



KNJIGA SAŽETAKA

Book of Abstracts

5. SKUP MLADIH HRVATSKOG
DRUŠTVA ZA ZAŠTITU OD
ZRAČENJA

5th Young Professionals Meeting
of the Croatian Radiation
Protection Association



Zagreb, Hrvatska / Croatia
INSTITUT ZA MEDICINSKA ISTRAŽIVANJA I MEDICINU RADA
Institute for medical research and occupational health

6. ožujka 2026.

March 6th 2026



5. SKUP MLADIH HRVATSKOG DRUŠTVA ZA ZAŠTITU OD ZRAČENJA

5th Young Professionals Meeting of the Croatian Radiation Protection Association

Znanstveno-organizacijski odbor / *Scientific and Organizing Committee*

Ante Matanić
Ivana Landripet
Helena Biljanić
Luka Pasariček
Galla Uroić
Marta Kolarek
Anita Crnov
Marko Gerić
Petra Tagliaretti
Tea Čvorišćec
Dragutin Hasenay

Organizator / *Organizer*

HRVATSKO DRUŠTVO ZA ZAŠTITU OD ZRAČENJA
Croatian Radiation Protection Association

Urednici / *Editors*

Helena Biljanić, univ. mag. appl. chem.
Dr. Ivana Landripet, PhD

Mjesto održavanja Skupa / *Meeting Venue*

Institut za medicinska istraživanja i medicinu rada (IMI)
Institute for medical research and occupational health
Ksaverska cesta 2
Zagreb
Hrvatska / Croatia

Uvodna riječ / Foreword

Pred vama je zbornik sažetaka 5. skupa mladih Hrvatskog društva za zaštitu od zračenja, održanog 6. ožujka 2026. godine na Institutu za medicinska istraživanja i medicinu rada (IMI) u Zagrebu. Skup je okupio 52 sudionika, od kojih 44 uživo, uz 8 online sudionika, uz 17 izlaganja održanih kroz tri tematske sekcije.

Ovogodišnji skup posebno je obilježilo međunarodno sudjelovanje – online uključenje kolegice Ksenije Kostjučenko iz Ukrajine, koja je održala pozvano predavanje o trenutnoj situaciji u Černobilu. Njezino predavanje bilo je dio sekcije posvećene obljetnicama nesreća u Černobilu i Fukušimi – 40 godina od Černobila i 15 godina od Fukušime – čime smo željeli podsjetiti na važnost kontinuiranog učenja iz prošlih nesreća te na aktualnost teme zaštite od zračenja u suvremenom svijetu.

Program je obuhvatio širok spektar tema – od radiolitičke sinteze naprednih nanomaterijala za biomedicinske primjene, preko kliničke dozimetrije u radioterapiji, do istraživanja vezanih uz ponašanje radionuklida u okolišu i razvoja novih detektorskih sustava. Sva izlaganja pokazala su visoku razinu znanstvene i stručne izvrsnosti mladih istraživača iz različitih institucija.

Na kraju skupa održan je sastanak mladih HDZZ-a na kojem je Galla Uroić izabrana za novu predstavnicu mladih HDZZ-a, naslijedivši Antu Matanića koji je tu dužnost obnašao od 2020. do 2026. godine. Ovim putem joj čestitamo i želimo puno uspjeha u daljnjem radu, a sve mlade članove pozivamo da se aktivno uključe u rad Društva.

Organizatori zahvaljuju domaćinima s Instituta za medicinska istraživanja i medicinu rada te svima koji su na bilo koji način pomogli u organizaciji skupa. Posebna hvala članovima Organizacijskog odbora – bez njihovog entuzijazma, predanog rada i brojnih sastanaka ovaj skup ne bi bio moguć.

Vjerujemo da će čitatelji u ovom zborniku naći korisne informacije i poticaj za svoj znanstveni i stručni rad u području znanosti o zračenju te zaštiti od zračenja. Svim sudionicima skupa želimo uspješan rad i ugodno druženje.

This book of abstracts presents the contributions to the 5th Young Professionals Meeting of the Croatian Radiation Protection Association (CRPA), held on March 6, 2026, at the Institute for Medical Research and Occupational Health (IMI) in Zagreb. The meeting gathered 52 participants, of whom 44 attended in person, alongside 8 online participants, with 17 presentations delivered across three thematic sessions.

This year's meeting was particularly marked by international participation – an invited online lecture by Ksenia Kostyuchenko from Ukraine, who provided valuable insights into the current situation at Chernobyl. Her lecture was part of a special session dedicated to the anniversaries of the Chernobyl and Fukushima accidents – 40 years since Chernobyl and 15 years since Fukushima – serving as a reminder of the importance of learning from past accidents and the relevance of radiation protection in today's world.

The program covered a wide range of topics – from the radiolytic synthesis of advanced nanomaterials for biomedical applications and clinical dosimetry in radiotherapy, to research on the behavior of radionuclides in the environment and the development of novel detector systems. All presentations demonstrated the high level of scientific and professional excellence of young researchers from various institutions.

At the conclusion of the meeting, a CRPA young professionals meeting was held, during which Galla Uroić was elected as the new youth representative of CRPA, succeeding Ante Matanić, who held this position from 2020 to 2026. We congratulate her and wish her every success in her future work, and we encourage all young members to actively participate in the Association's activities.

The organizers thank our hosts at the Institute for Medical Research and Occupational Health and everyone who contributed to the organization of the meeting. Special thanks go to the members of the Organizing Committee – without their enthusiasm, dedication, and numerous meetings, this event would not have been possible.

