Medical radiation dosimetry: some resent developments at Kaunas University of Technology

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Research areas at KTU

- **New materials for high technologies**
- Smart environments and information technologies
- Technologies for sustainable development and energetics
- **Diagnostic and measuring technologies**
- Sustainable growth and cohesive social development

Education and training at KTU

Number of study programs

- 42 at BSc level
- 54 at MSc level
- 19 at PhD level

The only MSc program in Health sciences is **Medical physics**, which is being implemented since 2003

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Research groups at Physics Department

Department of Physics

Reactive Gas Plasma Interaction with the Surfaces of Solids
Prof. dr. A.MARCINAUSKAS

Thin Solid Films, Surface Science and Physical Technologies for Hydrogen Energy
Prof. dr. G. LAUKAITIS

Radiation and Medical Physics
Prof. dr. D. ADLIENĖ

Phenomena in Heterogeneous Structures
Prof. dr. habil. S. TAMULEVIČIUS

Modeling of Heterogeneous Processes at the Surfaces of Solids
Prof. dr. habil. A. GALDIKAS

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Our team

PhDs:

D.Adlienė

J.Puišo,

N.Vaičiūnaitė,

J.Laurikaitienė,

B.G.Urbonavičius,

&

PhD students:

E.Jaselskė,

L.Gilys,

A.Ševčik,

A.Jreije,

M.Merkis

Research group “Radiation and medical physics”

Main research focus of our group

Radiation impact on environment, materials and individuals and its assessment methods

General research activities:

- Development of the new dose registration methods and techniques
- Personalized dosimetry in radiation treatment of patients, particularly in vivo dosimetry;
- Development of new materials and devices for radiation medicine applications ;
- Radiation protection and safety in medical field;
- Environmental contamination with technological radionuclides.

Main research focus of our group

Radiation impact on environment, materials and individuals and its assessment methods

Recent project activities (in collaboration with the Lithuanian University of Health Sciences :

2017-2019	Development of 3D phantom for individualized dosimetry in radiotherapy
2020	Development of a system for the evaluation of an external hand exposure of nuclear medicine personnel;
2020-2021	Development of neurosurgical treatment options for Parkinson`s disease applying molecular markers, gamma knife technology and individualized dosimetry;
2021	Implementation of dosimetry methods in gamma knife radiosurgery for the treatment of cerebral arteriovenous malformations after endovascular embolization

We are collaborating
with all Cancer treatment centers in Lithuania

Towards individualized medical treatment of patients

Individualized medicine is a key issue in a health sector recently.

Individualization in radiation medicine may be achieved:

- Exploring individual bio, molecular and genetic data of patient;
- Implementing patient suitable treatment and diagnostic method and equipment;
- Implementing individual patient phantoms for in vitro dose measurements;
- Implementing dose in vivo measurement concept during radiation treatment procedures;
- Adjusting and verifying dose treatment plans according the results of experimental dosimetry and independent theoretical simulations ;
- Implementing elements od AI and exploring advantages of machine based learning applications.

Individualized dosimetry

- Dose received by a patient during radiation therapy or radiology procedures is directly linked to radiation induced effects in biological tissues thus indicating the health risks for irradiated persons.
- Dose should be precisely delivered, optimized and the radiation induced harm should be as low as possible.
- The “responsibility” for dose assessment is addressed to dose measuring devices and dose evaluation method - all in one called “dosimetry”.

Recently only chemical dosimeters are fulfilling the requirement to provide information regarding volumetric (3D) dose distribution.
Dose gels are among them.

Why gel dosimetry?

- Conventional methods of patient dosimetry are either single point dosimetry (e.g. TLD's, ion chambers, diods, MOSFETs etc.) or 2-D dosimetry (film)

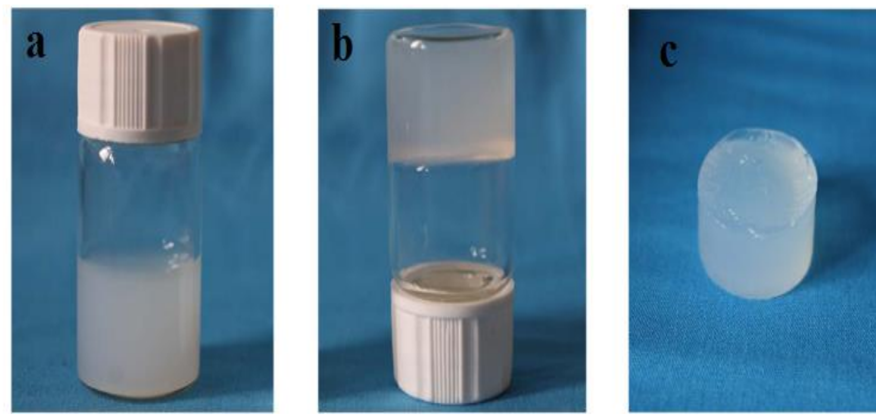
- Complex radiotherapy treatments (e.g., conformal therapy and brachytherapy) require 3-D measurements.

- Monte Carlo simulation is known to be capable of high accuracy … *but* … we still need experimental verification that delivery occurred as expected.

Polymer dose gels in medicine

Dosimetric gels are crosslinked networks of polymers which behave as viscoelastic solids.

- <u>These dosimeters record the radiation dose distribution in 3D.</u>
- <u>Polymerized gel can be treated as a 3D phantom</u>
- <u>Polymer dose gel is human tissue equivalent.</u>



<u>Potential applications</u>

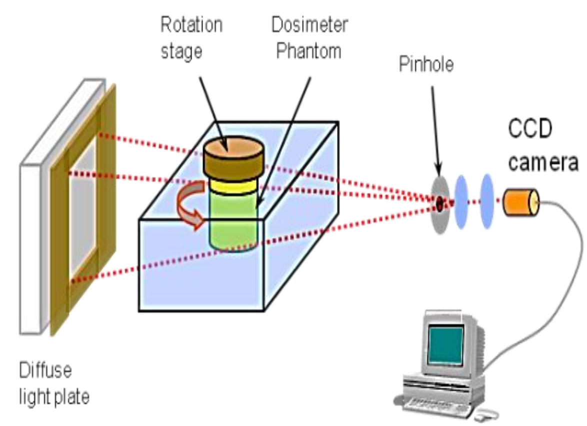
- Low-energy X-ray
- High-linear energy transfer (LET)
- Proton therapy
- Radionuclide therapy
- (Boron) neutron capture therapy
- Intensity-modulated radiation therapy (IMRT)
- Stereotactic radiosurgery
- Brachytherapy dosimetry

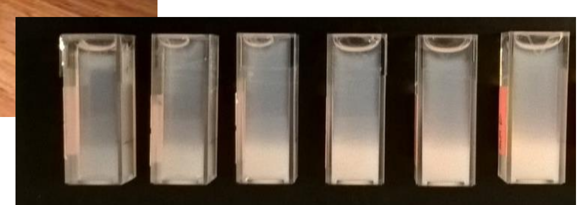
Principal steps of gel dosimetry

The radiation sensitive gel is fabricated and poured into an container, phantoms and associated calibration vials.

