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3D dosimetry of low radiation doses in radiotherapy and radiology applications

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[4]*Medical Physics Department, Copernicus Hospital, Lodz, Poland*
[5]*Institute of Materials Science and Engineering, Lodz University of Technology, Lodz, Poland*

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Dr. John Schreiner:

The current state-of-the-art related to 3D chemical dosimetry allows it to be used in radiotherapy for:

- commissioning the treatment planning system
- benchmarking performance both treatment planning and dose delivery
- periodic and routine patient specific treatment quality assurance

Schreiner LJ. Reviewing three dimensional dosimetry: basics and utilization as presented over 17 Years of DosGel and IC3Ddose. **J. Phys. Conf. Series 2017;847: 012001**

Apart from radiotherapy, 3D chemical dosimetry can be used in:

- radiology applications such as for measurements of low doses in diagnostic imaging

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3D dosimetry of low radiation doses in radiotherapy and radiology applications

1. **What is meant by 3D dosimetry? Components of the system and reaction mechanism.**
2. Example radiotherapy application of VIC/VIC-T 3D dosimetry + 3T MRI + polyGeVero data processing
3. Recording very low doses in radiology

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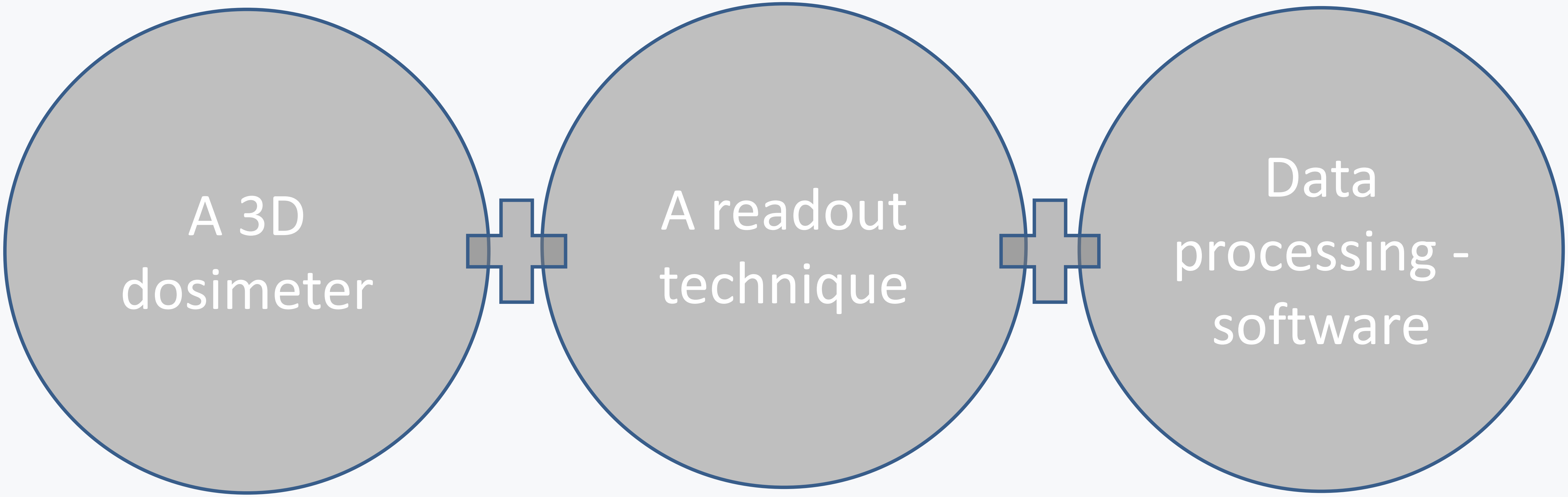
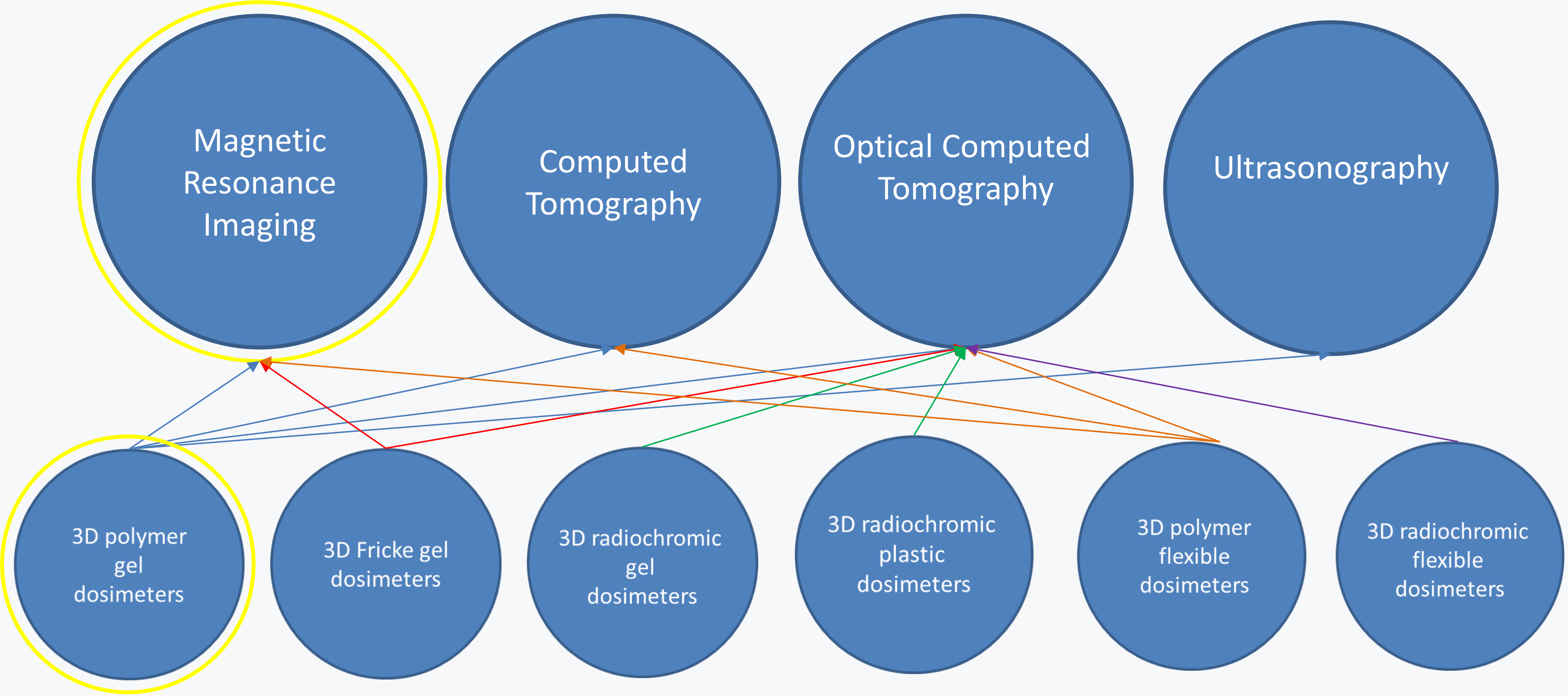


A 3D dosimeter

- 3D Fricke gel dosimeters
- 3D polymer gel dosimeters
- 3D radiochromic gel dosimeters
- 3D radiochromic plastic dosimeters
- 3D polymer flexible dosimeters
- 3D radiochromic flexible dosimeters

