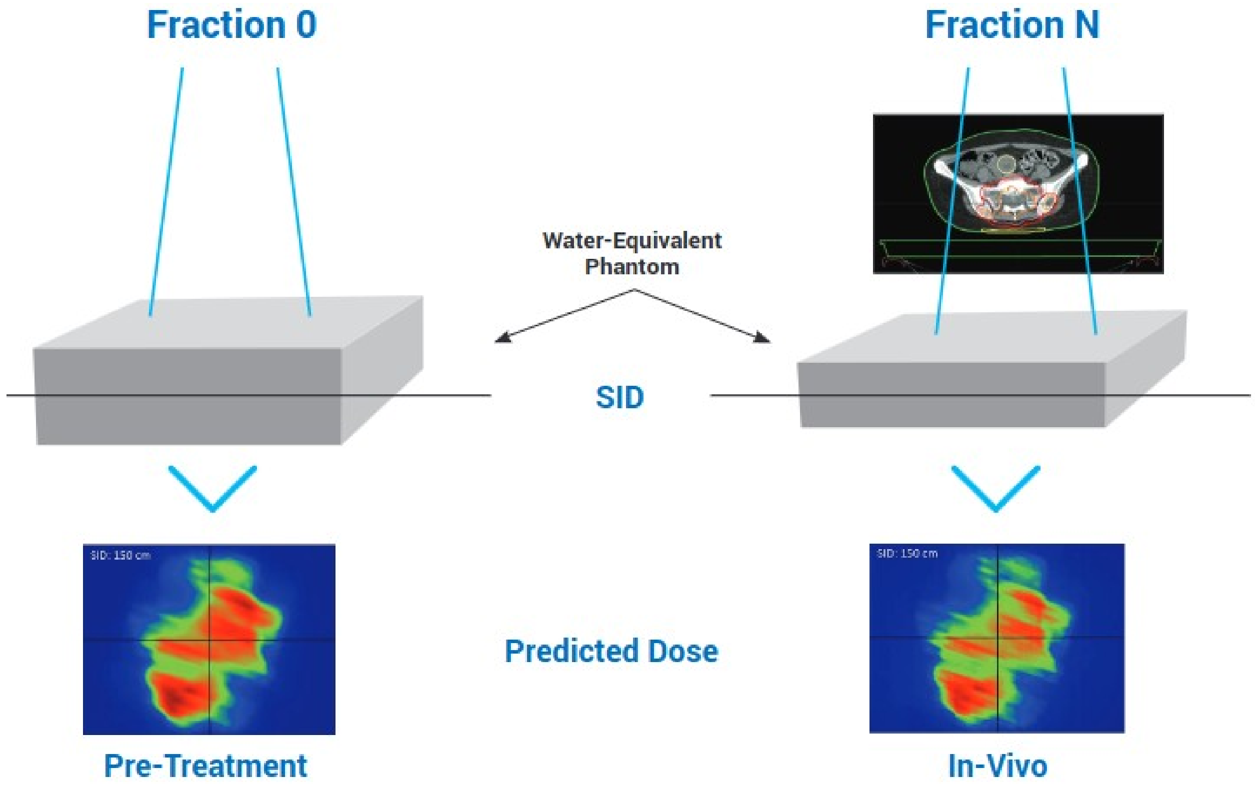
- Mediciones en un plano. Electronic Portal Image Device
  - Varian PortalDosimetry



Control de Calidad IMRT

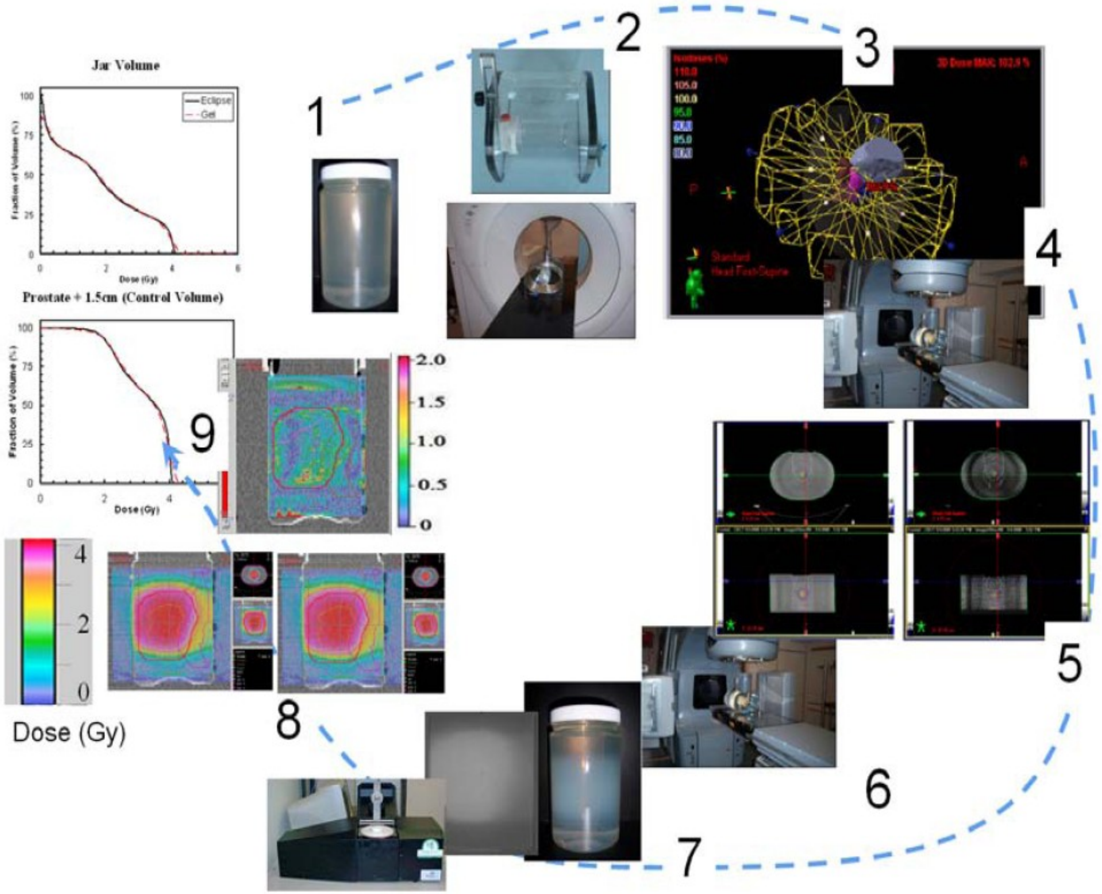
Paciente-Específico. Pruebas end-to-end

- **Mediciones en un plano. Electronic Portal Image Device**
  - **Sun Nuclear SUNCHECK, PerFRACTION**