The container, phantom and associated vials are irradiated.

After polymerization the gel is scanned by imaging technique, and the acquired images are subsequently analyzed.



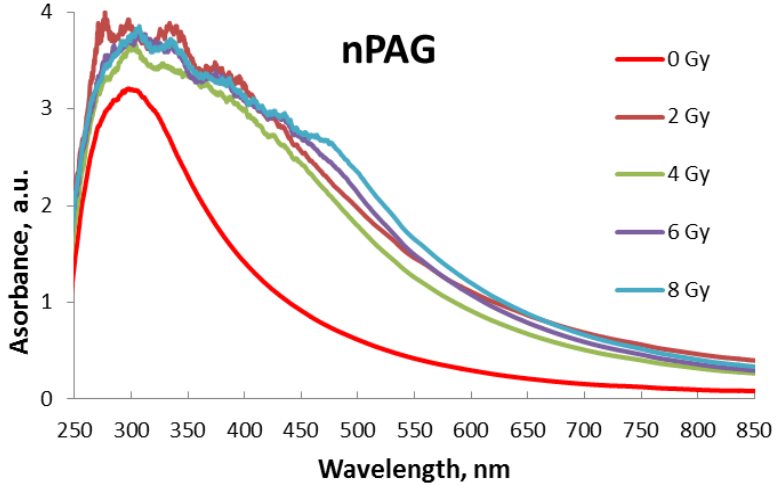


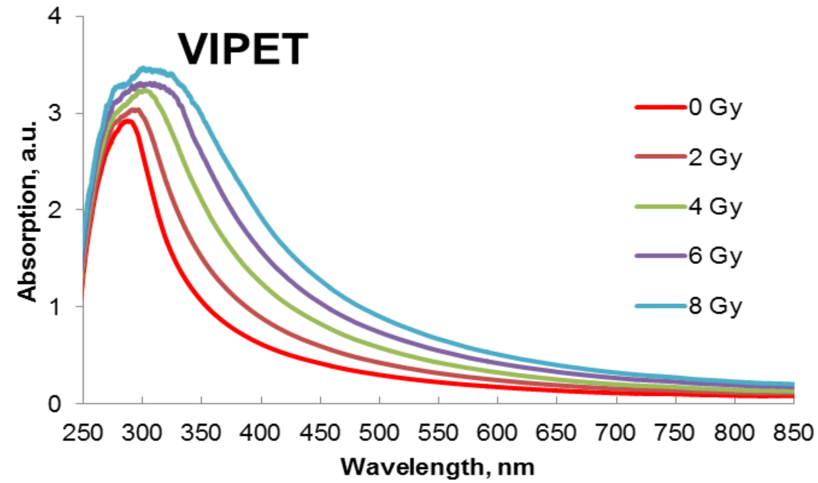
Dose evaluation methods

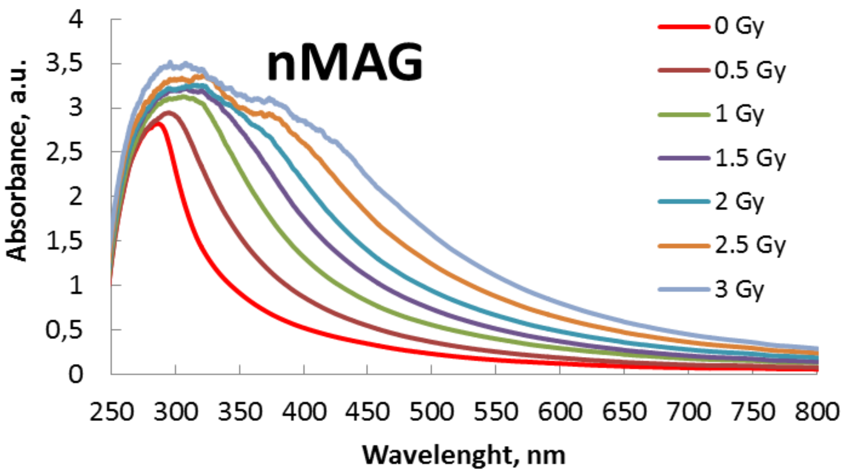
- Magnetic resonance imaging;
- Optical imaging;
- Computed tomography;
- Ultrasound;
- SEM and TEM scanning microscopy;

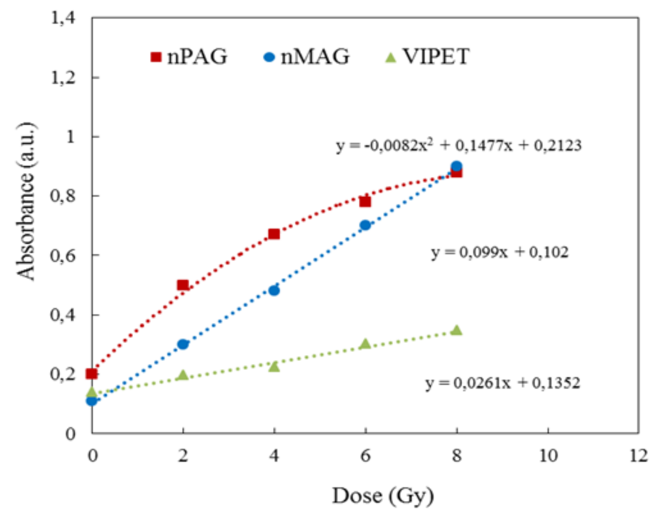
etc.

Irradiation of dose gels with gamma photons (Co-60)