We believe that readers will find useful information and inspiration for their scientific and professional work in the field of radiation science and protection in this book. We wish all participants a successful meeting and enjoyable time together.

Ante Matanić

Predstavnik mladih HDZZ-a (2020. – 2026.)

CRPA Young Professionals Representative (2020–2026)

Predavanja / Lectures

Primjena ionizirajućeg zračenja i njegovi biološki učinci /

Applications of Ionizing Radiation and Its Biological Effects

- | | |
|--|-----------|
| Helena Biljanić, Institut Ruđer Bošković | 1 |
| Radiation-assisted textile functionalization for military industry applications | |
| Ivana Landripet, Institut Ruđer Bošković | 2 |
| Gamma Irradiation Synthesis of Advanced Materials: Mechanisms and Applications | |
| Ivan Ilakovac, Institut Ruđer Bošković | 3 |
| Radiolytic synthesis as a route to phase and morphology controlled iron oxide nanoparticles for magnetic hyperthermia applications | |
| Ružica Šoić, Institut Ruđer Bošković | 5 |
| Radiation-driven synthesis of bismuth nanoparticles for enhanced radiosensitization | |
| Sara Čubek, Fakultet kemijskog inženjerstva i tehnologije | 7 |
| Polymer nanocoatings based on fatty acids for the protection of metallic medical implants | |
| Anita Crnov, KBC Zagreb | 8 |
| Usporedba tehnike zračenja u dubokom udahu i slobodnom disanju u radioterapiji lijeve dojke | |
| Klara Dobrin, KBC Zagreb | 9 |
| Dosimetric verification analysis of VMAT breast treatment plans delivered using O-ring coplanar linear accelerator | |
| Krunoslav Ilić, Institut za medicinska istraživanja i medicinu rada | 10 |
| Effects of Low Doses of Ionizing Radiation on rat Mesenchymal Stem Cells | |
-
- ## Nuklearne nesreće i radioaktivni otpad /
- ### *Nuclear Accidents and Radioactive Waste Management*
-
- | | |
|--|-----------|
| Galla Uroić, Fond za financiranje razgradnje NEK | 11 |
| Ponašanje bentonitnih barijera u odlagalištima iskorištenoga nuklearnog goriva | |
| Ante Matanić, KBC Osijek | 12 |
| Izloženost ionizirajućem zračenju: 40 godina nakon Černobila i 15 godina nakon Fukušime | |
| Ksenia Kostyuchenko, Central Enterprise for the Management of Radioactive Waste - Ukraine | |
| Chornobyl Now (online) | |
| Andrea Talian, Lara Karep, Fond za financiranje razgradnje NEK | |
| Komunikacijske aktivnosti u lokalnoj zajednici - Centar za zbrinjavanje RAO | |

Luka Cavaliere Lokas, Nuklearna elektrana Krško

Naučene lekcije nakon Chernobila i Fukushime

Instrumentacija, dozimetrija i napredne tehnike u znanosti o zračenju / *Instrumentation, Dosimetry, and Advanced Techniques in Radiation Science*

Luka Lotina, Institut za medicinska istraživanja i medicinu rada **13**

Ispitivanje odziva različitih dozimetara na Institutu za medicinska istraživanja i medicinu rada

Luka Pasariček, Institut Ruđer Bošković **14**

Dependence of Radiophotoluminescent Glass Dosimeter Relative Efficiency on Linear Energy Transfer for Ion Beams

Gabriela Jazvac, Institut za medicinska istraživanja i medicinu rada **15**

Optičke simulacije u optimizaciji scintilacijskih detektora ionizirajućeg zračenja

Ana Marija Kožuljević, Institut za medicinska istraživanja i medicinu rada **16**

Monte Carlo Study of Quantum Ghost Imaging in the Gamma Regime

Radiation-assisted textile functionalization for military industry applications

¹Ruđer Bošković Helena Biljanić¹, Ema Poljac², Jelena Kosanović¹, Katarina Marušić¹, Nives Matijaković Mlinarić¹

¹Ruđer Bošković Institute, Zagreb, Croatia

²Faculty of Science, Department of Chemistry, Zagreb, Croatia

hbachroj@irb.hr

The modern military industry requires textile materials that can provide long-lasting and reliable protection under extreme conditions of use. Standard fabrics often fail to meet requirements related to UV resistance, flammability, durability, and overall user safety. Moreover, existing functional finishing treatments frequently exhibit limited durability as well as potential environmental and health risks. Therefore, there is a pronounced need to develop new, sustainable methods for textile functionalization.

Ionizing gamma irradiation of fabrics represents an effective method of material activation, as it induces the formation of free radicals within and on the surface of fibers, leading to the cleavage of existing chemical bonds and increased surface reactivity. The resulting active sites enable efficient and durable binding of functional substances to the fibers without the need for aggressive chemicals. The process is carried out at room temperature and does not require the use of toxic reagents, making it an environmentally friendly and energy-efficient approach to textile functionalization. Natural polyphenolic acids are used in textile functionalization due to their favorable properties. Phytic acid, which is non-toxic and biodegradable, exhibits pronounced flame-retardant properties owing to its high phosphorus content and its ability to promote material char formation. UV-absorbing tannic acid possesses antimicrobial properties, thereby further contributing to fabric safety and hygiene. By combining gamma irradiation with natural polyphenolic acids, it is possible to develop multifunctional textiles with enhanced durability, safety, and sustainability, suitable for application in the military industry.

This research presents an innovative approach to the functionalization of various fabrics (cotton, nylon, polyester, and a nylon–cotton composite) through the application of different gamma irradiation conditions and the deposition of environmentally friendly tannic acid coordinated with iron ions and phytic acid, using different functionalization methods.