Control de Calidad IMRT
Paciente-Específico. Pruebas end-to-end

- **Mediciones 3D. Gels**



3D Dosimetry

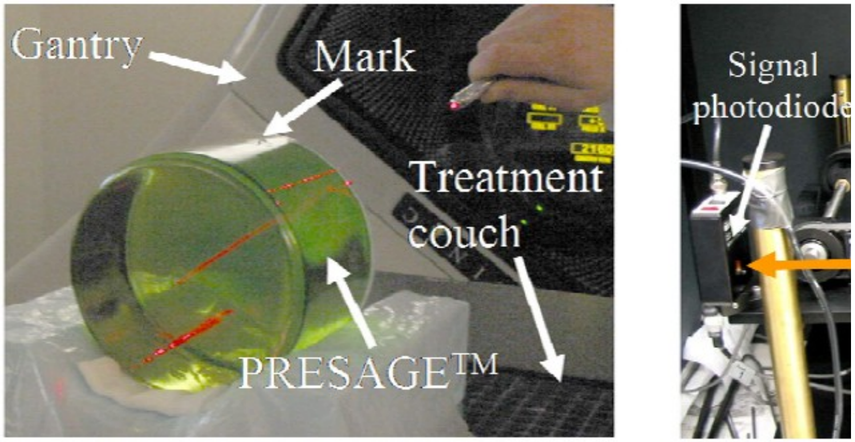


Figure 1. PRESAGE™ dosimeter in treatment position (lef
optical-CT scanner during imaging (right image). The arrow
ray paths.

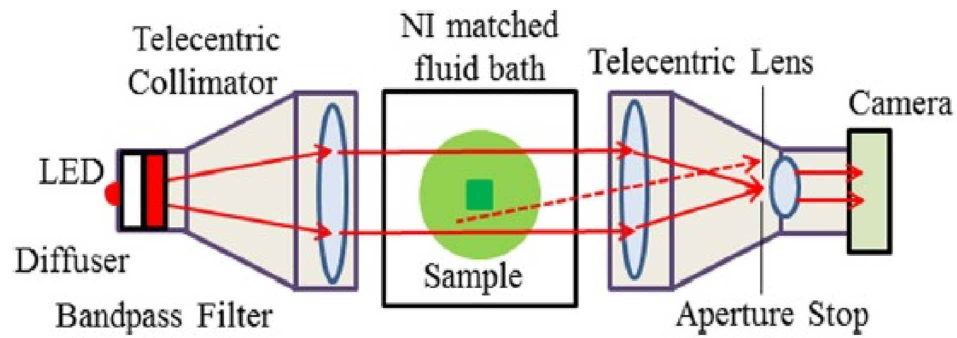


FIG. 1. Duke large field-of-view optical-CT scanner (DLOS). Light is collected by the matched telecentric imaging lens, which forms a precise image only from light rays that are parallel to the optic axis (with a 0.1° tolerance due to the aperture stop). Note rejected light rays due to the aperture such as the dashed scattered line. Each pixel in the image, measures the line-integral of optical attenuation through the dosimeter, with negligible scatter contamination upstream of the imaging lens.

New 3D dosimeters have overcome many of the challenges of prior 3D dosimeters: rigid, high resolution, no signal dispersion, no oxygen dependence

Dose can be read out quickly with new telecentric lens optical CT

DukeMedicine

Medical Physics, Vol. 38, No. 8, August 2011

Journal of Physics: Conference Series **56** (2006) 221–224

ESTRO Guidebook 9: GUIDELINES FOR THE VERIFICATION OF IMRT (2008)

Control de Calidad IMRT
Paciente-Específico. ¿Futuro?

- **QA en su mayoria son pre-tratamiento**
  - **Se asume el desempeño de la unidad es invariante**
  - **Se asume el paciente no cambia**

- **Dosimetria in vivo**
- **IGRT**
- **Reconstrucción de dosis y DVH administrados**
- **Otras variantes (MLC trajectory log files)**

Catching errors with *in vivo* EPID dosimetry

A. Mans,[a] M. Wendling,[b] L. N. McDermott,[c] J.-J. Sonke, R. Tielenburg, R. Vijlbrief,
B. Mijnheer, M. van Herk, and J. C. Stroom
Department of Radiation Oncology, The Netherlands Cancer Institute—Antoni van Leeuwenhoek Hospital, Plesmanlaan 121, 1066 CX Amsterdam, The Netherlands

Control de Calidad IMRT

Paciente-Específico. Reconstrucción de dosis y DVH

Métodos

- **Algoritmo de reconstrucción directa**
  - **IBA Compass, Sun Nuclear SunCHECK, PTW VERIQA, PRIMO**
- **Perturbación de la dosis planificada**
- **Reconstrucción en un maniquí**
  - **OCTAVIUS 4D**

Tolerance limits and methodologies for IMRT measurement-based verification QA: Recommendations of AAPM Task Group No. 218. Miften M et al. Med Phys, 2018