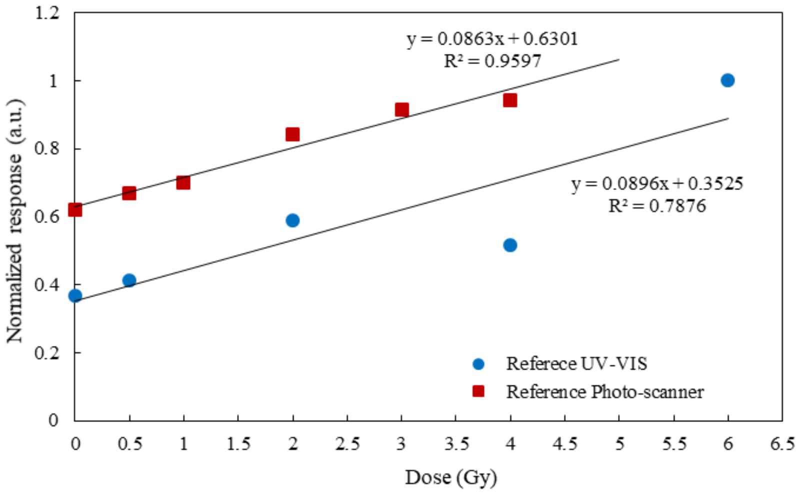




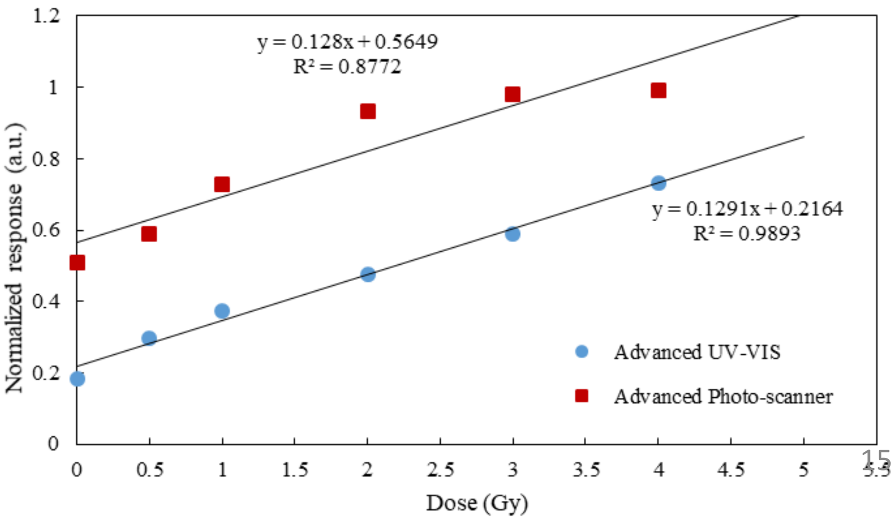


Gels response to irradiation dose

Comparison of reference and advanced nMAG gel sensitivity

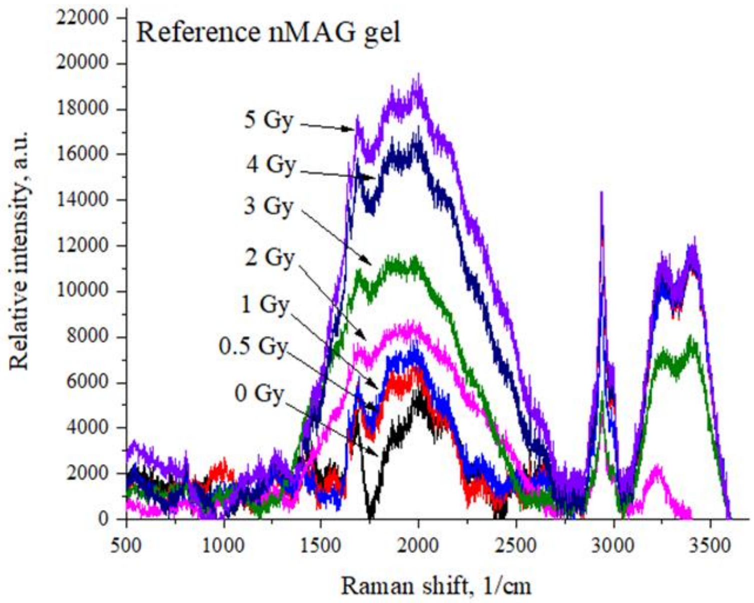


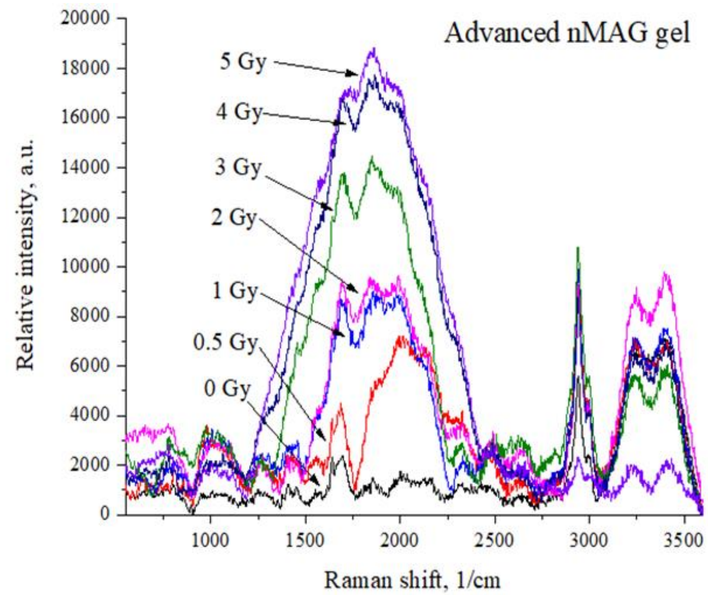
Dose response of reference nMAG gel investigated by UV-VIS spectroscopy and photo-scanning methods



Dose response of advanced nMAG gel investigated by UV-VIS spectroscopy and photo-scanning methods
(increased amount of MAA – 8%, reduced amount of gelatine – 6%)

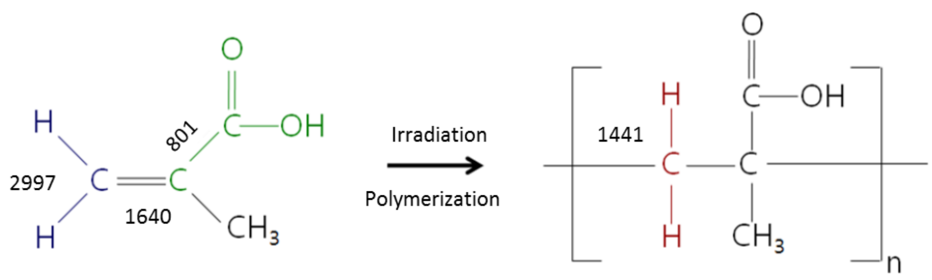
Raman spectra of nMAG gels



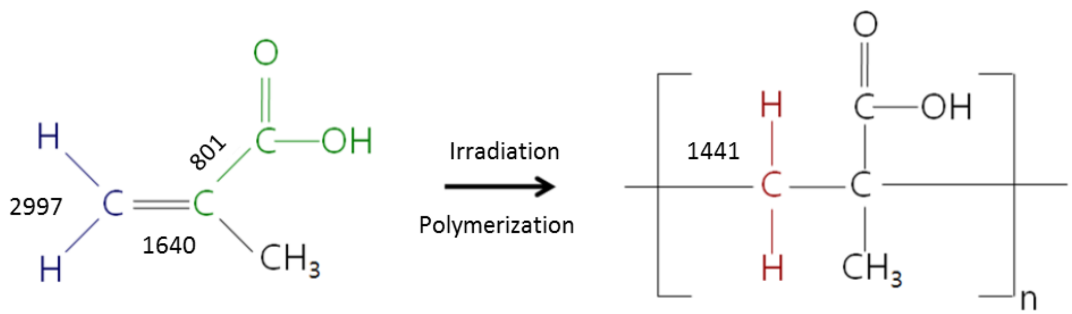


801cm^{-1}- ν (C-COOH), **1411 cm^{-1}- δ (CH_2),** 1441 cm^{-1}- ν $(CO)_s$, **1640 cm^{-1}- ν (C=C),** 2940 cm^{-1} and 2997 cm^{-1}- ν $(CH_2)_s$.

