HDZZ CRPA

ZBORNIK SAŽETAKA TRINAESTOG SIMPOZIJA HRVATSKOG DRUŠTVA ZA ZAŠTITU OD ZRAČENJA

BOOK OF ABSTRACTS OF THE 13TH SYMPOSIUM OF THE CROATIAN RADIATION PROTECTION ASSOCIATION

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Dragi članovi HDZZ-a, poštovani sudionici 13. simpozija,

Iako je u posljednje vrijeme dinamika održavanja simpozija bila svake dvije godine, zbog pandemije koronavirusa, možda simbolično, 13. simpozij se održava četiri godine nakon posljednjeg održanog 2019. godine u Varaždinu.

Proteklo razdoblje, unatoč brojnim globalnim izazovima, obilježilo je niz aktivnosti Društva. Kada su okolnosti dopustile, u listopadu 2021. godine, održana je izborna skupština Društva na kojoj je izabrano novo vodstvo. Na početku sljedeće godine održana je sjednica na kojoj je izvršena primopredaja dužnosti novom Upravnom odboru i Nadzornom odboru, od kada novo vodstvo Društva redovito održava sjednice ili elektroničke sjednice. Društvo je u proteklom razdoblju aktivno sudjelovalo na svim sastancima EU društava. Upravo je 16. sastanak održan u Zagrebu, nakon čega su slijedila dva on-line sastanka, dok je posljednji, 19. sastanak održan ponovno uživo u Münchenu krajem 2022. godine. Broj članova Društva je revidiran te HDZZ trenutno ima 130 članova. Zbog sve manjeg broja mladih članova HDZZ-a, 3. susret mladih održan je u izmijenjenom obliku na kojem su mladi članovi HDZZ-a predstavili rad svojih institucija i jedinica s ciljem da se međusobno bolje upoznaju, ali i privuku budući mladi članovi. Susret se kao i mnogobrojni događaji, održao on-line. U listopadu 2022. godine, HDZZ je zajedno s HDMF-om (Hrvatskim društvom za medicinsku fiziku) održalo prvi popularno-znanstveni piknik za polaznike viših razreda srednje škole i studente. Kombinacijom zanimljivih predavanja i radionica posjetiteljima je na vrlo kreativan način prikazan dio onoga čime se bave stručnjaci, članovi naših društava. U planu je redovito održavanje takvih manifestacija. Na svjetskoj i regionalnoj razini članovi Društva sudjelovali su na raznim kongresima; svjetskom kongresu IRPA u Seulu (Marko Gerić, nagrađen nagradom za najbolji rad mladih članova Društva 2019. godine), Europskom kongresu IRPA u Budimpešti, 30. i 31. simpoziju Društva za zaštitu od zračenja Srbije i Crne Gore u Divčibarama, odnosno Beogradu. Također, u protekloj i ovoj godini poslane su nominacije naših članova u čak pet radnih skupina IRPA-e. Kolegama želimo uspješno sudjelovanje, a vjerujemo da će svojim radom doprinijeti i većoj vidljivosti Društva.

Glavna aktivnost Društva u ovoj godini je organizacija 13. simpozija koji će se imati 10 znanstveno-stručnih sekcija. Glavna tema ovog simpozija posvećena je nuklearnim prijetnjama i izazovima koje nam se nameću. U Zborniku se nalazi ukupno 62 sažetka. Objavljeni su svi sažeci koji su pristigli u roku. Sažeci odražavaju stavove autora, a urednici su ispravili samo očite pogreške u tekstovima te tehnički uredili i ujednačili izgled sažetaka prema zadanom predlošku. Sažeci su pisani na hrvatskom i engleskom jeziku. Kvaliteta i standard engleskog jezika odgovornost su autora jer tekstovi nisu posebno lektorirani. Svi sažeci na engleskom jeziku bit će poslani nakon završetka simpozija u međunarodnu bazu INIS (International Nuclear Information System) koju održava IAEA (http://www.iaea.org/inis/) i u kojoj se već nalaze sažeci s prethodnih simpozija HDZZ-a. Kvaliteta grafičkih priloga također je odgovornost autora i u pojedinim slučajevima na nju nismo mogli utjecati.

Podsjećamo da je službeno glasilo HDZZ-a znanstveno-stručni časopis *Arhiv za higijenu rada i toksikologiju* (http://hrcak.srce.hr/aiht) koji u 2021. godini ima čimbenik odjeka (Impact Factor) 2,078. U časopisu se redovito objavljuju informacije vezane uz rad Društva. Ovom prigodom sve sudionike 13. simpozija HDZZ-a i članove Društva pozivamo da svoje znanstvene i stručne sažetke u proširenom obliku znanstvenog rada objave u *Arhivu* i time aktivno pridonesu njegovom daljnjem napretku. Uredništvu časopisa mogu se poslati na razmatranje i radovi prezentirani na Simpoziju ako dosad nisu objavljivani, koje u tom slučaju treba urediti prema uputi autorima za objavljivanje u *Arhivu*. Radovi će biti objavljeni ukoliko prođu uobičajenu znanstvenu recenziju.

Vjerujemo da ćemo u zajedničkom druženju i razmjeni iskustava na ovom Simpoziju uspostaviti novu ili unaprijediti postojeću znanstvenu i stručnu suradnju. Organizatori zahvaljuju suorganizatorima, pokroviteljima, sponzorima i izlagačima na podršci i pomoći tijekom organizacije.

Na kraju, nadamo se 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 simpozija želimo uspješan rad i ugodan boravak u Poreču.

Ivana Coha, predsjednica HDZZ-a
Branko Petrinec, predsjednik Znanstvenog odbora 13. simpozija i potpredsjednik HDZZ-a
Luka Pavelić, predsjednik Organizacijskog odbora 13. simpozija

Zagreb, travanj 2023.

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OPĆE TEME U ZAŠTITI OD ZRAČENJA

GENERAL TOPICS IN RADIATION PROTECTION

ACTIVITIES OF THE HEALTH PHYSICS SECTION OF THE ROLAND EÖTVÖS PHYSICAL SOCIETY

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Abstract
The aim of the presentation is to make a brief introduction to the activities of the Hungarian Health Physics Society, which operates as the second largest section of the Roland Eötvös Physical Society, as the Health Physics Section (REPS-HPS) since 1962.
The presentation describes the foundation of the society, its recognition as a founding member of the International Radiation Protection Association (IRPA) and its current status related to international affairs. Not just as a hindsight, but it elaborates on the latest success of organising last year's 6th European IRPA Congress in Budapest.
Since the society has almost 200 members who actively participate and develop methodologies on radiation protection, standards and provide a scientific basis for several of the activities related to the operation of the nuclear power plant in Paks, other industrial facilities and medical applications, there is a wide spectrum of knowledge amassed among them. Beside the aforementioned issues, education and training, metrology of radiological quantities, radioecology, personal dosimetry, naturally occurring radioactive materials and radon, waste management and geological disposal, regulatory affairs, radiobiology are making up the key topical subjects addressed by the REPS-HPS. The presentation also gives highlights on such activities and provides a demonstration of the work done by its membership.

Keywords: Hungarian Health Physics Society, history, nuclear power plant, medical applications, industrial applications

NEKE AKTIVNOSTI EURADOS RADNE SKUPINE SEDAM ZA UNUTARNJU DOZIMETRIJU

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Sažetak
Cilj je ovog rada prikazati međunarodne aktivnosti tijekom posljednjih nekoliko godina povezane s radnom skupinom sedam (*Working Group 7* - WG7) za unutarnju dozimetriju, kao dio članskih aktivnosti pojedinaca i ustanova udruženih u *European Radiation Dosimetry Group* (EURADOS) glede dozimetrije zračenja.
U prvom se projektu na temelju kliničkih mjerenja i računalnih simulacija razmatraju brzine doza zračenja na određenoj udaljenosti od tijela bolesnika u kojima se nalazi aktivnost unesena s dijagnostičkom ili terapijskom svrhom, primjerice ^{99m}Tc, ^{131}I i ^{18}F.
U drugom se projektu međusobno uspoređuju europski sustavi za *in-vivo* mjerenje radioaktivnosti tijela (brojači cijelog tijela / *whole-body counters*) izvršenjem do pet zadaća (*Victor, emergency, medicine, calibration, person*) koje se temelje na laboratorijskim mjerenjima različitih fantoma cijelog ljudskog tijela koji sadrže različite radionuklide (^{40}K, ^{60}Co, ^{68}Ga/^{68}Ge, ^{88}Y, ^{133}Ba, ^{134}Cs, ^{137}Cs, ^{152}Eu).
U trećem se projektu temeljem laboratorijskih mjerenja sustava za *in-vivo* mjerenja radioaktivnosti u štitnjači u različitim geometrijama međusobno uspoređuju različiti fantomi ljudskog vrata sa štitnjačom (*neck / thyroid phantoms*) koji odgovaraju različitoj dobi ispitanika, a sadrže različite radionuklide (^{125}I, ^{131}I, ^{133}Ba).
U četvrtom se projektu razmatra pisanje i izdavanje preglednog izvješća radnih naslova *Internal dosimetry of therapeutic radiopharmaceuticals / Toward a roadmap for patient-specific dosimetry in radiopharmaceutical therapy* o unutarnjedozimetrijskim aspektima sadašnjosti i budućnosti liječenja radiofarmakološkim pripravcima i radioobilježenim medicinskim uređajima.
Unutarnji problemi Republike Hrvatske povezani s unutarnjim ozračenjem otvorenim radioaktivnim izvorima su u načelu nepoštivanje zakona i na dokazima utemeljene medicinske znanosti i znanosti o zračenju. Sustavno i cjelovito se izloženi radnici niti mjere niti podvrgavaju procjeni unutarnjeg ozračenja, kao što se sustavno i cjelovito unutarnje ozračenje bolesnika niti planira niti intraterapijski provjerava pri radioterapijskim postupcima u nuklearnoj medicini. I slučaj neočekivanog i neželjenog odnosno izvanrednog događaja koji bi uključivao unutartjelesno radioaktivno onečišćenje također bi pripadao navedenoj problematici. Stoga je za nadati se kako bi uključivanje što više hrvatskih stručnjaka i ustanova u što više međunarodnih projekata povezanih u konačnici s unutarnjom dozimetrijom moglo najzad početi mijenjati svijest i praktična djelovanja svih dionika za opće dobro.

Ključne riječi: unutarnja dozimetrija, *European Radiation Dosimetry Group*, *in-vivo* mjerenje, radionuklid, unutarnje ozračenje

SOME ACTIVITIES OF THE EURADOS WORKING GROUP SEVEN ON INTERNAL DOSIMETRY

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Abstract
The aim of this paper is to present the international activities during the last few years related to Working Group Seven (WG7) for internal dosimetry, as part of the member activities of individuals and institutions associated in the European Radiation Dosimetry Group (EURADOS) regarding radiation dosimetry.
In the first project, radiation dose rates after the administration of diagnostic or therapeutic activities of, for example, ^{99m}Tc, ^{131}I and ^{18}F at a certain distance from the patient's body are investigated on the basis of clinical measurements and computer simulations.
In the second project, European systems for *in-vivo* measurements of bodily radioactivity (whole-body counters) are intercompared by completing up to five tasks (Victor, emergency, medicine, calibration, person) based on laboratory measurements of different phantoms of the whole human body containing different radionuclides (^{40}K, ^{60}Co, ^{68}Ga/^{68}Ge, ^{88}Y, ^{133}Ba, ^{134}Cs, ^{137}Cs, ^{152}Eu).
In the third project, different phantoms of the human neck / thyroid phantoms corresponding to the different age of the subjects and containing different radionuclides (^{125}I, ^{131}I, ^{133}Ba) are intercompared based on laboratory measurements in different geometries with different system for *in-vivo* measurements of activity in the thyroid gland.
In the fourth project, writing and publication of a review report with the working titles Internal dosimetry of therapeutic radiopharmaceuticals / Toward a roadmap for patient-specific dosimetry in radiopharmaceutical therapy is considered, dealing with the present and future internal dosimetry aspects of the treatments with radiopharmaceuticals and radiolabelled medical devices.
The internal problems of the Republic of Croatia related to internal irradiation with open radioactive sources are, in principle, non-compliance with the law and evidence-based medical and radiation science. The exposed workers are neither measured nor subjected to internal radiation assessment in a systematic and comprehensive manner, just as systematic and comprehensive internal irradiation of patients is neither planned nor intratherapeutically verified during radiotherapy procedures in nuclear medicine. The case of an unexpected and unwanted emergency event that would include internal contamination with radionuclides would also belong to the aforementioned issue. Therefore, it is to be hoped that participation of as many Croatian experts and institutions as possible in as many international projects ultimately related to internal dosimetry could finally begin to change the awareness and practical actions of all stakeholders towards the common good.

Keywords: internal dosimetry, European Radiation Dosimetry Group, *in-vivo* measurement, radionuclide, internal exposure

ENRAS (ENSURING RADIATION SAFETY) - INTERREG V-A SLOVENIJA-HRVATSKA 2014-2020

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Sažetak

Sustav zaštite od ionizirajućeg zračenja u Sloveniji i Hrvatskoj zasniva se primarno na znanjima unutar znanstvenih institucija. Interventne postrojbe poput vatrogasaca donedavno nisu bile opremljene adekvatnom opremom niti uvježbane za intervencije koje bi uključivale izvore ionizirajućeg zračenja. S tim povodom pokrenut je projekt ENRAS (ENsuring RAdiation Safety) čiji je cilj bio educirati i obučiti vatrogasce kako bi bili sposobni izvršiti intervencije u zadanim situacijama. Drugi cilj bio je uspostaviti infrastrukturu koja bi osigurala kontinuirano osposobljavanje i educiranje interventnih jedinica i osigurala koordinaciju prekograničnih aktivnosti između dvije države.

Kako su Slovenija i Hrvatska u zajedničkom vlasništvu nuklearne elektrane Krško, postrojbe iz 8 županija koje graniče sa Slovenijom uključene su u navedeni projekt. Nositelji projekta su bili Institut Jožef Stefan iz Ljubljane i Institut za medicinska istraživanja i medicinu rada iz Zagreba.

Na projektu je kao partner sudjelovala Gasilska zveza Slovenije a kao pridruženi partneri Hrvatska vatrogasna zajednica, Državni zavod za radiološku i nuklearnu sigurnost, Uprava Republike Slovenije za jedersko varnost i Uprava Republike Slovenije za zaščito in reševanje.

U razdoblju manjem od dvije godine, obučeno i osposobljeno je preko 800 vatrogasaca, od čega preko 540 iz Hrvatske.

Potvrda uspješne obuke koja je provedena u preko 60 vatrogasnih postrojbi u Sloveniji i Hrvatskoj bile su zajedničke simulirane intervencije koje su uključivale nekoliko scenarija u kojima su vatrogasci primijenili vještine i znanja koja su usvojili tijekom osposobljavanja.

Svi polaznici uspješno su riješili i pisani ispit kao provjeru usvojenih pojmova i znanja iz područja zaštite od ionizirajućeg zračenja.

Povratnu informaciju o temama, predavačima, načinu informiranja i stečenim vještinama dobili smo putem pisanog upitnika kojeg su polaznici ispunjavali, a same ocjene su bile vrlo visoke.

Projekt je u potpunosti opravdao ciljeve, odziv vatrogasaca bio je izvrstan, povratne informacije zaprimljene od sudionika pokazuju da su vrlo zadovoljni temom i načinom na koji im je prezentiran problem zaštite od ionizirajućeg zračenja.

Velika većina je bila vrlo motivirana u samom radu s opremom i u usvajanju novih znanja, te su izrazili želju da se takav program edukacije češće održava.

Također su naglasili korist od upoznavanja sa mogućim rizicima i načinima prevencije u mogućim intervencijama koje uključuju izvore ionizirajućeg zračenja.

Ključne riječi: zaštita od ionizirajućeg zračenja, interventne postrojbe, edukacija

ENRAS (ENSURING RADIATION SAFETY) - INTERREG V-A SLOVENIJA-HRVATSKA 2014-2020

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Abstract

The system of radiation protection in Croatia and Slovenia relies primarily on the expertise of laboratories within research institutes.

First responders, firefighters in particular, were until recently neither equipped nor trained for interventions that might involve sources of radiation protection.

For this reason, the ENRAS project (ENsuring Radiation Safety) was initiated, aiming to educate and train firefighters in carrying out interventions safely. The second goal of the project was to establish an infrastructure for maintaining these competences and ensuring coordinated cross-border activities.

Since Croatia and Slovenia are joint owners of the Krško Nuclear Power Plant, firefighter companies from 8 croatian counties that are situated alongside border with Slovenia have been included in this project.

The ENRAS project was carried out by the Jožef Stefan Institute from Ljubljana, Slovenia, and the Institute for Medical Research and Occupational Health from Zagreb, Croatia, with the support of the two countries' firefighter associations and state offices regarding radiological and nuclear safety.

In less then two years, more than 800 firefighters alltogether were trained, 540 being from Croatia.

The success of the training carried out in more than 60 firefighter companies in Croatia and Slovenia was checked through joint simulated interventions which included several scenarios where firefighters were abled to show skills they obtained during the training.

All trainees have succesfuly passed written exams considering radiation protection safety.

Additional feedback about all aspects of the project was obtained from questionnaires and the results were very good.

The response to the project was exceptionally good, and most of the firefighters stated that they benefited significantly in view of safety during potential interventions related to radiological and nuclear accidents.

Keywords: radiation protection safety, first responders, education

INCIDENT WITH EXTREMLY HIGH DOSE MEASURED IN STERILIZATION FACILITY

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Abstract
In Slovenia in Komenda, 20 km NE from Ljubljana sterilization facility operates to sterilise medical equipment mainly. For sterilization the high doses of beta radiation are used. The source of radiation are 2 linear accelerators with power of 10 MW. The radiation output is up to 50 000 Gy in few seconds what is enough to sterilise the equipment. Since the radiation is very strong, special arrangement of facility is required. Safety systems are designed to prevent entrance of the workers into radiation area. In August 2022 ZVD dosimetry service read personal dosimeters of the workers in sterilization facility. One reading showed extremly high measured dose of 1267 mSv. Immediately the radiation protection officer in the facility was informed as well as regulation authorities. In the article we describe the further action of regulation authorities, facility, authorised radiation protection expert (ZVD) and reconstruction the event. The sequence of the actions leading to high dose on dosimeter is explained.

Keywords: high dose sterilization, radiation incident, regulation and future action

EU INICIJATIVA ZA OSLIKAVANJE KARCINOMA – PERJANICA EU AKCIJSKOG PLANA ZA BORBU PROTIV KARCINOMA

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Sažetak
Europska inicijativa za snimanje raka jedna od predvodnika Europskog plana za borbu protiv raka (EBCP). Jedan od ciljeva Plana je maksimalno iskoristiti potencijal podataka i digitalnih tehnologija kao što su umjetna inteligencija (AI) ili računarstvo visokih performansi (HPC) u borbi protiv raka. Cilj Europske inicijative za snimanje raka je poticanje inovacija i primjene digitalnih tehnologija u liječenju raka, kako bi se postiglo preciznije i brže donošenje odluka, dijagnostika, liječenje i prediktivna medicina za oboljele od raka. Inicijativa će demonstrirati kako pristupiti, koristiti i objediniti medicinske snimke, a pritom će osigurati visoku razinu etike, povjerenja, sigurnosti i zaštite osobnih podataka u potpunom skladu s vrijednostima i pravilima EU-a. Učinit će velike količine snimki i povezanih kliničkih podataka lako dostupnim europskim kliničarima, istraživačima i inovatorima u skladu s europskom podatkovnom strategijom i podupiranjem ciljeva Europskog prostora zdravstvenih podataka. Skupovi podataka o snimkama raka postoje za različite vrste raka, ali su raštrkani po mnogim repozitorijima i kliničkim centrima u Europi pa nisu lako dostupni kliničarima, istraživačima i inovatorima. Kamen temeljac inicijative bit će udružena Europska infrastruktura za podatke o snimkama raka, razvijena u okviru projekta EUCAIM financiranog u okviru programa DIGITAL. Projekt počinje s 21 kliničkom lokacijom u 12 zemalja i ima za cilj kreirati najmanje 30 distribuiranih pružatelja podataka u 15 zemalja. Projekt će osigurati središte koje će povezivati inicijative na razini EU-a i one nacionalne, bolničke mreže kao i istraživačke repozitorije s podacima o snimanju raka. Kliničari, istraživači i inovatori imat će prekogranični pristup interoperabilnoj, sigurnoj infrastrukturi u svrhu objedinjene, raširene analize podataka o snimanju raka. Nadamo se da će se u projekt uključiti i neke od hrvatskih institucija. Europska središta digitalnih inovacija u okviru programa DIGITAL podržavat će uvođenje tehnologija relevantnih za Europsku inicijativu za snimanje raka, npr. informiranjem inovatora o pravnim zahtjevima i mogućnostima ustanova koje su im dostupne. Pružat će niz usluga korisnicima i pružateljima digitalnih rješenja, kao što su usluge testiranja prije ulaganja, mogućnosti obuke i umrežavanja kao i pristup financijama.

Ključne riječi: akcijski plan za borbu protiv karcinoma, oslikavanje, umjetna inteligencija, strojno učenje

EU CANCER IMAGING INTIATIVE – A FLASHIP OF EU CANCER BEATING ACTION PLAN

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Abstract
The European Cancer Imaging Initiative is one of the flagships of the Europe's Beating Cancer Plan (EBCP). One of the objectives of the Plan is to make the most of the potential of data and digital technologies such as Artificial Intelligence (AI) or High-Performance Computing (HPC) to combat cancer. The aim of the European Cancer Imaging Initiative is to foster innovation and deployment of digital technologies in cancer treatment and care, to achieve more precise and faster clinical decision-making, diagnostics, treatments and predictive medicine for cancer patients. The Initiative will showcase how medical images can be accessed, used and pooled, while ensuring a high level of ethics, trust, security and personal data protection in full compliance with EU values and rules. It will make large amounts of cancer images and linked clinical data easily accessible to European clinicians, researchers and innovators in line with the European data strategy and supporting the goals of the European Health Data Space. Cancer imaging datasets exist for different cancer types, but they are scattered among many repositories and clinical centres in Europe, and they are not easily accessible to clinicians, researchers and innovators. The cornerstone of the initiative will be a federated European infrastructure for cancer images data, developed by the EUCAIM project funded under the DIGITAL programme. The project starts with 21 clinical sites from 12 countries and aims to have at least 30 distributed data providers from 15 countries by the end of the project. The project will provide a central hub that will link EU-level and national initiatives, hospital networks as well as research repositories with cancer images data. Clinicians, researchers and innovators will have cross-border access to an interoperable, privacy-preserving and secure infrastructure for federated, distributed analysis of cancer imaging data. We hope that some of the Croatian institutions will join the project. The European Digital Innovation Hubs under the DIGITAL Programme will support the roll-out of the technologies relevant for the European Cancer Imaging Initiative, for example by informing the innovators about the legal requirements and testing facilities available to them. They will provide a range of services to digital solutions users and providers, such as test-before-invest services, training and networking opportunities as well as access to finances.

Keywords: Cancer Beating Plan, imaging, AI, machine learning

ISTRAŽIVAČKO PARTNERSTVO EUROPSKE UNIJE U PODRUČJU ZAŠTITE OD ZRAČENJA – *PIANOFORTE,* ŠTO JE TO U STVARNOSTI?