Control de Calidad IMRT

Paciente-Específico. EPID y ficheros de registro

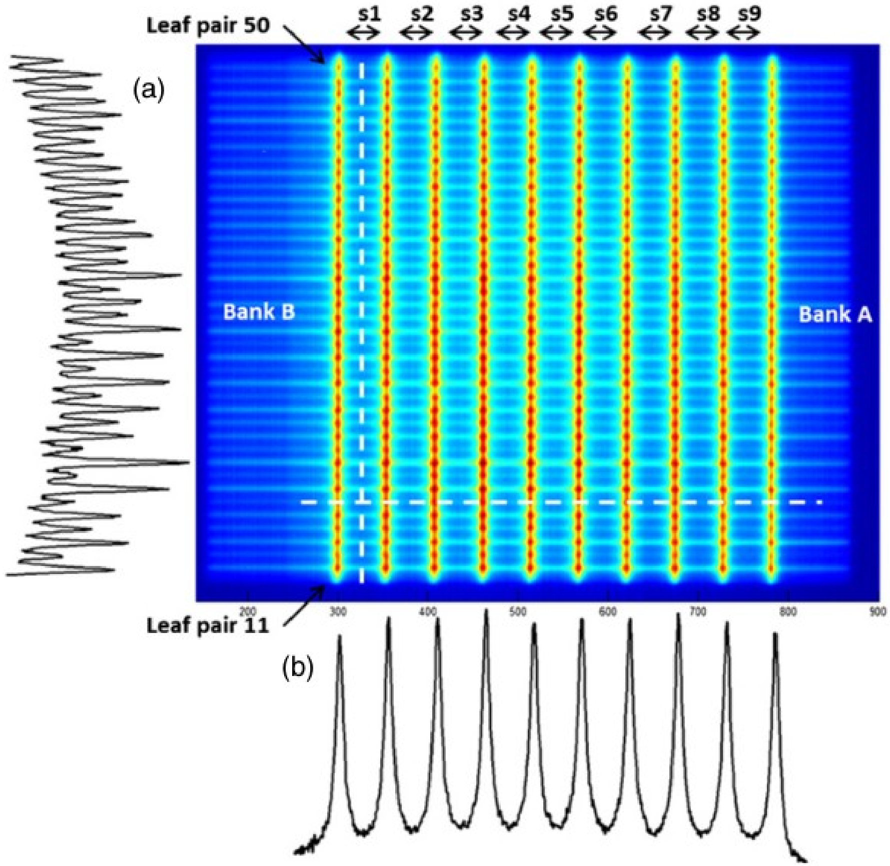


Figure 1. Picket fence test showing ten pickets (stripes), nine sub-sections (s1–s9), and profiles taken across (a) the leaves, and (b) the pickets.

Monitoring daily MLC positional errors using trajectory log files and EPID measurements for IMRT and VMAT deliveries.Agnew, A. et al. PMB, 2014.

Control de Calidad IMRT

Paciente-Específico. EPID y ficheros de registro

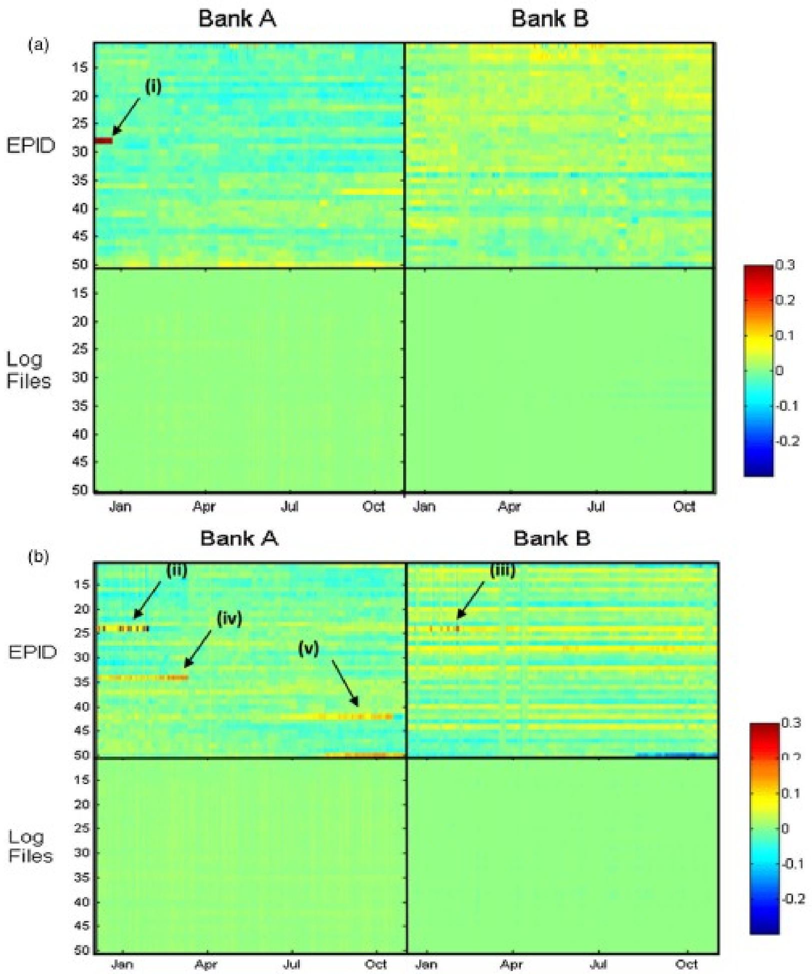


Figure 5. Leaf position errors over time for TB1 (a) and TB2 (b), analysed using both EPIDs and trajectory logs. *X*-axis represents time, *Y*-axis represents the leaf number, ranging from 10 to 50, and *Z*-axis (colour scale) represents the error in position.

Monitoring daily MLC positional errors using trajectory log files and EPID measurements for IMRT and VMAT deliveries.Agnew, A. et al. PMB, 2014.