Gamma Irradiation Synthesis of Advanced Materials: Mechanisms and Applications

Ivana Landripet¹, Ivan Marić¹, Ivan Ilakovac¹, Tanja Jurkin¹

¹Ruđer Bošković Institute, Zagreb, Croatia

ilandrip@irb.hr

Gamma radiation from ⁶⁰Co sources provides a clean and scalable route to synthesize advanced nanomaterials via water radiolysis. High-energy γ -rays ionize water molecules and generate a well-defined set of short-lived reactive species, most notably strongly oxidizing hydroxyl radicals and strongly reducing hydrated electrons produced in nearly equal yields. Together, these complementary species drive one-electron transfer reactions that enable finely controlled reduction or oxidation without added chemical reagents, yielding high-purity materials with none or minimal contamination.

Magnetic iron oxide nanoparticles (MNPs) are particularly attractive because of their potential in medical applications, especially magnetic hyperthermia for cancer treatment, where localized heating of tumor tissue is achieved using an alternating magnetic field. Radiolytic synthesis is an efficient technique for the controlled preparation of various iron oxide and oxyhydroxide polymorphs, making it well suited for tailoring MNP properties. In our work, we employ γ -irradiation to synthesize magnetite nanoparticles by reducing Fe³⁺ ions in aqueous solutions containing polymers that act both as stabilizers for the Fe³⁺ precursors and for the newly formed nanoparticles, thereby preventing aggregation.

The efficiency of this radiolytic reduction is strongly influenced by pH, polymer concentration, and molecular weight. There exists an optimal polymer concentration for maximum reduction: if it is too low, it cannot stabilize the Fe³⁺, resulting in a lower reduction rate; if it is too high, the dense polymer layer around precursor particles hinders the access of reducing species, again lowering the overall reduction efficiency.

This radiation-based strategy aligns well with green chemistry principles, offering room-temperature operation, the absence of toxic byproducts, and straightforward scalability, while still providing a versatile platform for designing materials for biomedical, catalytic, and energy-related applications.

Acknowledgements. This work was supported by the Croatian Science Foundation under the project number HRZZ-IP-2022-10-3687 (RadMagnNanoHyperT)

References:

- G. V. Buxton, C. L. Greenstock, W. P. Helman, A. B. Ross, *J. Phys. Chem. Ref. Data* **17** (1988) 513–886.
I. Marić, I. Landripet, I. Ilakovac, A. Pustak, M. Gotić, T. Jurkin, *Radiat. Phys. Chem.* **235** (2025) 112842

Radiolytic Synthesis as a Route to Phase- and Morphology-Controlled Iron Oxide Nanoparticles for Magnetic Hyperthermia Applications

Ivan Ilakovac¹, Ivan Marić¹, Ivana Landripet¹, Anđela Pustak¹, Tanja Jurkin¹

¹Ruđer Bošković Institute, Zagreb, Croatia

iilakov@irb.hr

With the rapid progress of nanotechnology, interest in magnetic hyperthermia (MHT) has surged as a promising cancer treatment method. MHT uses heat generated from magnetic nanoparticles (MNPs) in alternating magnetic field to induce a temperature increase in tissue in range from 42 °C to 46 °C. At that range, a cascade of different biochemical processes terminates in cancerous cells death, while healthy cells remain undamaged. To obtain a noticeable increase in temperature, MNPs must exhibit certain properties, such as single domain magnetic structure, high saturation magnetization, low coercivity, well defined shape and low polydispersity, dissipating heat through Néel relaxation, Brownian relaxation or hysteresis loss. To validate the efficiency of the heating, temperature over time is measured and expressed as specific absorption rate (SAR), which is defined as dissipated power per mass of MNPs. SAR depends on abovementioned material parameters, as well as on amplitude and frequency of the alternating magnetic field.

In this work, the influence of initial precursor concentration, phase and morphology of radiolytically synthesized iron-oxide nanoparticles on SAR values was examined. In order to obtain different morphologies, the synthesis was carried out in three different routes. Spherical magnetite nanoparticles were synthesized by irradiation of 20% and 40% Fe/DEAE-dextran (w/w) precursor suspensions with doses of 50 and 100 kGy, respectively. Feroxyhyte nanodiscs were synthesized by irradiation of 5% Fe/DEAE-dextran (w/w) precursor solution with dose of 75 kGy. After irradiation, the suspension was re-irradiated with 12.5 kGy or isolated and annealed in H₂/N₂ atmosphere to transform feroxyhyte into magnetite. Finally, akageneite nanorods were synthesized hydrothermally for 2 hours at 80 °C from 20% Fe/DEAE-dextran (w/w) precursor solution. Such suspension was irradiated with 50 kGy to transform akageneite to magnetite. Prior to irradiation, 2-propanol was added to samples with pH adjusted to 9 and purged with nitrogen gas. During the synthesis period, dose rate was in range from 10 to 12 kGy/h. Doses were chosen based on the [Fe²⁺]/[Fe_{total}] ratio, which was determined by UV-VIS spectrophotometry.

All samples were isolated for characterization. Phase and morphology were characterized using XRD and SEM, respectively, while Mössbauer spectroscopy and SQUID magnetometry were performed to give an insight in magnetic properties of the samples. SAR was determined at different field amplitudes and frequencies on the as-synthesized suspensions or dried samples dispersed at different concentrations in DEAE-dextran solution.

