Dosimetric properties of gel systems upon different irradiation conditions

14th Workshop on European Collaboration in Higher Education on Radiological and Nuclear Engineering and Radiation Protection, 29 May - 1 June 2018, Macugnaga (VB), Italy

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Summary

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2. Chemical dosimeters
   - Principles
   - Fricke gel dosimeters
   - Polymer gel dosimeters
   - Optical analysis
   - 3D techniques
3. Experimental
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   - Irradiation parameters
4. Results
5. Future developments

Introduction - Radiotherapy

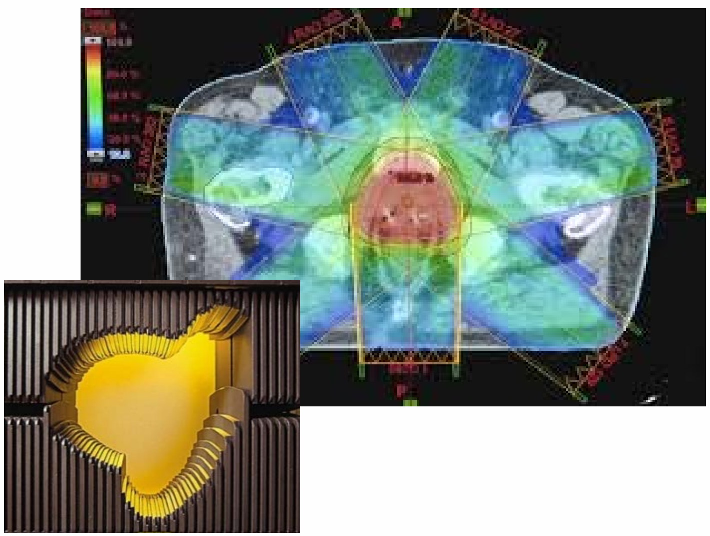
Aim: high dose to the tumor, low dose to healthy tissues

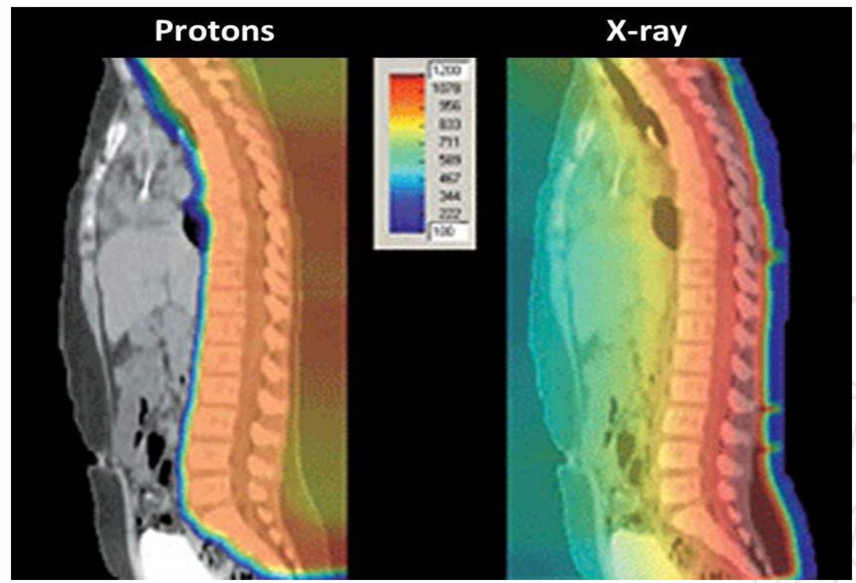
➡ high tumor control probability and low side effects

➡ high spatial precision

1. Beam collimation

Intensity-Modulated Radiation Therapy
IMRT with Photons



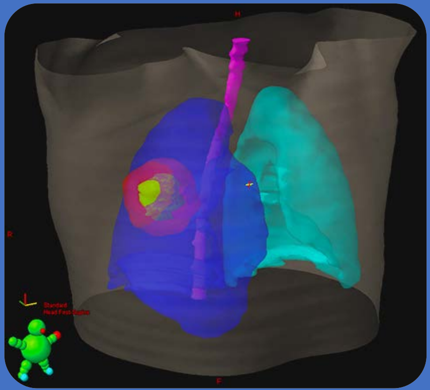


2. Intrinsic spatial precision

Adrotherapy with protons / C ions

- RT Treatment Planning workflow:

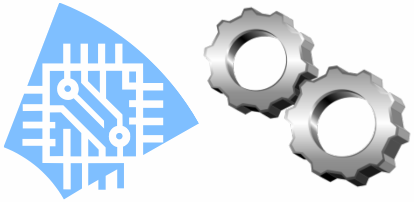
Imaging



3D dose distribution

Delivery ?