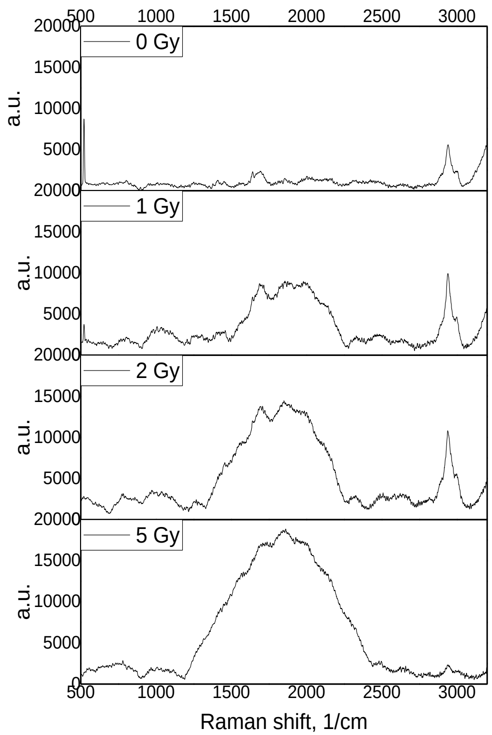
809 cm^{-1}- ν (C-COOH), **1414 cm^{-1}- δ (CH_2),** 1450 cm^{-1}- ν $(CO)_s$, **1687 cm^{-1}- ν (C=C),** **2937 cm^{-1}** and 2997 cm^{-1}- ν $(CH_2)_s$



Raman spectra of nMAG gels

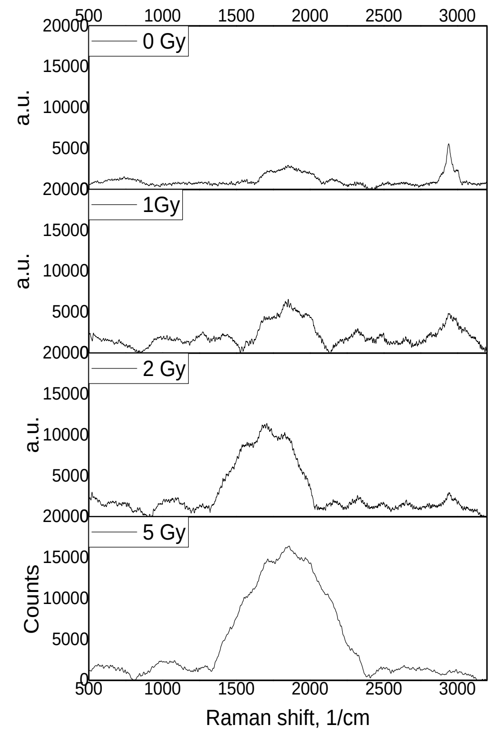


Photons



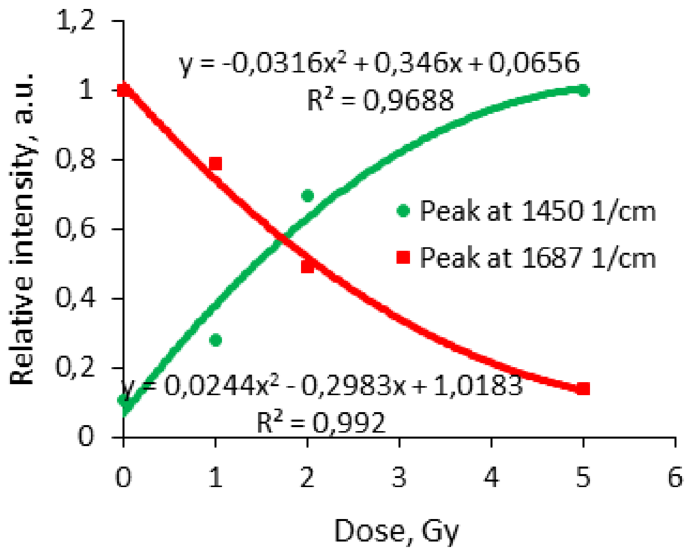
809 cm^{-1}- ν (C-COOH),
1414 cm^{-1}- δ (CH_2),
1450 cm^{-1}- δ (CH_2), PMA
1687 cm^{-1}- ν (C=C),
2937 cm^{-1} - ν (CH2)s
2997 cm^{-1}- ν $(CH_2)_s$

Protons

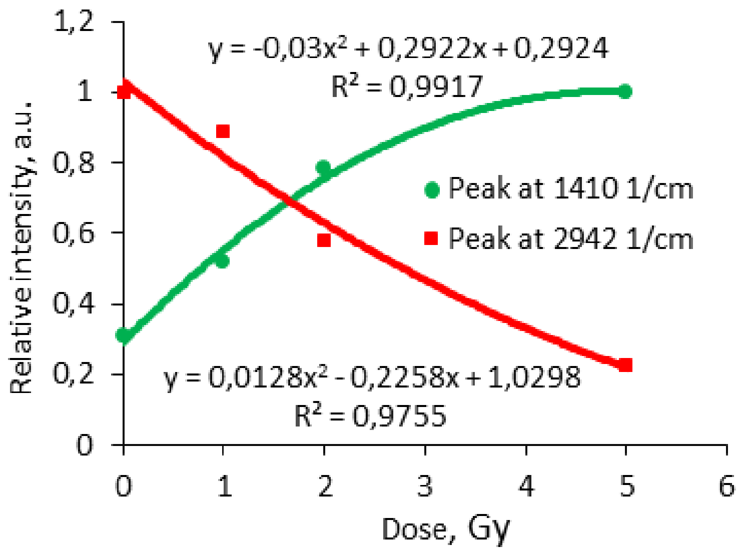


771 cm^{-1}- ν (C-COOH),
1410 cm^{-1}- δ (CH_2), PMA
1695 cm^{-1}- ν (C=C),
2942 cm^{-1} - ν $(CH_2)_s$