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Sažetak
Pokrenuto 14. lipnja 2022. u Parizu, istraživačko partnerstvo PIANOFORTE teži unaprijediti znanje i promicati inovacije u području zaštite od zračenja za dobrobit javnosti, pacijenata, radnika i okoliša u svim scenarijima izloženosti ionizirajućem zračenju. Kroz znanstvene izazove kojima će se baviti, ovo partnerstvo ima za cilj doprinijeti prioritetnim europskim politikama kao što su borba protiv raka (Europski akcijski plan za suzbijanje raka), zaštita zdravlja od ekoloških rizika (Zeleni pakt za rast) i konačno poboljšanje predviđanja i otpornost u situacijama katastrofe (provedba Okvira iz Sendaija za smanjenje rizika od katastrofa). Unutar ovog partnerstva, najmanje tri poziva za dostavu prijedloga bit će otvorena za cijelu europsku istraživačku zajednicu zaštite od zračenja. Usredotočit će se na sljedeće četiri teme: poboljšanje zaštite pacijenata od zračenja vezanog uz uporabu ionizirajućeg zračenja u medicini; bolje razumijevanje varijabilnosti individualnog odgovora na izloženost ionizirajućem zračenju; proučavanje mehanizama uključenih u kroničnu izloženost niskim dozama ionizirajućeg zračenja; poboljšanje sposobnosti predviđanja i otpornosti u nuklearnim ili radiološkim kriznim situacijama i upravljanje nakon akcidenta. Posebna pozornost posvetit će se uključivanju svih dionika (nadležna tijela, civilno društvo, stručnjaci u području zaštite od zračenja, itd.) u određivanju prioritetnih znanstvenih tema koje će biti predmetom natječaja te prenošenju istraživanja u stvarno pojačanu zaštitu od zračenja i korištenje novih tehnologija. Cilj je što je moguće bolje ispuniti i integrirati očekivanja širokog skupa dionika u zaštiti od zračenja. Ovo partnerstvo također ima za cilj stvoriti poveznicu s istraživačkim aktivnostima koje se provode na europskoj razini u „ne-Euratom" područjima, posebno u zdravstvu. Osim ovih istraživačkih aktivnosti, PIANOFORTE će doprinijeti stvaranju održive i međunarodno priznate stručnosti u europskoj zaštiti od zračenja promicanjem dostupnosti, korištenja i dijeljenja postojećih najsuvremenijih istraživačkih infrastruktura na europskoj razini kao i provedbom aktivnosti obrazovanja i osposobljavanja. Partnerstvo će se vezati na prethodni rad, a posebno na rezultate europskog zajedničkog programa CONCERT koji se provodio u okviru programa H2020. Također će se vezati na postignuća drugih europskih projekata koji su upravo završeni ili su u tijeku, kao što je MEDIRAD, HARMONIC, RadoNorm ili SINFONIA.
Danas PIANOFORTE uključuje 58 partnera iz 22 zemlje EU-a te Ujedinjenog Kraljevstva i Norveške. Angažira javne partnere (javne istraživačke organizacije, tijela u području zaštite od zračenja, sveučilišta), ali i šest europskih istraživačkih platformi u zaštiti od zračenja (MELODI, EURADOS, EURAMED, NERIS, ALLIANCE i SHARE). Očekuje se da će se ovaj inicijalni konzorcij proširiti dionicima koji će se odabrati otvorenim pozivima organiziranim tijekom partnerstva.

Ključne riječi: EU partnerstvo, PIANOFORTE, zaštita od zračenja, Euratom

EUROPEAN PARTNERSHIP IN RADIATION PROTECTION RESEARCH – PIANOFORTE, WHT IS IT IN REALITY?

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Abstract
Launched on June 14, 2022 in Paris, the PIANOFORTE research partnership has the ambition to improve knowledge and promote innovation in the field of radiation protection for the benefit of better protection of the public, patients, workers and the environment in all scenarios of exposure to ionizing radiation. Through the scientific challenges it will address, this partnership aims to contribute to priority European policies such as the fight against cancer (European Cancer Beating Action Plan), the protection of health from environmental risks (Green Pact for Growth) and finally the improvement of anticipation and resilience in disaster situations (implementation of the Sendai Framework for Disaster Risk Reduction). Within this partnership, at least three calls for proposals, open to the entire European research community for radiation protection. They will focus on the following four themes: improving patient radiation protection in relation to the use of ionizing radiation in the medical field; a better comprehension of variability of individual response to exposure to ionizing radiation; the study of mechanisms involved in chronic exposure to low doses of ionizing radiation; the improvement of anticipation capacities and resilience in nuclear or radiological crisis situations and post-accident management. Particular attention will be paid to the involvement of all stakeholders (authorities, civil society, radiation protection practitioners, experts, etc.) in the priority setting of the scientific topics that will be the subject of calls for tender and with respect to the question of translating this research into actual impact for strengthened radiation protection and harness new technologies. The objective is to meet and integrate the expectations of the wide set of radiation protection stakeholders as best as possible. This partnership also specifically aims to build bridges with research activities carried out at European level in the "non-Euratom" fields, in particular in the health sector. Beyond these research activities, PIANOFORTE will contribute to maintaining a sustainable capacity of expertise in radiation protection in Europe, which is internationally recognized, in particular by promoting the availability, use and sharing of existing state-of-the-art research infrastructures at the European level as well as by implementing education and training activities. The partnership will build on previous work, and in particular on the results of the European joint program CONCERT conducted under the H2020 framework program which ended in 2020. It will also benefit from the achievements of other European projects just completed or in progress such as MEDIRAD, HARMONIC, RadoNorm or SINFONIA.
To date, PIANOFORTE involves 58 partners from 22 EU countries as well as the UK and Norway. It mobilizes public partners (public research organizations, authorities in the field of radiation protection, universities) but also the six European research platforms in radiation protection (MELODI, EURADOS, EURAMED, NERIS, ALLIANCE and SHARE). This initial consortium is expected to expand with the entities that will be selected in the framework of the open calls for tenders organized during the partnership.

Keywords: EU partnership, PIANOFORTE, radiation protection, Euratom

ODREĐIVANJE KOREKCIJSKIH FAKTORA NA VOLUMNO USREDNJAVANJE ZA IONIZACIJSKE KOMORE RAZLIČITOG VOLUMENA U USKIM SNOPOVIMA ^{60}Co

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Sažetak
Volumno usrednjavanje mjerenog odziva detektora je poznat problem u dozimetriji malih polja. Taj efekt utječe na očitanje detektora tako što profil doze fotonskog snopa čini širim nego li on stvarno je zbog čega može biti podcijenjena apsorbirana doza na centralnoj osi snopa. Zbog toga odziv detektora mora biti korigiran na efekt volumnog usrednjavanja detektora koje se računa pomoću Kawach-ijeva formalizama. Zbog specifične geometrije raspodjele apsorbirane doze Gamma noža (Elekta, Stockholm, Švedska) navedeni formalizam mora biti korigiran i dopunjen kako bi bio primjenjiv. Svrha ovog rada je odrediti korekcije na volumno usrednjavanje za različite ionizacijske komore i različite veličine fotonskog snopa u izocentru uskih snopova ^{60}Co kakve koristi Gamma nož Icon.
U istraživanju su korištene sljedeće ionizacijske komore: Semiflex TM31010 V=125 mm^3, PinPoint TM31014 V=15 mm^3, PinPoint 3D TM31016 V=16 mm^3 (PTW, Freiburg, Njemačka), RAZOR komorica V=10 mm^3, i RAZORnano komorica V=3 mm^3 (IBA Dosimetry, Schwarzenbruck, Njemačka). Da bi odredili korekcije na volumno usrednjavanje za različite ionizacijske komore korišten je 3D eliptični model raspodjele apsorbirane doze s normaliziranim generičkim profilima doze. Koristeći normalizirane profile doze prilagođene na analitički izraz, napravljena je vizualizacija različitih polja Gamma noža u MATLAB-u (TheWathWorks Inc., SAD). Koristeći numeričko integriranje (Simpson-ova metoda) određene su korekcije na volumno usrednjavanje za snopove različitih veličina.
Ionizacijska komora Semiflex ima najveće korekcijske faktore na volumno usrednjavanje: 1,006, 1,042 i 1,627 za snopove veličine 16, 8 i 4 mm. Korekcijski faktori za PinPoint ionizacijsku komoru su 1,005, 1,011 i 1,181, dok za PinPoint 3D oni iznose 1,003, 1,005 i 1,057 za snopove veličine 16, 8 i 4 mm. Korekcijski faktori za RAZOR ionizacijski komoru su 1,004, 1,006 i 1,074 dok RAZORnano ima korekcijske faktore 1,003, 1,003, 1,025 za snopove veličine 16, 8 i 4 mm.
U radu je pokazana mogućnost određivanja korekcijskih faktora na volumno usrednjavanje u uskim snopovima Gamma noža koristeći eliptični model doze. Pokazano je da korekcijski faktori na volumno usrednjavanje rastu s porastom osjetljivog volumena detektora. Za sve ispitivane detektore korekcijski faktori na volumno usrednjavanje se smanjuju s povećanjem veličine snopa.

Ključne riječi: volumno usrednjavanje, ^{60}Co, Gamma nož, MATLAB

DETERMINATION OF VOLUME AVERAGING CORRECTION FACTORS FOR IONIZATION CHAMBERS OF DIFFERENT EFFECTIVE VOLUMES IN NARROW ^{60}Co BEAMS

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Abstract
Volume-averaging of a measured detector response is a known problem in small photon beam dosimetry. This affects the reading of detectors and erroneously makes wider the penumbra region of a measured dose profile which results in an underestimation of the absorbed dose on the beam central axis. To account for this, the measured response must be corrected by the volume averaging correction factor, calculated using Kawachi formalism. However, due to the difference in radiation field geometry, this formalism must be modified to be applicable to Gamma Knife (Elekta, Stockholm, Sweden). The purpose of this work was to determine the volume averaging correction factors for different ionization chambers and field sizes in narrow ^{60}Co beams used by Gamma Knife Icon.
Small-volume ionization chambers that were studied are: Semiflex TM31010 V=125 mm^3, PinPoint TM31014 V=15 mm^3, PinPoint 3D TM31016 V=16 mm^3 (PTW, Freiburg, Germany), RAZOR chamber V=10 mm^3, and RAZORnano chamber V=3 mm^3 (IBA Dosimetry, Schwarzenbruck, Germany). To determine a volume averaging correction for different detectors a 3D elliptical dose model was implemented using normalized dose profiles provided by Elekta (Sweden). With fitted dose profiles and an elliptical 3D dose model, an analytical expression and visualization of different field sizes were obtained using MATLAB (TheMathWorks Inc., USA). Using numerical integration (Simpson's rule), we were able to determine the volume averaging correction factors as a function of different field sizes.
Semiflex chamber has the largest volume averaging correction factor: 1.006, 1.042, and 1.627 for 16, 8, and 4 mm field sizes respectively. Furthermore, the corrections for the PinPoint ionization chamber are 1.005, 1.011, and 1.181; for PinPoint 3D, the corrections are 1.003, 1.005, and 1.057 for 16, 8, and 4 mm field sizes respectively. The corrections for the RAZOR chamber are 1.004, 1.006, and 1.074 while the RAZORnano chamber has corrections of 1.003, 1.003, and 1.025 for 16, 8, and 4 mm field sizes respectively.
This work has illustrated the possibility to determine volume averaging correction factors for narrow photon beams of Gamma Knife devices using an elliptical dose model. It is shown that volume averaging increases with the increase in the detector's sensitive volume. Therefore, the Semiflex ionization chamber had the largest correction factor for all field sizes and the RAZORnano chamber had the smallest. For all studied detectors volume averaging decreased with an increase in field size.

Keywords: volume averaging, ^{60}Co, Gamma Knife, MATLAB

NAPREDNI OKSIDACIJSKI PROCESI - IONIZIRAJUĆE ZRAČENJE

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Sažetak
Konvencionalne metode pročišćavanja otpadnih voda temelje se na kemijskim, fizikalnim ii biološkim procesima te često nisu dovoljno učinkovite u uklanjanju teško razgradivih zagađivala kao što su pesticidi, herbicidi i farmaceutici. Tretiranje vodenih otopina ionizirajućim zračenjem kao jednim od naprednih oksidacijskih procesa može biti efikasno u riješavanju problema otpadnih voda. Cilj ovog rada bio je istražiti utjecaj doze zračenja, brzine doze, anorganskih iona i pH na radiolitičku razgradnju često korištenog antihipertenziva, doksazosina. Utvrđeno je da su $^{\bullet}OH$ glavne reaktivne vrste odgovorne za razgradnju doksazosina, a efikasnost razgradnje polaznog spoja raste s porastom doze zračenja. Prisutnost nitrata je imala značajniji utjecaj na razgradnju doksazosina u usporedbi s karbonatima i fosfatima. Optimalna pH vrijednost za razgradnju vodene otopine doksazosina je u neutralnom, blago kiselom području (pH = 6,5), dok je pri izrazito kiselim i baznim uvjetima razgradnja bila slabija. Rezultati istraživanja ukazuju da je radijacijska tehnologija pogodna u procesu uklanjanja mikrozagađivala kao što su farmaceutici u realnim vodenim sustavima.

Ključne riječi: napredni oksidacijski procesi, farmaceutici, ionizirajuće zračenje

ADVANCED OXIDATIVE PROCESSES - IONIZING RADIATION

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Abastract
Conventional methods of wastewater treatment rely on chemical, physical and biological processes and are often not efficient enough to remove persistent pollutants such as pesticides, herbicides and pharmaceuticals. Treatment of aqueous solutions with ionizing radiation as one of the advanced oxidation processes can be effective in solving the wastewater problem. The aim of this work was to investigate the influence of radiation dose, dose rate, inorganic ions and pH on radiolytic degradation of the commonly used antihypertensive drug doxazosin. It was found that $^{\bullet}OH$ are the main reactive species responsible for the degradation of doxazosin and that the efficiency of degradation of the parent compound increases with the increase of the radiation dose. The presence of nitrates had a stronger influence on the degradation of doxazosin than that of carbonates and phosphates. The optimal pH for the degradation of the aqueous solution of doxazosin is in the neutral, slightly acidic range (pH = 6.5), while the degradation was weaker under extremely acidic and basic conditions. The research results indicate that irradiation technology is suitable for the removal of micropollutants such as pharmaceuticals in real water systems.

Keywords: advanced oxidative processes, pharmaceuticals, ionizing radiation

THE 60TH ANNIVERSARY OF ORGANISED RADIATION PROTECTION

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Abstract
Harmful effects of radiation and call for protection against it were recognized practically immediately upon the discovery of X-rays, but awareness about the harmful effects of the ionizing radiation have increased with the expansion of application of radioisotopes and nuclear methods. This resulted in the development of new scientific and professional discipline that is now known as the Radiation Protection. Radiation protection covers a wide range of domains and applications related to the development and operation of nuclear and radiation related technologies. Radiation protection regulation, at international level, was related to the foundation of the International Commission on Radiological Protection in 1963. Activities in the radiation protection field in Yugoslavia started in the beginning of the 60s of the 20th centuries. During the Symposium held in Portorož on October 8-12, 1963 the Yugoslav Radiation Protection Association (YRPA) was founded. In the period 1963-1970 the name of the society was Yugoslav Society for Radiological Protection, in the period 1972-2003 it was Yugoslav Radiation Protection Association, and in 2005 it became Radiation Protection Association of Serbia and Montenegro, which remained till present. The main tasks and aims of the YRPA were at that time almost the same as today: to organize activities on the continual environmental quality improvement and protection of the environment, human and animal population from the harmful effects of the radiation; initiation and support of scientific research in all fields where the radiation sources are used for peaceful purposes; to care for adequate social position of professionals dealing with radiation sources and working in radiation protection departments and promotion of professional and ethical principles application in the radiation sources use; to organize efforts and requirements for continuous public education and information about radiation and radiation protection and training of the professionals who work with radiation sources and in radiation protection services, for efficient work in accidental conditions; to organize of symposia, conferences and other scientific meetings for professional and scientific experience exchangeand to collaborate with IRPAand radiation protection associations and societies from other countries and international organizations. Over the past decades association have immensely contributed to the development of legislation and regulations, to the monitoring and control, to prediction of the consequences and the assessment of risks. The radiation protection professionals presented all the achieved results at XXXI symposiums which were organized every 2 years.

Keywords: Radiation Protection, regulation, scientific research

DOZIMETRIJA ZRAČENJA

RADIATION DOSIMETRY

ISPITIVANJE ODZIVA GREŠKOM OPRANIH TERMOLUMINISCENTNIH DOZIMETARA U STROJU ZA PRANJE RUBLJA

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Sažetak
Pri procjeni vanjske izloženosti radnika korištenjem osobnih dozimetara često se susrećemo s dozimetrima koji se na očitanje vrate oprani u stroju za pranje rublja. U ovom radu, analiziran je utjecaj temperature i vrste deterdženta na odziv ozračenih termoluminiscentnih dozimetara. Korišteni su termoluminiscentni dozimetri tipa TLD-100 (LiF:Mg, Ti), te industrijski stroj za pranje rublja. Kako bi pokrili što više mogućih slučajeva za vrijeme nošenja dozimetara, dozimetri su prani zajedno s odjećom na temperaturama od 30 °C, 40 °C, 60 °C i 95 °C. Dodatno, korišteni su sljedeći uvjeti: pranje bez deterdženta, pranje s tekućim deterdžentom te pranje s industrijskim praškastim deterdžentom.
Rezultati istraživanja pokazuju da su učinci prolaska TL dozimetra kroz ciklus pranja negativni i dovode do povećanja odziva aktivnog elementa. Posljedično doza zračenja koja se očita s takvog dozimetra pokazuje odziv do 1 mSv viši nego u slučaju da dozimetar nije greškom opran. Viši odziv ne ovisi o dozi koju je radnik primio, već se pokazuje apsolutno odstupanje. To se, najvjerojatnije, može pripisati kemijskim promjenama na površini aktivnog elementa uslijed djelovanja temperature, vlage i deterdženta za pranje. U slučaju da se dozimetar izloženog radnika opere, na krivulji isijavanja ne mogu se primijetiti razlike u odnosu na neoprani dozimetar te se će se radniku, vrlo vjerojatno, pridijeliti doza koja nije primio. Pozitivna je činjenica da se doza ne povećava u relativnom iznosu već u apsolutnom, od najviše 1 mSv. Svi oprani dozimetri pokazivali su isti prekomjeran odziv nakon svakog sljedećeg čitanja te se više ne mogu upotrebljavati u rutinskoj dozimetriji.

Ključne riječi: dozimetrija, termoluminiscentni dozimetar, stroj za pranje rublja

TESTING OF THE RESPONSE OF ACCIDENTALLY WASHED THERMOLUMINISCENT DOSIMETERS IN A WASHING MACHINE

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Abstract
When assessing the external exposure of workers using personal dosimeters, we often come across dosimeters that are returned after being washed in a washing machine. In this work, the influence of temperature and type of detergent on the response of irradiated thermoluminescent dosimeters was analysed. Thermoluminescent dosimeters of type TLD-100 (LiF:Mg, Ti) and an industrial washing machine were used. In order to cover as many possible cases as possible while wearing the dosimeters, the dosimeters were washed together with the clothes at temperatures of 30 °C, 40 °C, 60 °C and 95 °C. Additionally, the following conditions were used: washing without detergent, washing with liquid detergent and washing with industrial powder detergent.
The results show that the effects of passing the termoliminiscent dosimeter through the washing cycle are negative and lead to an increase in the response of the dosimeter's active elements. Consequently, the radiation dose read from such a dosimeter shows an overresponse up to 1 mSv higher than if the dosimeter was not washed by mistake. The higher response does not depend on the dose that the worker received, but shows an absolute deviation. This, most likely, can be attributed to chemical changes on the surface of the active element due to the effects of temperature, humidity and washing detergent. If the dosimeter of an exposed worker is washed, no differences can be observed on the radiation curve compared to an unwashed dosimeter, and the worker will most likely be assigned a dose that he did not receive. It is a positive fact that the dose does not increase in relative amount but in absolute amount, of a maximum of 1 mSv. All washed dosimeters showed the same overresponse after each subsequent reading and could no longer be used in routine dosimetry.

Keywords: dosimetry, thermoluminescent dosimeter, washing machine

ODREĐIVANJE REFERENTNE BRZINE KERME U ZRAKU BRAHITERAPIJSKOG IZVORA ^{192}Ir VELIKE BRZINE DOZE: PREGLED REZULTATA I ISKUSTVA JEDNE USTANOVE

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Sažetak
Određivanje referentne brzine kerme u zraku (RAKR) brahiterapijskog izvora velike brzine doze (HDRBT) ključna je komponenta kliničkog programa osiguranja kvalitete. Ono je temeljni korak koji osigurava točnu, pouzdanu i sigurnu brahiterapiju, pa ga stoga preporučuju glavna međunarodna i nacionalna stručna udruženja, a često je obavezan i prema nacionalnoj regulativi. Cilj ovog rada je prikaz postupaka određivanja RAKR izvora iridija (^{192}Ir) i analiza rezultata mjerenja u Klinici za onkologiju i nuklearnu medicinu, KBC Sestre milosrdnice, provedenih tijekom više od 20 godina kliničke brahiterapije. Ovaj pregled uključuje opis mjerne metode određivanja RAKR-a, promjene postupka i prilagodbe tijekom vremena, uključujući izmjenu uređaja za naknadno uvođenje izvora, vrste izvora te zamjenu mjerne opreme. Ispitan je utjecaj ovih varijabli na rezultate RAKR-a i provedena je procjena nepouzdanosti RAKR-a, razmatranjem svih važnih doprinosa nepouzdanosti tipa A i B, koji se odnose na model jednadžbe za račun RAKR-a, kombiniranih u standardnu nepouzdanost. Vrijednosti RAKR su određene za 59 izvora ^{192}Ir u periodu 2000.-2022. Tijekom tog perioda izmijenjena su dva uređaja za naknadno uvođenje izvora. Ionizacijska komora „bunarskog“ tipa (HDR 1000 Plus, Standard Imaging) je također zamijenjena s novom komorom istog modela dok je elektrometar (CDX-2000A, Standard Imaging) zamijenjen s CDX-2000B. Postotne razlike između mjerenih ($RAKR_{meas}$) vrijednosti i proizvođačke vrijednosti ($RAKR_{man}$), $\Delta\% = (RAKR_{meas} - RAKR_{man})/ RAKR_{man}$, pokazuju dobro slaganje i dokazuju da su uspostavljeni mjerni postupci pouzdani i stabilni. Srednja vrijednost razlika Δ% je -0,13% sa standardnom devijacijom 0,96%, a sve Δ% razlike su unutar preporučenog raspona od ± 3%. Raspodjela RAKR rezultata slijedi Gaussovu raspodjelu. Rezultati postotne razlike Δ% razvrstani u dvije grupe prema upotrijebljenom uređaju za uvođenje izvora ne pokazuju statistički značajne razlike. Korelacija razlike Δ% i vrijednosti RAKR nije opažena. Procijenjena kombinirana proširena nepouzdanost mjerene RAKR ima vrijednost 2,9% uz faktor pokrivenosti k=2. Ova retrospektivna analiza rezultata ukazuje na dugoročnu stabilnost i točnost mjerenja RAKR-a HDRBT izvora ^{192}Ir pomoću ionizacijske komore i primjerenost utvrđenih postupaka određivanja RAKR-a.