A readout technique



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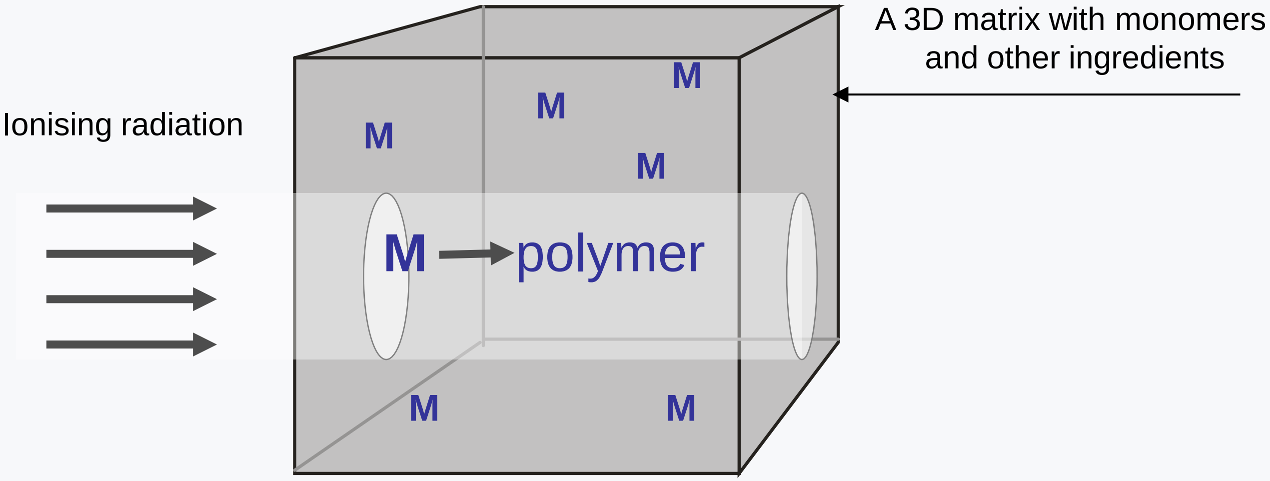
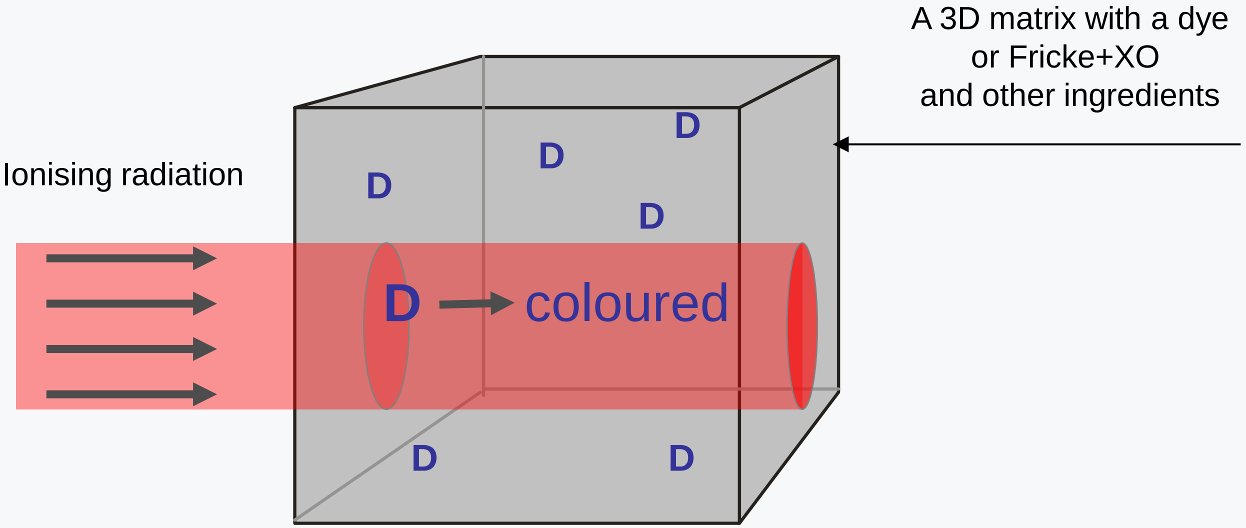
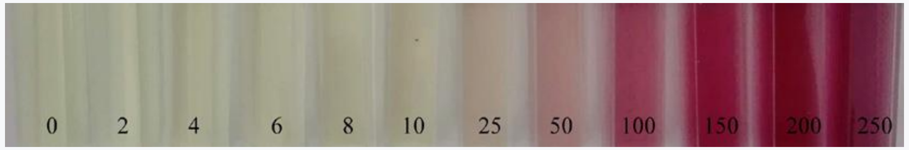
How does it work?







AIM

Verification of calculated 3D dose distributions by:

- a treatment planning system (TPS), and
- ArcCHECK®–3DVH®

related to a lung tumour eradication.

METHOD

- Two 3D polymer gel dosimeters: VIC and VIC-T
- Readout: remote magnetic resonance imaging (3 T MRI) @ High field MR-Center, Medical University of Vienna, Austria (600 km from centre of Poland)
- Processing of data: polyGeVero® software package (GeVero Co., Poland)

3D polymer gel dosimeters

VIC: *Phys. Med. Biol.* ***62*** *986–1008 (2017)*

Composition:

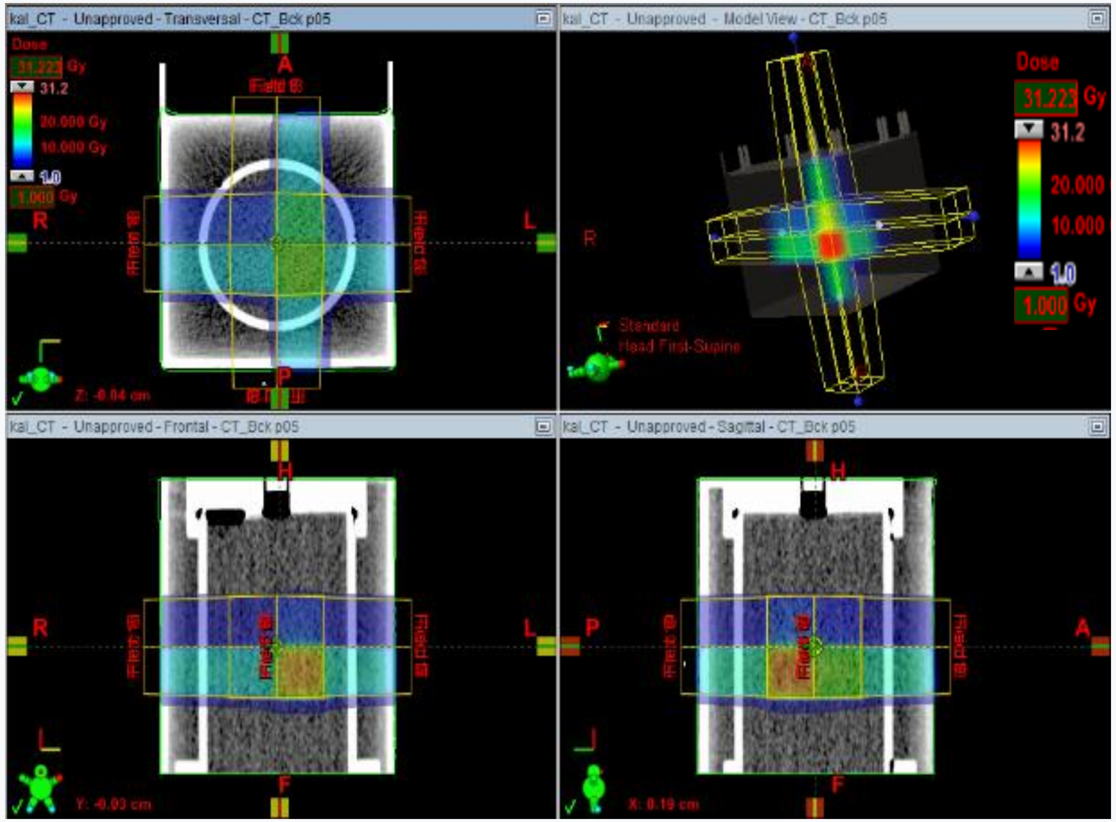
17% (w/v) *N*-vinylpyrrolidone (NVP),
8% (w/v) *N,N'*-methylenebisacrylamide (MBA or Bis),
12% (w/v) tert-butanol,
7.5% (w/v) gelatine,
0.007% (w/v) L-ascorbic acid,
0.0008% (w/v) $CuSO_4 \times 5H_2O$ and
0.02% hydroquinone.