Acknowledgements. This work was supported by the Croatian Science Foundation under the project number HRZZ-IP-2022-10-3687 (RadMagnNanoHyperT)

References:

- D. Ortega, Q. A. Pankhurst, *Nanoscience* **2013**, *1*, 60
- I. Marić, G. Dražić, G. Štefanić, K. Zadro, M. Gotić, T. Jurkin, *Mater. Charact.* **2020**, *159*, 110038
- I. Marić, M. Gotić, G. Štefanić, A. Pustak, T. Jurkin, *Rad. Phys. Chem.* **2020**, *170*, 108648
- I. Marić, I. Landripet, I. Ilakovac, A. Pustak, M. Gotić, T. Jurkin, *Rad. Phys. Chem.* **2025**, *235*, 112842

Radiation-driven synthesis of bismuth nanoparticles for enhanced radiosensitization

Ružica Šoić¹, Goran Štefanić¹, Marijan Gotić¹, Tanja Jurkin¹, Ivan Marić¹

¹Ruđer Bošković Institute, Zagreb, Croatia

rsoic@irb.hr

Radiosensitization is an enhancement of radiation effects through physical, chemical, or pharmacological interventions. Radiosensitization enhances cancer therapy through agents that inhibit proliferation and DNA repair or produce cytotoxic species. The unique physicochemical characteristics of the nanoparticles, such as tunable size, preferential tumour accumulation, ease of surface functionalization (consequently improved targeting capability) and generation of reactive oxygen species upon irradiation, enable precise modulation of radiation dose deposition at the cellular level, thereby enhancing the overall therapeutic efficacy of cancer treatment.¹

Metallic nanoparticles are promising agents for increasing the effectiveness of radiation therapy by making cells more sensitive to radiation due to their high atomic number, which improves generation of low-energy secondary electrons that initiate a cascade of physical and chemical reactions. This can lead to increased cellular damage and improved tumour control and it is an approach to maximize the differential response to radiation between tumour and normal tissue. The most investigated potential radiosensitizers are gold, silver, hafnium oxide and cerium oxide nanoparticles.²

The radiolytic synthesis method offers several advantages: it is rapid and environmentally friendly (it does not use often toxic chemical reducing agents, given that the hydrated electron generated by water radiolysis is a strong reductant). Due to the high energy and penetration depth of gamma radiation, reducing species are formed uniformly throughout the system, which promotes homogeneous nucleation and controlled, uniform particle growth. The method also enables simultaneous sterilization during synthesis, thereby allowing the direct application of the resulting nanomaterials in biomedical fields. Gamma irradiation is a highly efficient and well-established method for the synthesis of metallic nanoparticles, particularly noble metals, but it has rarely been applied to metal oxides and has scarcely been explored for bismuth and bismuth oxide nanoparticles.

The aim of this research is to investigate the possibility of synthesizing Bi-based nanoparticles using a radiolytic method and in the next step to evaluate the potential of these nanomaterials as novel radiosensitizers. Bismuth-based nanoparticles (Bi and Bi oxide) have been significantly less explored for radiosensitization purposes, despite being promising candidates due to their low toxicity. The radiolytic synthesis is carried out from an aqueous solution of Bi(III) nitrate with dextran as a particle stabilizer. Gamma-irradiation was carried out using a panoramic ⁶⁰Co gamma source at the Radiation Chemistry and Dosimetry Laboratory (RBI), under inert conditions. With adjusting only one parameter, for example the Bi³⁺ concentration in the precursor, nanoparticles with different Bi and Bi oxide phases can be produced. SEM and XRD analyses provided insight into particle morphology, size and phase composition.

Acknowledgments. This work has been supported by Croatian Science Foundation under the project IP-2022-10-3687.

References:

- A. Taheri, M. Uddin Khandaker, F. Moradi, D.A. Bradley, *Radiat. Phys. Chem.* **212** (2023) 111146.
- T. Paunesku, S. Gutiontov, K. Brown, G.E. Woloschak (ur.) *Radiosensitization and Nanoparticles*, Vol.166, Springer, 2015, p.151-171.

Polymer nanocoatings based on fatty acids for the protection of metallic medical implants

Sara Čubek¹, Helena Biljanić², Katarina Marušić²

¹Faculty of Chemical Engineering and Technology, Zagreb, Croatia

²Ruđer Bošković Institute, Zagreb, Croatia

saracubek22@gmail.com

Medical implants fabricated from metals such as stainless steel, titanium alloys, and cobalt-chromium are widely used to restore function by replacing, supporting or enhancing damaged tissues and load-bearing structures. Their performance and long-term stability strongly depend on corrosion resistance due to continuous exposure to aggressive physiological environments such as body fluids. Selecting materials with high corrosion resistance, combined with protective coatings, is essential for ensuring biocompatibility and long-term stability.

In this study, corrosion resistance of 316L stainless steel was improved by behenic acid self-assembled monolayers, crosslinked using gamma irradiation into polymer nanocoatings. Fatty acids such as behenic acid form stable monolayers on metal surfaces that act as effective barriers against corrosive media. Behenic acid solution concentration and adsorption time were optimized, followed by gamma irradiation at an absorbed dose of 110 kGy and a dose rate of 11 kGy/h.

The results demonstrate that the optimized parameters produced thin, homogeneous, and chemically stable nanocoatings. Crosslinking significantly improved corrosion protection compared to unirradiated self-assembled monolayers on 316L stainless steel. These findings indicate that radiation-induced crosslinking of behenic acid monolayers represents a promising strategy for functional surface coatings on medical implants.