Ključne riječi: brahiterapija, velika brzina doze, referentna brzina kerme u zraku, ionizacijska komora bunarskoga tipa

DETEREMINATION OF THE REFERENCE AIR KERMA RATE OF A HIGH DOSE RATE BRACHYTHERAPY ^{192}Ir SOURCE: A REVIEW OF THE SINGLE INSTITUTION EXPERIENCE AND RESULTS

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Abstract

Determination of the reference air kerma rate (RAKR) of a high dose rate brachytherapy (HDRBT) source, is the key component of a clinical quality assurance programme. It is the fundamental step that ensures accurate, reliable, and safe brachytherapy, and therefore it is recommended by the major international professional societies and usually required by the national regulations. The objective of this work is to review the ^{192}Ir HDRBT source RAKR determination procedures and analyse measurement results from a single institution, the Department of Oncology and Nuclear Medicine, UHC Sestre milosrdnice, in over 20 years of clinical brachytherapy. This review comprises the description of the RAKR measurement method, procedure changes and adjustments over time including the afterloader, source type and dosimetry measurement equipment replacement. The influence of these variables on the RAKR results was examined and an estimate of the RAKR uncertainty budget is conducted. The uncertainty of the measured RAKR was estimated by analysing all contributions relevant to the model equation that is used to calculate the RAKR from the measured ionisation current. Type A and type B uncertainties were considered where applicable and combined to a standard combined uncertainty following the international recommendations. RAKR determination of 59 ^{192}Ir sources was conducted in the period 2000-2022. During that time two HDR afterloader units were exchanged. The well type ionization chamber used for measurements (HDR 1000 Plus, Standard Imaging) was also replaced by a new one of the same model along with the electrometer (CDX-2000A, Standard Imaging) upgraded to CDX-2000B. The percentage differences between the measured ($RAKR_{meas}$) values and the manufacturer certificate ($RAKR_{man}$) values, $\Delta\% = (RAKR_{meas} - RAKR_{man})/ RAKR_{man}$, indicate good agreement between the two values and prove that the established measurement procedures are reliable and stable. The mean difference Δ% is -0.13% with a standard deviation of 0.95%, and all Δ% differences are well within the recommended range of ± 3%. The distribution of RAKR results follows the Gaussian distribution. No significant difference of the mean percentage difference Δ% results was observed when results were grouped by the afterloader used. Correlation between the Δ% difference and the actual source strength, RAKR value, was not noted. The estimated combined expanded uncertainty of the measured RAKR has a value of 2.9% with a coverage factor k=2. This retrospective analysis of the department's records on measured HDRBT RAKRs indicates the long-term stability and accuracy of well-chamber measurements and appropriateness of established RAKR determination procedures.

Keywords: brachytherapy, high dose rate, reference air kerma rate, well-type chamber

ODREĐIVANJE KOREKCIJSKIH FAKTORA IONIZACIJSKIH KOMORA ZA SPECIFIČNO REFERENTNO POLJE LEKSELLOVOG GAMA NOŽA

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Sažetak
Leksellov gama nož je radiokirurški uređaj koji se upotrebljava u neuroradiokirurgiji za liječenje malih intrakranijskih tumora. Uređaj sadrži 192 radioaktivna izvora ^{60}Co raspoređenih na plaštu krnjeg stošca, čije snopove fotona oblikuju kolimatori tako da promjer približno sferične raspodjele doze iznosi 4, 8 ili 16 mm u izocentru. U slučaju gama noža nije moguće postići konvencionalno dozimetrijsko referentno polje zračenja veličine 10 cm × 10 cm (f_{ref}). Uvodi se stoga specifično referentno polje za uređaj, f_{msr} (eng. *machine specific reference field*). Za gama nož to je najveće moguće polje, promjera 16 mm. Korekcijski faktor k_{fmsr} korigira razliku odziva ionizacijske komore u polju f_{ref} i polju f_{msr}. U ovom radu, k_{fmsr} je određivan eksperimentalno za tri ionizacijske komore: PTW Pinpoint TM31014, PTW Semiflex3D TM31021 i IBA RAZORChamber, koristeći poznate vrijednosti k_{fmsr} za tri druge ionizacijske komore: PTW Semiflex TM31010, PTW Pinpoint3D TM31022 i IBA CC04 (PTW, Freiburg, Njemačka; IBA Dosimetry, Schwarzenbruck, Njemačka). Navedene su u dozimetrijskom protokolu IAEA TRS483, te se koristi u protokolu opisan formalizam za određivanje k_{fmsr}. Za svih šest ionizacijkih komora, eksperimentalno je određivana absorbirana doza u referentnim uvjetima za uređaj. Mjerenja su provedena na Leksellovom gama nožu Icon (Elekta AB, Stockholm, Švedska) u Gamma knife centru Klinike za neurokirurgiju Kliničkog bolničkog centra Zagreb. Mjerenja su provedena u sferičnom, tkivu ekvivalentom fantomu, Solid Water (Elekta AB, Stockholm, Švedska) sa šest cilindričnih, atmosferski ventiliranih ionizacijskih komora. Signali izmjereni komorama korigirani su za učinak razlike gustoće zraka u odnosu na referentne uvjete (k_{TP}) i učinak rekombinacije iona (k_S). Za ionizacijske komore PTW Semiflex i PTW Pinpoint3D su relativne razlike brzine doze u odnosu na referentnu vrijednost, određenu tijekom puštanja u rad uređaja, veće u odnosu na očekivanja. Iznose redom (1,6±3,1)% te (1,5±2,1)%. Razlog tome bilo je nepotpuno postizanje toplinske ravnoteže ionizacijske komore s okolinom prije mjerenja, te povišena temperatura zraka u odnosu na referentnu temperaturu pri kojoj je komora umjerena. Za IBA CC04 ionizacijsku komoru izmjerena brzina doze vrlo je bliska referentnoj brzini doze (0,2±3,0)% jer je ona stigla postići toplinsku ravnotežu. Nepoznati korekcijski faktori k_{fmsr} za zadane tri ionizacijske komore određeni su usporedbom brzina doza određenih ionizacijskim komorama sa svakom komorom s poznatim k_{fmsr}. Za PTW Pinpoint dobiveno je k_{fmsr}=1,020±0,030, 1,020±0,019 te 1,004±0,026 usporedbom redom s PTW Semiflex, PTW Pinpoint3D te IBA CC04 komorama. Za PTW Semiflex3D rezultati glase redom 1,003±0,026, 1,002±0,013 te 0.986±0.023, a za RAZORChamber 1.021±0.030, 1.021±0.019 i 1.004±0.026. Poznavanje k_{fmsr} nam omogućava višestruku provjeru dozimetrijskog sustava.

Ključne riječi: gama nož, referentno polje, ionizacijska komora, korekcijski faktor

DETERMINATION OF IONIZATION CHAMBER CORRECTION FACTORS FOR THE SPECIFIC REFERENCE FIELD OF LEKSELL GAMMA KNIFE

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Abstract
Leksell Gamma Knife is a radiosurgery system used in neuroradiosurgery for treating small intracranial tumors. It contains 192 radioactive sources of ^{60}Co distributed on the surface of a truncated cone. Photon beams are shaped by collimators so that the diameter of the nearly spherical dose distribution equals 4, 8 or 16 mm at the isocenter. Gamma Knife cannot realize the conventional reference field of 10 cm x 10 cm (f_{ref}). Therefore, the machine-specific reference field f_{msr} is used. For Gamma Knife that is the largest possible field of 16 mm in diameter. The correction factor k_{fmsr} adjusts for the difference in response in fields f_{ref} and f_{msr}. In this work k_{fmsr} was experimentally determined for three ionization chambers: PTW Pinpoint TM31014, PTW Semiflex3D TM31021 and IBA RAZORChamber, using known values of k_{fmsr} for the three other chambers: PTW Semiflex TM31010, PTW Pinpoint3D TM31022 and IBA CC04 (PTW, Freiburg, Germany; IBA Dosimetry, Schwarzenbruck, Germany). The data is given in the dosimetry protocol IAEA TRS483, which describes the formalism for determining k_{fmsr}. The absorbed dose was experimentally determined for all six ionization chambers in machine reference conditions. The measurements were conducted using the Leksell Gamma Knife Icon (Elekta AB, Stockholm, Sweden) at the Gamma Knife Centre, Clinic for Neurosurgery, University Hospital Centre Zagreb. The measurements were conducted using six atmospherically vented cylindrical ionization chambers in a spherical tissue equivalent phantom Solid Water (Elekta AB, Stockholm, Sweden). The measured signals were adjusted for the different air densities from reference conditions (k_{TP}) and ion recombination (k_S). PTW Semiflex and PTW Pinpoint3D had larger than expected dose rate differences relative to the reference value determined during machine commissioning, (1.6±3.1)% and (1.5±2.1)% respectively, caused by the fact that thermal equilibrium of the chambers was not fully reached prior to measurement, and elevated air temperature relative to the reference temperature during chamber calibration. The dose rate of IBA CC04 is similar to the reference value, relative difference (0.2±3.0)%, because it had reached thermal equilibrium. We determined k_{fmsr} by comparing the dose rates of ionization chambers with unknown k_{fmsr} with those of chambers with known k_{fmsr}. The results for PTW Pinpoint are k_{fmsr}=1.020±0.030, 1.020±0.019 and 1.004±0.026 when compared, respectively, with PTW Semiflex, PTW Pinpoint3D and IBA CC04. For PTW Semiflex3D the results are 1.003±0.026, 1.002±0.013 and 0.986±0.023, and for RAZORChamber they are 1.021±0.030, 1.021±0.019 and 1.004±0.026. Knowing k_{fmsr} allows us to conduct multiple tests of the dosimetry system.

Keywords: Gamma knife, reference field, ionization chamber, correction factor

DOZIMETRIJA TEŠKIH NABIJENIH ČESTICA POMOĆU LUMINISCENTNIH DOZIMETARA

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Sažetak
Luminiscentni dozimetri su pasivni dozimetri napravljeni od materijala u kojima ozračivanjem nastaju stabilni luminiscentni centri. Davanjem odgovarajuće stimulacije dolazi do luminiscencije i intenzitet emitiranih fotona povezuje se s dozom. Ovisno o vrsti stimulacije razlikujemo termoluminiscentne (TL), radiofotoluminiscentne (RPL) i optički stimulirane (OSL) dozimetre.
Luminiscentni dozimetri su dobro istraženi u fotonskim i elektronskim poljima, pouzdani su i prikladni za mnoge primjene te se često koriste za mjerenja fotonskih doza u osobnoj dozimetriji, okolišu i medicini. Napravljen je i niz istraživanja vezan za odziv u neutronskim poljima te se neki od njih mogu koristiti za mjerenja neutronskih doza. Poseban izazov, i u posljednje vrijeme sve veći interes, predstavlja primjena luminiscentnih dozimetra u hadronskoj radioterapiji i dozimetriji svemira tj. u uvjetima gdje dominiraju teške nabijene čestice.
U predavanju će se dati pregled trenutnog stanja vezanog za dozimetriju teških nabijenih čestica pomoću luminiscentnih dozimetara s naglaskom na TL i RPL dozimetre.

Ključne riječi: luminiscentni dozimetri, RPL dozimetri, TL dozimetri, dozimetrija teških nabijenih čestica

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LUMINESCENT DOSIMETERS FOR HEAVY CHARGED PARTICLES

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Abstract
Luminescent dosimeters are passive solid state dosimeters made of materials in which stable luminescence centers are formed by irradiation. Luminescence is emmited when irradiated dosimeter is exposed to appropriate stimulation and intensity of the emitted photons is related to the absorbed dose. Depending on the stimulation, we are talking about thermoluminescence (TL), optically stimulated luminescence (OSL) and radiophotoluminescence (RPL).
Luminescent doismeters are well investigated in photon and electron fields and shown to be reliable and suitable for many applications and as such are very often used for photon dosimetry in individual and environmental monitoring and medicine. In addition, studies performed in neutron fields shown that some of them can be used for neutron dosimetry as well. A special chalenge and growing interest lately is possible application of luminescent dosimeters in hadron radoitherapy and space dosimetry i.e. in the fields with heavy charged particles.
In this lecture, overview of the current state related to the heavy charged particle dosimetry with luminescent dosimeters with the special emphasize on TL and RPL dosimeters will be given.

Keywords: luminecent dosimeters, RPL dosimeters, TL dosimeters, heavy charged particle dosimetry

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ISPITIVANJE SVOJSTAVA SKENERA EPSON PERFECTION V850 PRO ZA DOZIMETRIJU S EBT3 FILMOM U RADIOTERAPIJI

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Sažetak
Fotografski skeneri su našli široku primjenu u radiokromskoj dozimetriji zbog svoje pristupačne cijene i visoke razlučivosti. Radiokromski film i skener čine dozimetrijski sustav čija se intrinzična svojstva moraju ispitati prije kliničke uporabe u vanjskoj radioterapiji ili brahiterapiji. Cilj ovog rada je ispitivanje svojstava skenera Epson Perfection V850 pro s EBT3 radiokromskim filmom. Film je pozračen na linearnom akceleratoru (Elekta Synergy, Sweden) s fotonskim snopom energije 6 MV s rasponom doza od 2 do 7 Gy. Nakon toga digitaliziran je pomoću V850 skenera s različitim postavkama skeniranja i analiziran u programu ImageJ. Mjerenjem su provjereni: efekt zagrijavanja skenera, reproducibilnost, razlučivost, dubina boje i neuniformnost skenera. Film je očitan 20 puta zaredom odmah nakon uključivanja skenera. Za analizu efekta zagrijavanja skenera pikselske vrijednosti svih očitanja uspoređene su s prvim. Kao mjera reproducibilnosti iskorištena je standardna devijacija tih 20 očitanja. Film je očitan kao slika s 24- i 48-bitnom dubinom boje te s 72, 96, 300, 600 i 1200 dpi za analizu razlučivosti. Neuniformnost skenera je analizirana u lateralnom i longitudinalnom smjeru.
Rezultati su pokazali da je efekt zagrijavanja skenera zanemariv. Standardna devijacija pikselskih vrijednosti je manja od 0,15 %. Mjerenja su pokazala dobru reproducibilnost skenera (0,04 % za crveni i zeleni te 0,3 % za plavi kanal). Utvrđena je dobra konzistentnost razlučivosti i bitne dubine boje (Standardna devijacija manja od 0,3 % za razlučivost te 0,5-1,4 % kod analize slika 24 i 48 bitne dubine boje). Utvrđena je značajna neuniformnost u lateralnom smjeru dok je u longitudinalnom zanemariva. Najčešće korišteni, i proizvođački preporučeni, skener za filmsku dozimetriju je Epson Expression 10000XL. U odnosu na taj skener, rezultati su pokazali da je V850 ima bolja ili jednaka svojstva osim u slučaju lateralne neuniformnosti. Analiza svojstava skenera Epson Perfection V850 pro pokazala je da se isti može koristiti za preciznu i točnu radiokromsku dozimetriju s EBT3 filmovima u radioterapiji.

Ključne riječi: filmska dozimetrija, radiokromski film, EBT3, skener

EVALUATION OF AN EPSON PERFECTION V850 PRO SCANNER FOR EBT3 FILMS DOSIMETRY IN RADIOTHERAPY APPLICATIONS

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Abstract
Due to their high spatial resolution and affordable pricing, commercial flatbed scanners have been utilized extensively for scanning radiochromic films in dosimetry procedures. Radiochromic film and flatbed scanner form a dosimetry system whose intrinsic properties must be investigated prior to clinical applications in external beam radiotherapy or brachytherapy. The purpose of this work is to evaluate performance of Epson Perfection V850 pro flatbed scanner together with EBT3 film. Film was exposed to 9 dose fields (2×2 cm^2) ranging from 2 to 7 Gy with linear accelerator 6 MV photon beams (Elekta Synergy, Sweeden). Film was digitized using different scanning parameters and image analyses was performed with ImageJ software. Measurements were made to evaluate scanner warm-up effects, reproducibility, resolution, bit depth consistency and scan field non-uniformity. A film with nine dose points was scanned twenty times in succession immediately after the scanner was turned on. Pixel values of every read out were compared with first one to evaluate warm-up effects. Relative standard deviation of those 20 readings was used as a measure of scanner reproducibility. Scanner bit depth consistency was assessed by scanning and analyzing film as 24- and 48-bit depth color images. Similarly, same film was scanned with 72, 96, 300, 600 and 1200 dpi to evaluate scanner resolution. Scan field non-uniformity was also investigated in lateral and longitudinal direction.
Results have shown that warm-up effects are negligible, both on a red and green channel. Pixel values remain constant with standard deviation less than 0.15 %. Analysis has demonstrated good reproducibility of scanner (0.04 % for red and green channel, 0.3 % for the blue one). Measurements have confirmed good resolution and bit depth consistency (less than 0.3% of standard deviation for resolution and 0.5-1.4 % for bit depth evaluation). Longitudinal scan field non-uniformity can be ignored as standard deviation over the length of scanner bed was 0.15 % on all channels. Lateral scan field non-uniformity measurement showed strong lateral non-uniformity as reported in literature. The recommended scanner for EBT3 film dosimetry is Epson Expression 10000XL, as stated by its manufacturer. In comparison with it, V850 has performed same or better in all tests except lateral scan field non-uniformity for which correction is needed. Overall, Epson Perfection v850 pro scanner gave good performance over the range of tests and proved to be reliable and accurate for radiochromic film dosimetry.

Keywords: film dosimetry, radiochromic film, EBT3, flatbed scanner

KONTROLA KVALITETA TERAPIJSKIH DISTRIBUCIJA DOZE U ROBOTIZIRANOJ RADIOKIRURGIJI KORIŠTENJEM DVODIMENZIONALNOG DIODNOG DETEKTORA

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Sažetak
Kontrola kvalitete individualiziranih distribucija doze (eng. *Patient Specific Dosimetry* – PSD) za pojedine pacijente predstavlja važan korak u osiguranju korektne isporuke doze zračenja u radioterapiji. Robotizirana radiokirurgija sustavom za isporuku doze CyberKnife® (CK) (Accuray Inc., Madison, WI) u upotrebi je već više od desetljeća diljem svijeta. Sustav se koristi za isporuku radiokirurških tretmana bez invazivnog okvira, uz geometrijsku preciznost ciljanja unutar 0,95 mm. Preporuka proizvođača je provođenje PSD-a kalibriranom mikroionizacijskom komorom mjerenjima u točki, dok međunarodne grupe preporučuju provjere doznih distribucija korištenjem filmova ili prikladnih detektora u sklopu puštanja uređaja u pogon te kao dio periodičkih kontrola kvalitete.
U ovom radu opisujemo rezultate PSD kontrole više od 250 kliničkih CK planova zračenja kroz deset mjeseci rada. Terapija zračenjem na CK sustavu isporučuje se koristeći kompaktni linearni akcelerator pričvršćen na robotsku ruku i dva stereoskopska rendgenska uređaja za usmjeravanje i korekciju položaja robota. SRS MapCheck (SunNuclear Corporation, Melbourne, FL) je mjerni uređaj sačinjen od dvodimenzionalnog niza 1013 diodnih detektora razmaknutih 2,47 mm po dijagonali, na kvadratnoj površini stranice 77 mm. U detektor su ugrađena četiri fiducijala za slikovno navođenje te se za potrebe PSD-a detektor postavlja u StereoPHAN fantom (SunNuclear Corporation, Melbourne, FL).
Raspodjele zračenja su analizirane po međunarodnim preporukama koristeći gama analizu, u kojoj se uspoređuje razlika doze u točki i razmaku doznih, rezultirajući matricom gama vrijednosti. Sažeti rezultat analize je gama prolaznost, tj. postotak točaka koji zadovoljava propisane gama kriterije. Pri analizi je korištena normalizacija na globalni maksimum i 10% prag relativne doze, te je analizirano šest kombinacija gama kriterija od 1% / 1 mm do 3% / 3 mm. Rezultat analize je određivanje gama kriterija od 2%/1 mm kao relevantnog za detekciju problematičnih doznih distribucija u našoj instituciji. Planovi su dalje grupirani po sustavu za sekundarno oblikovanje snopa (fiksni konusi ili promjenjivi IRIS™ konusni kolimator) i anatomiji (glava ili tijelo) te analizirani po utvrđenom kriteriju. Dodatno, sve dozne distribucije su analizirane za preostali pomak po tri glavne osi koji je iznosio manje od 0,5 mm.

Ključne riječi: provjera planova zračenja, radioterapija, radiokirurgija, diodni detektor, CyberKnife

PATIENT-SPECIFIC DOSIMETRY FOR ROBOTIC RADIOSURGERY SYSTEM USING A DIODE DETECTOR 2D ARRAY

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Abstract

Patient-specific dosimetry (PSD) is a quality control procedure in radiation therapy ensuring correct dose delivery. Robotic radiosurgery using CyberKnife® (CK) treatment delivery system (Accuray Inc., Madison, WI) has been in clinical use for over a decade worldwide. The system is primarily used for frameless radiosurgery treatment delivery, achieving accuracy within 0.95 mm of the target. The manufacturer recommends PSD using calibrated microchamber for point measurements, while international expert groups recommend verifying planned dose distribution delivery using film or an appropriate detector array during commissioning as well as periodically.

In this work we present our experience in PSD for CK using a diode array for over 250 measured clinical plans in a span of 10 months. CK uses a compact linear accelerator mounted on a robotic arm to deliver radiation, two X-ray sources, and detectors producing stereoscopic planar images for targeting and positioning correction. SRS MapCheck (SunNuclear Corporation, Melbourne, FL) is a diode array consisting of 1013 diode detectors at 2.47 mm diagonal spacing, over 77 mm side square area. Four fiducials are built into the array for targeting and measurement is done with the array inserted in StereoPHAN phantom (SunNuclear Corporation, Melbourne, FL).

Treatment plans were analysed by gamma analysis, where measured and planned dose distribution are compared for dose difference as well as distance-to-agreement between dose profiles at each point. The results of the analysis can be summarized in the form of a percentage of points satisfying criteria also called the gamma passing rate. Analysis was done using global normalization and a 10% relative dose threshold for six combinations of criteria, ranging from 1% / 1 mm to 3% / 3 mm, resulting in accepting 2% / 1 mm as default for detecting problematic dose distributions in our institution. Further analysis was done by splitting plans into groups according to secondary collimation (fixed cones or variable IRIS™ collimator) and anatomy (head or body). Furthermore, all dose distributions were analysed for a residual shift, established to be below 0.5 mm for three principal axes.

Keywords: Patient-Specific Dosimetry, radiotherapy, radiosurgery, diode array, CyberKnife

MJERENJE DOZA ZRAČENJA U MONITORINGU OKOLIŠA PASIVNIM DOZIMETRIJSKIM SUSTAVIMA

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Sažetak

Praćenje ljudskih utjecaja na okoliš i oscilacije prirodnih razina zračenja dio je zaštite ljudskog zdravlja i okoliša. Laboratorij za radijacijsku kemiju i dozimetriju (LRKD), u sklopu ugovora između Nuklearne elektrane Krško (NEK) i Instituta Ruđer Bošković (IRB), radi dozimetrijski monitoring u okolici NEK-a na deset lokacija u Hrvatskoj.

Upotrebljavaju se pasivni dozimetrijski sustavi koji su se pokazali zadovoljavajućim za monitoring okoliša jer mogu pokazati antropogeni doprinos mjerenoj dozi i kad su dozimetri pod utjecajem atmosferilija, a relativno su jednostavni za rukovanje, pouzdani te pokrivaju širok raspon doza.

Koriste se termoluminiscentni (TL) i radiofotoluminiscentnog (RPL) dozimetrijski sustavi tijekom šestomjesečnih razdoblja monitoringa. TL sustav se sastoji od tri različita detektora LiF:Mg,Cu,P (MCP-N), Al_2O_3:C (TLD-500) i CaF_2:Mn (TLD-IJS-5) te instrumenata Toledo 654 Reader, Vinten Instruments, odnosno Harshaw3500, TermoScientific; dok se RPL sustav sastoji od dosimetara FD-7 / SC-1 te čitača FGD-202, AGC Tecno Glass. Dozimetri su pakirani u plastičnu foliju te imaju stalne pozicije na istim lokacijama (1 m iznad tla, udaljeni od građevina i objekata koji mogu zapriječiti ili utjecati na tok vanjskog zračenja na detektor). Svi dozimetri su kalibrirani u Sekundarnom Standardnom Dozimetrijskom Laboratoriju izvorom gama zračenja ^{137}Cs odgovarajućim ambijentalnim doznim ekvivalentom H*(10).