VIC-T: *Phys. Med. Biol.* ***64*** *035019 (2019)*

Composition:

17% (w/v) N-vinylpyrrolidone (NVP),
8% (w/v) N,N'-methylenebisacrylamide (MBA or Bis),
12% (w/v) tert-butanol,
5% (w/v) gelatine,
14 mM tetrakis(hydroxymethyl)phosphonium chloride (THPC) and
0.02% hydroquinone

Calibration: cross beam



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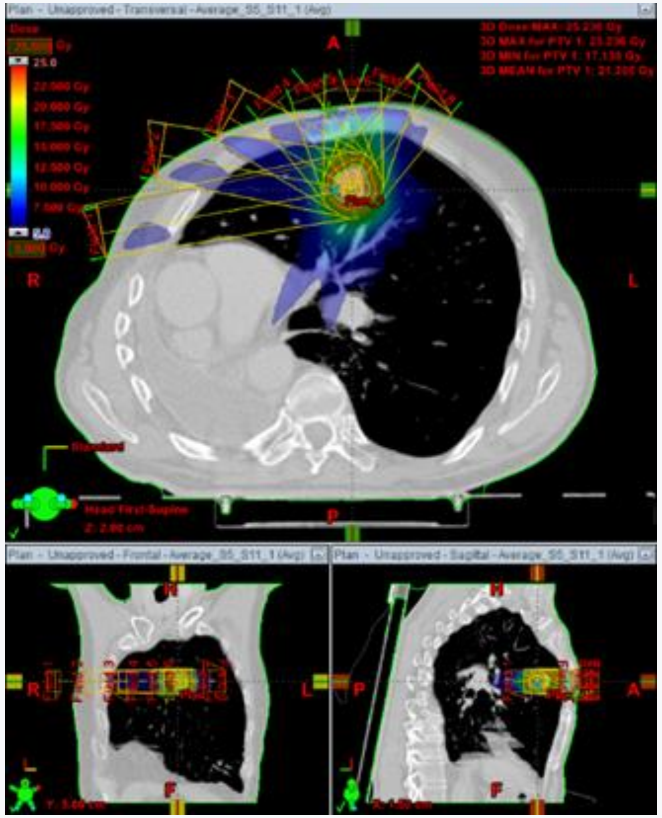
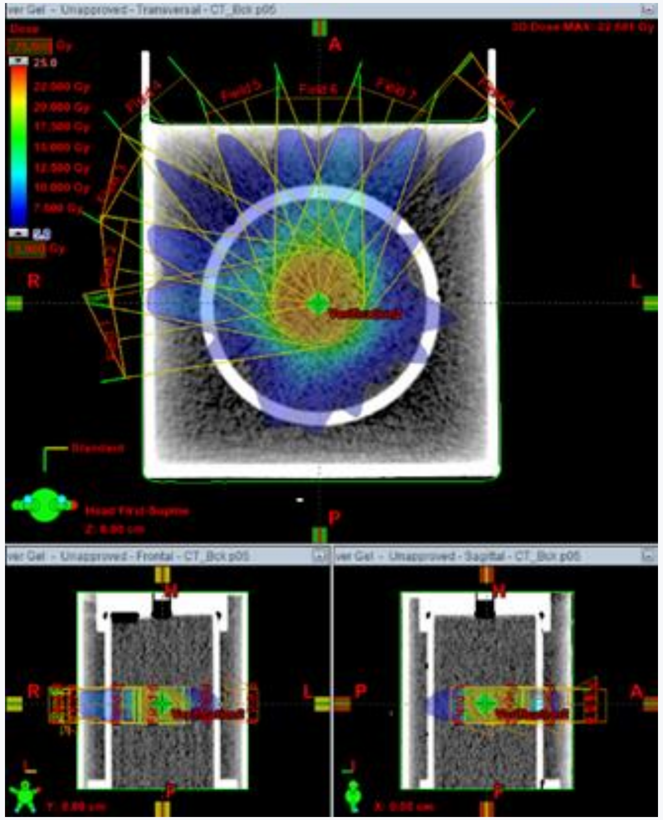
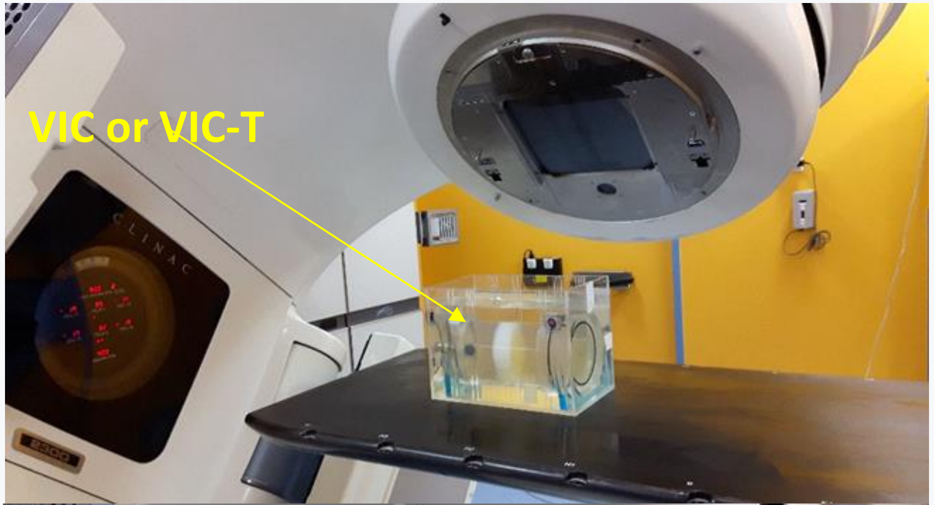
Verification: lung tumour