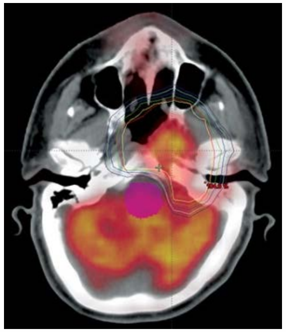
Treatment Planning System



QA of machine performance and of dose delivery

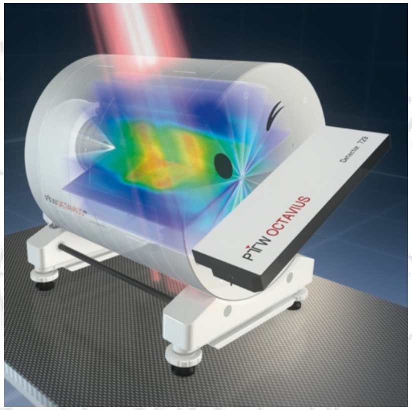
Introduction - Dosimetry

Modern techniques allow precise dose delivery to spare healthy tissues



Dose verification requires *high performance* instruments

Example: 2D array of diodes + axial rotation

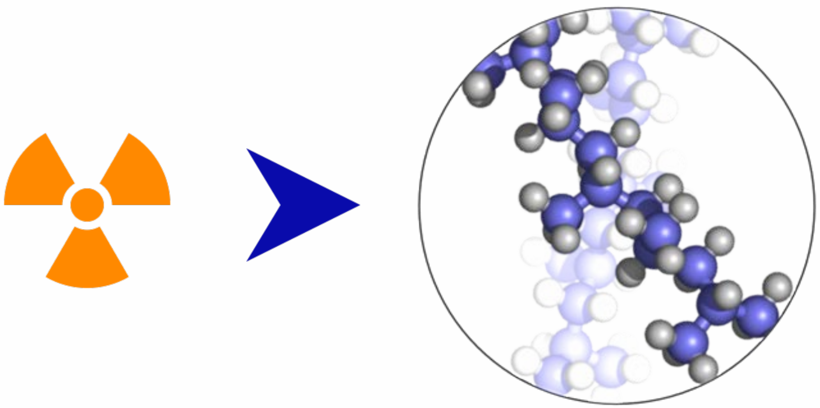


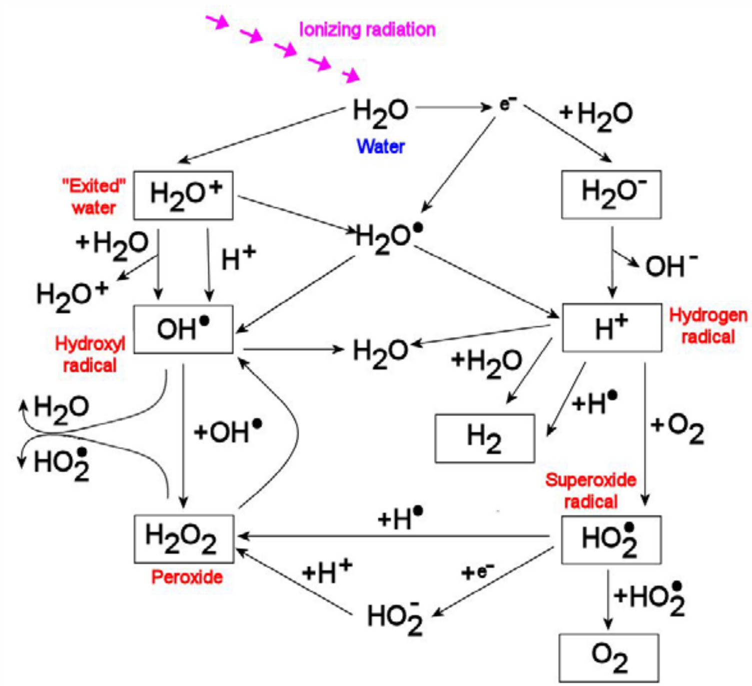
Pseudo-3D

Chemical gel dosimeters as a *true* 3D dosimeter

Chemical dosimeters - Principles

Chemical dosimeters: *information about absorbed dose is stored in the products or the changes induced by a chemical reaction*





Example: *water radiolysis*

Is of primary importance in the response of a tissue equivalent system

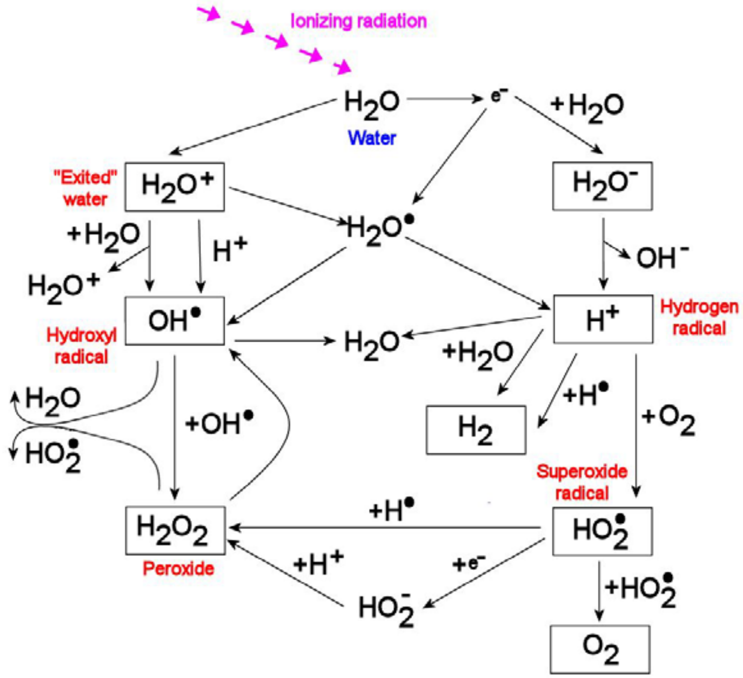
Standard Fricke dosimeter:

- aqueous solution of H_2SO_4, $FeSO_4$, NaCl

Water radiolysis creates many oxidizing species *Ox*

$$Fe(II) + Ox \rightarrow Fe(III)$$

$$Dose = \frac{\Delta A}{\rho \varepsilon l G(Fe^{3+})}$$



Fricke *gels:*

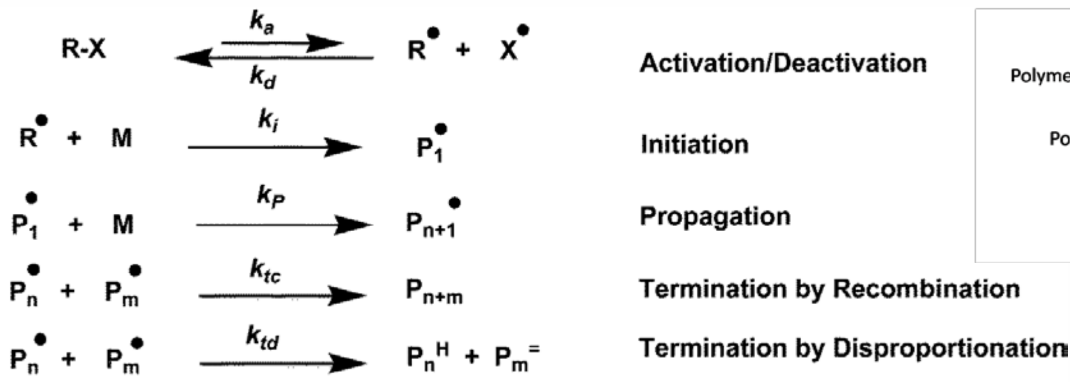
- gelatinous matrix + chelating agent (XO

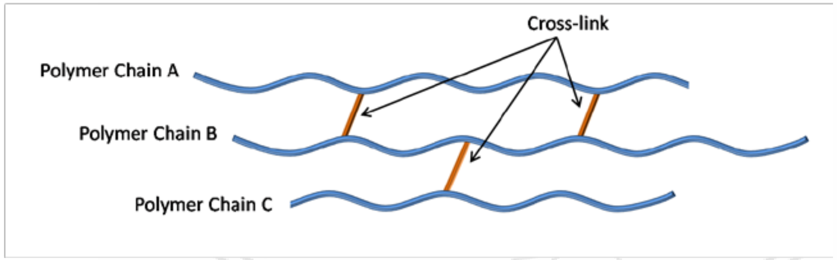
Loss of absolute response – only relative dosimetry

Chemical dosimeters - Polymeric

Polymer gel dosimeters:

- Monomers and cross-linkers in a gel matrix
- Free radical polymerization





3D

- Growing polymeric chains are immobilized in the gelatin matrix

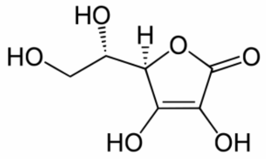
- Toxicity of monomers
- Oxygen contamination

Chemical dosimeters - Polymeric

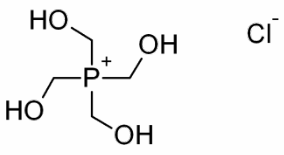
Composition	BANG-1	BANG-2	PABIC	PAC	MAGIC	VIPAR	ABAGIC	PAGAT	HEAG	MAGAS	MAGAT	nMAG	nPAG	NIPAM
Water	89.0	88.0	87.26	88.0	82.8	87.23	82.5	89.0	0.89	83.0	83.0	86.0	87.0	89.0
Gelatin	5.0	5.0	4.9	6.0	8.0	4.91	8	5.0	0.05	8.0	8.0	8.0	6.0	5.0
BIS	3.0	3.0	3.92	3.0	–	3.93	4.5	3.0	0.03	–	–	–	3.0	3.0
Acrylamide	3.0	–	–	3.0	–	–	4.5	3.0	–	–	–	–	3.0	–
Acrylic acid	–	3.0	–	–	–	–	–	–	–	–	–	–	–	–
Ascorbic acid	–	–	–	–	0.0352	–	0.0352	–	–	0.880	–	–	–	–
$CuSO_4 \cdot 5H_2O$	–	–	–	–	0.002	–	0.002	–	–	–	–	–	–	–
Hydroquinone	–	–	–	–	0.2	–	0.2	–	–	–	–	–	–	–
PEGDA	–	–	3.92	–	–	–	–	–	–	–	–	–	–	–
N–Vinyl pyrolidone	–	–	–	–	–	3.93	–	–	–	–	–	–	–	–
MAA	–	–	–	–	9.0	–	–	–	–	9.0	9.0	6.0	–	–
NaOH	–	1.0	–	–	–	–	–	–	–	–	–	–	–	–
THP	–	–	–	–	–	–	–	1.906	–	–	1.906	0.38	0.953	1.906
NIPAM	–	–	–	–	–	–	–	–	–	–	–	–	–	3.0
HEA	–	–	–	–	–	–	–	–	0.03	–	–	–	–	–

Normoxic

Antioxidants:



Ascorbic acid – Vitamin C



THPC

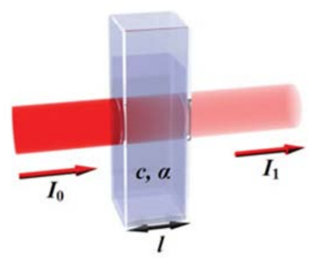
From glovebox to benchtop!

Chemical dosimeters – Optical analysis

How can we read the dosimeters?

Optical analysis

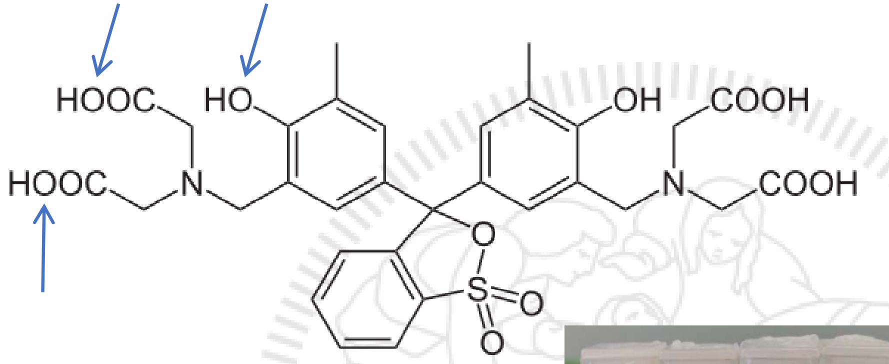
- Spectrophotometer for 1D evaluation
- Quantitative correlation Abs-D



$$Abs = -\log\left(\frac{I_0}{I_t}\right)$$

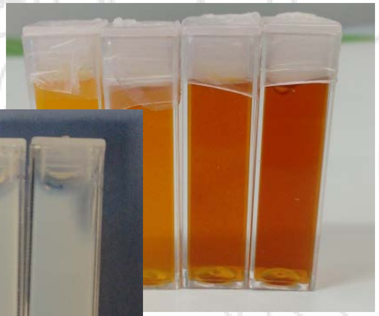
Fricke gels

Xylenol Orange chelates Fe(III)
➡ change in color



Polymer gels

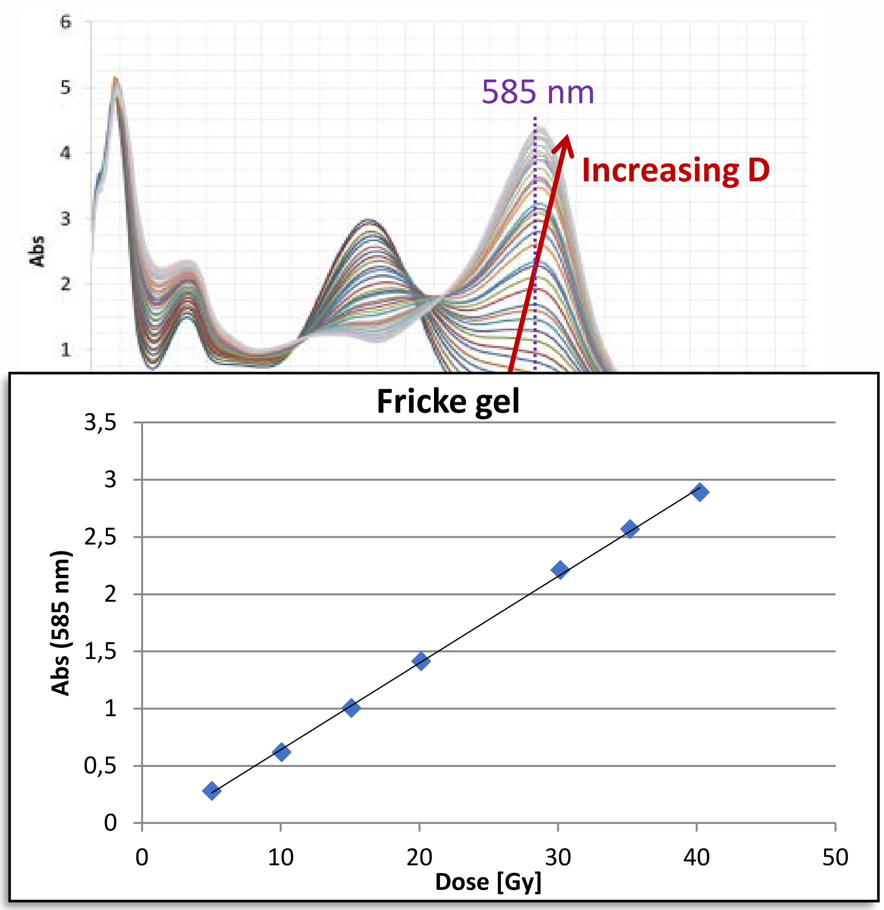
➡ growing polymer chains increase opacity