Control de Calidad IMRT

Paciente-Específico. Ficheros de registro

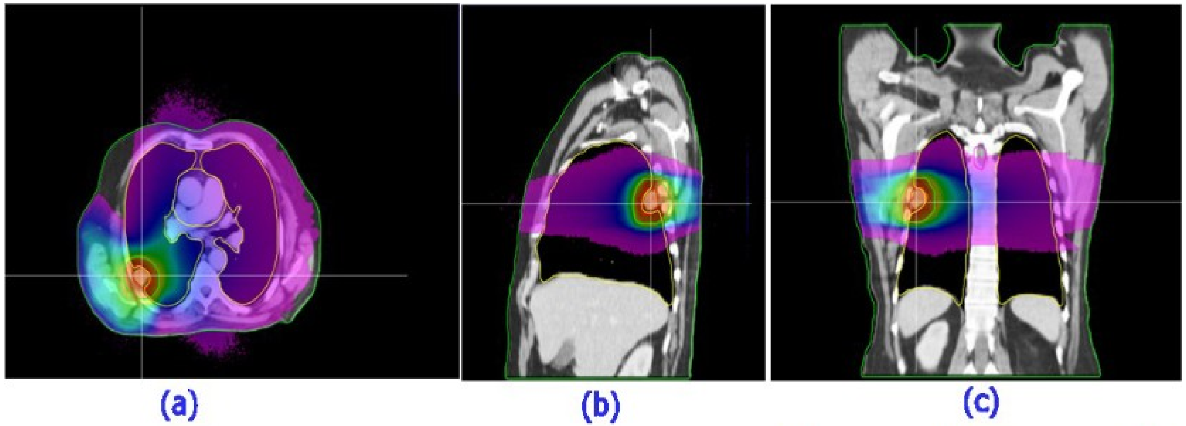


Figure 2. The PRIMO simulated dose distribution for an SBRT plan in the axial (a), sagittal (b) and coronal (c) isocenter planes.

Table 1. Comparison of DVH parameters from PRIMO simulation and TPS. DVH – dose-volume histogram, PTV – planning target volume, SD- standard deviation, TPS- treatment planning system. MC- Monte Carlo.

DVH parameter	TPS(Acuros XB) Mean±SD	MC(PRIMO) Mean±SD	P-Value
PTV_{mean} (Gy)	51.16 ± 0.85	51.31 ± 0.88	0.074
PTV_{max} (Gy)	56.05 ± 2.11	57.37 ± 2.49	0.007
PTV D_{95} (Gy)	46.74 ± 1.63	46.93 ± 1.61	0.169
LUNGS V_{20} (%)	5.93 ± 1.42	5.79 ± 1.23	0.102
LUNGS V_5 (%)	19.31 ± 3.24	20.33 ± 3.39	0.061
LUNGS $_{mean}$ (Gy)	4.38 ± 0.68	4.38 ± 0.65	0.953
SPINE $_{max}$ (Gy)	12.00 ± 3.88	11.94 ± 3.95	0.541
CI	1.08 ± 0.04	1.09 ± 0.04	0.058
GI	4.31 ± 0.38	4.3 ± 0.40	0.683

Table 2. Comparison of DVH parameters from PRIMO dynalog reconstructed plan and TPS.DVH – dose-volume histogram, PTV – planning target volume, SD- standard deviation, TPS- treatment planning system. MC- Monte Carlo.

DVH parameter	TPS (Acuros XB) (Mean±SD)	MC(PRIMO) Mean±SD	P-Value
PTV $_{mean}$ (Gy)	51.16 ± 0.85	51.33 ± 0.92	0.093
PTV_{max} (Gy)	56.05 ± 2.11	57.63 ± 2.89	0.009
PTV D_{95} (Gy)	46.75 ± 1.65	47.05 ± 1.98	0.139
LUNGS V_{20} (%)	5.93 ± 1.42	5.60 ± 1.34	0.083
LUNGS V_5 (%)	19.31 ± 3.24	20.63± 3.55	0.056
LUNGS $_{mean}$ (Gy)	4.38 ± 0.68	4.33± 0.67	0.484
SPINE $_{max}$ (Gy)	12.00 ± 3.88	12.17 ± 4.09	0.203
CI	1.08 ± 0.04	1.10 ± 0.04	0.101
GI	4.31 ± 0.38	4.45 ± 0.56	0.799