Raman spectra of nMAG gels



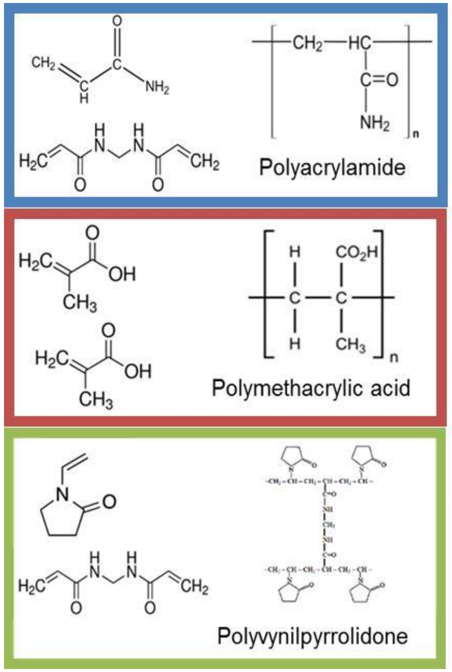
Monomer consumption and polymer formation in photon irradiated nMAG gels



Monomer consumption and polymer formation in proton irradiated nMAG gels

Development of dose gels with enhanced sensitivity to various irradiation beams

Fabrication → **Irradiation** → **Evaluation**



Basic constituents of dose gels	nPAG	nMAG	VIPET
Water Highly purified distilled (HPLC grade)	+	+	+
Gelatin From porcine skin (300 bloom)	+	+	+
Monomers: Acrylamide; Methacrylic acid; N-vinylpyrrolidone	+	+	+
Cross-linker N,N- methylene-bis-acrylamide	+	-	+
Oxygen scavenger Hydroxymethyl phosphonium chloride	+	+	+
Specific ingredients	+	+	+

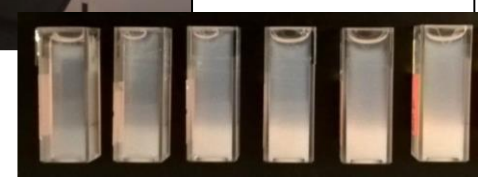
Radiotherapy beams:

- 15 MeV photons;

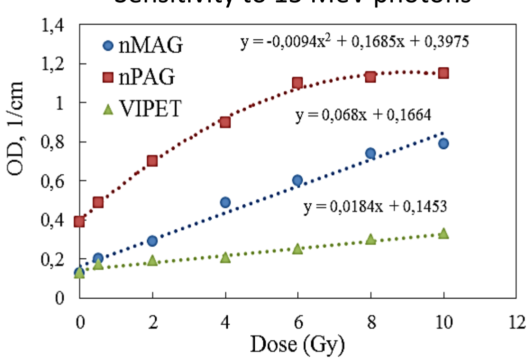
Gamma rays (Co-60);

- 16 MeV electrons;

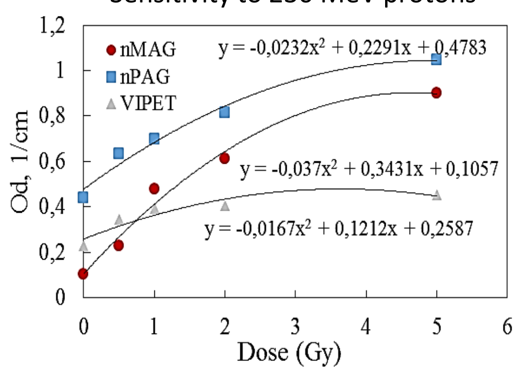
230 MeV protons



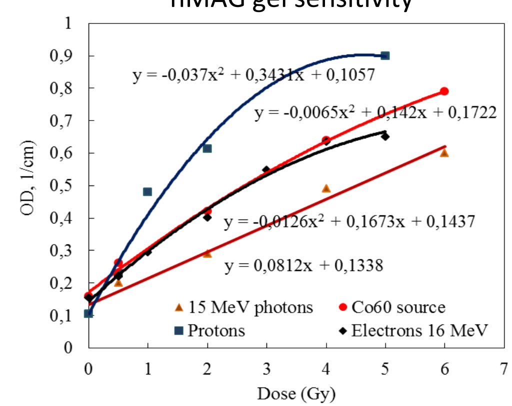
Sensitivity to 15 MeV photons



Sensitivity to 230 MeV protons

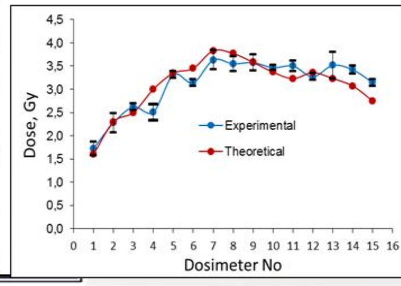


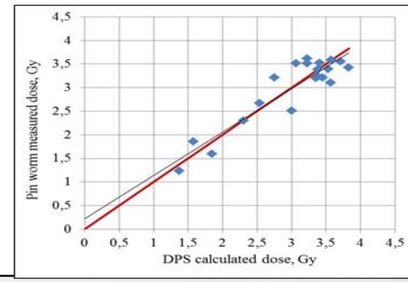
nMAG gel sensitivity

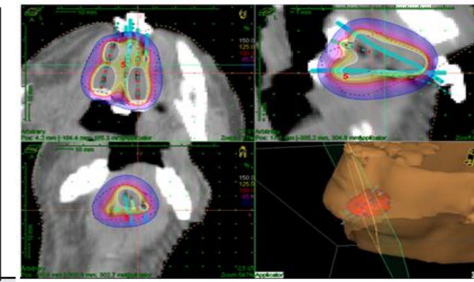


In vivo dosimetry in catheter based interstitial HDR brachytherapy

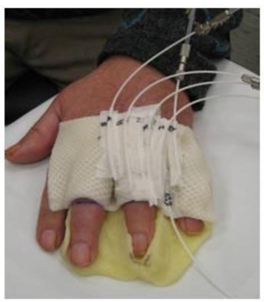
Dose measurements using **TLD (LiF:Mg, Cu, P)** pin worms (ø 0,5 mm; 2,5 mm) inserted into catheters during HDR brachytherapy procedure (^{192}Ir source)

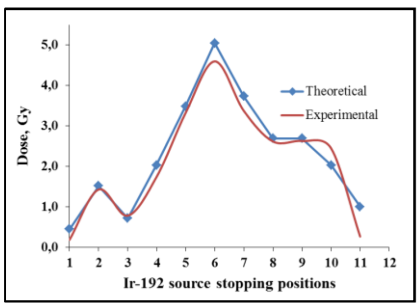


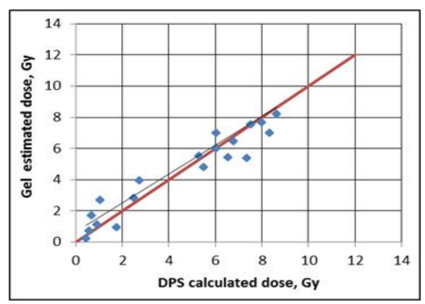


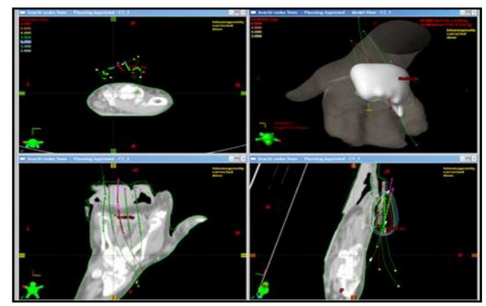


Dose measurements using **catheters filled with nPAG dose gel** during HDR brachytherapy procedure (^{192}Ir source)