Chemical dosimeters – Optical analysis

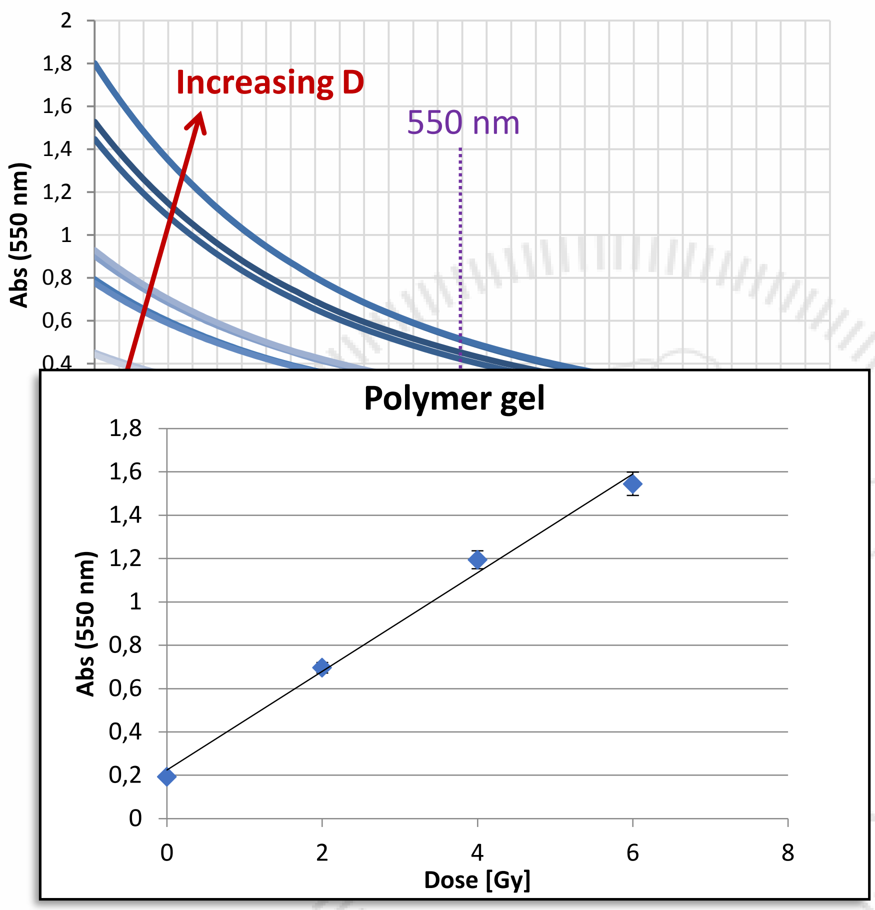
Fricke gels

- absorbance peak @ 585 nm



Polymer gels

- No absorbance peak, only scattering



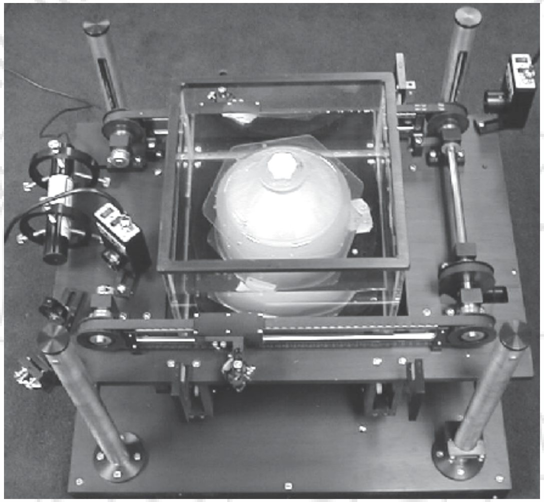
Chemical dosimeters – 3D analysis

A 3D signal requires a 3D analysis!

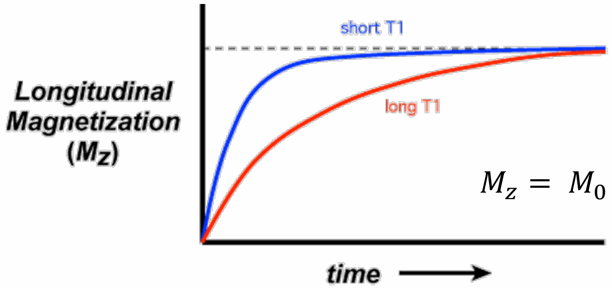
- MRI
- CT scan
- Optical tomography
- Ultrasound CT

Which method is the *best*?

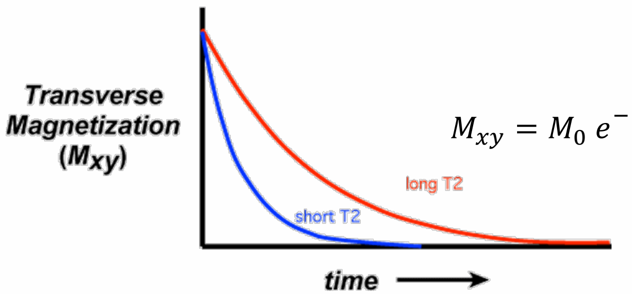
Quantitaive comparison of results from different methods is not meaningful