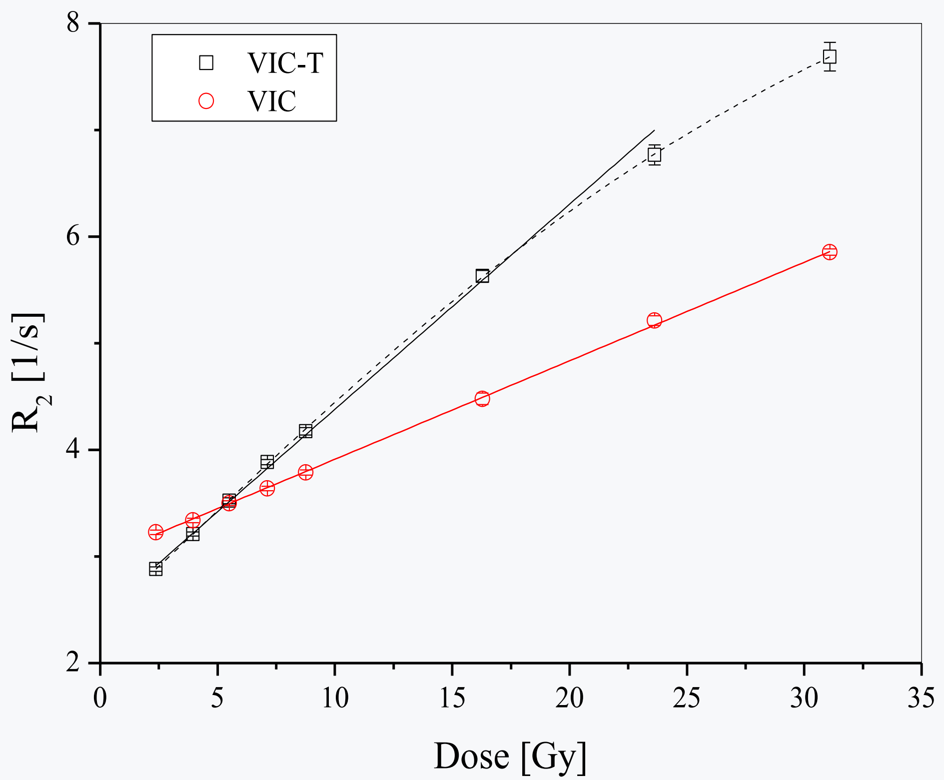






XVIII PTBR National Meeting Satellite Symposium, Applications of low radiation doses in medical, diagnosis and therapy, Kielce, September 17-18, 2019

Calibration graphs of VIC and VIC-T



VIC: $R_2 = 0.0928 \pm 0.0008\ [Gy^{-1}\ s^{-1}] \times D\ [Gy] + 2.985 \pm 0.012\ [s^{-1}]$

VIC-T: $R_2 = 0.1839 \pm 0.0044\ [Gy^{-1}\ s^{-1}] \times D\ [Gy] + 2.519 \pm 0.053\ [s^{-1}]$

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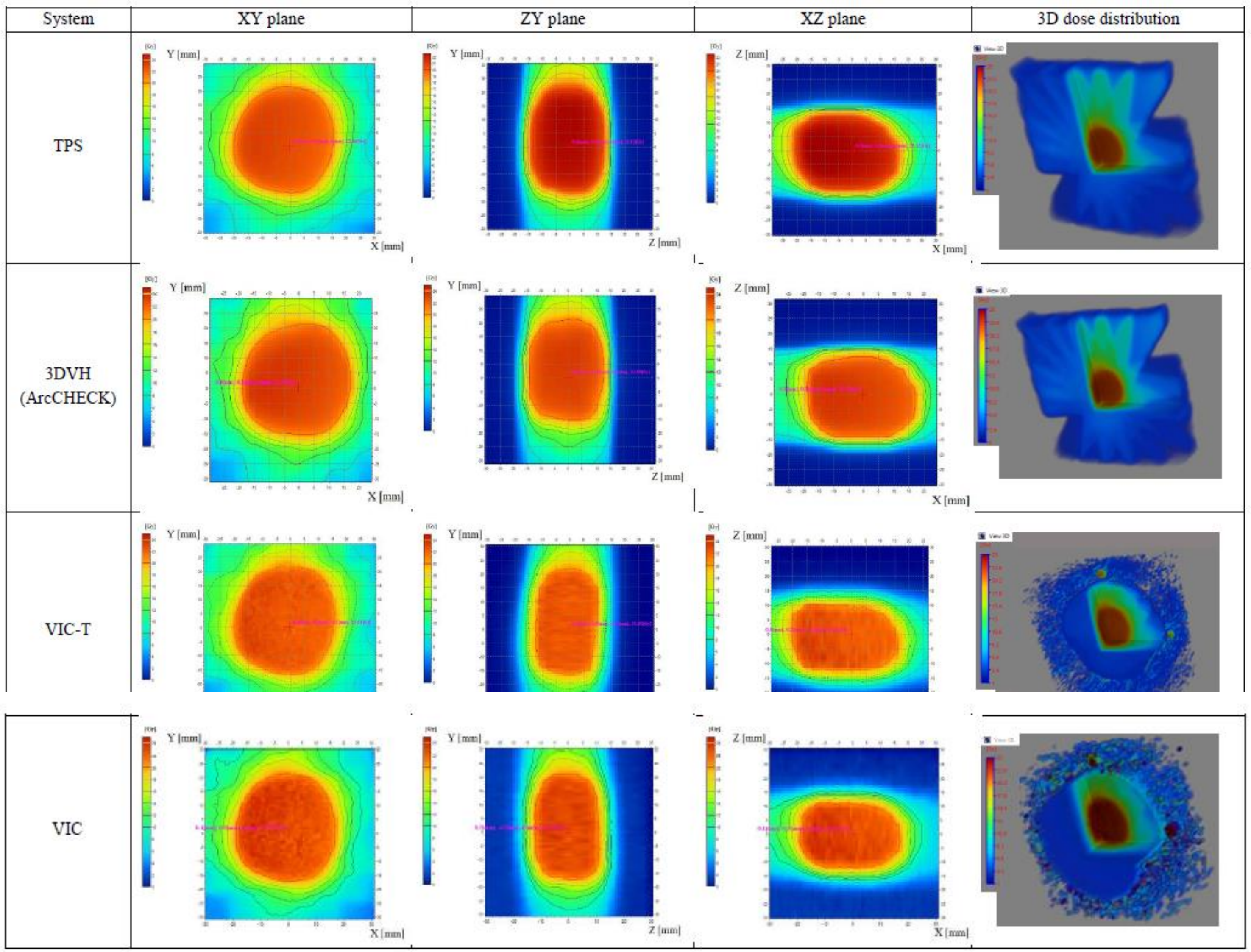
2D/3D dose distribution



A comparison of dose at a point (isocentre) and a mean dose for a volume (a 3D ROI) for different systems

No.	System	Dose at isocentre [Gy]	Percentage difference at isocentre [%]	A volume reduced to the ROI
1	VIC	21.97	0.9 (vs. TPS) 2.8 (vs. 3DVH)	-
2	VIC-T	21.61	2.5 (vs. TPS) 4.5 (vs. 3DVH)	-
3	TPS	22.16	-	-4.0% (vs. VIC) -1.6% (vs. 3DVH) 3.3% (vs. VIC-T)
4	ArcCHECK-3DVH	22.59	1.9 (vs. TPS)	4.5% (vs. vs. VIC-T) -2.8% (vs. VIC)

An accuracy requirement is ±3–5%:

Thwaites D. Accuracy required and achievable in radiotherapy dosimetry: Have modern technology and techniques changed our views? J Phys Conf Ser 2013;444: 012006.