Usporedba tehnike zračenja u dubokom udahu i slobodnom disanju u radioterapiji lijeve dojke

Anita Crnov

Klinički bolnički centar Zagreb, Odjel medicinske fizike, Zagreb, Hrvatska

anita.crnov@kbc-zagreb.org

Radioterapija karcinoma dojke značajno doprinosi poboljšanju lokalne kontrole bolesti i ukupnog preživljenja, no kasna kardiotsičnost i dalje predstavlja važan klinički problem, osobito kod zračenja lijeve dojke. Primjena tehnike zračenja u dubokom udahu (engl. Deep Inspiration Breath Hold, DIBH) omogućuje povećanje udaljenosti između srca i prsnog koša, čime se može značajno smanjiti apsorbirana doza na srce u usporedbi sa zračenjem u slobodnom disanju (engl. Free Breathing, FB). Cilj ovog rada bio je ispitati razlike u apsorbiranoj dozi zračenja na srce, lijevu prednju silaznu arteriju (engl. Left Anterior Descending artery, LAD) i lijevo plućno krilo između DIBH i FB planova zračenja lijeve dojke.

Studija je obuhvatila 13 pacijentica kod kojih se provelo radioterapijsko zračenje lijeve dojke u DIBH-u na Odjelu za radioterapiju, Klinike za onkologiju KBC-a Zagreb. Za svaku pacijenticu učinjene su CT simulacije u slobodnom disanju (FB) i u dubokom udahu (DIBH), a zatim su izrađeni pripadni planovi zračenja primjenom iste tehnike planiranja. Analizirane su srednja i maksimalna doza zračenja na srce i LAD, volumeni srca i pluća koji primaju 5 Gy, 10 Gy i 20 Gy, te udaljenost srca od prsnog koša. Statistička obrada podataka provedena je u statističkom paketu R primjenom Wilcoxonovog testa. Rezultati su interpretirani na razini značajnosti od 5 %.

U DIBH planovima utvrđene su statistički značajno niže vrijednosti srednje i maksimalne doze zračenja na srce ($p < 0.001$; $p = 0.002$) te srednje doze na LAD ($p = 0.014$) u usporedbi s FB planovima. Jednako tako, uočeno je značajno smanjenje volumena srca koji prima 20 Gy i 5 Gy ($p = 0.003$; $p = 0.002$). U slučaju DIBH-a utvrđeno je značajno povećanje volumena pluća i udaljenosti srca od prsnog koša ($p = 0.002$). Iako je kod više od polovice ispitanih pacijentica uočeno smanjenje srednje doze na lijevo plućno krilo te volumena pluća koji primaju 5 Gy, 10 Gy i 20 Gy, razlike nisu bile statistički značajne. Analizom korelacije utvrđena je statistički značajna negativna korelacija između povećanja volumena pluća u DIBH-u i srednje doze na srce ($p = 0.026$) te LAD ($p = 0.003$). DIBH planovima postignuta je statistički značajno bolja pokrivenost 95 % ciljnog volumena s 95 % propisane doze u odnosu na FB planove ($p = 0.002$). Razlog tomu jest činjenica da kod DIBH planova nije bilo potrebno subdozirati ciljni volumen kako bi se postigla niža doza na srce.

DIBH tehnika kod zračenja lijeve dojke značajno smanjuje apsorbirane doze zračenja na srce i LAD, dok učinak na pluća ovisi o individualnoj anatomiji pacijenta. Rezultati ove studije potvrđuju zaključke prethodnih studija i podupiru kliničku primjenu DIBH tehnike u smanjenju rizika od kardiotsičnosti.

Dosimetric verification analysis of VMAT breast treatment plans delivered using O-ring coplanar linear accelerator

K. Dobrin^{1*}, A. Murković², M. Murković², T. Bokulić¹

¹Faculty of science, Department of physics, Zagreb, Croatia

²University Hospital Centre Zagreb, Medical Physics Department, Zagreb, Croatia

klara.dobrin@kbc-zagreb.hr

Dosimetric verification of advanced radiotherapy techniques gives an important contribution to the quality assurance (QA) program in clinical radiotherapy. Different verification modalities ensure accurate, reliable and safe radiotherapy treatment of cancer patients.

This work focuses on the dosimetric verification of the newly established volumetric modulated arc therapy (VMAT) technique for breast cancer irradiation using the Halcyon (Varian Medical Systems) ring accelerator. We compared results of dosimetric verifications of absorbed dose distributions from 33 radiation treatment plans which differed in number of isocenters, arcs, monitor units (MU-s), dose difference normalization, side of the body, and date of dosimetric check to determine how each of the mentioned variables affect the results of dosimetric verification.

Two methods were used for dosimetric verification. In the first, absorbed dose distributions were measured using the ArcCHECK cylindrical detector array, while in the second, they were determined using the electronic portal imaging device (EPID) integrated into Halcyon. These dose distributions were then compared using gamma analysis with the corresponding dose distributions calculated with the treatment planning system (Eclipse, V18.1, Varian Medical Systems). The gamma analysis produced gamma index passing rate (GIPR) values. This was followed by a statistical analysis of the GIPR results for 33 absorbed dose distributions that included the calculation and comparison of descriptive statistics for treatment plans that had common characteristics, the Shapiro-Wilk test and quantile-quantile (Q-Q) plots to check the normality of the sample distribution, the Kruskal-Wallis test to compare the medians of the sample distributions, beta regression analysis to examine the influence of individual independent variables on the gamma index pass rate. The Spearman correlation matrix was calculated to check the trend of the relationship between the gamma index pass rate measurement results obtained using ArcCHECK and EPID.