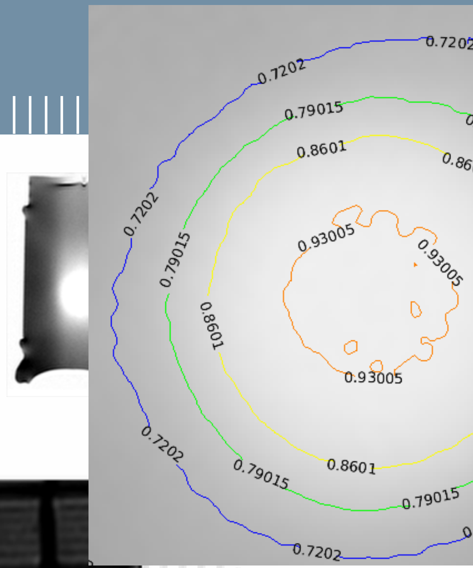
Chemical dosimeters – MRI



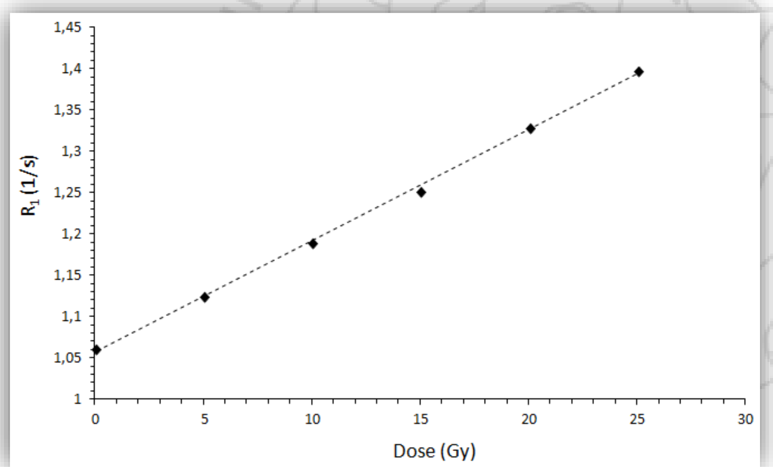
$$M_z = M_0 \left(1 - 2e^{-\frac{TI}{T1}}\right)$$



$$M_{xy} = M_0\, e^{-\frac{TR}{T2}}$$



Increasing Dose

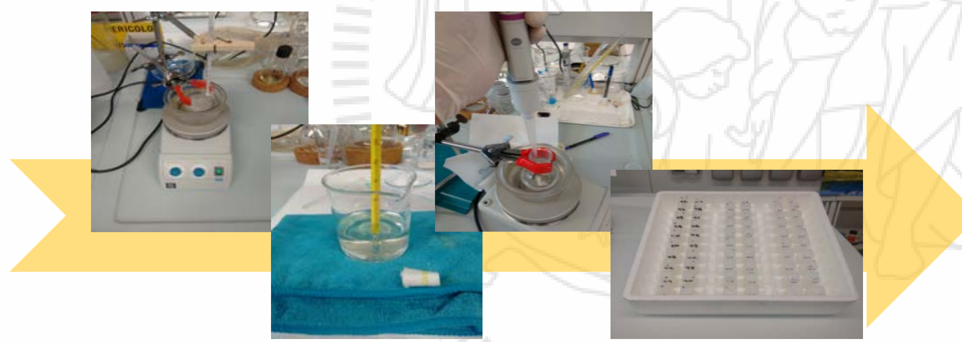


Experimental - Procedure

PAGAT	
Component	**Concentration**
Water	89% w/w
Gelatin	5% w/w
AA	3% w/w
BIS	3% w/w
THPC	10 mM

Fricke gel	
Component	**Concentration**
Agarose	1,5% w/w
Fe(II)	0,5 mM
XO	0,165 mM
H_2SO_4	25 mM
Sucrose	2 g/L

Water @45-50°C
↓
Gelatin @45°C
↓
AA/BIS @45°C
↓
THPC @37°C
↓
Transfer
↓
Refrigeration @4°C



Reproducibility

OBJECTIVES

- Dependence on energy and dose rate?
- Temporal stability

Experimental - Setup

X-ray tube

- 300 kV, 10 mA
- Avg. Energy 199 keV
- 1,4 Gy/h

^{60}Co irradiator

- 1,17 and 1,33 MeV
- 0,14 and 0,014 kGy/h

LINAC

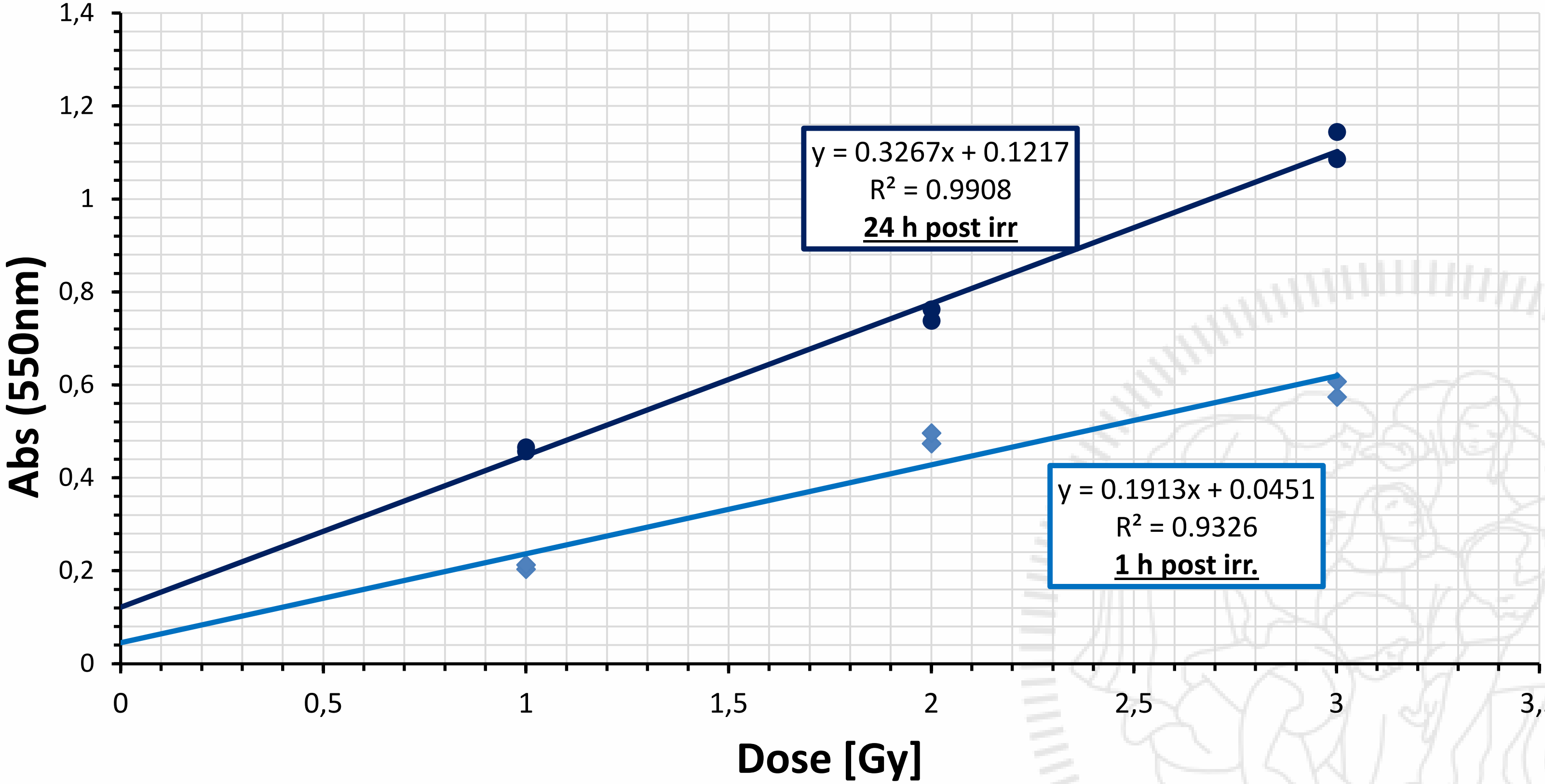
- Varian Trilogy
- 6 MV @ 600 MU/min
- 0,28 mGy/pulse