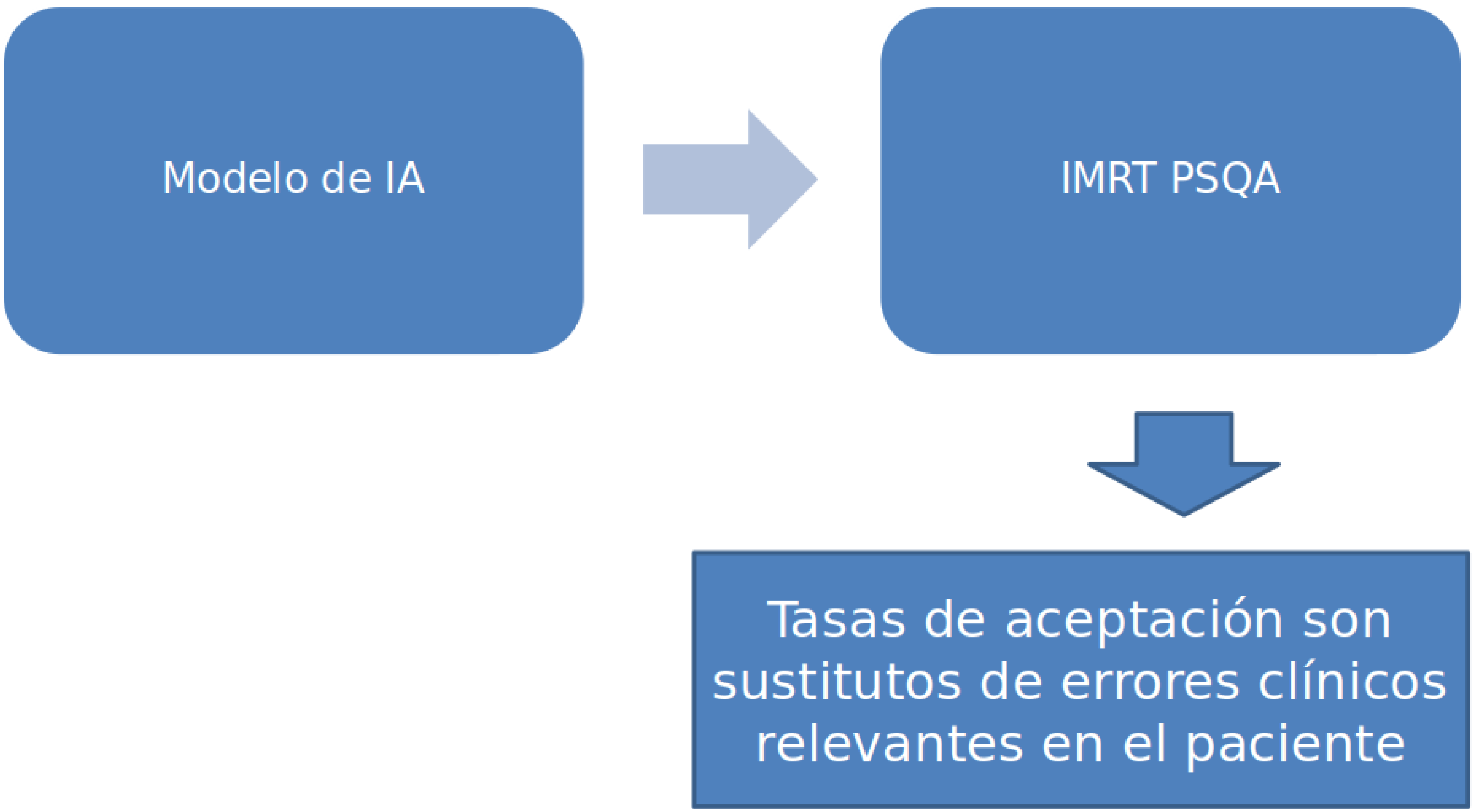
Clinical implementation of a PRIMO Monte Carlo-based dose verification and quality assurance model for stereotactic body radiotherapy (SBRT) treatment plans of the lung. Sarin B et al. Int. J. Radiat. Res. 2022

Treatment verification using Varian's dynalog files in the Monte Carlo system PRIMO. Rodriguez M, Brualla L. RO, 2019

Control de Calidad IMRT

Paciente-Específico. Inteligencia Artificial

ML IMRT PSQA



A mathematical framework for virtual IMRT QA using machine learning. Valdes G et al, Med Phys, 2016