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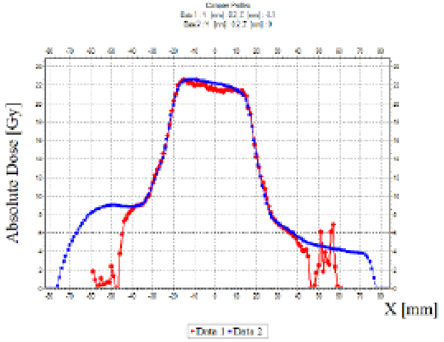
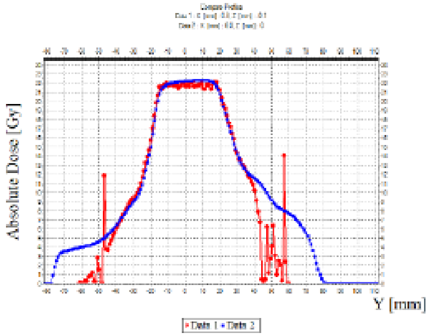
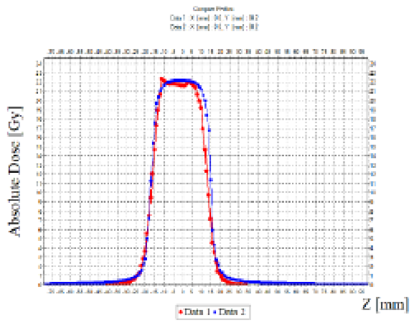
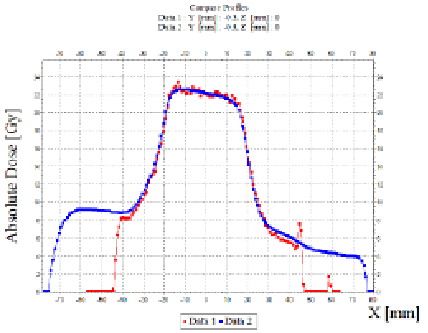
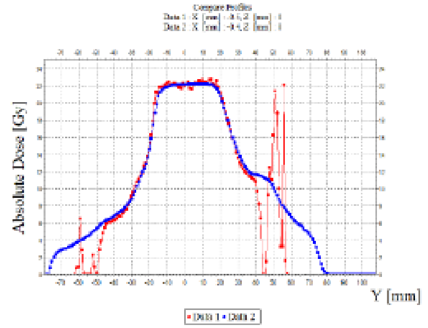
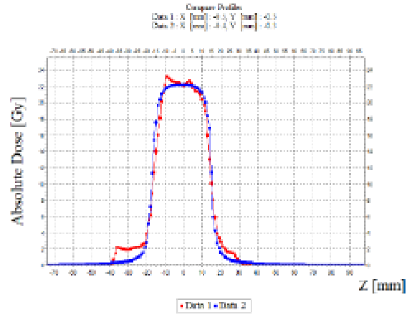
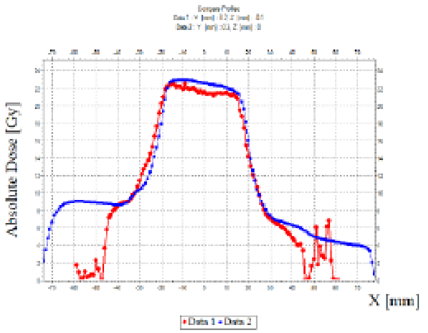
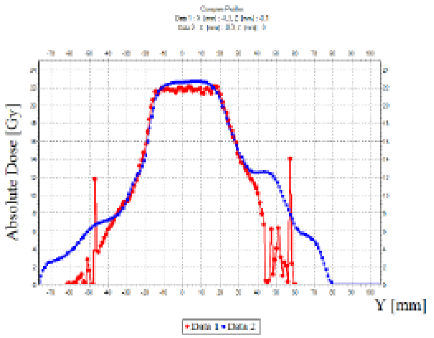
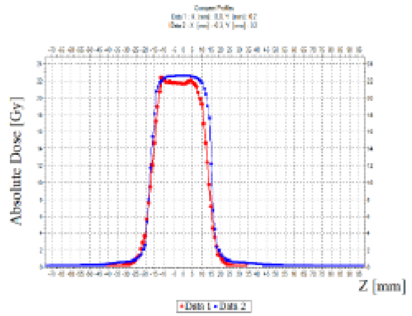
Comparison of profiles: Example results

Systems	ZY Plane	XZ plane	XY plane
VIC-T (Data1) vs. TPS (Data2)			
VIC (Data1) vs. TPS (Data2)			
VIC-T (Data1) vs. 3DVH (ArcCHECK) (Data2)			

3D gamma index

Number of pixels falling below 1 for 3D gamma index

No.	System	Gamma index agreement
1	VIC	96.1% vs. TPS 97.9% vs. 3DVH
2	VIC-T	96.6% vs. TPS 92% vs. 3DVH
3	ArcCHECK-3DVH	99.7% vs. TPS

A gamma evaluation might be stated as acceptable if the percentage number of points with gamma value beyond 1 ranges between 0–5% ($P_{>1}$ = 0–5%) corresponding to 100-95% agreement.

Conclusions

- Modern high-field MR-scanner equipped with sensitive multi-channel rf-detectors + polyGeVero = reduced total time for 3D measurements and data processing (**~40 min total**).

- The highest agreement was obtained between the calculated 3D dose distributions by 3DHV (ArcCHECK) and Eclipse External Beam treatment planning system. The lowest agreement was obtained for the verification of 3D dose distribution calculated by 3DVH (ArcCHECK) with the VIC-T dosimeter.

- We consider VIC or VIC-T coupled with the 3T MRI and polyGeVero software as truly 3D high resolution dosimetric system that verified the TPS calculated dose distribution plan.

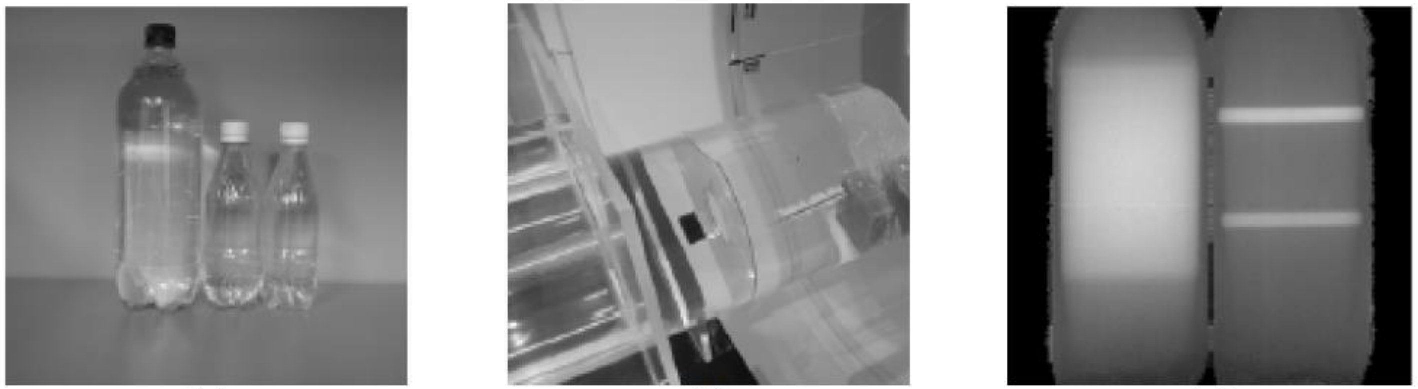
- The results obtained suggest the implementation of the irradiation plan for eradication of the lung tumour.

- Possibilities of 3D chemical dosimetry radiotherapy applications even in cases, when the centers involved are far distant from each other (**600 km in this study**).

Use of normoxic polymer gel dosimeters for measuring diagnostic doses on CT scanners

as reported by B Hill, A J Venning and C Baldock Journal of Physics: Conference Series **3** (2004) 224–227

1. MAGIC 3D polymer gel dosimeter
2. Irradiation with CT scanner
   (Philips Medical Systems)
3. Scanning with 1.5 T MRI
   (multi spin echo pulse sequence)



(a) (b) (c)

Figure 1. Experimental set-up: (a) Bottles filled with gel, (b) Water phantom set-up in CT scanner, (c) R2-map of exposed bottles.