The results of the statistical analysis for both methods of dosimetric verification showed that GIPR-s were not normally distributed. It was found that the locally normalized GI dose difference and the treatment of the left side of the body significantly reduced the GIPR. Beta regression analysis of the ArcCHECK measurement results revealed that a more enhanced dose distribution optimization, involving a larger number of arcs, significantly improved the GIPR. The number of isocenters, MU-s and the date of the dosimetric verification relative to the regular beam output calibrations had little or no effect on the pass rate. Additionally, the correlation between GIPR-s measured with ArcCHECK, per specific arc, and those obtained using EPID ranged from weak (~0.3) to strong (~0.7).

Effects of Low Doses of Ionizing Radiation on rat Mesenchymal Stem Cells

Krunoslav Ilić¹, Ana Marija Marjanović Čermak¹, Luka Pavelić¹, Ana-Marija Kožuljević¹, Gabriijela Jazvac¹, Ivan Pavičić¹, Vedran Micek¹, Ivica Prlić¹

Institute for Medical Research and Occupational Health, Zagreb, Croatia

kilic@imi.hr

Ionizing radiation (IR) can profoundly influence cellular function and viability, primarily through direct damage to nucleic acids (DNA and RNA), and by producing oxygen radicals through water radiolysis. While the health risks associated with high doses of ionizing radiation are well established, risks associated with low doses are poorly defined, and depend on the type of cells or tissue exposed to radiation. To better understand risks associated with low doses, rat mesenchymal stem cells (MSC) were extracted from rat bone marrow and exposed to different doses of ionizing radiation below 1 Gy, comparable to doses received during diagnostic procedures such as PET or CT. DNA damage, cell cycle progression, activity of antioxidant enzymes and cell proliferation were assayed 2 and 24 h after exposure. Results have shown an increase in cell proliferation in cells exposed to 100 mGy of radiation, and decreased proliferation in cells irradiated with 1 Gy dose. Exposure to low doses of radiation also increased the activity of antioxidant enzymes in a dose-dependent manner, as well as increasing the number of single-stranded DNA lesions. These results underscore potential risks associated with low doses of ionizing radiation used in medical diagnostics.

Ponašanje bentonitnih barijera u odlagalištima iskorištenog nuklearnog goriva

Galla Uroić^{1,2}, Želimir Veinović², Michaela Hruškova Hasan², Vinko Baranašić²

¹Fond za financiranje razgradnje i zbrinjavanja radioaktivnog otpada i istrošenoga nuklearnog goriva Nuklearne elektrane Krško, Zagreb, Hrvatska

²Rudarsko-geološko-naftni fakultet, Zagreb, Hrvatska

galla.uroic@fond-nek.hr

Na-bentonit se u dubokim geološkim odlagalištima (DGO) iskorištenoga nuklearnog goriva (ING) i visokoradioaktivnog otpada (VRAO) koristi kao ključna inženjerska barijera za usporavanje migracije radionuklida prema biosferi. Njegova učinkovitost temelji se na niskoj propusnosti, sposobnosti zadržavanja radionuklida, niskom koeficijentu difuzije i povoljnim toplinskim svojstvima. Obzirom da se odlagališta ING-a i VRAO-a projektiraju na period od 100 000 godina, procesi koji utječu na stabilnost bentonitne barijere (povišena temperatura uzrokovana raspadom radionuklida, geokemijski uvjeti stijene i podzemne vode te korozijski produkti spremnika) nužno je predvidjeti moguću postupnu degradaciju svojstava bentonita i vjerojatne posljedice.

Dosadašnja istraživanja provedena u LAGEMA laboratoriju RGNF-a pokazuju da već pri umjereno povišenim temperaturama (≈ 40 °C) dolazi do značajnih promjena svojstava bentonita, što upućuje na još izraženije promjene pri temperaturama očekivanim u DGO-u (≥ 90 °C). Bentonit sadrži visok udio smektita, minerala gline čija su bubrenje i izmjena kationa ključni za zadržavanje radionuklida. Zagrijavanjem dolazi do dehidracije smektita i kolapsa međuslojnog prostora, čime se smanjuje broj aktivnih mjesta za izmjenu kationa i funkcionalnost barijere.

Daljnja istraživanja usmjerena su na praćenje promjena bentonita tijekom dugotrajne izloženosti povišenim temperaturama te na interakcije na kontaktu bentonit–bakar u uvjetima karakterističnima za DGO.

Izloženost ionizirajućem zračenju: 40 godina nakon Černobila i 15 godina nakon Fukušime

Ante Matanić

Klinički bolnički centar Osijek, Odjel medicinske fizike, Osijek, Hrvatska

ante.matanic@kbco.hr

Četrdeset godina nakon černobilske nuklearne nesreće (1986.) i petnaest godina nakon nesreće u nuklearnoj elektrani u Fukušimi (2011.), raspoloživi dozimetrijski i zdravstveni podaci omogućuju usporednu analizu zdravstvenih posljedica izloženosti ionizirajućem zračenju u dvjema bitno različitim situacijama. Cilj ovog rada je prikazati zdravstvene učinke akutne visoke i kronične niskodozne izloženosti, s naglaskom na profesionalno izložene skupine, opću populaciju i djecu, te istaknuti čimbenike koji su doveli do izrazito različitih ishoda.