Control de Calidad IMRT

Paciente-Específico. Inteligencia Artificial

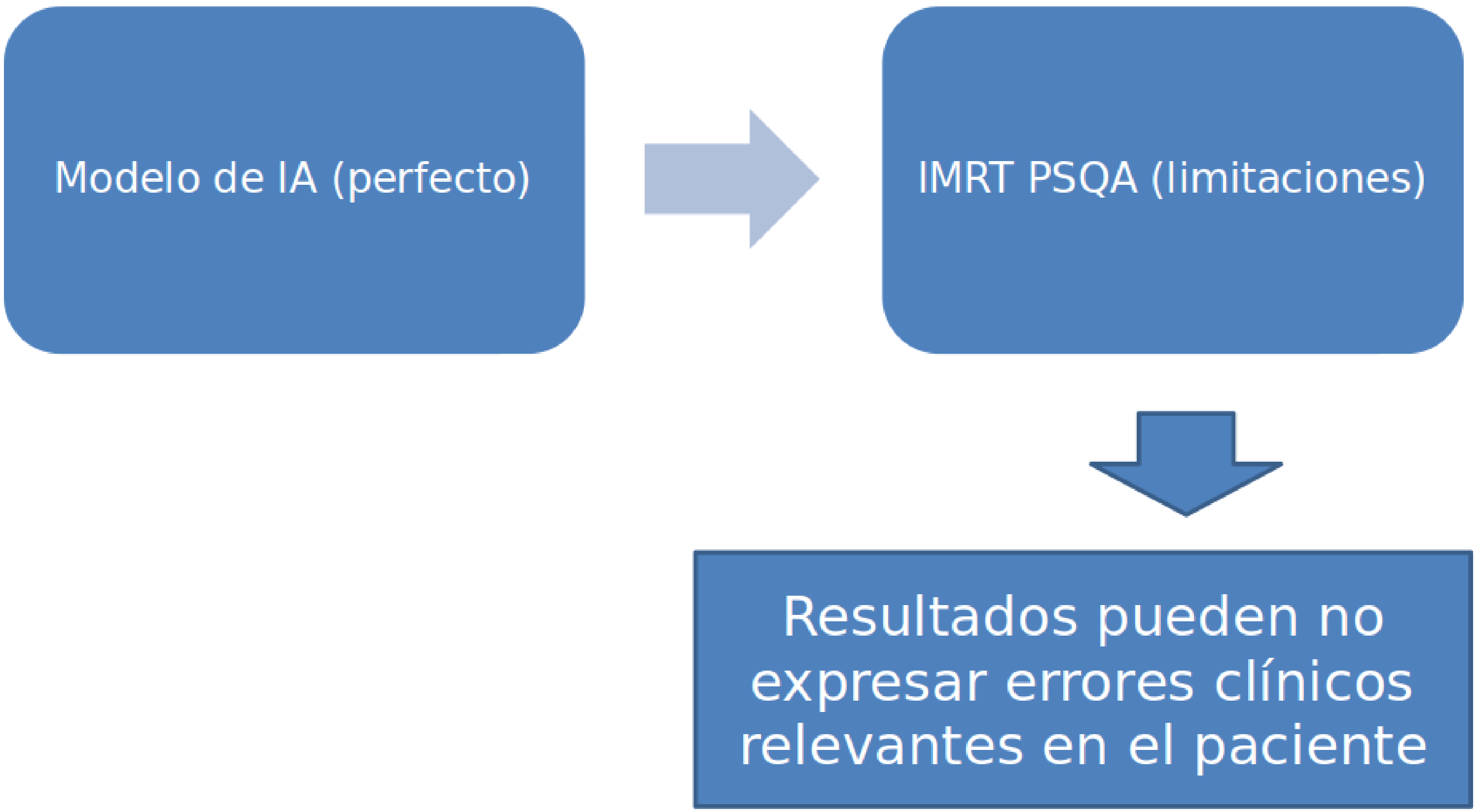
IMRT PSQA Paradigma

- **Múltiples fuentes de incertidumbres conjugadas en una medición única hacen retador desligar sus componentes individuales**
  - **Incertidumbres en el cálculo de dosis (modelado/limitaciones del algoritmo)**
  - **Desempeño de la unidad de tratamiento durante la administración**
  - **Calibración/Respuesta del detector**
  - **Configuración de medición**
    - **TC, PFF, PC**

Control de Calidad IMRT

Paciente-Específico. Inteligencia Artificial

ML IMRT PSQA Relevancia clínica



Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Nelms B. et al, Med Phys, 2013.

Control de Calidad IMRT

Paciente-Específico. Inteligencia Artificial

ML IMRT PSQA Ventajas

- **Reducir carga de trabajo a la unidad de tratamientos y el personal responsable**
- **La planeación de planes de IMRT puede ser más eficiente**
- **Aumentar la sensibilidad en la comprobación de los planes de IMRT**
- **Definir tasa de aceptación específicas por localizaciones anatómicas o estrategias de planeación**

Control de Calidad IMRT

Paciente-Específico. Inteligencia Artificial

ML IMRT PSQA Desventajas

- **Podemos confiar en los resultados del modelo de IA?**
  - **Depende de los datos de entrada utilizados**
  - **Modelo de IA**
- **Como detectar fallos en la predicción del modelo de IA?**
- **Como y por qué el modelo de IA predice el resultado en cuestión?**
  - **Interpretación**

Towards a safe and efficient clinical implementation of machine learning in radiation oncology by exploring model interpretability, explainability and data-model dependency. Barragan-Montero, A et al. Phys Med Biol, 2023.

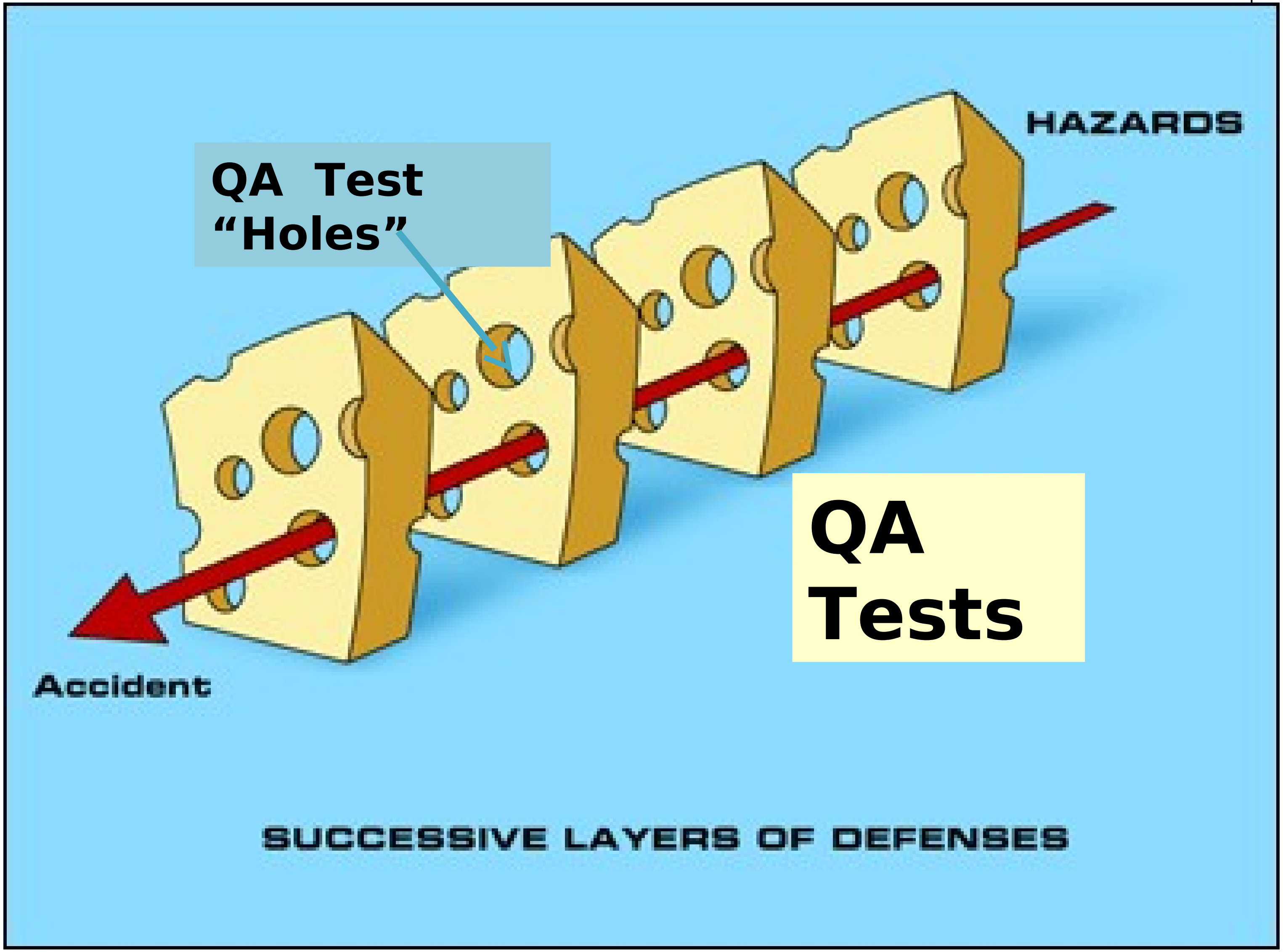
Control de Calidad IMRT

Paciente-Específico. Inteligencia Artificial

ML IMRT PSQA Influencia en el flujo de trabajo

- Entrenar al modelo de IA puede suponer una considerable esfuerzo
- La planeación de planes de IMRT puede ser más complicada
- Aumento de la carga de trabajo en los procedimientos de QA a la unidad de tratamiento.
- Comprobación de otros parámetros ajenos al desempeño de la unidad de tratamiento, e.g. transmisión de datos en el sistema RV.