Use of normoxic polymer gel dosimeters for measuring diagnostic doses on CT scanners

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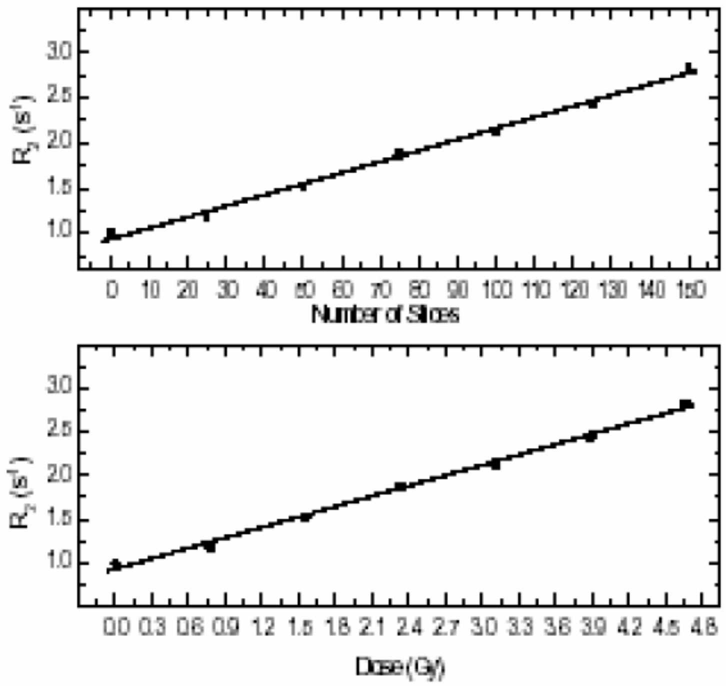


Figure 2. R2-dose response of the MAGIC gel dosimeter.

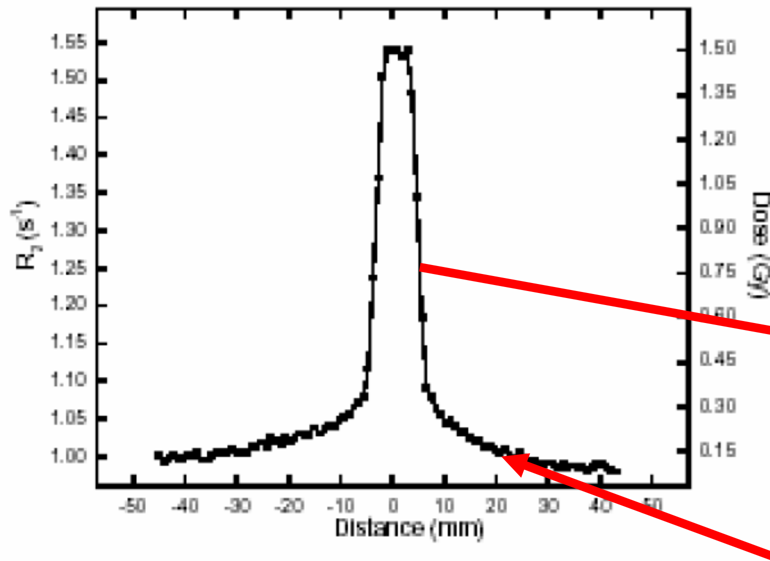
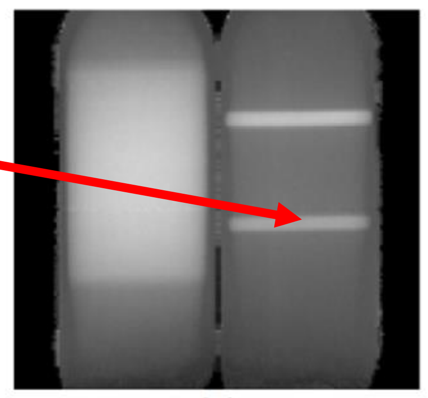


Figure 3. Dose profile for 8 mm slice width.

Dose range:
~7.5 mGy – 1500 mGy



About 0.1 mm resolution

Use of normoxic polymer gel dosimeters for measuring diagnostic doses on CT scanners

as reported by B Hill, A J Venning and C Baldock Journal of Physics: Conference Series **3** (2004) 224–227

Table 1. Summary of results.

	Nominal slice width	MAGIC measurement (mGy)	Ion chamber measurement (mGy)
50 slices delivered	2	6.70	10.76
	3	15.88	15.98
	4	18.36	18.42
	5	21.30	22.05
25 slices delivered	8	28.46	28.78

End of presentation

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Supplementary material

Some DosLab papers related to 3D dosimetry (radiochromic and polymer gel)

Kozicki M, Jaszczak M, Maras P, Dudek M and Cłapa M 2017a On the development of a VIPARnd radiotherapy 3D polymer gel dosimeter *Phys. Med. Biol.* **62** 986–1008

Kozicki M, Kwiatos K, Kadłubowski S and Dudek M 2017b TTC-Pluronic 3D radiochromic gel dosimetry of ionizing radiation *Phys. Med. Biol.* **62** 5668–90

Kozicki M, Kwiatos K, Dudek M and Stempien Z 2018 Radiochromic gels for UV radiation measurements in 3D *J. Photochem. Photobiol. A Chem.* **351** 197–207

Kozicki M and Maras P 2015 The polyGeVero® software for fast and easy computation of 3D radiotherapy dosimetry data *J. Phys.: Conf. Ser.* **573** 012070

Kozicki M. Maras P and Karwowski A C 2014 Software for 3D radiotherapy dosimetry. Validation *Phys. Med. Biol.* **59** 4111-36

Kozicki M, Maras P and Karwowski A C 2015 Introduction to polyGeVero® software for 3D radiotherapy dosimetry GeVero Co. publication, November 4, 2015, pages 1-17 (available through ResearchGate at https://www.researchgate.net/publication/283711431_INTRODUCTION_to_polyGeVeroR_software_for_3D_radiotherapy_dosimetry)

Kozicki M, Maras P, Rybka K, Bieganski T, Kadłubowski S and Petrokokkinos L 2007 On the development of the VIPAR polymer gel dosimeter for three-dimensional dose measurements *Macromol. Symp.* **254** 345–52

Kwiatos K, Maras P, Kadłubowski S, Stempień Z, Dudek M and Kozicki M 2018 Tetrazolium salts-Pluronic F–127 gels for 3D radiotherapy dosimetry *Phys. Med. Biol.* **63** 095012

Kozicki M 2011 How do monomeric components of a polymer gel dosimeter respond to ionising radiation: a steady-state radiolysis towards preparation of 3D polymer gel dosimeter *Radiat. Phys. Chem.* **80** 1419–36

Jaszczak M, Kolesińska B, Wach R, Maras P, Dudek M and Kozicki M 2019 Examination of THPC as an oxygen scavenger impacting VIC dosimeter thermal stability and comparison of NVP-containing polymer gel dosimeters *Phys. Med. Biol.* **64** (2019) 035019 (21pp)

Jaszczak M, Wach R, Maras P, Dudek M, and Kozicki M 2018 Substituting gelatine with Pluronic F–127 matrix in 3D polymer gel dosimeters can improve nuclear magnetic resonance, thermal and optical properties *Phys. Med. Biol.* **63** 175010