Bit će prezentirani rezultati pomoću TL i RPL dozimetrijskih sustava. Određena prosječna godišnja doza kreće se, ovisno o lokaciji, u rasponu od 0,64 do 1,00 mSv što upućuje da se radi o terestrijalnom i kozmičkom, a ne antropogenom doprinosu godišnjoj dozi zračenja.

LRKD redovito sudjeluje u laboratorijskim interkomparacijama i znanstvenoistraživačkim projektima. Tako su u sklopu EMPIR projekta 16ENVO4 Preparedness ispitane karakteristike oba sustava: linearna dozna ovisnost (u području od 0,1 mSv do 100 mSv), kutna ovisnost (0°, 30°, 60°, 90° i 180°), energetska ovisnost (u rasponu od 48 keV do 1250 keV) te odziv u spektru radionuklida prirodno prisutnih u okolišu. TL i RPL dozimetrijski sustavi pokazali su se pogodnim za uporabu u monitoringu okoliša te za potencijalnu upotrebu nakon izvanrednih događaja.

Literatura

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Ključne riječi: monitoring, okoliš, TLD, RPL

DOSE MEASUREMENTS OF RADIATION IN ENVIRONMENTAL MONITORING WITH PASSIVE AREA DOSIMETRY SYSTEMS

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Abstract

Any monitoring of human activity and natural radiation oscillation is part of the protection of human health and the environment. The Radiation Chemistry and Dosimetry laboratory (RCDL), within the contract between the Krško NPP and the Ruđer Bošković Institute, performs environmental monitoring with passive dosimetry systems in the surroundings of the Krško NPP, at ten locations in Croatia.

Solid state dosimetry systems were found sufficient for environmental monitoring purposes because they can fulfill the requirement to measure the man-made contribution to environmental radiation under variable environmental conditions, easy handling, reliability and covers a wide range of doses.

Our group is using two different dosimetric systems, one thermoluminescence (TL) and one radiophotoluminescence (RPL), during the six months monitoring periods. The TL dosimeter set consists of three different detectors LiF:Mg,Cu,P (MCP-N), Al_2O_3:C (TLD-500) and CaF_2:Mn (TLD-IJS-5) together with Toledo 654 Reader (Vinten Instruments) or Harshaw3500 (TermoScientific). The RPL system consists of dosimeters type FD-7 / SC-1 with the reader FGD-202, AGC Tecno Glass. The dosimeters are packed in plastic bags and strictly placed at the same locations, 1 m above the ground, away from buildings and objects that could block or influence the flux of the external radiation to the detector. All dosimeters are calibrated by ^{137}Cs source as the ambient dose equivalent $H^*(10)$. The calibrations are performed in the Secondary Standard Dosimetry Laboratory.

Results collected by both systems will be presented and discussed during the presentation. Depending on location, an average determinated annual dose has been determinated between 0.64 and 1.00 mSv. Hence, recorded annual doses were within terrestrial and cosmic radiation levels, without measured man-made contribution.

The RCDL has participated regularly in inter-laboratory comparisons and scintific colaborations. The performance of the TL and RPL systems were tested in the scope of the EMPIR project 16ENVO4 Preparedness. Studied dependencies were: linear dose dependence over a wide range of doses (from 0.1 mSv to 100 mSv), average angular dependence (for 0°, 30°, 60°, 90° and 180°), energy dependence (in a range from 48 keV to 1250 keV), and dependence to natural environment spectrum. The TL and RPL dosimetric systems demonstrated sutable and usable for radiation monitoring and after possible future accidents.

References

Knežević et al. Investigations into the basic properties of different passive dosimetry systems used in environmental radiation monitoring in the aftermath of a nuclear or radiological event. Radiat Meas 2021;146:106615.

Keywords: monitoring, environment, TLD, RPL

UTJECAJ PARAMETRA „IDELT“ U PROGRAMSKOM PAKETU PHITS I METODE RAČUNANJA NA IZNOS LINEARNOG PRIJENOSA ENERGIJE PRIMARNIH PROTONA U RADIOTERAPIJI

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Sažetak
Prilikom prolaska kroz sredstvo nabijene čestice međudjeluju s atomima sredstva i pritom gube energiju. Budući da za pojedinu vrstu međudjelovanja znamo samo vjerojatnost zbivanja, ovaj sustav ne možemo riješiti determinističkim metodama. Jedno od rješenja je korištenje Monte Carlo (MC) metode, matematičke metode koja predviđa moguće ishode nasumičnih događaja ili procesa. Kod našeg primjera prolaska nabijenih čestica kroz sredstvo, MC kod pomoću udarnih presjeka različitih međudjelovanja i generiranjem nasumičnih brojeva simulira prolazak čestice kroz sredstvo. Očekujemo da srednja vrijednost dovoljno velikog broja ovakvih simulacija teži stvarnoj putanji čestice. Bilježenjem različitih veličina tijekom simulacije transporta čestice kroz sredstvo moguće je izračunati druge veličine, jedna od kojih je linearni prijenos energije (eng. *linear energy transfer*, LET) koji predstavlja prosječnu energiju koja se pohrani u sredstvu po jedinici duljine nabijene čestice koja prolazi kroz sredstvo. LET je važan u radioterapiji jer se može dovesti u vezu s biološkim učinkom zračenja i stoga je važno imati pouzdane vrijednosti, bilo mjerenjem bilo računanjem.
Jedan od programskih paketa koji primjenjuju MC metodu za simulacije prolaska nabijenih čestica kroz neko sredstvo i računanje veličina od interesa je PHITS (*Particle and Heavy Ion Transport code System*) [1]. U ovom radu PHITS je korišten za računanje LET-a primarnih protona radioterapijskog snopa na različitim dubinama u vodenom fantomu. Prvi cilj rada je ispitati kako PHITS-om izračunate vrijednosti LET-a ovise o metodi računanja LET-a. Drugi cilj je usporediti dobivene rezultat s rezultatima dobivenim istom metodom, ali drugim MC programskim paketom [2]. Autori rada [2] koristili su programski paket Geant4 i posebno istražili utjecaj parametra „*step size limit*“. Odgovarajući parametar u PHITS-u je parametar „idelt“. Prikazat ćemo kako odabir parametra „idelt“ utječe na vrijednost LET-a i usporediti s rezultatima koji su s istim postavkama odgovarajućih parametara i istom metodom dobiveni koristeći Geant4 u radu [2].

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Ključne riječi: Monte Carlo metoda, PHITS, protonska radioterapija, LET, parametar „idelt“

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INFLUENCE OF THE PHITS MONTE CARLO CODE PARAMETER „IDELT“ AND THE CALCULATION METHOD ON THE VALUE OF THE LINEAR ENERGY TRANSFER FROM PRIMARY PROTONS IN RADIOTHERAPY

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Abstract
While travelling through a medium, charged particles interact with the atoms of the medium and lose energy. Since we only know the probability of occurrence of each type of interaction, this system cannot be solved by deterministic methods. One way to solve this problem is the Monte Carlo (MC) method, a mathematical method that predicts the possible outcomes of random processes or events. In our example of charged particles moving through a medium, the MC code uses interaction cross sections and random number generators to simulate the particle transport. The expected value, should approximate the actual trajectory of the particle if a large enough number of these simulations are performed. By keeping track of different quantities during the particle transport simulation we can calculate other quantities, such as linear energy transfer (LET), which describes the average energy transfer per unit length travelled by charged primary particles. In radiotherapy, this quantity is important because it can be related to the radiobiological effect of radiation. Therefore, it is important to have reliable LET values, whether measured or calculated. PHITS (Particle and Heavy Ion Transport code System) [1] is a software that uses the MC method to simulate particle transport and calculate quantities of interest. In this work, PHITS is used to calculate the LET of primary protons in a radiotherapeutic beam at different depths in a water phantom. The first objective is to use PHITS to investigate how the calculated LET values depend on the calculation method. The second is to compare the results obtained with PHITS with those obtained with the same method but with a different MC code[2]. The authors of the article [2] used the Geant4 MC code to investigate the influence of the „step size limit“ parameter. The corresponding parameter in PHITS is called „idelt“. The influence of the „idelt“ paremeter on the LET values and comparison with the results obtained by Geant4 using the same paremater settings and same method will be presented.

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Keywords: Monte Carlo Method, PHITS, Proton Therapy, LET, „idelt“ parameter

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KALIBRACIJA I ODREĐIVANJE ENERGIJSKE OVISNOSTI RADIOKROMSKOG EBT3 FILMA U MEGAVOLTNIM SNOPOVIMA FOTONA

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Sažetak
U ovom radu su uspoređeni različiti pristupi kalibraciji EBT3 radiokromskog filma ozračenog s 6 MV i 10 MV fotonskim snopovima linearnog akceleratora Elekta Synergy (Agility MLC) kao i snopovima ^{60}Co Leksellovog gama noža u odgovarajućim referentnim uvjetima, u rasponu doza od 0,4 Gy do 8,0 Gy. Procijenjena je nepouzdanost apsorbirane doze određene filmskom dozimetrijom i određen relativni energijski odziv filma za upotrijebljene kvalitete fotonskih snopova. Na podatke neto optičke gustoće u ovisnosti o apsorbiranoj dozi u sva tri kanala boje prilagođene su tri analitičke kalibracijske funkcije: linearna funkcija s eksponencijalnom korekcijom, fiksnog i slobodnog eksponenta (dvo- i troparametarska) te funkcija inverza logaritma racionalne funkcije (troparametarska). Dobrota prilagodbe funkcija procijenjena je iz vrijednosti korijenskog srednjeg kvadratnog odstupanja (engl. RMSE). Fiksiranje eksponenta u prilagodbi ne utječe bitno na RMSE vrijednost, osobito u crvenom i zelenom kanalu. Upotreba racionalne funkcije rezultirala je većim RMSE vrijednostima u crvenom kanalu. Nepouzdanosti apsorbirane doze procijenjene su iz nepouzdanosti parametara prilagodbe i relativne eksperimentalne nepouzdanosti mjerene doze za pretpostavljenu prilagodbenu funkciju. Za crveni optički kanal i dvoparametarsku kalibracijsku funkciju nepouzdanosti su bile oko 4% za doze iznad 2 Gy. Troparametarska funkcija uvodi dodatni član zbog čega ukupna nepouzdanost značajno raste. Nepouzdanosti u zelenom i plavom kanalu su veće od onih u crvenom. U provedenoj trokanalnoj metodi filmske dozimetrije, u ograničenom broju filmova, zabilježeno je da na dozama do 2 Gy ona može ukloniti lokalne neuniformnosti i oštre diskontinuitete u raspodjelama. Analiza relativnog energijskog odziva filma (relativna energijska osjetljivost detektora na apsorbiranu dozu, $S_{AD,\,med}^{r}$) prema snopu ^{60}Co nije pokazala sistematsko odstupanje na različitim dozama kao ni kvalitetama snopa. Prosječno odstupanje iznosilo je 2,1% i 1,7% u crvenom kanalu za 6 MV i 10 MV snopove, redom. Rezultati mjerenja su uspoređeni s preliminarnim rezultatima energijske ovisnosti apsorbirane doze, f(Q), izračunate Monte Carlo simulacijama pomoću programa *dosxyznrc* (EGSnrc programski paket) uz uporabu točkastog izvora koji daje pravokutni snop fotona na površini fantoma i EGSnrc energijskih spektara razmatranih kvaliteta snopova. Proučavanjem odziva EBT3 radiokromskog filma ozračenog s 6 MV i 10 MV fotonskim snopovima linearnog akceleratora i ^{60}Co snopovima Leksellovog gama noža ustanovljeno je da ukupna nepouzdanost za doze veće od 2 Gy, ostvarena u crvenom optičkom kanalu uz uporabu dvoparametarske kalibracijske funkciju s fiksiranim eksponentom, iznosi približno 4%. U promatranom rasponu energija i apsorbiranih doza nije zamijećena ovisnost osjetljivosti filma na apsorbiranu dozu o energiji fotonskog snopa.

Ključne riječi: filmska dozimetrija, EBT3, nepouzdanost, energijski odziv

CALIBRATION AND ENERGY DEPENDENCE DETERMINATION OF GAFCHROMIC EBT3 FILM IN MEGAVOLTAGE PHOTON BEAMS

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Abstract
In this work, different approaches to the calibration of EBT3 radiochromic film irradiated with 6 MV and 10 MV photon beams produced by the Elekta Synergy linear accelerator (Agility MLC) as well as ^{60}Co Leksell gamma knife were compared in respective reference conditions, in the dose range from 0.4 Gy to 8.0 Gy. The uncertainty of the absorbed dose determined by film dosimetry was evaluated and the relative energy response of the film was determined for the photon beam qualities used. Three analytical calibration functions were fitted to the net optical density data versus the absorbed dose in all three colour (R, G, B) channels; a linear function with an exponential correction having a fixed and free exponent (two- and three-parameter function) and the inverse of a logarithm of the rational function (three-parameter). The goodness of the function fit was estimated from the root mean square error (RMSE) value. Fixing the exponent in the curve fit process, does not significantly affect the RMSE value, especially in the red and green channels. The use of a rational function resulted in higher RMSE values in the red channel. Uncertainties of the absorbed dose were estimated from the uncertainties of the fitting parameters and the relative experimental uncertainty of the measured dose for the assumed fitting function. For the red optical channel and the two-parameter calibration function, the uncertainties were about 4% for doses above 2 Gy. The three-parameter function introduces an additional term due to which the total uncertainty increases significantly. Uncertainties in the green and blue channels are larger than those in the red channel. In the instigated three-channel method of film dosimetry, in a limited number of films, it was noted that at doses of up to 2 Gy, it can remove regional non-uniformities and sharp discontinuities in the dose distributions. The analysis of the relative energy response of the film (relative absorbed dose sensitivity of a detector, $S_{AD,\,med}^{r}$) to the ^{60}Co beam did not show any systematic deviation at different doses or beam qualities. The average deviation was 2.1% and 1.7% in the red channel for the 6 MV and 10 MV beams, respectively. The measurement results were compared with the preliminary results of the energy dependence of the absorbed dose, k(Q), calculated by Monte Carlo simulations using the *dosxyznrc* program (EGSnrc toolkit) using a point source that provides a rectangular beam of photons on the surface of the phantom and EGSnrc energy spectra of the considered beam qualities. By studying the response of EBT3 radiochromic film irradiated with 6 MV and 10 MV photon beams of a linear accelerator and ^{60}Co beams of the Leksell gamma knife, it was found that the total uncertainty for doses higher than 2 Gy obtained in the red optical channel using a two-parameter calibration function with a fixed exponent is approximately 4%. In the observed range of energies and absorbed doses, no energy dependence of the absorbed dose sensitivity on the energy of the photon beam was observed.

Keywords: film dosimetry, EBT3, uncertainty, energy response

BIOLOŠKI UČINCI ZRAČENJA

BIOLOGICAL EFFECTS OF RADIATION

PRIMARNA OŠTEĆENJA DNA U PERIFERNOJ KRVI I JETRI SWISS ALBINO MIŠEVA NAKON IZLOŽENOSTI IZOFLURANU, SEVOFLURANU I HALOTANU TE γ-ZRAČENJU OD 1 I 2 Gy

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Sažetak

Kombinirani učinak hlapljivih anestetika (VA) halotana/sevoflurana/izoflurana i gama zračenja u stanicama periferne krvi i jetre *in vivo* nije nikad bio analiziran iako je utvrđeno da svaki zasebno mogu uzrokovati oštećenje molekule DNA. Cilj istraživanja bio je procijeniti oštećenja DNA u krvi i jetri Swiss albino miševa (ukupno 240, 48 skupina) nakon jednokratnog izlaganja terapijskim dozama halotana/sevoflurana/izoflurana ili gama zračenju u dozama od 1 ili 2 Gy, te njihovim kombinacijama; uporabom alkalnog kometa testa i analize indeksa staničnog popravka neposredno nakon, 2, 6 i 24 sata nakon izloženosti. Pojedinačno izlaganje svakom od VA uzrokovalo je više razine oštećenja DNA i sporiji popravak u odnosu na kontrolu. Izofluran i sevofluran nakon kombiniranog izlaganja sa zračenjem od 1 i 2 Gy su pokazali slične razine popravka onima utvrđenim u kontrolnim uzorcima. Halotan je, naprotiv, pokazao povišene razine oštećenja DNA, kako pri pojedinačnoj, tako i u kombiniranoj izloženosti, što još jednom pokazuje da bi ovaj anestetik trebao biti zabranjen ne samo kod ljudi, već i u postupcima liječenja životinja. Potrebno je provesti dodatna istraživanja koja će uključivati utvrđivanje učinaka i rizika pri višestrukom izlaganju VA i zračenju, koje se obično primjenjuje u radioterapijskim postupcima.

Slika 1: Prikaz oštećenja DNA i staničnog popravka mjerenog alkalnim komet testom i parametrom intenziteta repa (%) u perifernoj krvi i stanicama jetre Swiss albino miševa nakon izlaganja zasebno hlapljivim anesteticima: sevofluran (S), halothan (H) ili isofluran (I) ili gama zračenju u dozama od 1 ili 2 Gy; ili kombiniranom izlaganju; odmah nakon, te 2, 6 i 24 h od izloženosti.

Ključne riječi: alkalni komet test, halogeni anestetici, radioterapija, zračenje, oštećenje DNA

PRIMARY DNA DAMAGE IN PERIPHERAL BLOOD AND LIVER OF SWISS ALBINO MICE AFTER EXPOSURE TO ISOFLURANE, SEVOFLURANE AND HALOTHANE, AND 1 AND 2 Gy γ-RADIATION EXPOSURE

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Abstract

The combined effect of the volatile anaesthetics (VA) halothane/sevoflurane/isoflurane and gamma radiation in peripheral blood and liver cells has never been studied *in vivo* although individually they can cause DNA damage. The aim of the study was to assess DNA damage in the blood and liver of Swiss albino mice (240 total in 48 groups) after a single exposure to therapeutic doses of halothane/sevoflurane/isoflurane or gamma radiation at doses of 1 or 2 Gy and their combinations, using the alkaline comet assay and cell repair index analysis immediately after, 2, 6 and 24 hours after exposure. Individual exposure to each of the VAs caused higher levels of DNA damage and slower repair compared to the control. Isoflurane and sevoflurane showed similar levels of repair to the control samples after combined exposure to 1 and 2 Gy of radiation. Halothane, on the other hand, showed increased levels of DNA damage in both single and combined exposures, demonstrating once again that this anaesthetic should be banned not only in humans but also in the treatment of animals. Further studies are needed to determine the effects and risks of multiple exposures to VA and radiation commonly used in radiotherapy.

Figure 1: DNA damage and cellular repair measured by alkaline comet assay and tail intensity parameter (%) in peripheral blood and liver cells of Swiss albino mice after exposure to separately volatile anaesthetics: Sevoflurane (S), Halothane (H) or Isoflurane (I) or gamma radiation at doses of 1 or 2 Gy; or combined exposure; immediately after, and 2, 6 and 24 hours after exposure.

Keywords: alkaline comet assay, volatile anaesthetics, radiotherapy, radiation, DNA damage

ULOGA AUTOMATIZIRANE ANALIZE KROMOSOMSKIH ABERACIJA U SLUČAJEVIMA VELIKIH RADIJACIJSKIH INCIDENATA: BUDUĆA PRIMJENA SUSTAVA *METAFER*

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Sažetak
Citogenetičke metode ključne su u biomonitoringu za procjenu postojanja i razine kromosomskih oštećenja u populaciji izloženoj genotoksičnim agensima, što uključuje i zračenje. U slučaju radio-nuklearne nesreće velikih razmjera, tisuće bi ljudi potencijalno bile izložene ionizirajućem zračenju, a bilo bi ključno identificirati one s ozbiljnom izloženošću. U kontekstu takvih nesreća, biološka dozimetrija je vrijedan alat za određivanje doze koju je pojedinac primio u slučajevima kad osobna dozimetrija nije dostupna. Test kromosomskih aberacija, točnije određivanje dicentrika, dobro je uspostavljen biodozimetrijski alat koji se koristi za procjenu izloženosti ionizirajućem zračenju. Dicentrični kromosomi smatraju se specifičnim markerima izloženosti ionizirajućem zračenju jer ih prvenstveno uzrokuje takva vrsta zračenja. Budući da su pozadinske razine dicentričnih kromosoma niske kod neizloženih ljudi, njihova učestalost može procijeniti doze zračenja od 0,1 Gy. Na taj način se brojanje dicentrika još uvijek smatra zlatnim standardom biodozimetrije zračenja. Jedna od najvećih prednosti testa kromosomskih aberacija je odgovor dicentrika na dozu ionizirajućeg zračenja te povezanost ukupnog broja aberacija i predviđenog rizika za inicijaciju raka. Najveće ograničenje testa kromosomskih aberacija je naporna i dugotrajna analiza metafaza koju treba provesti iskusni stručnjak. Kako bi se prevladalo ovo ograničenje, proteklih su godina napravljeni određeni koraci prema automatizaciji procesa. Jedno od najboljih rješenja za prevladavanje tih ograničenja je korištenje softvera *Metafer* (MetaSystems, Njemačka) koji prikladno automatizira široko područje aplikacija za analizu slike u mikroskopiji. Sustav *Metafer* može se koristiti za visokopropusne automatizirane analize dicentrika kao i drugih vrsta kromosomskih aberacija automatskim odabirom aberantnih kromosoma s metafazne ploče. Općenito, sustav *Metafer* skenira uzorke različitih veličina, koristi mnogo različitih kontrastnih metoda i povećanja i pronalazi mnogo različitih ciljanih objekata. Zbog svoje modularnosti i fleksibilnosti, *Metafer* se može koristiti u citogenetici, toksikologiji, hematologiji, patologiji, forenzici itd. Takva automatizirana analiza slike aberantnih kromosoma pouzdan je alat za procjenu oštećenja kromosoma. Omogućuje analizu velikog broja stanica, uz dodatnu prednost ograničene subjektivnosti i nepristranosti koji su neizbježni tijekom analize. Sustav *Metafer* olakšava analize velikog broja uzoraka nudeći i mogućnost pohranjivanja slika za kasniju upotrebu. Stoga se može smatrati obećavajućim alatom za poboljšanje procjene rizika ljudske populacije izložene mutagenima, što je ključno za prevenciju raka i za visokoučinkovitu biodozimetriju nakon radio-nuklearnih nesreća velikih razmjera.

Ključne riječi: *Metafer*, kromosomske aberacije, dicentrici, radijacijski incidenti, automatizacija

THE ROLE OF AUTOMATED SCORING OF CHROMOSOMAL ABBERATIONS IN CASE OF A LARGE-SCALE RADIATION INCIDENTS: FUTURE PERSPECTIVES OF *METAFER* SYSTEM

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Abstract
Cytogenetic methods are crucial in human biomonitoring in assessing the existence and level of chromosomal damage in populations exposed to genotoxic agents including radiation. In case of a large-scale radio-nuclear accident, thousands of people would potentially be exposed to ionizing radiation, and it would be crucial to identify those with severe exposure. In the context of such accidents, biological dosimetry is a valuable tool for determining the dose received by an individual if physical dosimetry is unavailable. Chromosome aberration assay, namely scoring of dicentrics, is a well-established biodosimetry tool used to estimate exposure to ionizing radiation. Dicentric chromosomes are considered to be a specific marker of ionizing radiation exposure as they are primarily generated by such radiation type. Because background levels of dicentric chromosomes are low in non-exposed people, their frequency can assess irradiation doses as low as 0.1 Gy. In that way, counting dicentrics is still regarded as the gold standard of radiation biodosimetry. One of the greatest advantages of the chromosome aberration assay is the dose-response of dicentrics to ionizing radiation as well as the predictivity of the total number of aberrations for cancer initiation. The greatest limitation of the chromosome aberration assay is the laborious and time-consuming analysis of metaphases by a highly trained scorer. To overcome this limitation, certain steps towards the automation of the process were made in past years. One of the best solutions to overcome those limitations is the usage of the *Metafer* software (*MetaSystems*, Germany) that conveniently automates a wide area of image analysis applications in microscopy. The *Metafer* system can be used for high-throughput automated analyses of dicentrics as well as other types of chromosome aberrations by automatically selecting aberrant chromosomes from the metaphase plate. In general, the *Metafer* system scans specimen of various sizes, use many different contrasting methods and magnifications, and find many different target objects. Due to its modularity and flexibility, *Metafer* can be used in cytogenetics, toxicology, haematology, pathology, forensics, and so on. Such automated image analysis of aberrant chromosomes is a reliable tool for the assessment of chromosomal damage. It allows for the analysis of large numbers of cells, with the additional advantage of limited subjectivity and lack of scoring bias, which is inevitable during visual scoring. The *Metafer* system facilitates high-throughput scoring offering also the option of image storage for later use. Therefore, it can be regarded as a promising tool for improving risk assessment of human populations exposed to mutagens, which is crucial for the prevention of cancer and the high-throughput biodosimetry following large-scale radio-nuclear accidents.