Accident Prevention



Control de Calidad IMRT

Paciente-Específico. Evaluación

- 7 casos reales
- Planeaciones IMRT/VMAT
- TG 119, 3 %/ 3 mm y Tasa de aceptación 88-90 %
- Resultados PSQA, Tasa de aceptación
  - Por campo, 99%
  - Plan compuesto, 93.4-100%
- Todos los casos presentaban errores sistemáticos
- Tipos de errores detectados
  - Configuración del modelo del algoritmo de cálculo
  - Limitaciones intrínsecas del algoritmo
  - Modelación y alineación del maniquí de QA en el TPS

Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Nelms B. et al, Med Phys, 2013.

Control de Calidad IMRT
Paciente-Específico. Evaluación

TABLE I. Details of the case studies, including TPS, linac, energy, MLC type, delivery modality, and type of error.

ID	TPS	Linac/MV/MLC	Delivery modality	Error type
1	Pinnacle	Elekta 6 MV 80-leaf (10 mm)	IMRT (step and shoot)	TPS model setting
2	MSK	Varian 6 MV 120-leaf	IMRT (dynamic)	TPS model setting
3	Eclipse	Varian 15 MV 120-leaf	IMRT (dynamic)	TPS input data
4A	Monaco	Elekta 6 MV 80-leaf (4 mm)	IMRT (step and shoot)	TPS algorithm
4B	Monaco	Elekta 6 MV 80-leaf (4 mm)	VMAT (1 arc)	TPS algorithm
5	Pinnacle	Varian 6 MV 120-leaf	VMAT (2 arc)	TPS algorithm
6	Pinnacle	Elekta 10 MV 80-leaf	Open field	TPS phantom setting
7	Eclipse	Varian 6 MV 120-leaf	VMAT (2 arc)	TPS phantom setting

Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Nelms B. et al, Med Phys, 2013.

Control de Calidad IMRT

Paciente-Específico. Evaluación

TABLE II. Passing rate method (per beam planar or composite), dosimeters, and analysis methods employed for each case study.

ID	Passing rate	Dosimeter(s)	Advanced diagnostic methods
1	Per-beam 2D	MapCHECK2	Dose profiles; 3D MGDR
2	Per-beam 2D	EPIDose	2%L/2 mm error pattern; 3D MGDR
3	Per-beam 2D	MapCHECK	2%L/2 mm error pattern; dose profiles; EPID-based
4A	Composite 3D	ArcCHECK	2%L/2 mm error pattern; dose profiles; 3D MGDR
4B	Composite 3D	ArcCHECK	2%L/2 mm error pattern; 3D MGDR
5	Composite 3D	Delta4; ArcCHECK	2%L/2 mm error patterns; dose profiles; 3D MGDR
6	Composite 3D	ArcCHECK	2%L/2 mm error pattern; ion chamber; 3D MGDR
7	Composite 3D	ArcCHECK	2%L/2 mm error pattern; 3D MGDR; dose grid inspection

Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Nelms B. et al, Med Phys, 2013.

Control de Calidad IMRT

Paciente-Específico. Evaluación

TABLE IV. Observed passing rates using the TG-119 instructions, i.e., 3%G/3 mm, 10% dose threshold, and (when available) measurement uncertainty turned "on."

ID	Observed passing rates (%)	Details
1	99.2 ± 0.7 (1SD, range 98.1–99.8)	Mean over 7 IMRT beams
2	99.4 ± 1.2 (96.7–100)	Mean over 7 IMRT beams
3	99.3 ± 0.6 (98.9–100)	Mean over 5 IMRT beams
4A	96.6	Composite plan dose, 5 IMRT beams
4B	95.9	Composite plan dose, 1 VMAT beam
5	93.9[a], 94.7[b]	Composite plan dose, 2 VMAT beams
6	97.8	Composite plan dose, 1 open field
7	100	Composite plan dose, 2 VMAT beams

[a] AC.

[b] Delta4.

Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Nelms B. et al, Med Phys, 2013.

Control de Calidad IMRT

Paciente-Específico. Evaluación

3.B.1. Case Study 1: Incorrect TPS settings for leaf-end modeling

This case presented a 99.2% MapCHECK 3%G/3 mm passing rate (averaged over all beams) for a head and neck