Kouvati K, Jaszczak M, Papagiannis P, Kadlubowski S, Wach R, Maras P, Dudek M and Kozicki M 2019 Leuco crystal violet-Pluronic F-127 3D radiochromic gel dosimeter *Phys. Med. Biol.* **64**175017 (14pp)

http://mkozicki-sci.eu/nowa167.php

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3D dosimetry of low radiation doses in radiotherapy and radiology applications

Supplementary material

Example radiochromic gel dosimeter

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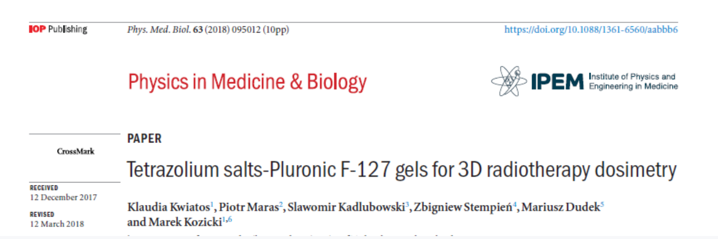
NBT-Pluronic – the best tetrazolium salt-Pluronic gel dosimeter


IOP Publishing Phys. Med. Biol. 63 (2018) 095012 (10pp) https://doi.org/10.1088/1361-6560/aabbb6

Physics in Medicine & Biology

IPEM Institute of Physics and Engineering in Medicine

PAPER

Tetrazolium salts-Pluronic F-127 gels for 3D radiotherapy dosimetry

RECEIVED 12 December 2017

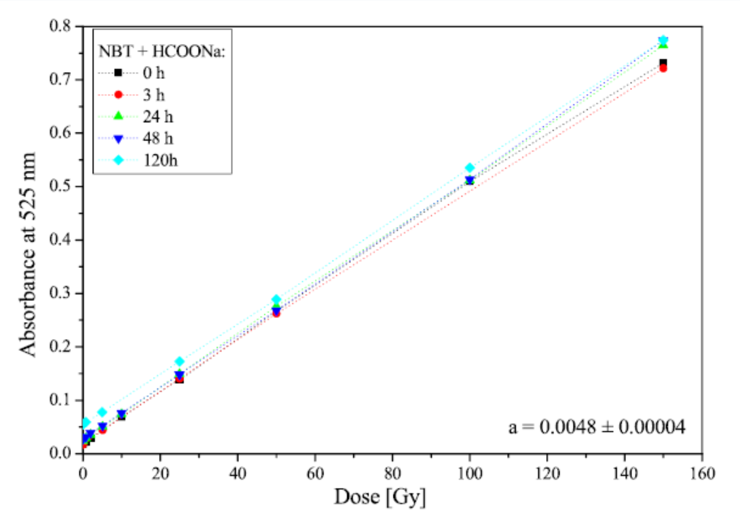
REVISED 12 March 2018

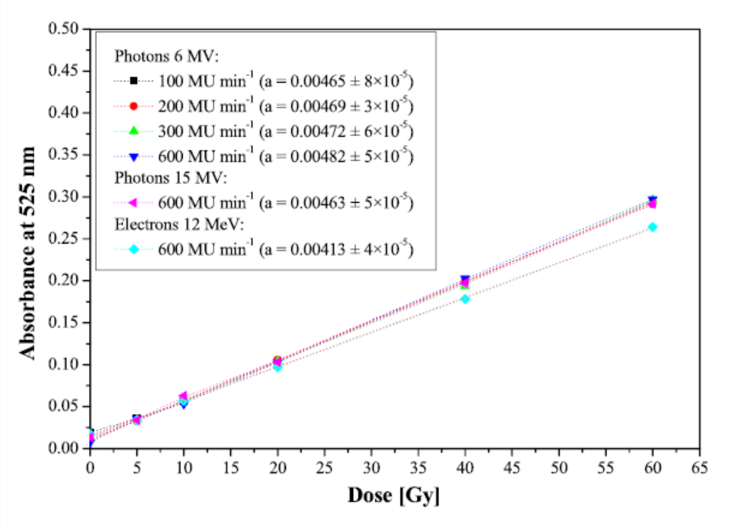
Klaudia Kwiatos[1], Piotr Maras[2], Slawomir Kadlubowski[3], Zbigniew Stempień[4], Mariusz Dudek[5] and Marek Kozicki[1,6]

(0.0818% NBT (1 mM), 25% Pluronic F-127 and 0.136 × 10^{-2}% sodium formate)

The best composition:

- Insensitive to changes in dose rate for photons of different energies
- A diversion in the dose-response was observed for the gel irradiated with electrons
- Dose sensitivity $0.0047 \pm 0.1 \times 10^{-4}$ $(Gy\ cm)^{-1}$
- A linear-dose range and a dynamic-dose range between <1 and ⩾150 Gy
- A dose threshold of <1 Gy.





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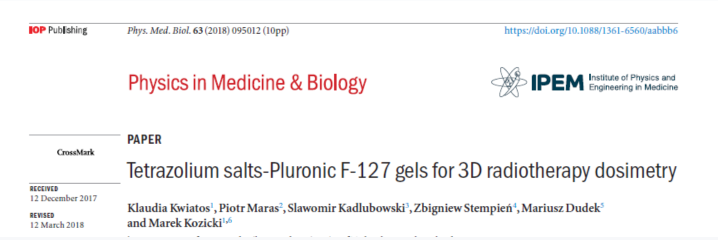
IOP Publishing — *Phys. Med. Biol.* 63 (2018) 095012 (10pp) — https://doi.org/10.1088/1361-6560/aabbb6

Physics in Medicine & Biology — IPEM Institute of Physics and Engineering in Medicine

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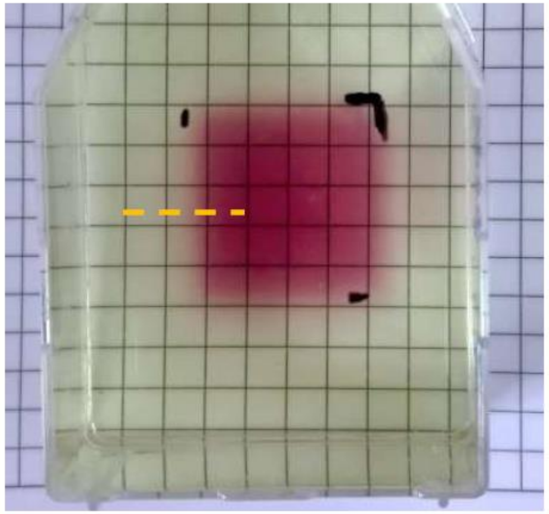
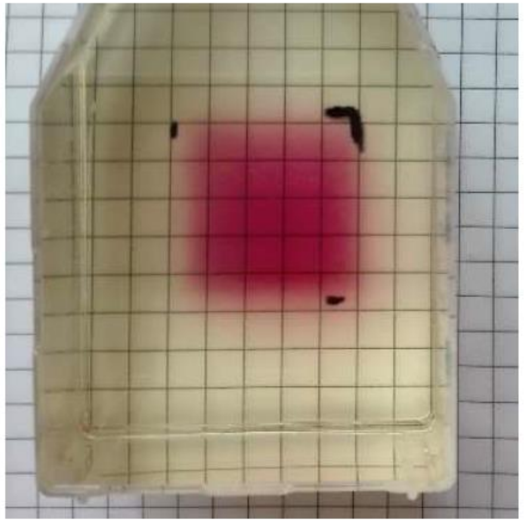
(0.0818% NBT (1 mM), 25% Pluronic F-127 and 0.136 × 10^{-2}% sodium formate)

The best composition:

- The dose distribution registered for the NBT-Pluronic gel was stable after irradiation for over 7 d with no visible diffusion of the irradiated part, which is analogous to the original TTC-Pluronic gel.
- **Diffusion coefficient equals to 0 mm^2/h**


0 h


7 days

Stability of the dose distribution in the best-performing gel dosimeter as observed with the naked eye.