Keywords: *Metafer*, chromosomal aberrations, dicentrics, radiation incidents, automation

ODREĐIVANJE RADIONUKLIDA U KOMERCIJALNOJ DJEČJOJ HRANI KORIŠTENOJ U HRVATSKOJ

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Sažetak
Prikazani su dosadašnji rezultati mjerenja radioaktivnosti u odabranoj dječjoj hrani koja se koristi za prehranu djece do jedne godine starosti. Istraživanje je provedeno u sklopu HrZZ projekta RiChFALL (2020. – 2024.). Odabrani su uzorci pripravaka dječje hrane koja je u Hrvatskoj komercijalno široko dostupna i korištena. Uzorci su podijeljeni prema dobi djeteta u kategorije prema vrsti pripravka za djecu, od mliječnih formula preko žitnih i voćnih kašica do pripravljenih obroka s mesom i/ili povrćem. Kvantitativna analiza radionuklida koje je moguće određivati gama-spektometrijski direktno ili posredno putem potomaka, rađena je korištenjem germanijskih detektora visoke čistoće. Beta emiter ^{90}Sr određivan je nakon radiokemijske separacije korištenjem proporcionalnog α/β brojača te Čerenkovljevim brojanjem tekućinskim scintilacijskim brojačem. Dobiveni rezultati korišteni su za proračun godišnje ingestijske doze. Rezultati analiza pokazali su da u ukupnoj aktivnosti najviše očekivano doprinosi ^{40}K koji je detektiran u svim uzorcima, sa masenim aktivnostima koje se kreću u rasponu od 30 Bq/kg do iznad 250 Bq/kg. Najveće su vrijednosti redovno mjerene u adaptiranom mlijeku u prahu (150 – 200 Bq/kg), dok je općenito najveća vrijednost od 262 Bq/kg određena u žitnoj zobenoj kaši. U većini uzoraka detektirana je i prisutnost ^{226}Ra, no aktivnost nije niti u jednom uzorku prelazila vrijednost od 1 Bq/kg. Antropogeni radionuklid ^{137}Cs detektiran je u malim količinama, i to samo u nekoliko uzoraka adaptiranog mlijeka u prahu u kojima je također pronađena i najveća aktivnost ^{40}K. ^{90}Sr detektiran je u neznatnim količinama u većini uzoraka voćnih i povrtnih kašica, te mesnih obroka, zatim u malom broju mliječnih pripravaka dok niti u jednom uzorku žitnih kašica nije prelazio granicu detekcije.
Budući da se za pripremu mliječnih formula i žitnih kašica u preporučenom omjeru koristi i voda, za određivanje primljene ingestijske doze korišteni su rezultati radioaktivnosti u vodi s područja Hrvatske preuzeti iz prethodnih istraživanja. Ingestijska doza procijenjena je na vrijednost od 0,72 mSv/god, čime ne prelazi preporučeni limit od 1 mSv godišnje. U primljenoj dozi prevladava doprinos ^{40}K sa preko 70%. Pri tome najveći dio dolazi od unosa voća, zatim mlijeka te žitarica.
Kako se u dječju prehranu postupno uvode pojedine namirnice, u nastavku ovog istraživanja prikupljani su i uzorci voća i povrća sa OPG-ova diljem Hrvatske, te će biti prikazani preliminarni rezultati njihovih radioaktivnosti po vrsti i regijama.

Ključne riječi: dječja hrana, radioaktivnost, ingestijska doza

DETERMINATION OF RADIONUCLIDES IN COMMERCIAL CHILDREN'S FOOD CONSUMED IN CROATIA

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Abstract
This work presents the results of the radioactivity measurements in selected early children's food (up to 1 year old). This research is conducted as a part of Croatian Science Foundation project RiCHFALL (2020. – 2024.). The selected samples are widespread and commercially easily available in Croatia. The samples are divided according to growth of a child into food categories – from adapted powdered milk, cereal porridge powder and homogenized fruit porridge to mushed meals with vegetables and/or meat. Quantitative analysis of radionuclides which can be determined by gamma-spectrometry directly or through their progenies is done using high purity germanium detectors (HPGe). Beta emitter ^{90}Sr is determined after radiochemical separation using proportional α/β counter and by Cherenkov counting using liquid scintillation counter (LSC). The results are used to determine the annual ingestion doses. The results showed that ^{40}K prevails in total activities, as expected. It is detected in all the measured samples. Massic activities range from 30 Bq/kg up to 250 Bq/kg. Highest values are regularly determined in adapted powdered milk samples (150 – 200 Bq/kg), while generally highest value of 262 Bq/kg is obtained in cereal sample containing oat. ^{226}Ra is detected in most of the samples, but the activity did not exceed the value of 1 Bq/kg. Anthropogenic radionuclide ^{137}Cs is detected in small amounts in only few samples of powdered milk, the same in which the highest amount of ^{40}K is determined. ^{90}Sr is detected in small very amounts in majority of the samples of fruit, vegetable and meat meals. It is detected in only one sample of powdered milk and in none of the cereal porridge samples.
The contribution of radioactivity in water for consumption and preparation of the meals, taken from previous studies of radioactivity in drinking water in Croatia, is also taken into account for the ingestion doses calculation. The committed effective annual dose via food and water consumption estimated to 0.72 mSv, which is below the 1 mSv/year recommended limiting value. ^{40}K dominates in contribution with more than 70%. When it comes to type of food, the biggest part comes from intake of fruit, followed by intake of milk formulas, and by cereals.
As certain types of food are gradually being introduced into children's diets, in the continuation of this research, fruit and vegetable samples were collected from family farms throughout Croatia. Preliminary radioactivity results by type and region will be presented.

Keywords: children's food, radioactivity, ingestion dose

BUDUĆNOST RADIOBIOLOŠKIH ISTRAŽIVANJA U PODRUČJU NISKIH DOZA IONIZIRAJUĆEG ZRAČENJA

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Sažetak
Ionizirajuće zračenje međudjeluje s ljudskim tkivima i može uzrokovati štete po ljudsko zdravlje zbog posljedičnih direktnih oštećenja molekule DNA te indirektnih oštećenja putem stvaranja reaktivnih kisikovih vrsta. Unatoč poznatim nepovoljnim utjecajima na organizam, visoke doze ionizirajućeg zračenja često se koriste u radioterapiji kao učinkovito sredstvo za uklanjanje tumora. S druge strane, izlaganje niskim dozama ionizirajućeg zračenja moguća je nuspojava ne samo radioterapije (sekundarni učinci izloženosti tkiva), nego i dijagnostičkih postupaka kao što je upotreba rendgenskih pretraga i kompjuterizirane tomografije (CT). Mogući utjecaji niske doze zračenja na zdravlje puno su slabije opisani te prema dosadašnjim spoznajama nije moguće isključiti njihove štetne posljedice nakon opetovanog i posebno, kroz život dugotrajnog izlaganja. Razlog tome su metodološke teškoće u praćenju i analizi oštećenja na staničnoj razini za dugoročne škodljive utjecaje niskog intenziteta ionizirajućeg zračenja, što otežava procjenu rizika za čitav organizam i/ili pojedine organe i vrste tkiva.
Kako bi se mogli provesti istraživački projekti na temu utjecaja niskih doza ionizirajućeg zračenja na zdravlje, Institut za medicinska istraživanja i medicinu rada je u sklopu projekta ReC-IMI opremljen sa suvremenom tehnologijom koja omogućuje analizu promjena staničnog metabolizma koje neće nužno dovesti do stanične smrti, ali mogu imati posljedice po čitav organizam. Te promjene uključuju narušavanje integriteta staničnog skeleta i nukleinskih kiselina, promjene u statusu epigenetskih biljega, zastoje u staničnom ciklusu i otežanu diobu stanica, promjene u imunosnom statusu i aktivaciji stanica, te mnoge druge. Primjena ovakvih suvremenih metoda u radiobiološkim istraživanjima dat će im dodatan značaj i omogućiti bolju procjenu utjecaja niskih doza ionizirajućeg zračenja na ljudsko zdravlje.

Ključne riječi: oštećenja DNA, reaktivni kisikovi spojevi, stanični metabolizam

THE FUTURE OF RADIOBIOLOGICAL RESEARCH IN THE FIELD OF LOW DOSE IONISING RADIATION

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Abstract
Ionizing radiation interacts with human tissue and can cause detrimental health effects due to direct DNA damage, as well as indirect damage *via* generation of reactive oxygen species. Despite known harmful effects to the human body, high doses of ionizing radiation are often used in radiotherapy as an effective method for tumour removal. On the other hand, exposure to low doses of ionizing radiation is a possible side effect not only of radiotherapy (secondary exposure effects), but also of diagnostic procedures such as X-ray scan and computed tomography (CT). Much less is known about the health effects of low dose radiation and based on the current findings, it is not possible to rule out their harmful consequences due to repeated radiation exposure, especially after life-long exposure. Because of methodological difficulties in monitoring and analysing damage for long-term harmful effects of low intensity ionizing radiation at the cellular level, it makes it difficult to assess the risk for the whole organism and/or particular organs or tissues.
In order to be able to carry out research projects regarding the health effects of low doses of ionizing radiation, as a part of the ReC-IMI project the Institute for Medical Research and Occupational Medicine was furnished with modern equipment which enables the analysis of changes in cellular metabolism that will not necessarily lead to the cell death, but could affect the whole organism. These changes include disruption of integrity of the cytoskeleton and nucleic acids, changes in the epigenetic markers, cell cycle arrest and impaired cell division, changes in immune status and cell activation, and many more. The use of such modern methods in radiobiological research will enable a better assessment of the impact of low doses of ionizing radiation on human health.

Keywords: DNA damage, reactive oxygen species, cell metabolism

PROCJENA OŠTEĆENJA DNA U BUBREZIMA I MOZGU *IN VIVO* NAKON IZLAGANJA HLAPLJIVIM ANESTETICIMA I γ-ZRAČENJU U DOZAMA KOJE SE KORISTE U RADIOTERAPIJI

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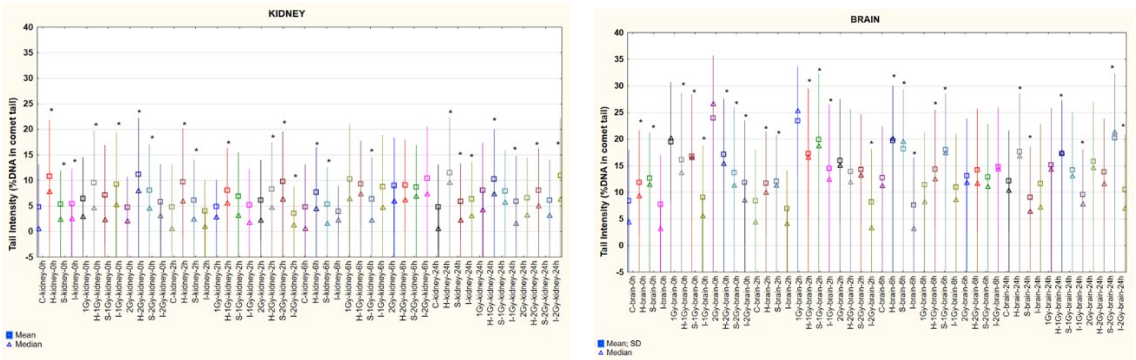
Sažetak

Iako su se smatrali sigurnima, izlaganje hlapljivim anesteticima (VA) u zadnjem desetljeću otkriva sve više njihovih negativnih učinaka. Pošto se do sada nisu ispitivali zajednički učinci izloženosti VA i ionizirajućem zračenju, odlučili smo analizirati razine oštećenja DNA u organima bubrega i mozga zdravih mužjaka Swiss albino miševa koji su jednokratno bili izloženi: zasebno samo jednom VA (halotanu, izofluranu ili sevofluranu) u terapijskim dozama; ili gama zračenju od 1 ili 2 Gy; ili pak njihovoj kombiniranoj izloženosti uporabom alkalnog komet testa. Rezultati upućuju na razlike u razini oštećenja i popravka DNA u odnosu na korišteni anestetik. Veća oštećenja utvrđena su u stanicama mozga nego u stanicama bubrega, a u kombiniranoj izloženosti, izofluran je pokazao zaštitni učinak u obje vrste organa i pri obje doze. Halotan, općenito govoreći, nije pokazao toliko zaštitno djelovanje. Analize bi se trebale ponoviti na višestrukim izloženostima kombiniranom utjecaju anestetika i zračenja, kao što se najčešće i događa u radioterapiji, a također bi se uzorci trebali uzeti i u dužem vremenskom razmaku nego što je to 24 sata da se vidi dolazi li do popravka DNA na kraju nekog perioda od izlaganja ili takva razina oštećenja ostaje prisutna i duže vrijeme.



Slika 1: Prikaz oštećenja DNA u stanicama mozga i bubrega mužjaka Swiss albino miševa nakon izlaganja samo hlapljivim anesteticima halotanu (H), sevofluranu (S) ili izofluranu (I); ionizirajućem zračenju od 1 ili 2 Gy gama zračenja; ili kombiniranom učinku ova dva agensa u uzorcima uzetima odmah nakon, 2, 6, te 24 sata nakon izlaganja. Oštećenja DNA su prikazana kao intenzitet repa kometa (%) u alkalnom komet testu. Zvjezdice označavaju statistički značajne razlike u odnosu na odgovarajuću kontrolu u tom vremenskom periodu.

Ključne riječi: alkalni komet test, popravak DNA, Swiss albino miševi

ASSESSMENT OF DNA DAMAGE IN KIDNEY AND BRAIN *IN VIVO* AFTER COMBINED EXPOSURE TO VOLATILE ANAESTHETICS AND γ-RADIATION IN DOSES USUALLY USED IN RADIOTHERAPY TREATMENT

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Abstract

Although considered safe, exposure to volatile anaesthetics (VA) has shown more adverse effects over the last decade. Since the joint effects of exposure to VA and ionizing radiation have not been studied before, we decided to analyse DNA damage in the kidney and brain organs of healthy male Swiss albino mice exposed once only: to VA (halothane, isoflurane or sevoflurane) at therapeutic doses; or to gamma radiation of 1 or 2 Gy; or to a combined exposure of these two agents using the alkaline comet assay. The results suggest differences in the extent of DNA damage and repair depending on the anaesthetic used. Higher damage was found in brain cells than in kidney cells, and in combined exposure, isoflurane showed a protective effect in both types of organs and at both doses. Halothane, generally, did not show similar protective effect. Analyses should be repeated using multiple exposures to the combined effects of anaesthetics and radiation, as most often scenario within radiotherapy treatment, and samples should also be taken over a longer period than 24 hours to determine whether DNA repair occurs at the end of a given period of exposure or whether such a level of damage persists over a longer period.

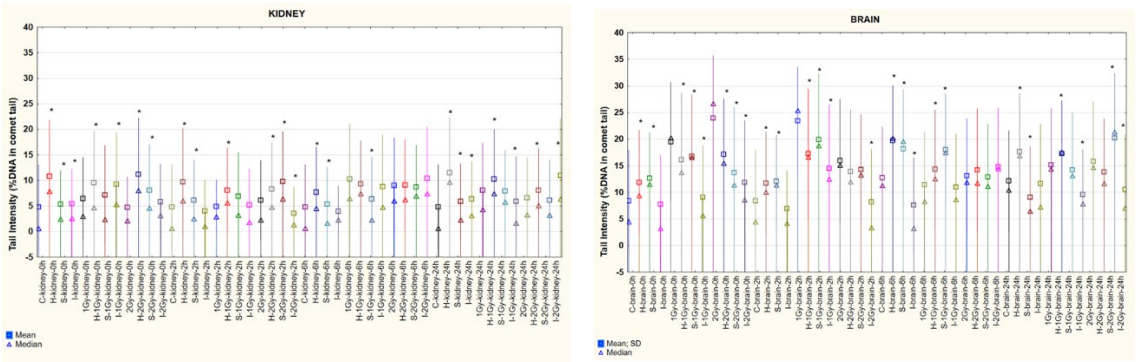

Figure 1: Presentation of DNA damage in brain and kidney cells of male Swiss albino male mice after exposure to: the volatile anesthetics halothane (H), sevoflurane (S) or isoflurane (I) only; ionizing radiation of 1 or 2 Gy gamma radiation; or the combined effect of these two agents in samples taken immediately after, 2, 6 and 24 hours after exposure. DNA damage is expressed as intensity of comet tail (%) in the alkaline comet assay. Asterix represents statistical difference from the corresponding control in particular time period.

Keywords: alkaline comet assay, DNA repair, Swiss albino mice

UTJECAJ GSM MODULIRANOG RF ZRAČENJA NA STRUKTURU MIKROTUBULA U ŽIVOJ STANICI

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Sažetak
Cilj istraživanja bio je ispitati narušava li GSM modulirano radiofrekvencijsko zračenje (RF) frekvencije 915 MHz strukturu mikrotubula te utječe li na rast stanica. Stanice V79 izložene su GSM-moduliranom polju unutar gigahercne transverzalne elektromagnetske komore (GTEM-komora) tijekom jednog, dva i tri sata. Generator signala u kombinaciji s pojačalom i modulatorom signala generirao je elektromagnetsko polje (EMF). Jačina električnoga polja namještena je na vrijednosti od 10, 20 i 30 V/m, a izračunane vrijednosti specifične brzine apsorpcije (SAR) u stanici bile su 0,23, 0,8 i 1,6 W/kg. Struktura mikrotubularnih proteina utvrđena je posrednom imunocitokemijom, a stanični rast određen je na temelju broja stanica izmjerenih za svako vrijeme izloženosti zračenju tijekom šest dana nakon ozračivanja. Značajne promjene u strukturi mikrotubula zabilježene su nakon tri sata zračenja, neovisno o jakosti električnoga polja. Također, značajno smanjen rast stanica zabilježen je tri dana nakon trosatne izloženosti zračenju. Navedene promjene uočene su bez obzira na primijenjenu jakost električnoga polja. Značajno smanjen rast stanica zabilježen je također tri dana nakon dvosatne izloženosti zračenju pri jakosti električnoga polja od 20 i 30 V/m. Možemo zaključiti da je učinak GSM moduliranoga RF zračenja frekvencije 915 MHz na proteine mikrotubula i stanični rast ovisan o trajanju izloženosti zračenju. Zabilježene promjene bile su izraženije pri višoj jakosti električnoga polja.

Ključne riječi: 915 MHz; citoskelet; *in vitro*; stanični rast; zračenje mobilne telefonije

IMPACT OF GSM-MODULATED RF RADIATION EXPOSURE ON CELLULAR MICROTUBULE IN LIVING CELL

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Abstract
The objective of the study was to investigate whether low-level 915 MHz GSM-modulated radiofrequency (RF) radiation impairs microtubular structure and affects normal cell growth. V79 cells were exposed to a GSM-modulated field in a Gigahertz Transversal Electromagnetic Mode cell (GTEM cell) for 1, 2 and 3 h. Signal generator combined with power and chip modulator generated the electromagnetic field (EMF). The electric field strength was adjusted to power of 10, 20 and 30 V/m, and the average specific absorption rate (SAR) was calculated to be 0.23, 0.8 and 1.6 W/kg. The structure of microtubule proteins was assessed by indirect immunocytochemistry, and cell growth was determined based on cell counts taken every day over six post-exposure days. Three-hour radiation exposure significantly altered microtubule structure regardless of the electric field strength. Moreover, on the third post-exposure day, three-hour radiation significantly reduced cell growth, regardless of field strength. The same was observed with two-hour exposure at 20 and 30 V/m. In conclusion, 915 MHz GSM-modulated RF radiation affects microtubular proteins in a time-dependent manner, which, in turn, affects cell proliferation. Future research will focus on microtubule and actin structure throughout the cell cycle and RF radiation effects on mitotic spindle.

Keywords: cell growth; cytoskeleton; *in vitro*; 915 MHz; mobile phone radiation

UČINCI MALE DOZE GAMA ZRAČENJA NA KOLESTEROL I MASNE TVARI U KRVNOJ PLAZMI PILIĆA OZRAČENIH PRIJE INKUBACIJE

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Sažetak
Cilj ovog istraživanja bio je odrediti koncentraciju kolesterola i ukupne masne tvari u krvnoj plazmi pilića ozračenih *in ovo*. Jaja pasmine Ross 308 (n=100) nasumično su podijeljena u dvije skupine: pokusnu skupinu ozračenu jedan sat prije inkubacije te kontrolnu skupinu koja je izložena lažnom (eng. *sham*) zračenju. Jaja iz pokusne skupine primila su 0,3 Gy gama zračenja iz radioaktivnog izvora ^{60}Co panoramskog tipa, smještenog u Institutu Ruđer Bošković u Zagrebu, Hrvatska. Uzorci krvi od po 10 pilića iz kontrolne i pokusne skupine prikupljeni su punkcijom *v. jugularis* 1., 3., 5., 7. i 10. dana nakon valjenja. Kolesterol i ukupne masne tvari određene su spektrofotometrijski. Jednodnevni pilići izloženi zračenju imali su značajno niže koncentracije kolesterola u usporedbi s kontrolnom skupinom. Srednje vrijednosti ukupnih masnih tvari u pokusnoj skupini bile su značajno niže 5. dana, a značajno više 10. dana života pilića. Rezultati ovog istraživanja sugeriraju kako gama zračenje u dozi od 0,3 Gy utječe na metabolizam masnih tvari u pilića ozračenih prije inkubacije jaja.

Ključne riječi: krvna plazma; lipidi; kolesterol; pileći embrij; ionizirajuće zračenje

EFFECTS OF LOW-DOSE GAMMA RADIATION ON CHOLESTEROL AND PLASMA LIPIDS IN CHICKENS EXPOSED BEFORE INCUBATION

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Abstract
The aim of this research was to determine plasma cholesterol and total lipids response to gamma radiation in chickens irradiated *in ovo*. Ross 308 eggs (n=100) were randomized to two groups, the experimental group that received gamma radiation one hour before incubation, or to the control group that received sham radiation. The eggs were irradiated at 0.3 Gy, using a panoramic ^{60}Co source at the Ruđer Bošković Institute, Zagreb, Croatia. Blood samples from 10 chickens per group were taken by jugular vein venepuncture at 1st, 3rd, 5th, 7th, and 10th day after hatching. In the blood plasma the content of total lipids and cholesterol was determined by the spectrophotometric method. Ionizing radiation significantly reduced plasma concentrations of cholesterol in one-day-old chickens. In response to radiation, total lipids were decreased 5th and increased 10th day of chicks life, compared to the control group. The results of the present research have shown that 0.3 Gy gamma radiation can influence lipid metabolism in chickens hatched from eggs irradiated before incubation.