Analysis

- Spectrophotometric analysis

Results - PAGAT

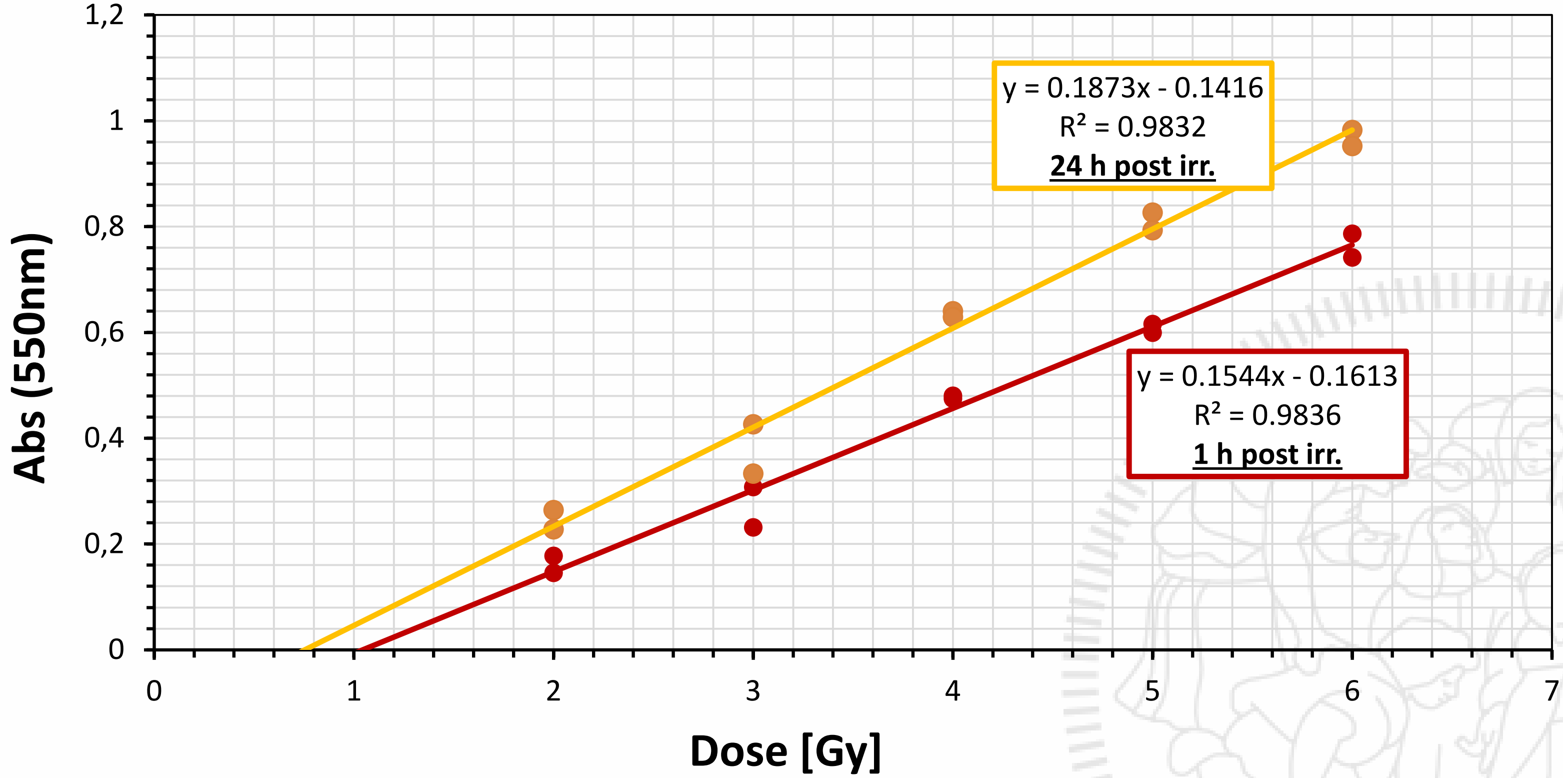
Setup: 300 kV, 10 mA @ 1,4 Gy/h **Analysis:** 1h and 24h post irradiation