Dose resolution:

$$D_{\Delta}^{p} = k_p \cdot \sqrt{2} \cdot \sigma_D$$

k_P – coverage factor enabling the uncertainty to be determined to a specific level of confidence (at 95%, k=1,96)

σ_D uncertaity of measuremet divided by dose sensitivity of a 3D dosimeter

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Supplementary material

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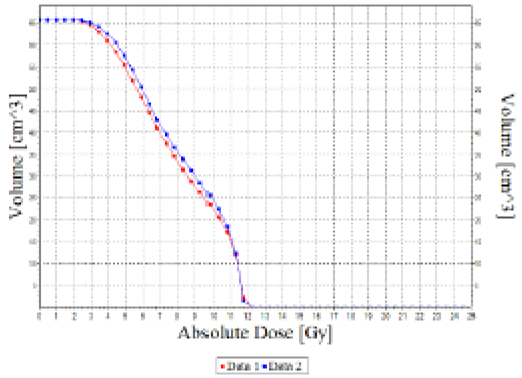
Histograms of 3D dose distribution and gamma index

<table>
<tr>
<td>VIC (Data1) vs. 3DVH (ArcCHECK) (Data2)</td>
<td>
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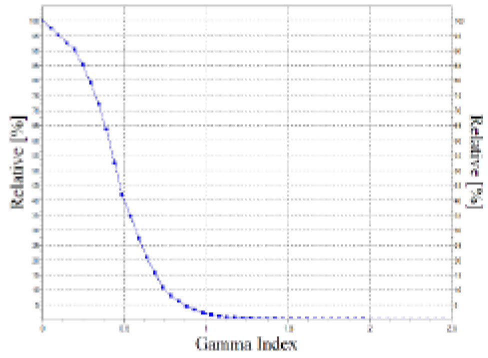
<td>
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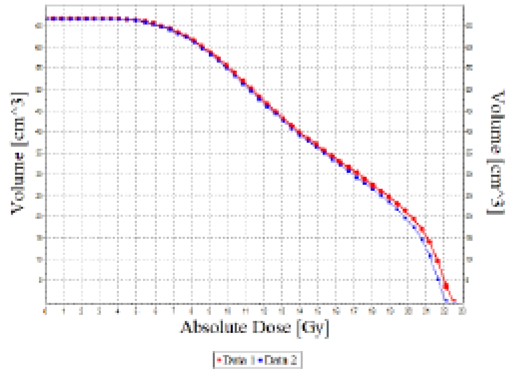
<tr>
<td>3DVH (ArcCHECK) (Data1) vs. TPS (Data2)</td>
<td>
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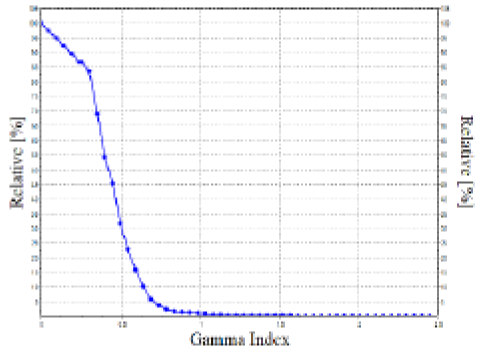
<td>
</td>
</tr>
</table>

GeVero Co. Poland
http://polygevero.com

Supplementary material

Lodz University of Technology, Poland
http://mkozicki-sci.eu

Siemens PrismaFit, Erlangen, Germany

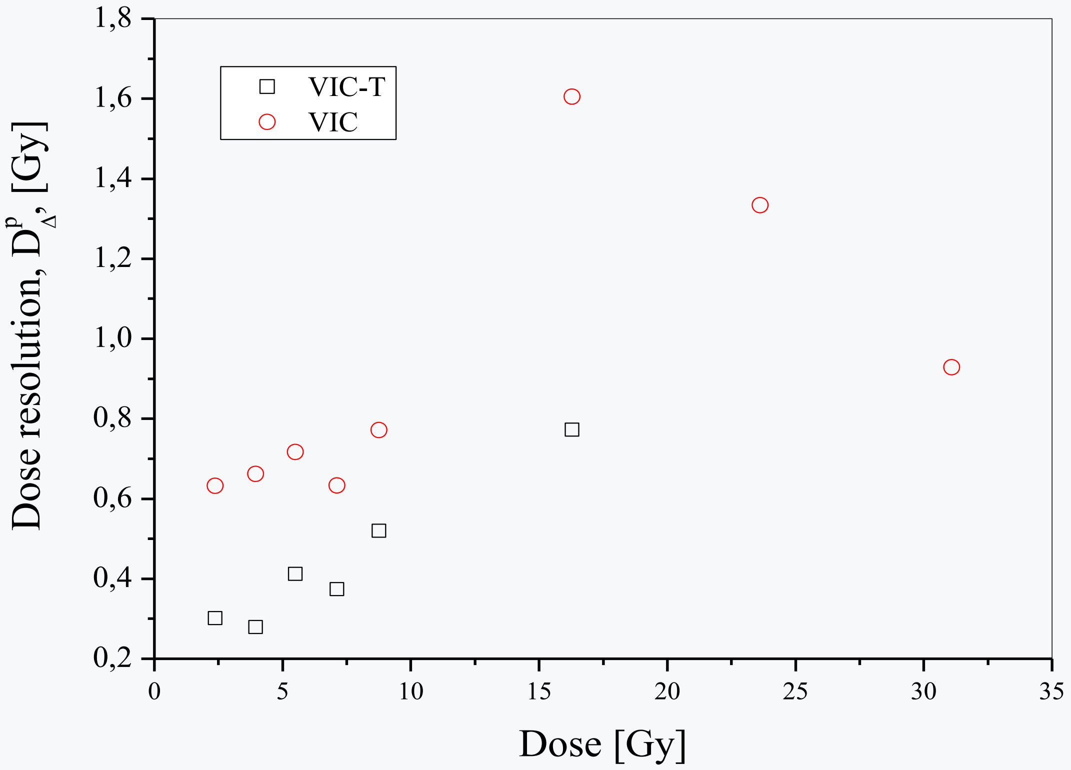
Parameters of the measurements:

A CPMG-multi-slice multi-echo sequence:

- number of echoes: 10; spin echo time: TE = 40, 80, …, 400 ms; repetition time: TR = 10 s; number of averages: av. = 1;
- slice thickness and distance: sldist = 3 mm; number of slices: nr sl. = 24; pixel size: ps = 0.9375 × 0.9375 mm^2;
- **measurement time: TM = 21 min 10 s**
- phantoms were measured located in a 24-channel knee coil of the MRI device,

VIC or VIC-T inside

Dose resolution ($D_{\Delta}^{p}, p = 95$ %) of VIC and VIC-T



Dose resolution formula:

Baldock C, Lepage M, Bäck SÅJ, Murry PJ, Porter D, Kron T. Dose resolution in radiotherapy polymer gel dosimetry: effect of echo spacing in MRI pulse sequence. Phys Med Biol 2001;46: 449–60.

Lepage M, Jayasakera PM, Bäck SÅJ, Baldock C. Dose resolution optimization of polymer dosimeters using different monomers. Phys Med Biol 2001;46: 2665–80.