Keywords: blood plasma; total lipids; cholesterol; chicken; ionizing radiation

IZLOŽENOST STANOVNIŠTVA ZRAČENJU

PUBLIC EXPOSURE

KONCENTRACIJE AKTIVOSTI ^{137}Cs U RAZLIČITIM VRSTAMA GLJIVA

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Sažetak

Gljive vrlo dobro apsorbiraju radionuklide iz tla i uvode ih u hranidbene lance, a jedan od njih je ^{137}Cs. Cezij kao element kemijski sličan kaliju što pogoduje ulasku i zadržavanju ^{137}Cs u živim organizmima.

Institut za medicinska istraživanja i medicinu rada iz Zagreba (IMI) ovlašten je za obavljanje stručnih poslova zaštite od zračenja. Suradnici Jedinice za zaštitu od zračenja IMI provode gamaspektrometrijske analize uzoraka za utvrđivanje koncentracije aktivnosti ^{137}Cs u uzorcima namirnica namijenjenim izvozu ili onih uvezenih u Republiku Hrvatsku.

U ovome radu prikazani su rezultati određivanja koncentracija aktivnosti ^{137}Cs u uzorcima gljiva ispitanih tijekom razdoblja od 1.9.2020. do 12.8.2022. godine. Gljive su podrijetlom iz trećih zemalja te se uvoze preko graničnih prijelaza Bajakovo i Stara Gradiška. Prema propisima u Provedbenoj uredbi Komisije (EU) 2020/1158, od 5. kolovoza 2020. godine, o uvjetima koji uređuju uvoz hrane i hrane za životinje podrijetlom iz trećih zemalja koncentracije aktivnosti ^{137}Cs ne smiju prelaziti vrijednosti od 600 Bq/kg za hranu. Gamaspektrometrijska mjerenja provedena su na CANBERRA HPGe detektoru (FWHM 1,8 keV na 1,332 MeV ^{60}Co s relativnom efikasnošću od 54 % na 1,332 MeV ^{60}Co), spojenim s višekanalnim analizatorom. Mjerenja se provode u trajanju od 1000 do 3000 s.

Tablica 1. Koncentracije aktivnosti ^{137}Cs uzorcima gljiva (Bq/kg)

		Koncentracija aktivnosti (Bq/kg)	
VRSTA	**broj uzoraka**	**prosjek**	**min.-maks.**
crna truba	21	20,1	0,2-78,4
lisičarke	33	9,8	0,5-173,3
lisičarke suhe	13	269,1	17,6-1566,4
smrčkovi (smrčkovica)	13	4,4	0,7-26,5
ježevka / prosenjak	6	186,6	24,0-462,2
rujnice	16	1,9	0,4-5,5
đurđevača, lactarius, reduša	12	3,8	0,4-18,0
tartufi razni	6	1,2	0,1-3,1

Na temelju rezultata prikazanih u Tablici 1 vidimo da prosječna vrijednost aktivnosti ^{137}Cs u ispitanim gljivama nije jednaka, već varira ovisno o vrsti gljiva. Od svih uzorkovanih gljiva, suhe lisičarke i ježevke sadrže nešto veće koncentracije aktivnosti. Najveća izmjerena koncentracija aktivnosti je u uzorku suhe lisičarke iz kolovoza 2020. godine u kojem je izmjereno (1560 ± 40 Bq/kg) ^{137}Cs (što znatno nadmašuje uobičajene vrijednosti). Kod ostalih uzoraka najveća dopuštena vrijednost nije prekoračena.

Ključne riječi: radioaktivnost, gljive, gamaspektrometrija, koncentracija aktivnosti

ACTIVITY CONCENTRATIONS OF ^{137}Cs IN DIFFERENT MUSHROOM SPECIES

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Abstract

Mushrooms absorb radionuclides from soil and introduce them into food chains. Potassium is essential for biological processes, and it can be replaced by elements with similar chemical properties such as ^{137}Cs.

The Institute for Medical Research and Occupational Health (IMI) is authorized to carry out activities related to radiation protection, a part of which is refers to a regular control of food intended for import into the European Union. In this paper, we present the results of determining the concentration of ^{137}Cs activity in mushroom samples tested during the period from 1 September 2020 to 12 August 2022. According to the Commission Implementing Regulation (EU) 2020/1158, 5 August 2020, on the conditions governing the import of food and feed originating from third countries, the maximum allowed activity concentration of ^{137}Cs is 600 Bq/kg for food. The activity concentration of ^{137}Cs was measured using a gamma-ray spectrometry system based on a CANBERRA HPGe detector (relative efficiency of 54% and FWHM of 1.8 keV, all at 1.332 MeV ^{60}Co) coupled with a multi-channel analyser.

Table 1. Activity concentrations of ^{137}Cs in mushroom samples (Bq/kg).

		Activity concentration (Bq/kg)	
SPECIES	**number of samples**	**average**	**min-max**
Craterellus cornucopioides	21	20.1	0.2-78.4
Cantharellus cibarius	33	9.8	0.5-173.3
Dry *Cantharellus cibarius*	13	269.1	17.6-1566.4
Morchela	13	4.4	0.7-26.5
Hydnum repandum	6	186.6	24.0-462.2
Lactarius deliciosus	16	1.9	0.4-5.5
Calocybe gambosa	12	3.8	0.4-18.0
Truffle	6	1.2	0.1-3.1

Based on the results shown in Table 1, the activity concentration of ^{137}Cs in the tested mushrooms depended on mushroom species. Of all the mushrooms sampled, dry *Cantharellus cibarius* and *Hydnum repandum* contained the highest activity concentrations. The highest value (1560 ± 40 Bq/kg) was found for a sample of dried *Cantharellus cibarius* from August 2020 (which significantly exceeded usual values). For the other samples, the maximum allowed value was not exceeded.

Keywords: radioactivity, mushrooms, gamma spectrometry, activity concentration

DUGOROČNO PRAĆENJE ^{137}Cs U JABUKAMA

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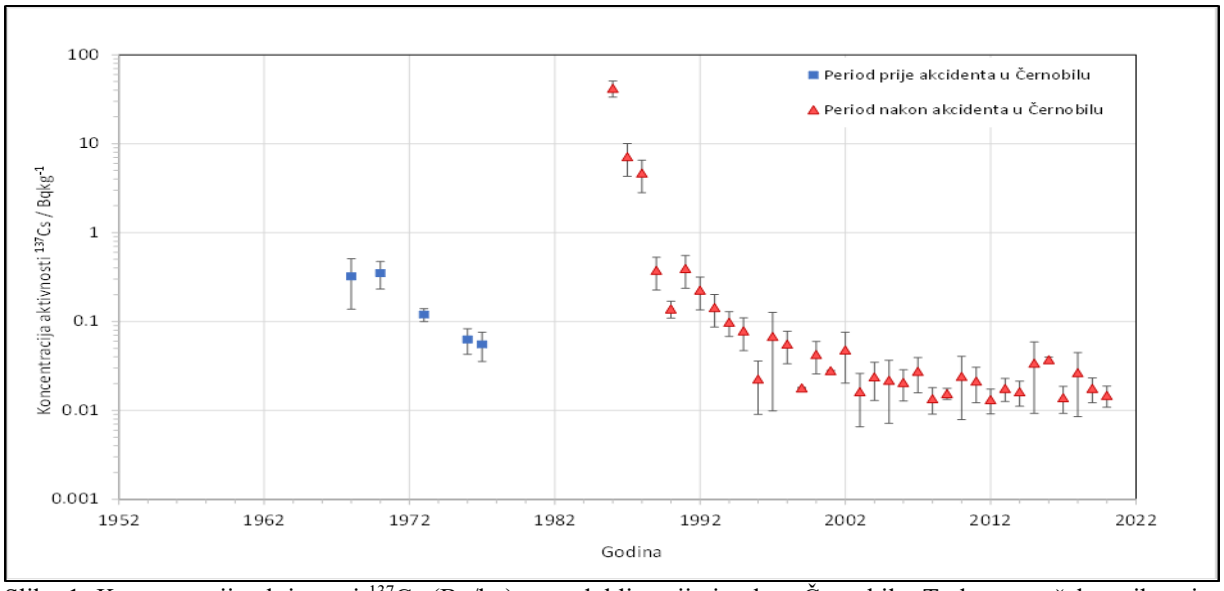
Sažetak
Sustavno praćenje radioaktivnosti u okolišu pokazalo se vrlo važnim osobito zbog posljedica koje ostavljaju nuklearne i/ili radiološke nesreće (kao što su npr. nesreće u Černobilu ili Fukushimi), a također zbog potencijalnih novih događaja u budućnosti. Ingestija, inhalacija, vanjsko ozračivanje itd. čine različite putove prijenosa radionuklida iz okoliša u ljudski organizam. Konzumacija hrane uvelike pridonosi ukupnoj efektivnoj dozi, stoga je praćenje ljudske izloženosti zračenju kroz hranu od velike važnosti.
Rezultati dugoročnog praćenja koncentracija aktivnosti ^{137}Cs u jabukama iz sjeverozapadne Hrvatske u periodu od 1968. – 2021. godine prikazani su na Slici 1. Najveća koncentracija aktivnosti ^{137}Cs u jabukama izmjerena je 1986. godine, što je posljedica nesreće u Černobilu, te se od tada eksponencijalno smanjuje. Akcident u Fukushimi-Daiichi 2011. godine nije uzrokovao znatno povećanje vrijednosti koncentracija aktivnosti ^{137}Cs u jabukama, iako je utjecaj tog akcidenta bio vidljiv pojavom ^{134}Cs u nekim uzorcima.
Procijenjena efektivna doza primljena ingestijom radiocezija jabukama (15 kg/god) kod odrasle populacije u Hrvatskoj za cijeli period nakon akcidenta u Černobilu iznosi 6,4 µSv. Tako mala doza ne predstavlja opterećenje za odraslo stanovništvo sjeverozapadne Hrvatske i može se zaključiti kako konzumacija jabuka nije kritičan način unosa radiocezija u organizam.



Slika 1. Koncentracije aktivnosti ^{137}Cs (Bq/kg) u razdoblju prije i nakon Černobila. Trake pogrešaka prikazuju standardnu devijaciju (rezultati za razdoblja od 1987. do 1995. godine i od 1998. do 2000. godine su aproksimirani).

Ključne riječi: monitoring, ^{137}Cs, jabuke, efektivna doza

LONG-TERM MONITORING OF ^{137}Cs IN APPLES

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Abstract

Due to the consequences of nuclear and/or radiological accidents in the history (Chernobyl, Fukushima, etc.), and potential events in the future, constant monitoring of environmental radioactivity is important. There are different pathways of the transfer of radionuclides from environment to humans: ingestion, inhalation, external etc. Food ingestion greatly contributes to the total effective dose; hence it is of great importance to investigate human exposure through food. The results of long-term monitoring of ^{137}Cs activity concentrations in apples in northwest Croatia for the period 1968 – 2021 are presented (Figure 1). The highest ^{137}Cs activity concentration in apples was measured in year 1986, which is caused by Chernobyl accident and it is decreasing exponentially ever since. The Fukushima-Daiichi accident in year 2011 did not cause significant increase of ^{137}Cs activity concentration in apples, although the influence of the accident was observed through detection of ^{134}Cs in some components of the environment. The estimated effective dose received by adult members of the Croatian public due to intake of radiocaesium from apples (15 kg/year) for overall post-Chernobyl period are very small, 6.4 µSv. Therefore, consumption of apples was not a critical pathway for the transfer of radiocaesium to humans.

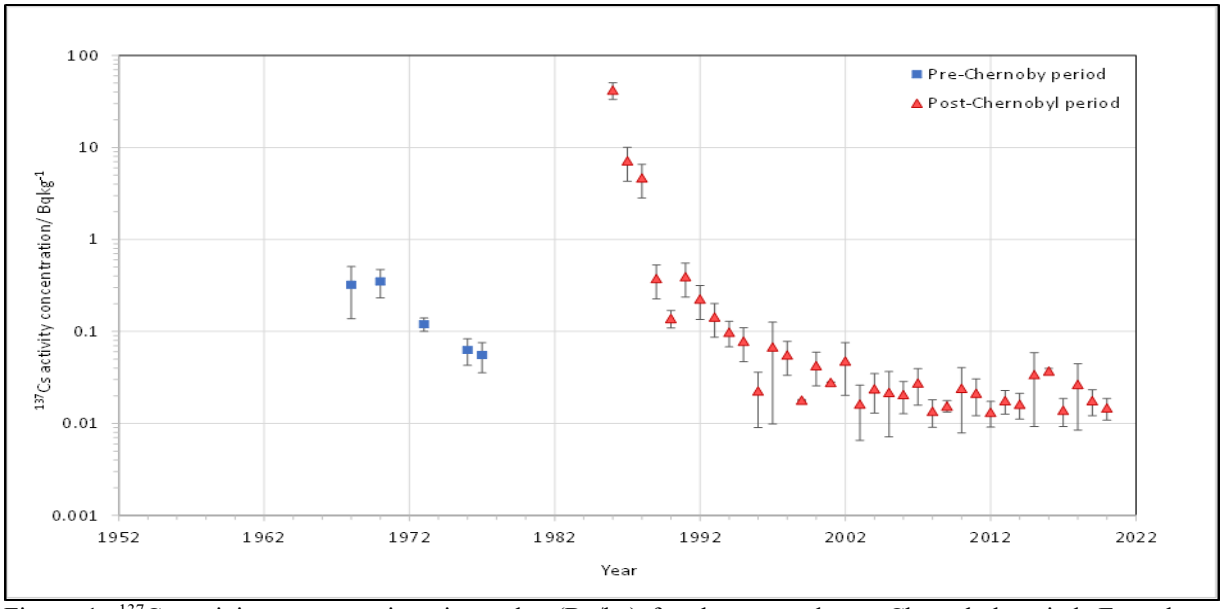

Figure 1: ^{137}Cs activity concentrations in apples (Bq/kg) for the pre and post-Chernobyl period. Error bars represent standard deviation (the data for the years 1987 – 1995, and 1998 - 2000 are approximated).

Keywords: monitoring, ^{137}Cs, apples, effective dose

RADIOLOGICAL ANALYSIS OF SELECTED MEDICINAL HERBS FROM THE REGION OF FRUŠKA GORA, SERBIA

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Abstract

Natural radionuclides are omnipresent in the environment. However, our environment is also contaminated with anthropogenic radionuclides that appear as a consequence of human activities. One of the main sources of increased radioactive contamination in environment was nuclear accident in Chernobyl in 1986.

Medicinal herbs have long history of worldwide consumption in traditional medicine. Therefore, it is necessary to control the usage of medicinal herbs and their products, from radiological point of view, as well. In that way, unwanted radiological effects on human health can be avoided.

The paper deals with radiological analysis of 7 selected medicinal herbs: (*Thymus serpyllum* L., Breckland thyme; *Hypericum perforatum* L., St. John's wort; *Rosa canina* L., Dog-rose; *Mentha sp.*, mint; *Melissa officinalis* L., Lemon balm; *Tilia tomentosa* L., Silver Linden; *Achillea millefolium,* Yarrow) from the region of Fruška Gora, Republic of Serbia. Specific activities of ^{137}Cs, ^{40}K and ^{210}Pb in medicinal herbs samples are determined by using HPGe gamma-ray spectrometer system. From obtained specific activities individual annual effective doses due to daily ingestion of 200 ml infusion of medicinal herbs were deduced.

Obtained specific activities are in intervals: <1.4 Bq/kg, (303 – 1073) Bq/kg and (3.58 – 35.6) Bq/kg, for^{137}Cs, ^{40}K and ^{210}Pb, respectively. Deduced individual annual effective doses due to ingestion are similar to the literature data and are smaller than the recommended limit of 100 μSv, defined in Article 8 of the Regulation on limits of radionuclide content in drinking water, foodstuffs, feeding stuffs, drugs, items of general use, building materials and other goods to be placed on the market (Official Gazette of the Republic of Serbia, 2018).

Therefore, a daily use of 200 mL of herbal infusion during a year made from the investigated medicinal herbs does not pose a significant radiological health risk for consumers.

Keywords: medicinal herbs, radioactivity, gamma spectrometry, annual effective dose of ingestion

KONCENTRACIJA AKTIVNOSTI ^{137}Cs U SUHIM I ZAMRZNUTIM VRGANJIMA

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Sažetak
Institut za medicinska istraživanja i medicinu rada, u Jedinici za zaštitu od zračenja, bavi se praćenjem stanja radioaktivnosti u okolišu od 1959. godine. Radioekološka istraživanja čine osnovu za procjenu doza ionizirajućeg zračenja i utjecaja radioaktivnog zagađenja na ljudsko zdravlje. Nakon nesreće u nuklearnoj elektrani u Černobilu, u okolišu je završila veća količina antropogenog radionuklida ^{137}Cs. Najviše zabilježene razine ^{137}Cs bile su u šumskim prehrambenim proizvodima, a posebno visoke koncentracije aktivnosti pronađene su u gljivama, bobicama i divljači. U ovom radu fokus je na koncentraciji aktivnosti ^{137}Cs u suhim i zamrznutim gljivama vrganjima (lat. *Boletus edulis*).
U okvirima suradnje Jedinice za zaštitu od zračenja sa Carinskom upravom i Državnim inspektoratom Republike Hrvatske svakodnevno se mjeri koncentracija aktivnosti ^{137}Cs u gljivama. Vrganji se uvoze iz država trećih zemalja preko graničnih prijelaza Bajakovo i Stara Gradiška. Koncentracija aktivnosti ^{137}Cs mjeri se gamaspektrometrijskim sustavom koji se temelji na CANBERRA HPGe detektoru (FWHM 1,8 keV na 1,332 MeV ^{60}Co s relativnom efikasnošću od 54 % na 1,332 MeV ^{60}Co), spojenim s višekanalnim analizatorom. Mjerenja se provode u trajanju od 1000 do 3000 s, što se pokazalo dovoljnim za postizanje granice detekcije manje od 10 Bq/kg za suhe vrganje i 5 Bq/kg za zamrznute vrganje. Navedene granice detekcije značajno su manje od zakonskog limita koji je propisan u Provedbenoj uredbi Komisije (EU) 2020/1158, od 5. kolovoza 2020. godine, o uvjetima koji uređuju uvoz hrane i hrane za životinje podrijetlom iz trećih zemalja nakon nesreće u nuklearnoj elektrani u Černobilu, a iznosi 600 Bq/kg.
U radu su prikazani rezultati za uzorke suhih i zamrznutih vrganja prikupljenih u razdoblju od 27. kolovoza 2020. godine do 18. kolovoza 2022. godine. Srednja vrijednost koncentracije aktivnosti za suhe vrganje iznosi 29,8 Bq/kg uz standardnu devijaciju od 2,0 Bq/kg, a za zamrznute vrganje 6,7 Bq/kg uz standardnu devijaciju od 0,9 Bq/kg. Rezultati koncentracije aktivnosti variraju u rasponu od 6 Bq/kg do 165 Bq/kg za suhe vrganje i od 0,7 Bq/kg do 115 Bq/kg za zamrznute vrganje.
Tijekom navedenog razdoblja mjerenja svi su ispitani uzorci gljiva vrganja ispod granice zakonom propisanog limita od 600 Bq/kg.

Ključne riječi: radioaktivnost, ^{137}Cs, koncentracija aktivnosti, gamaspektrometrija, vrganji

CONCENTRATION OF ^{137}Cs ACTIVITY IN DRY AND FROZEN PENNY BUNS

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Abstract
The Institute for Medical Research and Occupational Health, through its Radiation Protection Unit, has been monitoring radioactivity levels in the environment since 1959. Radioecological research forms the basis for assessing ionizing radiation doses and the impact of radioactive pollution on human health. During the Chernobyl accident, a large quantity of ^{137}Cs was released into the environment. The highest levels of ^{137}Cs were found in edible flora and fauna, the activity concentrations being particularly high in mushrooms, berries, and game meat. In this paper, we focus on ^{137}Cs in dry and frozen penny buns (*Boletus edulis*).
Within a cooperation of the Radiation Protection Unit, the Customs Administration of the Republic of Croatia, and the State Inspectorate of the Republic of Croatia, the activity concentration of ^{137}Cs in mushrooms has been measured on a daily basis. Penny buns have been imported from non-EU countries through the Bajakovo and Stara Gradiška border crossings. The activity concentration of ^{137}Cs has been measured using a gamma-ray spectrometry system based on a CANBERRA HPGe detector (relative efficiency of 54% and FWHM of 1.8 keV, all at 1.332 MeV ^{60}Co) coupled with a multi-channel analyser. Measurements have been carried out for 1000-3000 s, which has been proven to be sufficient for obtaining detection limits below 10 Bq/kg for dry penny buns and 5 Bq/kg for frozen ones. These detection limits are significantly lower than the legal limit of 600 Bq/kg set by the Commission Implementing Regulation (EU) 2020/1158 of 5 August 2020 on the conditions governing imports of food and feed originating in third countries following the accident at the Chernobyl nuclear power station.
We present results for samples of dry and frozen penny buns measured between 27 August 2020 and 18 August 2022. The mean value of the activity concentration of ^{137}Cs was 29.8 Bq/kg for dry penny buns, with a standard deviation of 2.0 Bq/kg, and 6.7 Bq/kg for frozen ones, with a standard deviation of 0.9 Bq/kg. The range of measured values was 6 Bq/kg to 165 Bq/kg for dry penny buns and 0.7 Bq/kg to 115 Bq/kg for frozen ones.
During the measurement period, all of the tested penny bun samples exhibited ^{137}Cs activity concentrations below the legal limit of 600 Bq/kg.

Keywords: radioactivity, ^{137}Cs, activity concentration, gamma spectrometry, penny buns

BETA AKTIVNOST I RAZINE OLOVA I TALIJA U PM_{10} LEBDEĆIM ČESTICAMA U GRADU ZAGREBU

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Sažetak
Praćenje i određivanje radioaktivnih tvari u zraku provodi se u cilju detekcije neželjenih akcidenata kao i za procjenu efektivnih doza koje primi stanovništvo. Jedna od metoda kojom se određuje količina radioaktivnih tvari u zraku je mjerenje ukupne beta aktivnosti zraka. Lebdeće čestice aerodinamičnog promjera manjeg od 10 µm su inhalabilne, ulaze u dišne puteve i mogu štetno djelovati na ljudsko zdravlje. U sklopu državne mreže za trajno praćenje kvalitete zraka u Republici Hrvatskoj se na više lokacija prate razine lebdećih čestica, a u Institutu za medicinska istraživanja i medicinu rada je smješten referentni laboratorij za određivanje sastava čestica. U ovom su radu prikazani rezultati određivanja PM_{10} frakcije lebdećih čestica, razine olova i talija te ukupne beta aktivnosti u toj frakciji, na mjernoj postaji državne mreže u gradu Zagrebu (postaja Zagreb-1) tijekom 2021. godine. 24-satni uzorci sakupljeni su prosisavanjem 720 m^3 zraka na filtre od kvarcnih vlakana (Whatman, QMA). Masena koncentracija PM_{10} čestica određena je gravimetrijski. Iz alikvota filtra, nakon mikrovalne razgradnje uz dušičnu kiselinu, određene su razine olova i talija metodom masene spektrometrije uz induktivno spregnutu plazmu. Ukupna beta aktivnost mjerena je iz drugog alikvota filtra, najmanje 120 sati nakon uzorkovanja, u beta brojaču niskih aktivnosti Low-level beta Geiger-Müller multicounter system; model RISØ GM-25-5. Rezultati pokazuju da je srednja godišnja masena koncentracija PM_{10} čestica iznosila 24,1 µg/m^3, a kretala se u rasponu od 2,4 µg/m^3 do 140,6 µg/m^3. Srednja godišnja masena koncentracija olova u PM_{10} česticama iznosila je 1,59 ng/m^3, a talija 0,004 ng/m^3. Najviše dnevne vrijednosti masenih koncentracija olova i talija izmjerene su u veljači i iznosile su 10,31 ng/m^3 za olovo i 0,016 ng/m^3 za talij. Značajno više vrijednosti PM_{10} čestica zabilježene su tijekom sezone grijanja, od siječnja do ožujka i od listopada do prosinca. Nije nađena sezonska ovisnost razina olova i talija, kao niti ukupne beta aktivnosti u PM_{10} česticama. Prosječna vrijednost ukupne beta aktivnosti zraka u promatranom razdoblju iznosila je 1,41 mBq/m^3, s dnevnim vrijednostima od 0,24 mBq/m^3 do 5,17 mBq/m^3. Uočeno je da su se pojedine više vrijednosti ukupne beta aktivnosti podudarale s povišenim vrijednostima PM_{10} čestica, olova i talija.