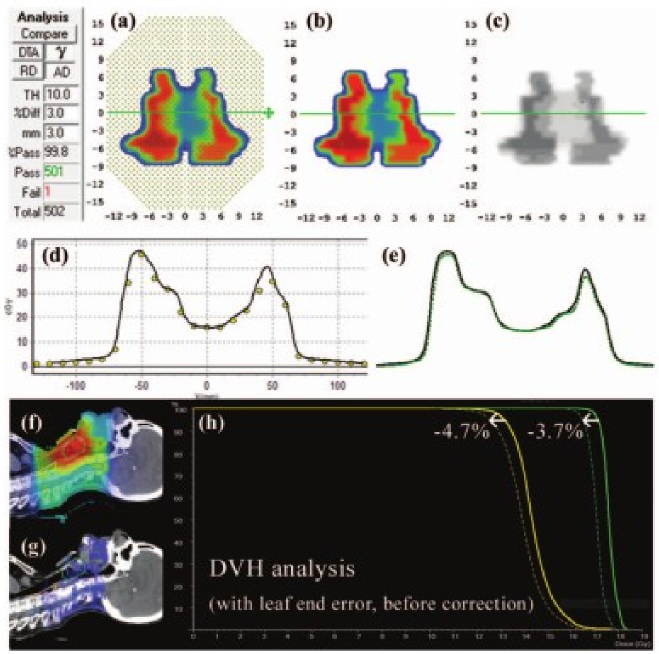


FIG. 1. Absolute dose planes at 10 cm depth, 100 cm source-detector-distance (SDD) shown for (a) measured and (b) calculated dose. (c) 3%G/3 mm gamma failing points. (d) Dose profiles, dots represent calibrated diode measurements and solid lines the interpolated TPS profiles and (e) with measured profile (dotted) up-sampled using a commercial method (Refs. 12, 13, and 34). (f) Patient sagittal planar dose from TPS and (g) with 3DVH-esimated error showing lower estimated patient dose as dose difference, and (h) as shifts in DVH curves for two target volumes.

Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Nelms B. et al, Med Phys, 2013.

Control de Calidad IMRT

Paciente-Específico. Evaluación

3.B.1. Case Study 1: Incorrect TPS settings for leaf-end modeling

This case presented a 99.2% MapCHECK 3%G/3 mm passing rate (averaged over all beams) for a head and neck

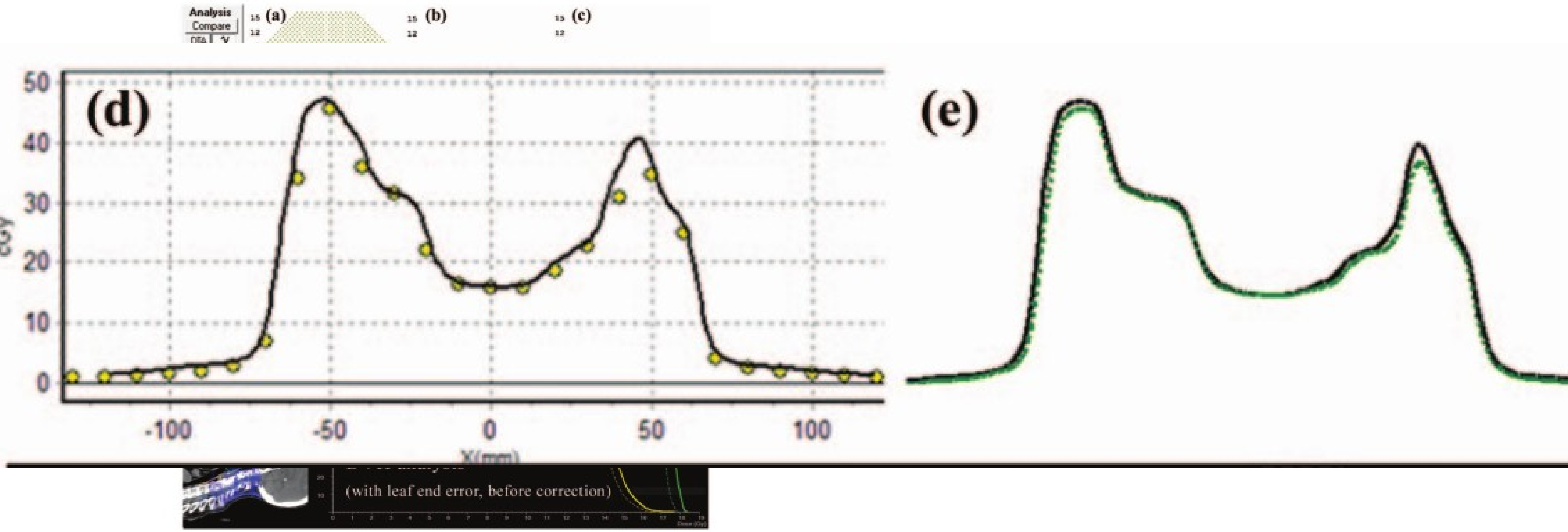


FIG. 1. Absolute dose planes at 10 cm depth, 100 cm source-detector-distance (SDD) shown for (a) measured and (b) calculated dose. (c) 3%G/3 mm gamma failing points. (d) Dose profiles, dots represent calibrated diode measurements and solid lines the interpolated TPS profiles and (e) with measured profile (dotted) up-sampled using a commercial method (Refs. 12, 13, and 34). (f) Patient sagittal planar dose from TPS and (g) with 3DVH-esimated error showing lower estimated patient dose as dose difference, and (h) as shifts in DVH curves for two target volumes.

Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Nelms B. et al, Med Phys, 2013.

Control de Calidad IMRT

Paciente-Específico. Evaluación

- Tasa de aceptación gamma 3 %/ 3 mm puede ser sub-óptima para la aceptación y puesta en servicio de técnicas de IMRT/VMAT
- Métricas más sensibles pueden identificar errores dosimétricos sistemáticos que de otra manera serían indetectables
- La adopción de métricas más sensibles y tolerancias más restrictas posibilitará:
  - el mejoramiento continuo de la exactitud en la administración de dosis en Radioterapia al nivel tanto del usuario final como del diseño del producto por el fabricante
  - la mejor estandarización de los métodos y procedimientos de aceptación y puesta en servicio del producto
  - Incrementar la calidad y reducir la variación, al punto de no ser necesarias las comprobaciones en masa

Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Nelms B. et al, Med Phys, 2013.

Control de Calidad IMRT
Paciente-Específico. Evaluación

Tarea

- **Revisión bibliográfica del artículo referenciado**
- **Escoger dos de los casos restantes y hacer un informe explicando el error detectado, el método utilizado en la detección y las medidas tomadas para corregir el mismo (los casos no pueden solaparse en los informes individuales)**

Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Nelms B. et al, Med Phys, 2013.