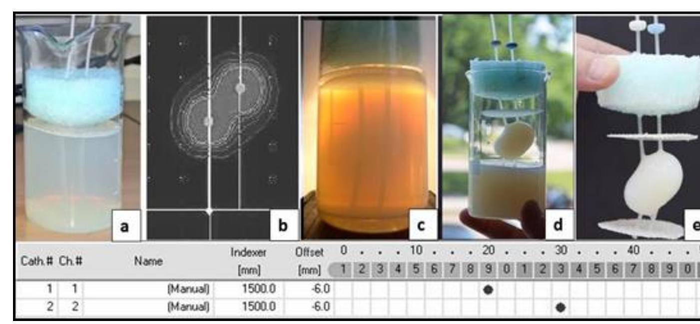








Concept of ionzing radiation based 3D printing: Free standing dose gels for simulation of irradiated tumor shapes



1. Adlienė, D. et al. First approach to ionizing radiation based 3D printing: fabrication of free standing dose gels using high energy gamma photons. NIMB (2018) 435, p. 246-250.
2. Jaselskė, E. et al. In vivo dose verification method in catheter based high dose rate brachytherapy. Physica Medica (2017) 44, p. 1-10.
3. Adlienė, D. et al. In vivo TLD dose measurements in catheter-based high-dose-rate brachytherapy. RPD (2015) 165 (1-4) p. 477-481.

Radiation induced 3D printing of free standing dose gel shapes

Polymerized gel after irradiation with Ir-192 source.

Doses in three catheters delivered at the different height from the bottom are: 5Gy, 6Gy and 7Gy).

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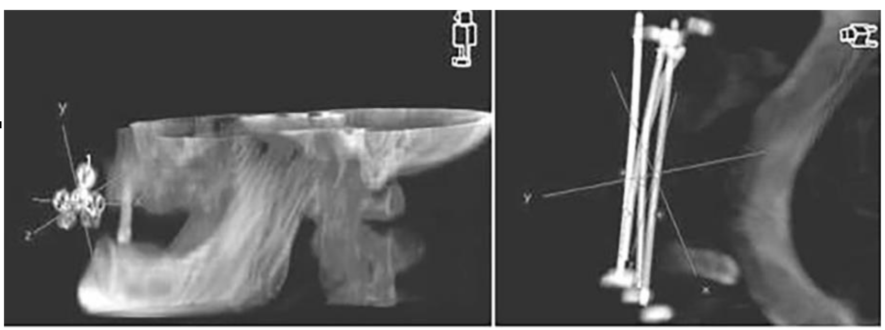


Squamous cell carcinoma of the lip

Currently active research areas in dose gels

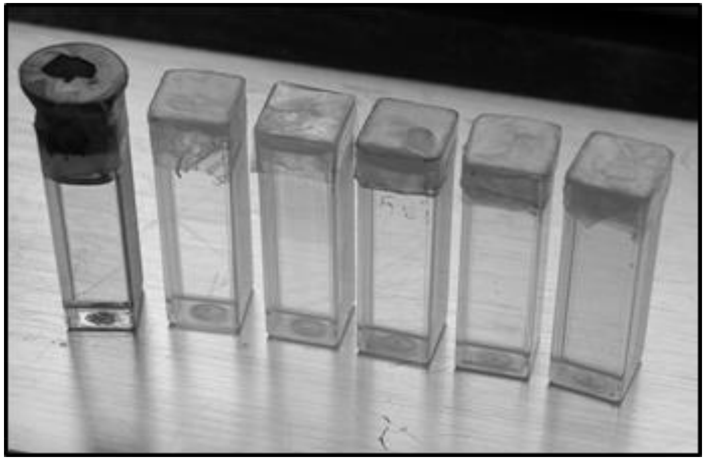
- Understanding in details how the gels work $\Rightarrow$ physical chemistry;
- Development of new types of polymer gels (free standing; not spoiled by oxygen; sensitive to different types of irradiation...)
- Development of new imaging modalities (optical methods, ultrasound…)

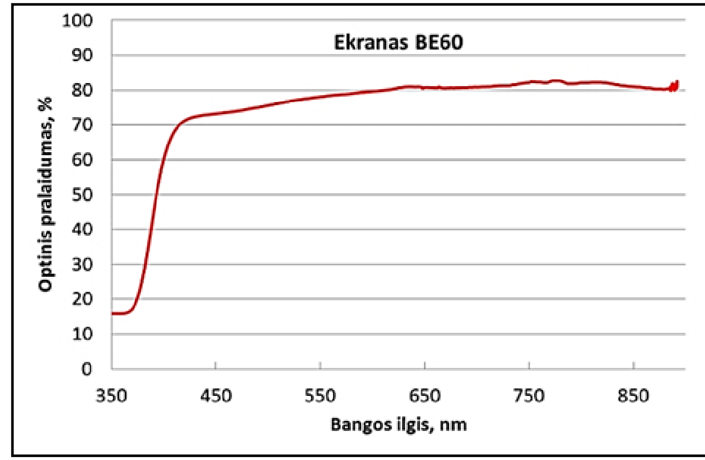
We are working on:

- gel sensitivity issues for specific dose gel application in radiotherapy (LINACs, Co-60 units, proton accelerators and especially in brachytherapy and neutron capture therapy);
- Free standing dose gel investigations is another key point of our research