Ključne riječi: radioaktivne tvari, PM_{10} frakcija, metali, onečišćenje zraka

BETA ACTIVITY AND LEVELS OF LEAD AND THALLIUM IN PM_{10} PARTICULATE MATTER IN ZAGREB

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Abstract
Monitoring and determination of radioactive substances in the air is conducted to detect unwanted accidents as well as to assess the effective doses received by the population. One of the methods for detecting the amounts of radioactive matter in air is to measure the total beta activity of air. Particulate matter with an aerodynamic diameter less than 10 µm is inhalable, enters the respiratory tract and can have a harmful effect on human health. Levels of particulate matter are continuously monitored within the State Network for Continuous Air Quality Monitoring on several locations in Croatia and the Institute for Medical Research and Occupational Health has a reference laboratory for the determination of particle composition. This paper presents the results of determination of the PM_{10} particle fraction, levels of lead and thallium and total beta activity in that fraction on a sampling station within the State network in Zagreb (station Zagreb-1) during 2021. 24-hour samples were collected from 720 m^3 of air on quartz filters (Whatman, QMA). Mass concentrations of PM_{10} particles were determined by gravimetry. One aliquot of a filter was digested with microwaves and nitric acid and analysed on lead and thallium by inductively coupled plasma mass spectrometry. Total beta activity was measured from another filter aliquot, at least 120 hours after sampling, in a Low-level beta Geiger-Müller multicounter system; model RISØ GM-25-5. The results show that the annual mean mass concentration of PM_{10} particles was 24.1 µg/m^3 and ranged from 2.4 µg/m^3 to 140.6 µg/m^3. The annual mean mass concentrations of lead and thallium in PM_{10} particles were 1.59 ng/m^3 and 0.004 ng/m^3 respectively. The maximum daily value of lead was 10.31 ng/m^3 and for thallium 0.016 ng/m^3, both found in February. Significantly higher values of PM_{10} particles were found during heating seasons, from January to March and from October to December. Seasonal variations in lead and thallium levels, as well as for total beta activity in PM_{10} particles were not found. The average value of the total beta activity in the observed period was 1.41 mBq/m^3, with daily values ranging from 0.24 mBq/m^3 to 5.17 mBq/m^3. It was observed that certain higher values of total beta activity coincided with elevated values of PM_{10} particles, lead and thallium.

Keywords: radioactive matter, PM_{10} particle fraction, metals, air pollution

ZAŠTITA OD ZRAČENJA U MEDICINI

RADIATION PROTECTION IN MEDICINE

ZNANJE O PRIMJENI MJERA ZAŠTITE OD IONIZIRAJUĆEG ZRAČENJA U INTERVENCIJSKOJ SALI – PRVI REZULTATI ISTRAŽIVANJA

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Sažetak
Intervencijski postupci koji se u medicini provode uporabom rendgenskih uređaja podrazumijevaju potrebu za zaštitom od ionizirajućeg zračenja i pacijenata i osoblja koje te postupke provodi. Međunarodna stručna društva izdala su preporuke vezano uz mjere kojima se zaštita pacijenata i osoblja provodi na optimalan način. U cilju stjecanja uvida u poznavanje i primjenu tih mjera provedeno je ispitivanje među liječnicima i radiološkim tehnolozima koji sudjeluju u provedi intervencijski postupaka.
Ispitivanje je provedeno putem upitnika koji je sadržavao 38 pitanja iz područja praćenja osobnog ozračenja te mjera zaštite pacijenata i osoblja od ionizirajućeg zračenja, uključujući i samoocjenu vlastitog znanja. U ispitivanju je sudjelovalo 93 ispitanika koji provode ili sudjeluju u provedbi radioloških i kardioloških intervencijskih postupaka te postupaka u okviru vaskularne kirurgije i endoskopske retrogradne kolangiopankreatografije. Najveći broj ispitanika imao je više od 10 godina radnog iskustva u intervencijskoj sali (41%), 39% ispitanika do 5 godina, a 20% ispitanika 6 - 10 godina. Rezultati provedenog ispitivanja pokazuju podjednaku razinu znanja i kod liječnika i kod radioloških tehnologa. Nešto bolje rezultate ostvarili su ispitanici u grupi s 6 - 10 godina radnog iskustva u intervencijskoj sali.
Zaključak: Rezultati provedenog ispitivanja ukazuju na potrebu unapređenja kvalitete obrazovanja liječnika i radioloških tehnologa koji provode ili sudjeluju u provedbi intervencijskih postupaka uporabom rendgenskih uređaja.

Ključne riječi: upitnik, rendgenski uređaji, radiološki i kardiološki intervencijski postupci, prećenje osobnog ozračenja

LEVEL OF THE RADIATION PROTECTION KNOWLEDGE AMONG PROFESSIONALS PERFORMING INTERVENTIONAL PROCEDURES – FIRST RESULTS OF THE SURVEY

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Abstract
Interventional procedures performed in medicine using X-ray devices imply the need for radiation protection for both patients and staff performing these procedures. International professional societies have issued recommendations regarding the radiation protection measures to ensure optimal protection of patients and staff. In order to gain insight into the knowledge and implementation of these measures, a survey was conducted among physicians and radiographers who are involved in performance of the interventional procedures.
The survey was conducted through a questionnaire containing 38 questions in the field of personal exposure monitoring and radiation protection of patients and staff, including a self-assessment of one's own knowledge. 93 subjects who perform or participate in the performance of radiological and cardiological interventional procedures, as well as of interventional procedures as part of vascular surgery and endoscopic retrograde cholangiopancreatography, took part in the study. The largest number of respondents had more than 10 years of work experience in the interventional room (41%), 39% of respondents up to 5 years and 20% of respondents 6 - 10 years. The results of the study show an equal level of knowledge among both physicians and radiographers. Somewhat better results were achieved by the respondents in the group with 6 - 10 years of work experience in the interventional room.
Conclusion: The results of the study indicate the need to improve the quality of education of physicians and radiographers who perform or participate in the performance of interventional procedures using X-ray devices.

Keywords: questionnaire, X-ray devices, radiological and cardiological interventional procedures, personal exposure monitoring

DOZE IZVAN CILJANOG VOLUMENA U DJEČJOJ PROTONSKOJ I FOTONSKOJ RADIOTERAPIJI – PREGLED AKTIVNOSTI EURADOS RADNE GRUPE 9

Željka Knežević u ime EURADOS radne grupe 9

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Sažetak
Interakcija protona s materijom rezultira stvaranjem sekundarnog zračenja koje se najvećim dijelom sastoji od neutrona i gama zračenja. Neželjene doze zračenja koje se apsorbiraju izvan područja radioterapijskog tretmana mogu dovesti do neželjenih kasnih efekata zračenja uključujući i pojavu sekundarnog malignog oboljenja. Absorbirane doze izvan ciljanog volumena od posebne su važnosti kod dječje populacije koja je najosjetljivija na utjecaj zračenja. U okviru EURADOS-ove (European Radiation Dosimetry Group) radne grupe 9, podgrupe 2 (Hadronska radioterapija) napravljena su detaljna dozimetrijska mjerenja sekundarnog zračenja kod terapije protonskim snopovima unutar dječijih antropomorfnih fantoma (fantomi predstavljalju petogodišnje i desetogodišnje dijete). Dobiveni podaci uspoređeni su sa prethodnim mjerenjima za različite fotonske radioterapijske tehnike (3D-CRT, IMRT, i gama nož). Tumori mozga su jedni od najčešćih karcinoma u djece, pa je u svim eksperimentima simuliran tumor mozga te su napravljeni planovi zračenja za realnu kliničku situaciju. Fantomi i detektori korišteni u eksperimentima kao i ciljani volumen bio je isti za sve korištene modalitete (fotone i protone). Rezultati su pokazali da radioterapija skenirajućim protonskim snopovima (engl. *active-scanning proton beam radiotherapy*) rezultira nižim dozama izvan ciljanog volumena u usporedbi s fotonskim tehnikama 3D-CRT, GK i IMRT za jedan red veličine u blizini mozga i više od dva reda veličine dalje od mozga. Neutronske doze su niže u odnosu na doprinos doza koje nisu od neutrona. Kod petogodišnjeg fantoma doze su veće u usporedi sa desetogodišnjim fantomom zbog povećane blizine organa. Ukupni dozni ekvivalent u protonskoj terapiji kreće se od 0,6 mSv/Gy u štitnjači do <0,01 mSv/Gy u području gonada, dok se za fotonske tehnike ukupni dozni ekvivalent u organima kreće od 12 mSv/Gy u štitnjači do 0,22 mSv/Gy u predjelu gonada. Rezultati mjerenja radne grupe 9 dali su bazu podataka doza izvan ciljanog volumena za različite radioterapijske tehnike koje su potrebne za validaciju matematičkih i Monte Carlo modela za dozimetriju izvan polja zračenja koja je neophodna za epidemiološku studije koje procjenjuju rizik od sekundarnog karcinoma i drugih kasnih učinaka pedijatrijskih bolesnika liječenih radioterapijom

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Ključne riječi: protonska radioterapija, doze izvan ciljanog volumena, antropomorfni fantomi

OUT-OF-FIELD DOSES IN PEADIATRIC PHOTON AND PROTON RADIOTHERAPY - SUMMARY OF THE EURADOS WG9 ACTIVITY

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Abstract
The interaction of protons with matter leads to the generation of secondary radiation, consisting mainly of neutrons and gamma radiation. Unwanted radiation doses absorbed outside the area of radiotherapy treatment can lead to unwanted late effects of irradiation, including the appearance of secondary malignant disease. Doses absorbed outside the target volume are particularly important for the pediatric population, which is most sensitive to radiation exposure. Detailed dosimetric measurements of secondary radiation during proton beam therapy in anthropomorphic pediatric phantoms (representing five- and ten-year-old children) were performed as part of Working Group 9 of EURADOS (European Radiation Dosimetry Group), Subgroup 2 (Hadron Radiation Therapy). The obtained data were compared with previous measurements for different photon radiotherapy techniques (3D-CRT, IMRT, and Gamma Knife). Since brain tumors and CNS tumors are among the most common cancers in children, a brain tumor was simulated in all experiments and radiation plans were created for a realistic clinical situation. The phantoms and detectors used in the experiments, as well as the target volume, were identical for all modalities used (photons and protons). The results showed that active-scanning proton beam radiotherapy results in lower doses outside the target volume compared with 3D-CRT, GK, and IMRT techniques, by an order of magnitude near the brain and by more than two orders of magnitude farther away. Neutron doses are lower compared to the contribution of non-neutron doses. In the case of the five-year-old phantom, the doses are higher than in the case of the ten-year-old phantom because of the greater proximity to the organs. T The total dose equivalent in proton therapy ranges from 0.6 mSv/Gy in the thyroid to <0.01 mSv/Gy in the gonad region, while for photon techniques the total organ dose equivalent ranges from 12 mSv/Gy in the thyroid to 0.22 mSv/Gy in the gonad region. The results of the measurements made by Working Group 9 provided a database of doses outside the target volume for various radiotherapy techniques needed for validation of mathematical models and Monte Carlo models for out-of-field dosimetry required for epidemiological studies evaluating the risk of secondary cancer and other late effects in pediatric patients treated with radiotherapy

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Keywords: out of field doses; proton radiotherapy, anthropomorphic phantoms, photon radiotherapy

PRAĆENJE UČINKA TERAPIJE U BOLESNIKA S KARCINOMOM PLUĆA CT PREGLEDOM PREMA ULTRANISKODOZNOM PROTOKOLU – PILOT STUDIJA

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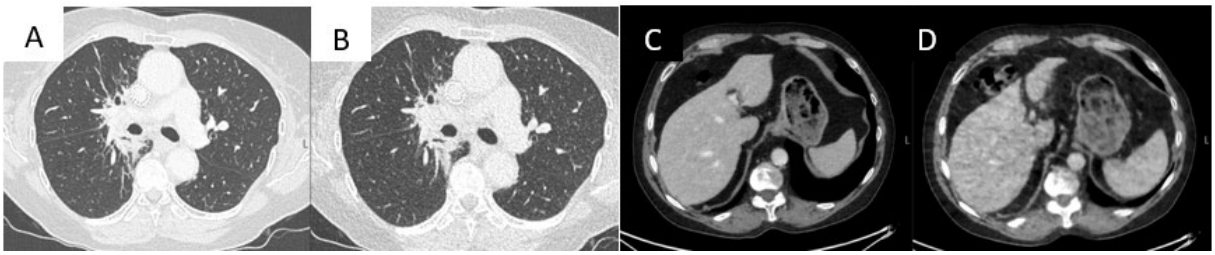
Sažetak
Cilj: Odrediti osjetljivost i specifičnost ultraniskodoznog pregleda kompjutoriziranom tomografijom (ULDCT) u usporedbi sa standardnim pregledom kompjutoriziranom tomografijom (CT) s punom dozom zračenja u detekciji mjerljivih lezija u bolesnika s karcinomom pluća, te usporediti dozu zračenja te dvije vrste pregleda.
Materijali i metode: U pilot studiju uključeno je 30 ispitanika s karcinomom pluća koji su s ciljem praćenja maligne bolesti upućeni na CT toraksa i gornjeg abdomena uz intravensku primjenu kontrastnog sredstva. Svi ispitanici ispunili su informirani pristanak za uključenje u studiju. Snimanje je napravljeno je na CT uređaju Revolution Apex 160 nakon intravenske primjene jodnog kontrastnog sredstva. Snimanje standardnog CT protokola započelo je 60 sekundi nakon primjene kontrastnog sredstva uz napon od 120 kVp te automatsku kontrolu ekspozicije. ULDCT pregled napravljen je neposredno nakon standardnog CT pregleda uz korigiranu vrijednost napona (100 kVp) i automatsku kontrolu ekspozicije. Izračunata je osjetljivost i specifičnost ULDCT pregleda u detekciji mjerljivih lezija (tumora, uvećanih limfnih čvorova i presadnica) u usporedbi sa standardnim CT protokolom. Wilcoxonovim testom rangova uspoređen je umnožak doze i duljine (DLP) između dva protokola snimanja.
Rezultati: Osjetljivost ULDCT pregleda u detekciji mjerljivih lezija iznosi 88%, a specifičnost 80% u usporedbi s CT protokolom s punom dozom zračenja. DLP kod ULDCT protokola (medijan 52 mGy*cm, IQR 40-55 mGy*cm) bio je značajno niži nego kod standardnog CT protokola (medijan 190 mGy*cm, IQR 132-210 mGy*cm; W=465, p<0,001).
Zaključak: Prema rezultatima preliminarnog istraživanja, osjetljivost i specifičnost ULDCT pregleda u detekciji mjerljivih lezija u bolesnika s karcinomom pluća je prihvatljiva uz značajno niže doze zračenja. Potrebno je provesti daljnja istraživanja na većem broju ispitanika kako bi se utvrdilo za koju vrstu lezija je dostatno ULDCT snimanje, s ciljem smanjenja kumulativne doze zračenja u tijeku produljenog aktivnog praćenja učinka terapije.



Slika 1: Usporedba prikaza CT presjeka u plućnom (A i B) i mekotkivnom prozoru (C i D) na pregledu s punom dozom zračenja (A i C) i pregledu s ultraniskom dozom zračenja (B i D).

Ključne riječi: karcinom pluća, praćenje učinka terapije, CT po ultraniskodoznom protokolu

MONITORING THE EFFECT OF THERAPY IN PATIENTS WITH LUNG CANCER USING ULTRALOW-DOSE CT EXAMINATION – A PILOT STUDY

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Abstract

Objectives: To determine the sensitivity and specificity of ultra-low-dose computed tomography (ULDCT) compared to standard computed tomography (CT) with a full radiation dose in the detection of measurable lesions in patients with lung cancer, and to compare the radiation dose of these two types of examinations.

Materials and methods: The pilot study included 30 subjects with lung cancer who were referred for a follow-up chest and abdomen CT scan with intravenous administration of a contrast agent. All participants filled out informed consent for inclusion in the study. CT scan was done on a Revolution Apex 160 scanner after intravenous iodine contrast agent administration. The delay for the standard CT protocol was 60 seconds with the tube peak voltage of 120 kVp and automatic exposure control. The ULDCT examination was performed immediately after the standard CT examination with a corrected tube peak voltage (100 kVp) and automatic exposure control. The sensitivity and specificity of the ULDCT examination in the detection of measurable lesions (tumors, enlarged lymph nodes, distant metastases) were calculated in comparison with the standard CT protocol. The Wilcoxon signed-rank test was used to compare the dose-length product (DLP) between the two imaging protocols.

Results: The sensitivity of the ULDCT examination in the detection of measurable lesions is 88%, and the specificity is 80% compared to the CT protocol with a full dose of radiation. DLP with the ULDCT protocol (median 52 mGy*cm, IQR 40-55 mGy*cm) was significantly lower as compared to the standard CT protocol (median 190 mGy*cm, IQR 132-210 mGy*cm; $W=465$, $p<0.001$).

Conclusion: According to the results of the preliminary study, the sensitivity and specificity of the ULDCT examination in the detection of measurable lesions in patients with lung cancer is acceptable, with a significantly lower radiation dose. It is necessary to conduct further research on a larger number of subjects to determine for which type of lesions ULDCT imaging is sufficient, intending to reduce the cumulative radiation dose during prolonged active follow-up.

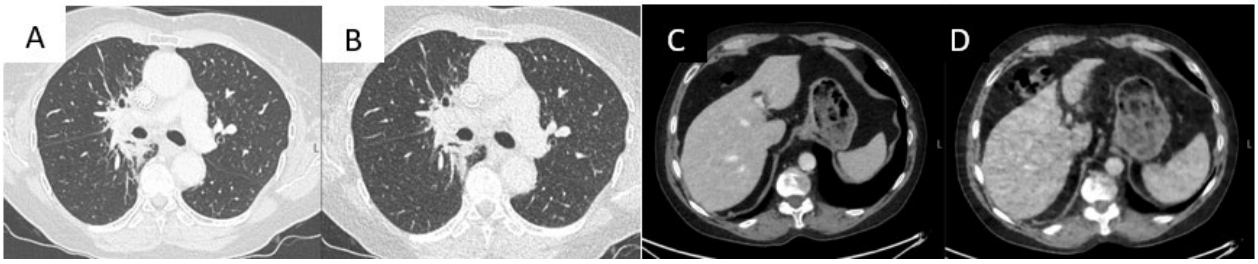

Figure 1: Comparison of CT axial images in the lung (A and B) and soft tissue window (C and D) in the full-dose (A and C) and ultra-low-dose (B and D) scans.

Keywords: lung cancer, the effect of therapy, ultralow-dose CT protocol

NISKODOZNI PROTOKOL CT-A I UMJETNA INTELIGENCIJA U RANOM OTKRIVANJU RAKA PLUĆA- NACIONALNI PROGRAM PROBIRA

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Sažetak
Snimanje pluća niskodoznim protokolom za razliku od snimanja uobičajenim protokolom povezano je sa znatno nižom dozom zračenja za pacijenta uglavnom manjom od 1mSv, dok uobičajeno iznosi 10-20 mSv. Ovo snimanje je zbog nižih doza stoga opravdano u ranom otkrivanju tumora pluća obzirom većina tumora počinje kao plućni nodul. Ono omogućuje raniju dijagnozu i bolji ishod terapije u pacijenata s karcinomom pluća. Dodatno uporaba umjetne inteligencije u očitavanju niskodoznog MSCT-a pluća, prema posljednjim istraživanjima omogućuje manje pogreške pri očitavanju plućnih nodusa i može pomoći radiolozima u ovoj dijagnostici. *US National Lung Cancer Screening Trial* (NLST) i druga randomizirana klinička istraživanja u Europi pokazuju da niskodozni MSCT je zadovoljavajuća pretraga za smanjenje raka pluća kod dugogodišnjih pušača. Kod niskodoznog MSCT-a, koristeći neuralne mreže i "duboko učenje", program u sklopu probira analizira veličinu i distribuciju nodusa, ubrzava proces očitavanja nalaza od strane radiologa, a tako analizirane noduse softver čuva i za kasniju usporedbu.
Ovaj se program provodi u Republici Hrvatskoj u 16 ustanova, a prosječne doze tijekom takvih snimanja usporedive su s redgenskom snimkom pluća, dok je dokazana uspješnost dijagnoze tumora značajno veća.
No važno je naglasiti i visok je postotak lažno pozitivnih nalaza, što posljedično može dovesti do povećanog dodatnog broja pretraga. Otvoreno je pitanje integracije sustava umjetne inteligencije u PACS (engl. *picture and archiving software*), budući da sada funkcionira na odvojen način, edukacije radiologa za softver umjetne inteligencije te dostupnosti programa unutar zdravstvenog sustava, kao i mogućnosti optimizacije snimanja koje su različite na različitim uređajima i u koju bi trebalo uključiti medicinske fizičare.

Ključne riječi: niskodozni protokol snimanja pluća, plućni nodul, optimizacija snimanja, umjetna inteligencija.

LOW-DOSE CT PROTOCOL AND ARTIFICIAL INTELLIGENCE IN THE EARLY DETECTION OF LUNG CANCER – THE NATIONAL SCREENING PROGRAM IN CROATIA

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Abstract
In contrast with standard protocol scanning, low-dose protocol lung scanning is associated with a significantly lower radiation dose for the patient, typically less than 1 mSv, whereas the standard dose is 10-20 mSv. This scanning is justified due to lower doses used for the early detection of lung tumors as most tumors start as a lung nodule. It enables an earlier diagnosis and better therapeutic outcomes in patients with lung cancer. Additionally, the use of artificial intelligence in reading low-dose MSCT lung scans enables fewer errors in reading lung nodules and can help radiologists in this diagnosis, according to recent research. The US National Lung Cancer Screening Trial (NLST) and randomized clinical trials in Europe show that low-dose MSCT constitutes satisfactory screening for reducing lung cancer in long-term smokers. With low-dose MSCT, using neural networks and "deep learning", the screening program analyzes the size and distribution of nodules, accelerates the process of reading findings by radiologists, and saves the analyzed nodules for later comparison.
This program is carried out in 16 institutions in Croatia. The average dose during these scans is comparable to chest X-rays, while the proven success of tumor diagnosis is significantly higher.
However, it is important to note that there is a high rate of false positive findings, which can result in an increased number of additional screenings. The issue of integrating artificial intelligence into the PACS system remains, as these systems are currently separate. Another issue is the availability of artificial intelligence software. It is also important to consider how to optimize scans, including medical physicists in the discussions.

Keywords: low-dose protocol lung scanning, lung nodule, scanning optimization, artificial intelligence.