U Černobilu su akutne visoke doze zračenja dovele do 134 potvrđena slučaja akutnog radijacijskog sindroma (ARS), od kojih su 28 završila smrtnim ishodom u prvim mjesecima nakon nesreće. Oko 600 000 likvidatora bilo je izloženo profesionalno, s prosječnim dozama koje su u 1986. godini iznosile oko 170 mSv, a u sljedećim godinama postupno opadale. Među evakuiranim stanovništvom (oko 136 000 ljudi) prosječna efektivna doza iznosila je približno 30 mSv. Najteže posljedice zabilježene su kod djece izložene radioaktivnom jodu: prosječne doze na štitnjaču kretale su se od 200 do 600 mGy, a maksimalno do 13 Gy. To je rezultiralo epidemijom karcinoma štitnjače s više od 19.000 zabilježenih slučajeva do 2015. godine, od kojih se oko 5 000 smatra izravno pripisanima zračenju.

Nasuprot tome, u Fukushimi su procijenjene doze radnika i stanovništva bile znatno niže. Većina radnika primila je manje od 50 mSv, dok je manji broj dosegnuo doze u rasponu približno 100–250 mSv. U općoj populaciji, uključujući djecu, efektivne doze bile su uglavnom ispod 10 mSv. Dosadašnje analize ne pokazuju detektabilan porast leukemije ni solidnih tumora. Ipak, pojedini slučajevi leukemije kod radnika administrativno su priznati kao profesionalna bolest i kompenzirani, na temelju individualne procjene doze i primjene principa vjerojatne uzročnosti, što ne predstavlja dokaz populacijskog učinka. Zabilježeni porast incidencije karcinoma štitnjače u Fukushimi u velikoj je mjeri posljedica intenzivnog ultrazvučnog screeninga i prekomjerne dijagnostike, a ne radijacijskog učinka.

Usporedba dviju nesreća naglašava ključnu ulogu dozne brzine, interne kontaminacije i pravovremenih zaštitnih mjera u određivanju zdravstvenih ishoda te ističe važnost razdvajanja stvarnog rizika od detektiranog rizika u suvremenoj zaštiti od zračenja

Ispitivanje odziva različitih dozimetara na Institutu za medicinska istraživanja i medicinu rada

Luka Lotina¹, Luka Pavelić¹

¹Institut za medicinska istraživanja i medicinu rada, Odjel za zaštitu od zračenja

llotina@imi.hr

U ovom izlaganju bit će predstavljene metode i rezultati mjerenja energijskog odziva i odziva na brzinu doze na nekoliko različitih dozimetara za mjerenje ambijentalnog doznog ekvivalenta ($H^*(10)$). Za svaki dozimetar, provedena su dva različita mjerenja. U prvom mjerenju, referentna sferna ionizacijska komora volumena 1 L, na udaljenost od 2 m od izvora zračenja, ozračena je narrow spectrum radiation protection snopovima (prema IEC 4037): N-25, N-30, N-40, N-60, N-80, N-100, N-120, N-150 i N-200 pri struji od 10 mA. Za svaki snop, komora je ozračena dozom koja je iznosila otprilike 1 mSv. Nakon toga, na istu udaljenost od izvora postavljali smo različite dozimetre koji su ozračivani pod istim uvjetima kao i referentna komora (kvaliteta zračenja, vrijeme ekspozicije, temperatura, tlak). Dosljednost ozračivanja bila je osigurana monitor komorom. Temeljem izmjerene $H^*(10)$ doze na dozimetrima izračunati su relativni odzivi dozimetara u odnosu na referentnu ionizacijsku komoru. Za svaki dozimetar izrađen je graf relativnog energijskog odziva normaliziranog na odziv za N-100 snop, u ovisnosti o tipu snopa. U drugom setu mjerenja, mjeren je odziv dozimetara u ovisnosti o stopi doznog ekvivalenta. Za potrebe ovog mjerenja, referentna ionizacijska komora je ozračivana RQR-8 snopom (na potencijalu od 100 kV), ali za različite vrijednosti struje, što odgovara različitim stopama doznog ekvivalenta. Za svaku vrijednost struje, komora je ponovno ozračivana sve dok nije postignuta $H^*(10)$ doza od otprilike 1 mSv. Nakon toga, dozimetri su ozračivani pod istim uvjetima kao i referentna komora. Očitane izmjerene doze uspoređene su s dozama izmjerenima u ionizacijskoj komori, te su također izrađeni grafovi relativnih odziva dozimetara u ovisnosti o stopi doznog ekvivalenta.

Dependence of Radiophotoluminescent Glass Dosimeter Relative Efficiency on Linear Energy Transfer for Ion Beams

Luka Pasariček¹, Mercedes Horvat¹, Željka Knežević¹, Christina Mooshammer², Fereshte Saheli¹, Christina Stengl^{3,2}, Stefan Schmidt^{3,2}, José Vedelago^{3,2}, Marija Majer¹

¹ Ruđer Bošković Institute, Zagreb, Croatia

² German Cancer Research Center (DKFZ), Heidelberg, Germany

³ Heidelberg University Hospital (UKHD), Heidelberg, Germany

lpasaric@irb.hr

Hadron therapy is an increasingly used radiotherapy modality that employs ion beams to treat radioresistant and inoperable tumors while minimizing dose to surrounding healthy tissue. Radiophotoluminescent (RPL) glass dosimeters are promising candidates for ion beam dosimetry, but their response under ion irradiation must first be thoroughly characterized. Studies of other luminescent dosimeters have shown a decrease in relative efficiency with increasing linear energy transfer (LET) and a dependence on ion type. Relative efficiency is defined as the ratio of detector response to absorbed dose for a given radiation type relative to that for a reference radiation. While the relative efficiency of RPL dosimeters for proton beams has been investigated, systematic studies comparing different ion species over a wide and overlapping LET range are lacking. This study aims to address this gap.