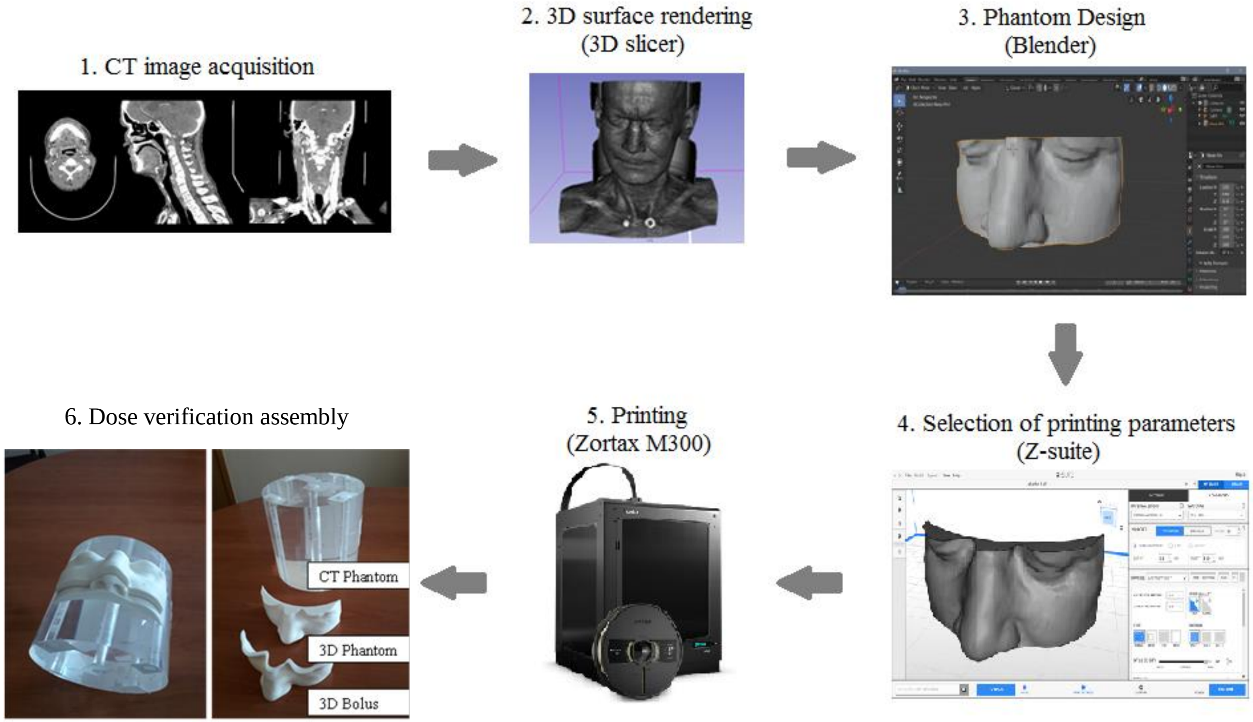
We are also interested in new collaborations!

Lead free nanocomposites for radiation shielding



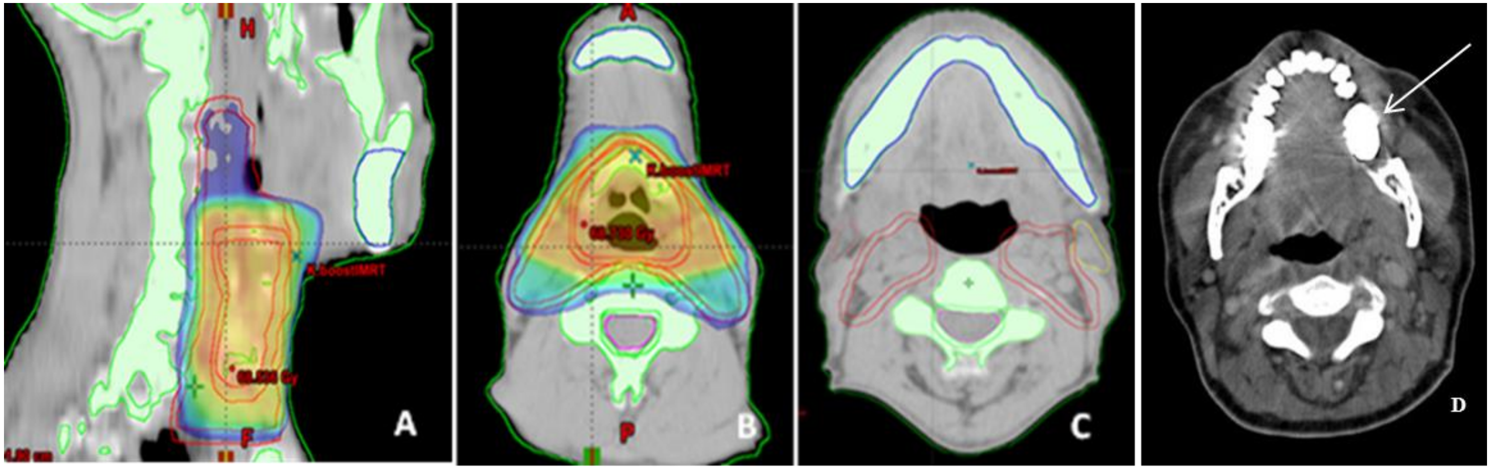


Development of patient specific 3D printed phantom/bolus for dose verification in radiotherapy



Development of patient specific 3D printed phantom for dose verification in radiotherapy

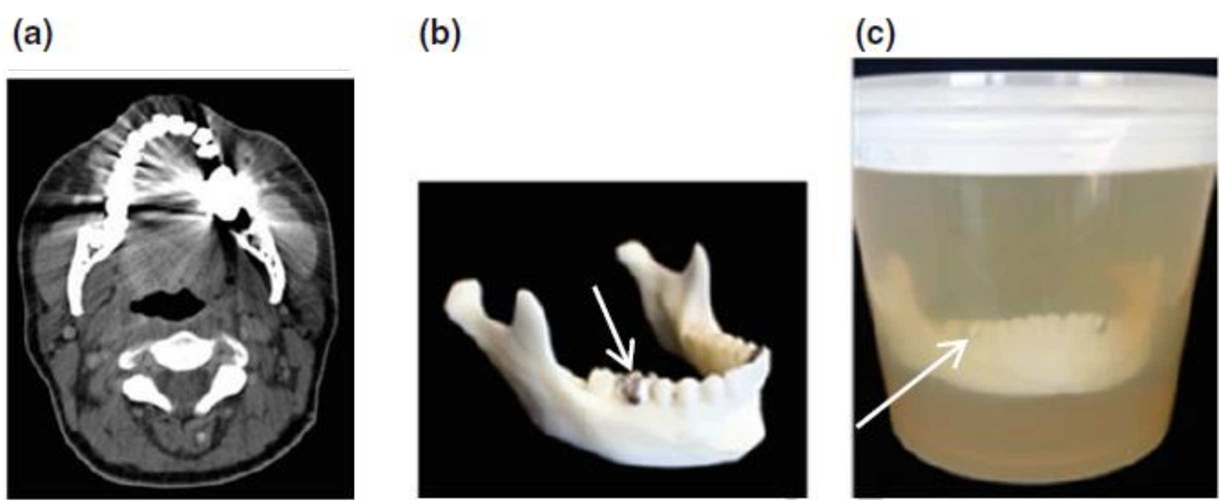
Clinical case with laryngeal squamous cell carcinoma was selected for investigation taking into account that CT images of the lower jaw of this patient indicated presence of metal tooth. This clinical case is very sensitive due to the risk of osteoradionecrosis (ORN) in relation to the dose absorbed in the lower jaw.