- Increase of 70% in dose sensitivity and improvement of R^2

Results - PAGAT

Setup: ^{60}Co @ 0,014 kGy/h **Analysis:** 1h and 24h post irradiation

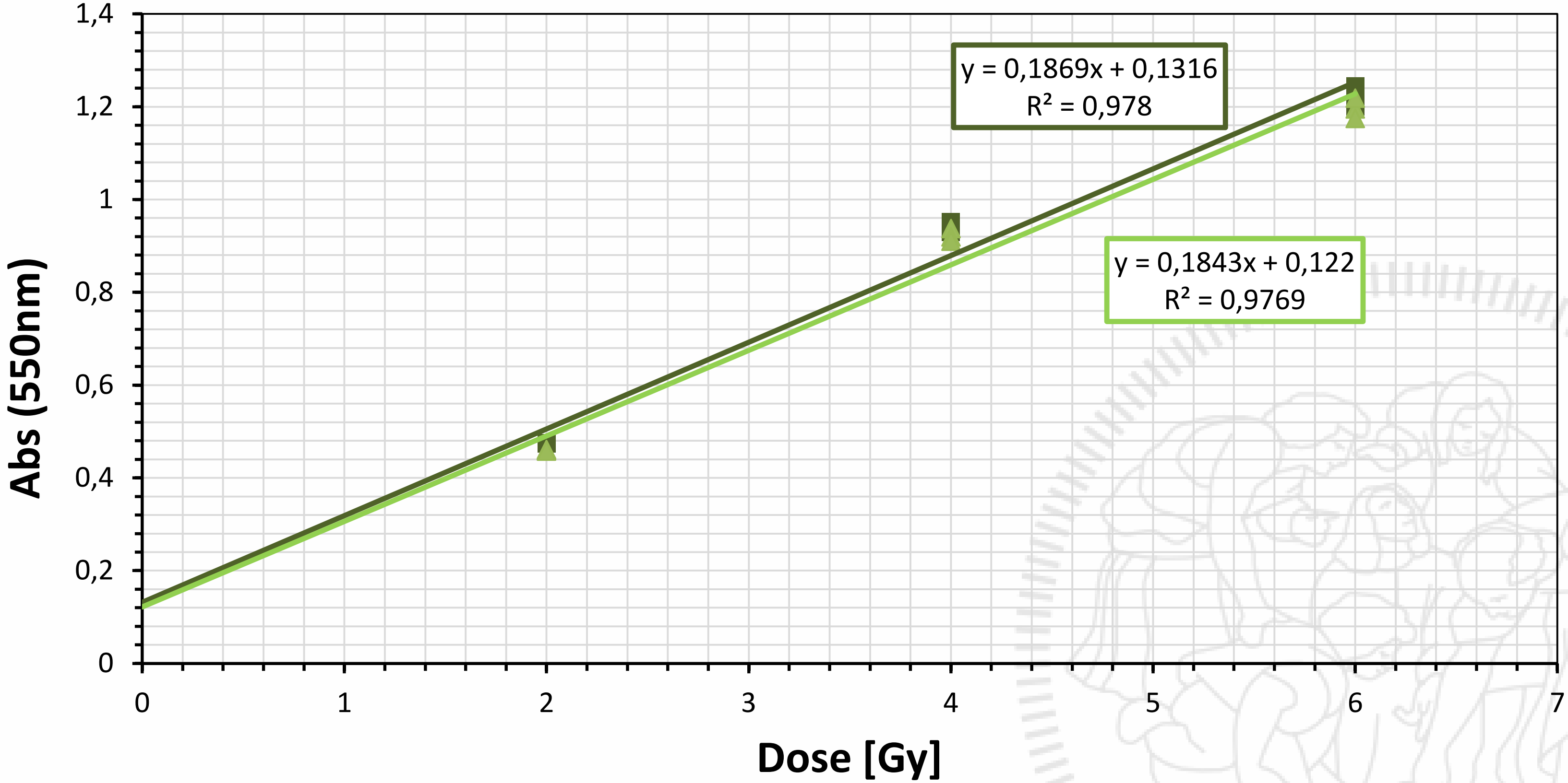


- Increase of 21% in dose sensitivity

Results - PAGAT

Setup: ^{60}Co @ 0,14 kGy/h

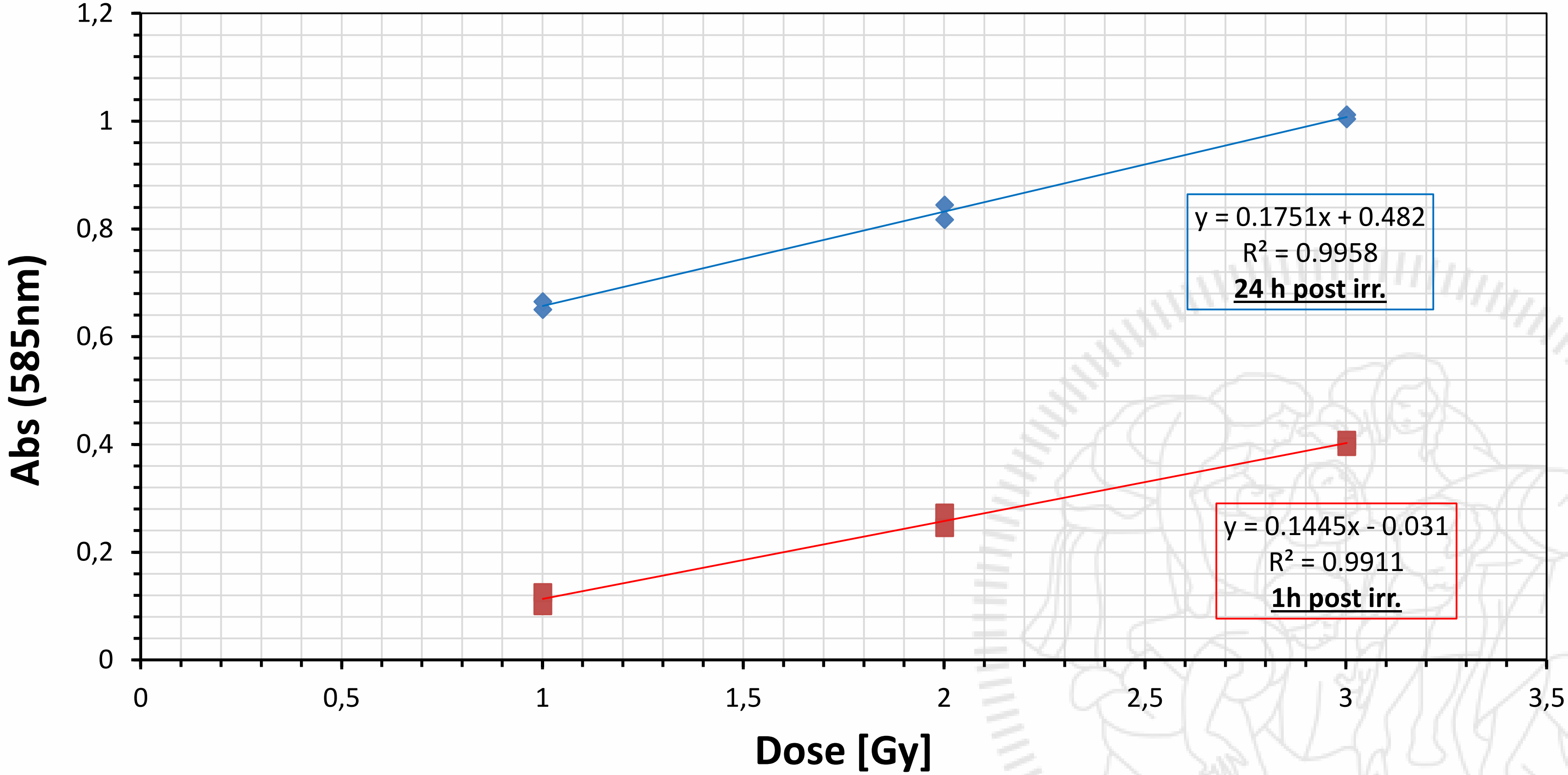
Analysis: 1h and 24h post irradiation



- Stable behavior, no major variations over time

Results – Fricke

Setup: 300 kV, 10 mA @ 1,4 Gy/h **Analysis:** 1h and 24h post irradiation

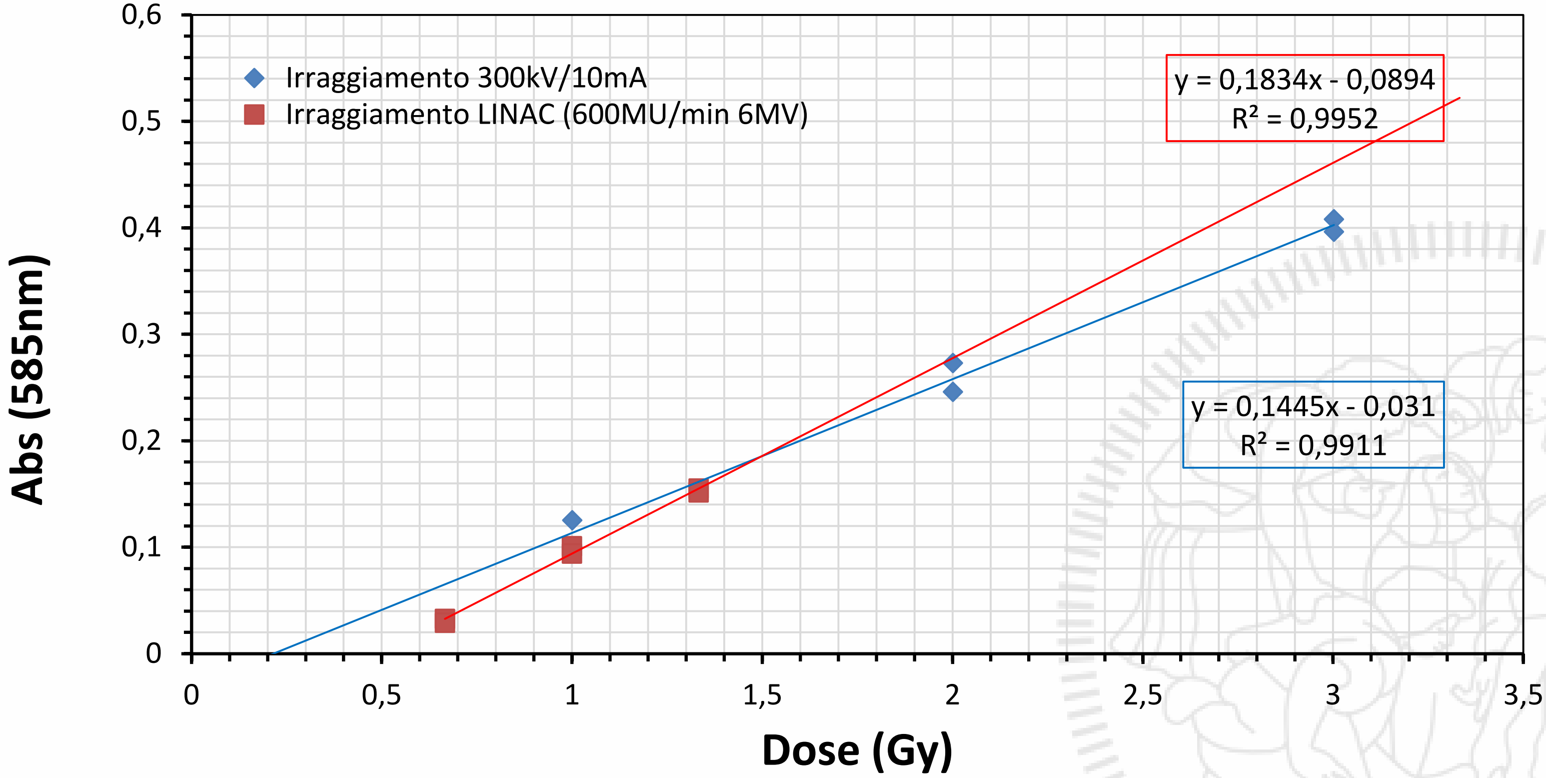


- 20% increase in dose sensitivity

Results – Fricke

Setup: 300 kV, 10 mA @ 1,4 Gy/h
LINAC 6MV @ 600 MU/min

Analysis: 1h post irradiation