RPL dosimeters (GD-302M) embedded in a polymethyl methacrylate (PMMA) phantom were irradiated at the Heidelberg Ion Beam Therapy (HIT) Center using H-1, He-4, C-12, and O-16 ion beams. A broad LET range was investigated by varying initial beam energies and by placing dosimeters at different depth along the Bragg curve within the phantom. The Monte Carlo particle transport code PHITS was used to model the experimental setup and to calculate energy spectra at dosimeter positions. These spectra were converted to LET spectra in water using SRIM data. Fluence-averaged (LET_f) and dose-averaged (LET_d) values were derived. To investigate the influence of dosimeter modelling on LET estimation, RPLs were additionally modelled as water cuboids and water cylinders.

Results show a decrease in RPL relative efficiency with increasing LET for all investigated ion species, with efficiency–LET curves exhibiting a clear dependence on ion type. Furthermore, the choice of LET calculation method and dosimeter modelling approach was found to significantly influence the derived LET values.

This work provides important insights for the reliable application of RPL dosimeters in ion beam dosimetry.

Acknowledgements. This research was conducted as part of the HRZZ project IP-2020-02-3593, "Characterization of Radiophotoluminescent Dosimeters for Measurements in Heavy Charged Particle Fields."

References: Majer, M. et al. Relative efficiency of radiophotoluminescent glass dosimeters in a scanning pencil proton beam. *Radiat. Phys. Chem.* 216 (2024) <https://doi.org/10.1016/j.radphyschem.2023.111396>

Optičke simulacije u optimizaciji scintilacijskih detektora ionizirajućeg zračenja

Gabriela Jazvac¹, Ana Marija Kožuljević¹, Luka Lotina¹, Luka Pavelić^{1,2}

¹ Institut za medicinska istraživanja i medicinu rada, Zagreb, Hrvatska

² Nucleometrix, Zagreb, Hrvatska

gjazvac@imi.hr

Radiološko oslikavanje prostora pomoću bespilotnih letjelica omogućava sigurno oslikavanje velike površine u kratkom vremenskom razdoblju. Međutim, ograničenja težine i dimenzija tereta koje letjelica može nositi ograničavaju i konstrukciju detektora ionizirajućeg zračenja. U te svrhe razmatramo scintilacijski detektor jednostavne konstrukcije. Scintilacijski kristali prilikom apsorpcije ionizirajućeg zračenja emitiraju fotone vidljivog spektra. Udio tih fotona se potom detektira fotodetektorima poput silicijskih fotomultiplikatora (eng. silicon photomultiplier, SiPM). Silicijski fotomultiplikatori su uobičajeno malih dimenzija, aktivne površine $<1 \text{ cm}^2$. Učinkovitost detekcije optičkih fotona ovisi o geometriji scintilatora i silicijskog fotomultiplikatora, mjestu emisije fotona i refleksiji unutar kristala, odnosno o gubitku i atenuaciji svjetlosti. Oblaganjem kristala reflektivnim materijalom može se povećati učinkovitost detekcije. Detektor s većim scintilacijskim kristalom ima veću učinkovitost detekcije ionizirajućeg zračenja, ali da bi se održala jednaka učinkovitost prikupljanja optičkih fotona, potrebno je više silicijskih fotomultiplikatora. To bitno komplicira i poskupljuje konstrukciju detektora. Upotrebom optičkih simulacija usporedili smo nekoliko geometrija scintilacijskog kristala i položaja silicijskog fotomultiplikatora. Simulacije su prvo provedene za pločasti kristal. Uspoređena je učinkovitost prikupljanja fotona za difuzni bijeli i spekularni reflektor te za različite položaje silicijskog fotomultiplikatora. Potom su provedene simulacije za potrebe optimizacije prikupljanja svjetlosti. Uspoređen je prvobitni oblik s oblikom dobivenim nakon optičkih simulacija.

Monte Carlo Study of Quantum Ghost Imaging in the Gamma Regime

Ana Marija Kožuljević, Gabriela Jazvac, Luka Lotina, Mihael Makek, Luka Pavelić

Institute for Medical Research and Occupational Health, Zagreb, Croatia

akozuljevic@imi.hr

Ghost imaging is a non-local imaging technique in which an object is reconstructed using radiation that does not directly interact with it. The method relies on coincidence measurements of spatially correlated photons, either quantum-entangled or classically correlated. While ghost imaging has been extensively studied with optical, infrared, and X-ray photons, investigations in the gamma-ray regime remain scarce. In this work, we present a Monte Carlo study of quantum ghost imaging using annihilation photon pairs. The simulated coincidence setup consists of two detector modules, each composed of 64 Gadolinium Aluminum Gallium Garnet crystals doped with cerium (GAGG:Ce) arranged in an 8×8 matrix, with individual crystal dimensions of $3 \times 3 \times 20 \text{ mm}^3$ and a pitch of 3.2 mm. The detector modules are positioned face-to-face with a Na-22 source placed between them. An object is positioned in front of one detector module, while the corresponding ghost image is formed in the second module through coincidence detection. We investigate the ghost imaging performance for objects composed of materials with varying thicknesses and densities. The results demonstrate the feasibility of gamma-ray quantum ghost imaging and indicate its potential for imaging high-Z, low-transmission objects, with possible applications in homeland security and industrial inspection.



5. SKUP MLADIH HRVATSKOG DRUŠTVA ZA ZAŠTITU OD ZRAČENJA

5th Young Professionals
Meeting of the Croatian
Radiation Protection
Association

Kontakt

Contact



mladi@hdzz.hr

Obavijesti i novosti

News and Updates



<https://www.hdzz.hr>

Hvala na sudjelovanju!
Thank you for your participation!