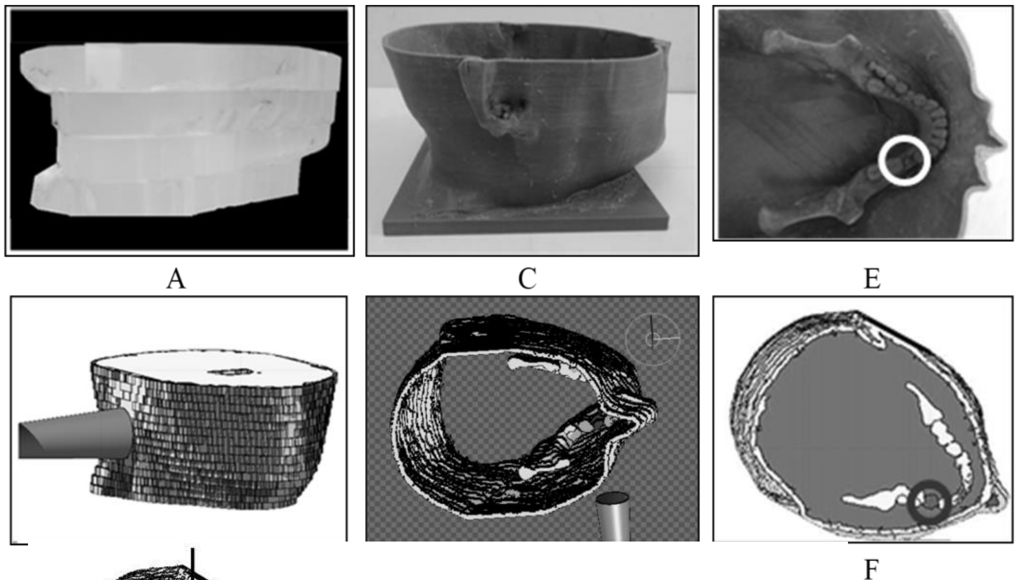
Clinical case: laryngeal squamous cell carcinoma: a - dose distribution in sagittal view; b - dose distribution in transversal view; c - transversal view with marked parotid glands; d - CT image with masked scattering effect due to the presence of metal tooth.

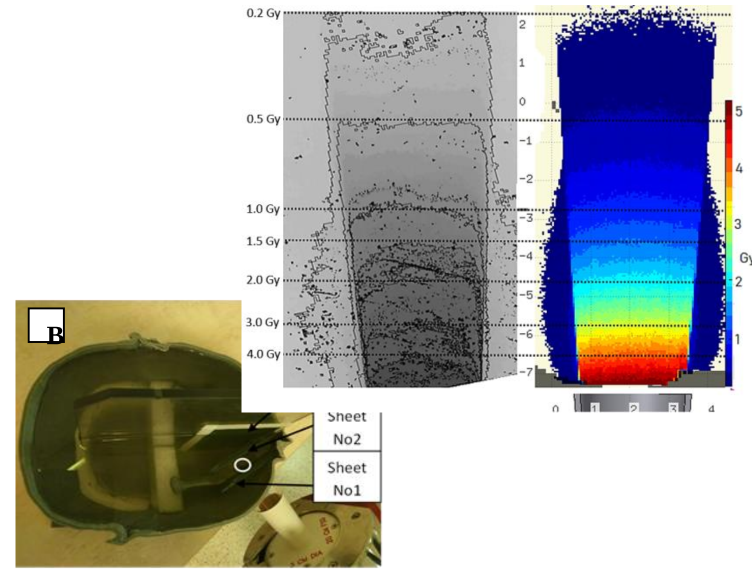
Development of patient specific 3D printed phantom for dose verification in radiotherapy

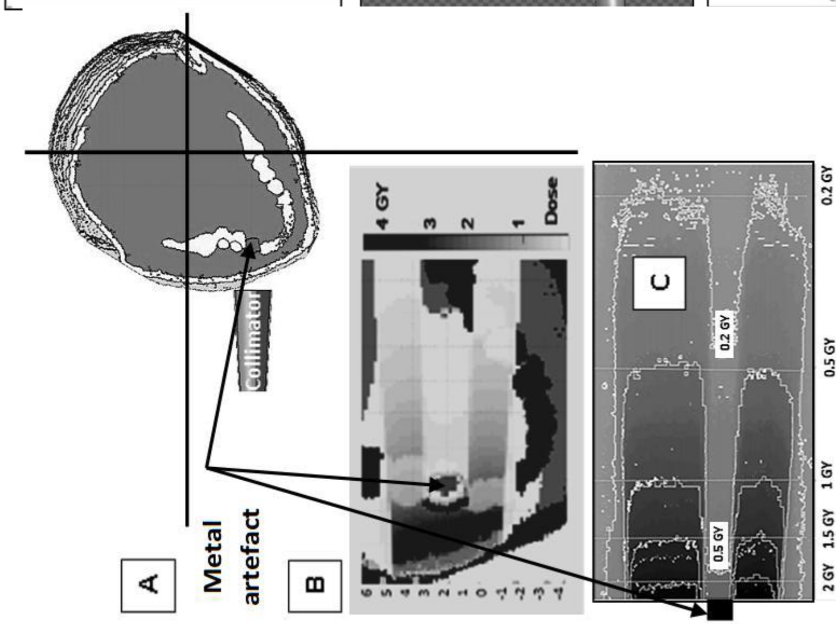
- Patient specific 3D model of lower jaw including teeth has been proposed and fabricated using 3D printing technique;
- 3D printer ZORTRAX M300, FDM (fused deposition modelling) technology was used for printing of anatomical parts;
- The possibility to insert metal artefacts (metal dental crowns, implants and dental restoration materials "LEGO type construction" was also foreseen.

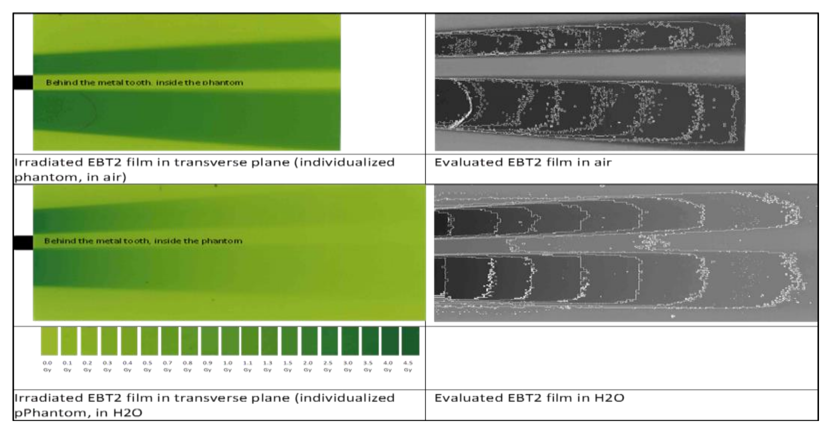


Comparison of the MC package FLUKA based modeling results with those obtained from irradiated gafchromic films.









thank you