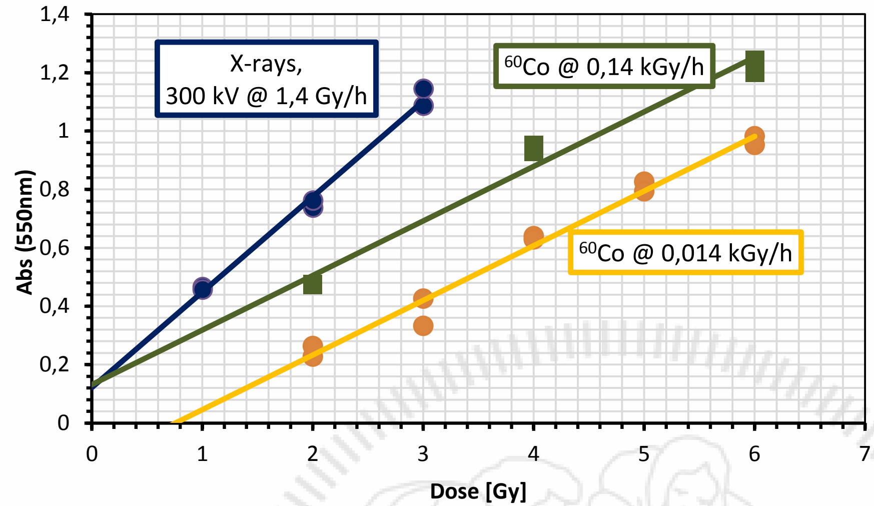
- 25% higher sensitivity for LINAC

Conclusions

Analysis at 24 h post irr.

PAGAT

Irradiation	Sensitivity @ 24 h
X-ray, 300 kV @ 1,4 Gy/h	0,3267 Gy^{-1}
^{60}Co @ 0,014 kGy/h	0,1873 Gy^{-1}
^{60}Co @ 0,14 kGy/h	0,1869 Gy^{-1}



- Inverse relationship between Energy and Sensitivity
- Minor dependence on dose rate at fixed energy

Fricke

- Increase in sensitivity with Energy and Dose rate

Future Developments

- More Energies & Dose rates *vs* Sensitivity, LOD, LOQ Dose Resolution
- Different radiation sources: e^-, protons, C ions
- Absolute response
- Behaviour of small *vs* big volumes

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