PROCJENE OZRAČENJA IZLOŽENIH RADNIKA PRI KORIŠTENJU INTERVENCIJSKIH I DIJASKOPSKIH RENDGENSKIH UREĐAJA TEMELJENE NA AMBIJENTALNIM ISPITIVANJIMA I DOZNIM IZVJEŠĆIMA RENDGENSKIH UREĐAJA

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Sažetak
Kategorizacija radnih prostora i izloženih radnika temelji se, među ostalim, i na rezultatima ispitivanja koja se u okviru radiološkog nadzora mjesta rada provode prijenosnim mjerilima ambijentalnog doznog ekvivalenta (H*(10)) i/ili brzine ambijentalnog doznog ekvivalenta (H*(10)/t). Procjene ozračenja izloženih radnika snažno su ovisne i o koeficijentu zauzeća prostora i/ili radnom opterećenju izvora ionizirajućeg zračenja. Od posebnog interesa su radna mjesta u neposrednoj blizini C-luk dijaskopskih i intervencijskih rendgenskih uređaja. Procjene ozračenja u ovakvim su situacijama kompleksnije te uključuju različite načine rada rendgenskog uređaja, varijacije u geometriji ozračenja, veličini polja zračenja, načinu korištenja dostupnih zaštitnih sredstava i radnim navikama timova. Radno opterećenje rendgenskog uređaja izraženo dozimetrijskom veličinom produkt doze i površine polja (DAP) uobičajeno se automatski bilježi u strukturiranom doznom izvješću rendgenskog uređaja, a podatak o DAP-u dodatno uključuje varijacije brzine doze u korisnom snopu i varijacije u veličini polja zračenja. Cilj je istraživanja provjeriti pretpostavljene teorijske odnose H*(10) o DAP-u te razviti rekonstrukcijsku metodu procjene ozračenja temeljenu na ambijentalnim ispitivanjima te uvidu u vrijednost DAP-a i geometriju ozračivanja tijekom provedbe postupka. Rezultati ispitivanja H*(10) i H*(10)/t u različitim uvjetima ozračenja pokazuju velik raspon H*(10)/t na pozicijama od interesa i značajno različite odnose H*(10)/DAP za različite pozicije mjerenja i različite uvjete korištenja rendgenskog uređaja. Za određenu poziciju u prostoriji i geometriju ozračenja potvrđen je pretpostavljeni linearan odnos H*(10) s DAP-om, kao i niz jednostavnih temeljnih odnosa parametara korisnog snopa zračenja i H*(10) neophodan za računsku rekonstrukciju ozračenja.
Zaključak: Velik raspon bitno različitih rendgenskih uređaja, različitih operativnih protokola i uvjeta pod kojima se koriste te lokalna organizacija rada zahtijevaju pojedinačan pristup svakom radilištu. Uvidom u strukturirana dozna izvješća te određivanjem karakterističnih odnosa H*(10)/DAP za pojedine načine rada i pozicije u prostoriji, uz uvažavanje korištenih zaštitnih sredstava, moguće je vjerodostojno procijeniti ozračenje radnika na određenoj poziciji u prostoriji.

Ključne riječi: Procjena ozračenja, ambijentalni dozni ekvivalent, DAP, intervencijska radiologija, dijaskopija

RADIATION EXPOSURE ASSESSMENTS FOR EXPOSED WORKERS IN INTERVENTIONAL AND FLUOROSCOPY X-RAY PROCEDURES BASED ON WORKPLACE MONITORING AND X-RAY MACHINE DOSE REPORTS

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Abstract
The categorization of workplaces and exposed workers is based, among others, on the results of the workplace monitoring performed using portable survey meters calibrated in the ambient dose equivalent (H*(10)) and/or the ambient dose equivalent rate (H*(10) /t) units. Exposure assessment of exposed workers strongly depend on the occupancy coefficients and/or workload of ionizing radiation source. Workplaces in the close vicinity of C-arm fluoroscopy and interventional X-ray devices are of particular interest. Exposure assessments in these situations are more complex and include different operation modes of X-ray device, variations in the irradiation geometry, the size of the irradiation field, use of available protective equipment and the work organization. The workload of the X-ray device expressed by dosimetric quantity dose-area product (DAP) is automatically recorded in the structured dose report where DAP information additionally includes variations of dose rate in the useful beam and variations in the size of irradiation field. The aim of this research is to validate assumed theoretical relations between H*(10) and DAP and to develop a reconstruction method of exposure assessment for exposed workers based on DAP and imaging geometry.
Measurements results of H*(10) and H*(10)/t under different exposure conditions gives a large range of H*(10)/t values at the positions of interest and significantly different ratios of H*(10)/DAP for different measurement positions and different conditions of the X-ray device use. For a certain position in the room and the certain irradiation geometry, the assumed linear relationship between H*(10) and DAP was confirmed, as well as a series of simple basic relationships between physical parameters of X-ray beam and H*(10), necessary for reconstruction of exposed workers exposure.
Conclusion: A large range of significantly different X-ray devices, different operating protocols, conditions under which protocols are used and local work organization, requires an individual approach to each workplace. By reviewing the dose reports and determining the characteristic H*(10)/DAP ratios for specific modes of X-ray unit operation and positions in the room, takin into account protective equipment used, it is possible to reliably assess the radiation exposure of workers at a certain position in the room.

Keywords: radiation exposure assessment, ambient dose equivalent, DAP, interventional radiology, fluoroscopy

OPTIMIZACIJA ZAŠTITE OD ZRAČENJA ZA NOVI SPECT/CT UREĐAJ U OB VARAŽDIN

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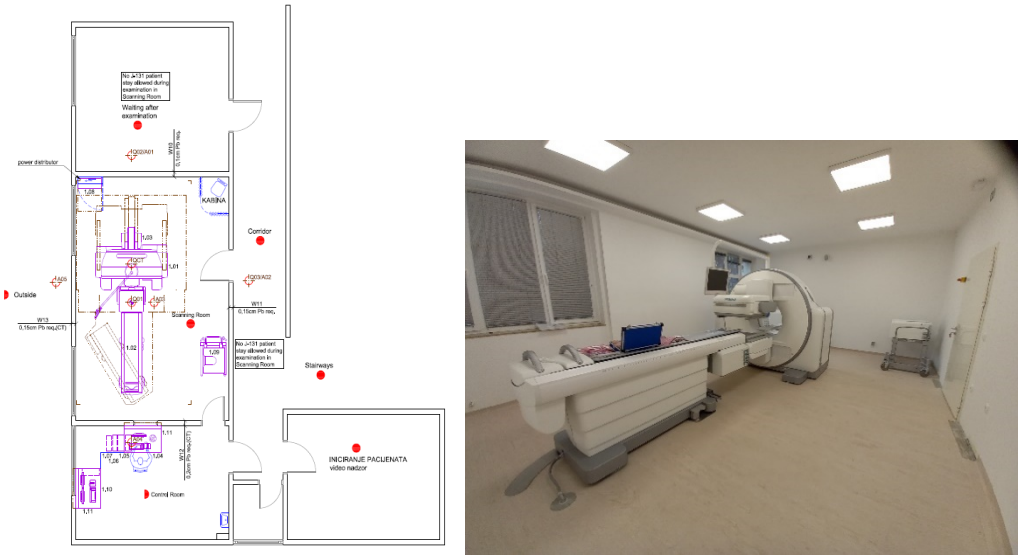
Sažetak
Proračun i optimizacija zaštite za SPECT/CT uređaj u sklopu izrade procjene rizika za sve sudionike tog dijagnostičko/terapijskog medicinskog postupka uporabom radiofarmaceutika je posebno zahtjevna. Ona obuhvaća zaštitu izloženih radnika i građanstva od zračenja SPECT/CT uređaja, ali i od pacijenata kojima se, u ovom slučaju, aplicira jedan od 3 različita radiofarmaceutika koji se koriste u OB Varaždin.



Slika 1: a) Tlocrt prostorija u koje je na kraju postavljen SPECT/CT uređaj, s popratnim prostorijama; b) slika postavljenog SPECT/CT uređaja u prirodnom staništu

Proračun i optimizacija zaštite napravljena je koristeći *NCRP Report No. 147 „Structural shielding design for medical X-ray imaging facilities“*, prema zahtjevima „Zakona o radiološkoj i nuklearnoj sigurnosti” i pratećih pravilnika.
Ukoliko bi se za proračun zaštite koristili najkonzervativniji modeli, zaštita od ionizirajućeg zračenja uređaja i pacijenata bila bi previše debela, zahtijevala bi značajna dodatna novčana sredstva, a možda bi zahtjevala i dodatne strukturne građevinske radove. Zbog toga smo zaštitu optimizirali u nekoliko koraka: računanje sa stvarnim opterećenjem (dnevni broj pacijenata, raspodjela pacijenata po radiofarmaceuticima koji imaju značajno različite zahtjeve za zaštitom), uračunavanje stvarnog dijagnostičkog protokola (npr. koliki je maksimalni broj iniciranih pacijenata u čekaonici), ali i korištenjem Microshield programa za modeliranje netočkastih izvora, jer velika je razlika u zračenju točkastog izvora i pacijenta kojem je iniciran radiofarmaceutik. Nakon izvršenih građevinskih radova i instalacije uređajaizvršeno je ispitivanje prostora kojim je potvrđen adekvatan nivo ugrađene zaštite od ionizirajućeg zračenja.

Ključne riječi: SPECT/CT, zaštita od zračenja, radiofarmaceutik

SHIELDING OPTIMIZATION FOR THE NEW SPECT/CT SCANNER IN VARAŽDIN GENERAL HOSPITAL

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Abstract
The shielding design and optimization for a SPECT/CT device as a part of risk assessment for all the participants of this diagnostic/therapeutic procedure using radiopharmaceuticals is particularly demanding. It encompasses protection for employees and members of general populace from radiation that comes from the SPECT/CT scanner, but also from the radiation that comes from patients that were given, in this case, one of three radiopharmaceuticals that are used in Varaždin General Hospital.

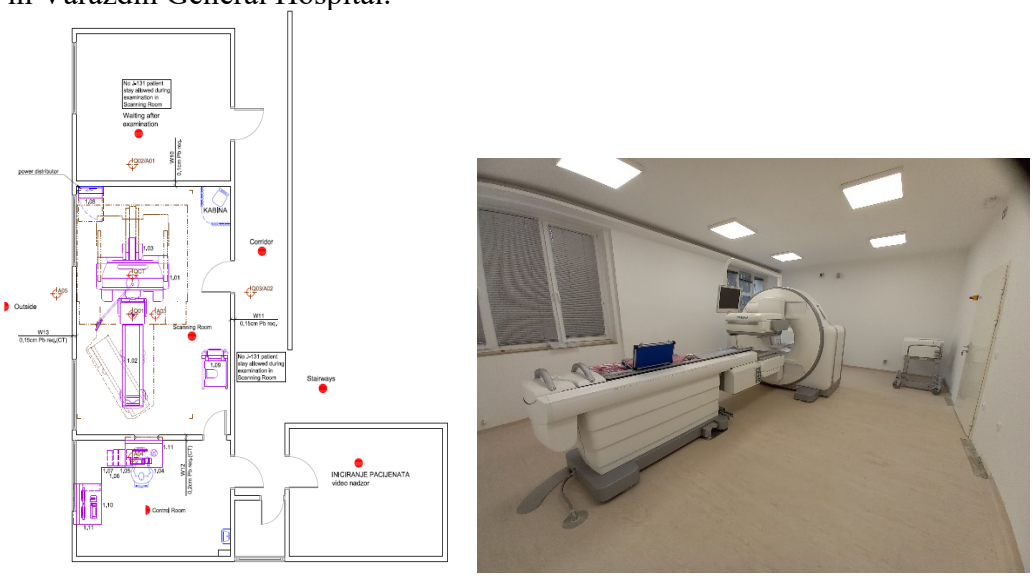

Figure 1: a) Floor plan for the diagnostic block where SPECT/CT scanner was eventually installed; b) the installed SPECT/CT scanner in its natural habitat

The shielding design and optimization was made using NCRP Report No. 147 „Structural shielding design for medical X-ray imaging facilities“, taking into account demands of the „Law on the Radiological and Nuclear Safety“ and accompanying rulebooks and regulations.
If one was to design the radiation shielding using the most conservative models, it would be too thick, it would require considerable additional funding, and maybe even additional structural construction works. Therefore, we optimized the shielding in several steps: we did the calculation using real world data (e.g. daily number of patients, distribution of patients regarding different radiopharmaceuticals because they have significantly different shielding demands), considering the diagnostic protocol as it is really performed (e.g. number of patients that are waiting in the waiting room), but also using the Microshield program that models non-point sources, because there is a big difference in radiation emission between a point radiation source and a patient that was injected with a radiopharmaceutical.
After the construction work was finished and SPECT/CT scanner was installed, an inspection was performed that affirmed that the radiation protection was adequate.

Keywords: SPECT/CT, radiation protection, radiopharmaceuticals

RADIOEKOLOGIJA

RADIOECOLOGY

RADIOLOŠKA KARAKTERIZACIJA NAPUŠTENOG ODLAGALIŠTA PEPELA U ŠTRMCU (ISTRA)

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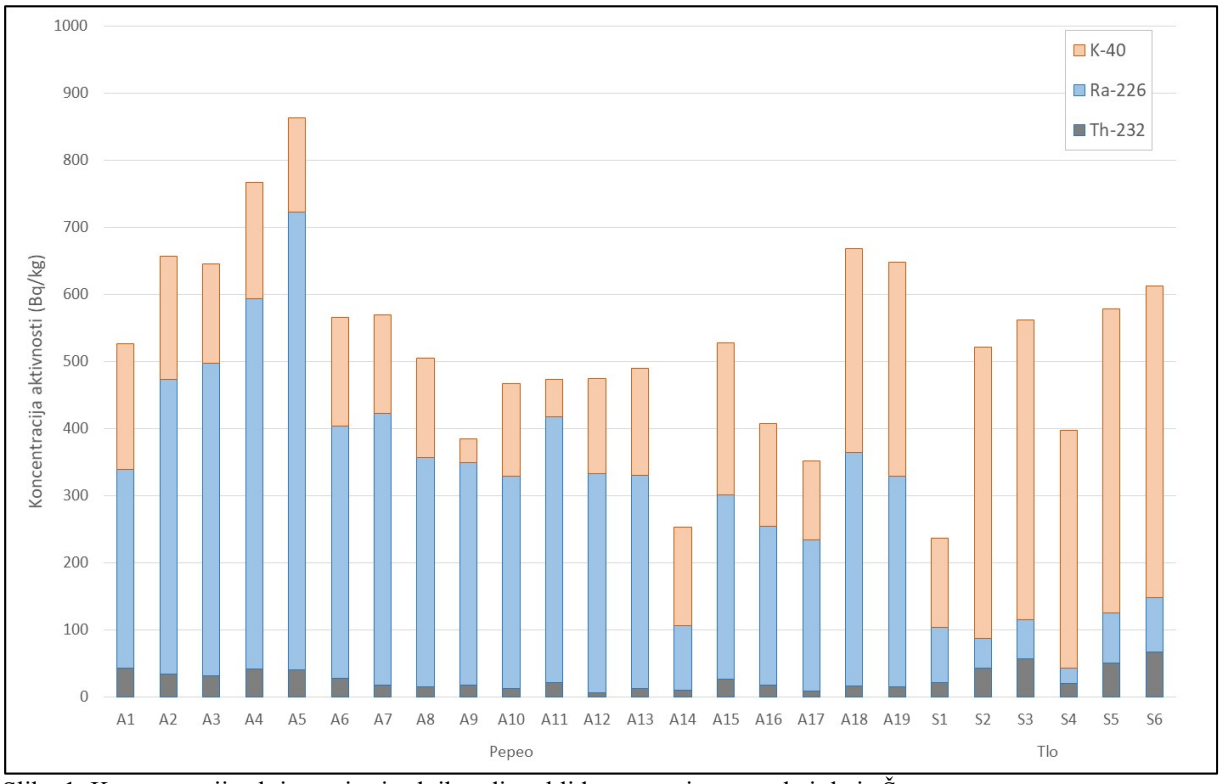
Sažetak
Napušteno odlagalište pepela nalazi se u mjestu Štrmac (Istra). Korišteno je kao odlagalište u počecima rada termoelektrane Plomin, kad je u proizvodnji korišten Istarski ugljen (antracit) u kojemu su prirodno povišene količine radionuklida, što je uzrokovalo povišene koncentracije radionuklida u pepelu. Odlagalište je oko 5 km udaljeno od Plominskog zaljeva.
Uzorkovanje je provedeno u svibnju i srpnju 2019. godine. Uzorkovano je 19 uzoraka pepela (A1-A19) i 6 uzoraka tla (S1-S6) oko odlagališta (Slika 1). Visokorezolucijskom gamaspektrometrijom određene su koncentracije aktivnosti prirodnih radionuklida (^{232}Th, ^{226}Ra, and ^{40}K). Rezultati su prikazani na Slici 1. Koncentracije aktivnosti u uzorcima pepela su se kretale u rasponu: 96 – 681 Bq/kg za ^{226}Ra, 7 – 44 Bq/kg za ^{232}Th i 36 – 319 Bq/kg za ^{40}K. Koncentracije aktivnosti u uzorcima tla usporedive su s uobičajenim vrijednostima Istarskih tala.



Slika 1. Koncentracije aktivnosti prirodnih radionuklida u uzorcima pepela i tla iz Štrmca

Ključne riječi: NORM, ugljen, pepeo, odlagalište, Raša

RADIOLOGICAL CHARACTERIZATION OF AN ABANDONED ASH DUMP IN ŠTRMAC (ISTRIA)

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Abstract

The abandoned ash dump in Štrmac (southeastern part of the Istrian peninsula) was used as a deposition site for ash from the Plomin CFPP in its early years, during which period the operator used domestic coal (anthracite from Istrian peninsula) with higher radionuclide amounts and it resulted in higher radioactivity levels. The study area is close to the Plomin bay (about 5 km of air distance).

Two sampling campaigns were carried out in May and July 2019. Total of 19 ash (A1-A19) and 6 soil samples (S1-S6) were analyzed using high resolution gamma-ray spectrometry and activity concentrations of natural radionuclides (^{232}Th, ^{226}Ra, and ^{40}K) were determined. The results are presented in Figure 1. Activity concentrations in ash samples were in the range 96 – 681 Bq/kg, 7 – 44 Bq/kg and 36 – 319 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K, respectively. Activity concentrations for soil samples were comparable with usual values for Istrian soils.

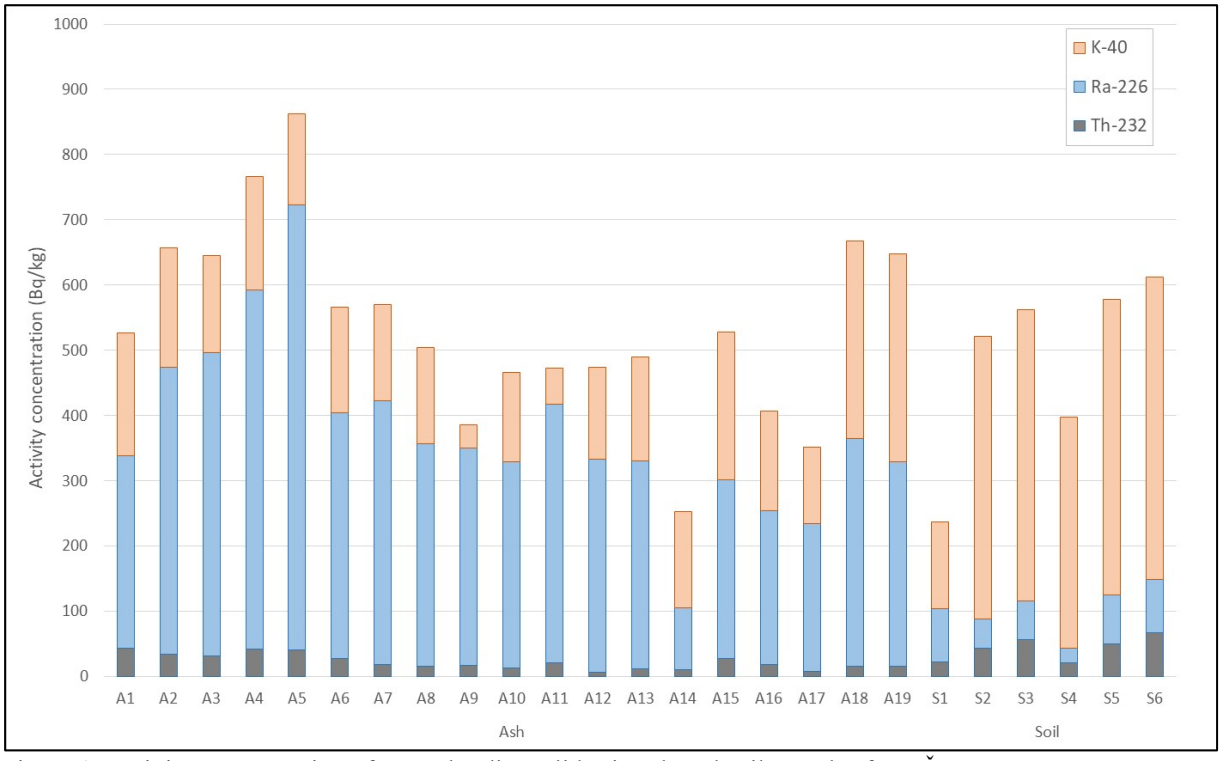

Figure 1. Activity concentration of natural radionuclides in ash and soil samples from Štrmac

Keywords: NORM, coal, ash, deposition site, Raša

RADIOCARBON ^{14}C ACTIVITIES IN ATMOSPHERIC CO_2 IN ZAGREB AND CVETKOVIĆ, CENTRAL CROATIA

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Abstract
Radiocarbon (^{14}C) is both the cosmogenic and anthropogenic isotope. Anthropogenic ^{14}C is produced in atmospheric nuclear bomb tests, and in various nuclear facilities. The bomb-produced ^{14}C has been globally distributed across the planet and can be considered as a new-natural level. Furthermore, combustion of fossil fuels that do not contain ^{14}C causes increase of atmospheric CO_2 concentration and consequently depletion of local ^{14}C levels. Naturally produced CO_2 and that formed by fossil fuel combustion are characterized by different stable isotopic composition of carbon ($\delta^{13}C$). Therefore, the carbon isotopes (^{13}C and ^{14}C) of the atmospheric CO_2 can indicate sources of CO_2 at each location.
^{14}C activity in the atmospheric CO_2 in Zagreb, Croatia, has been monitored since 1985. Recently (2018 ongoing) we started monitoring at location of Cvetković village (near Jastrebarsko, Zagreb County). Additionally, we took samples for $\delta^{13}C$ analyses during period 2021 – 2022. Here we compare the data from period 2018 – 2022.
A static sampling method has been used for monitoring ^{14}C activity – concentrated NaOH is exposed in a tray for 4 weeks. The method is simple and requires neither electric power nor any control, so it can be used at remote sites. However, the method introduces large isotope fractionation in ^{13}C due to high alkalinity of NaOH and it cannot be applied for monitoring $\delta^{13}C$. A dynamic method of continuous CO_2 collection on NaOH (3M) with a constant air-flow requires source of electricity for pumping and heating, and occasional control of sampler performances. Both static and dynamic sampling methods give an average ^{14}C activity over the sampling period. We also developed an instant sampling of atmospheric air in 10-L bags, what gives instant values of ^{14}C and $\delta^{13}C$. Grab (instant) samples of CO_2 for $\delta^{13}C$ have been collected and measured at Jožef Stefan Institute, Ljubljana.
Comparison of liquid scitnillation counting of the benzene (LSC-B) and accelarator mass spectrometry (AMS) measurement methods resulted in good agreement of ^{14}C activities. The ^{14}C activity of the instant sample revealed comparable results with the samples collected by the static method indicating that the two sampling methods could be combined. $\delta^{13}C$ values of samples collected by the dynamic method showed no fractionation in ^{13}C and comparable ^{14}C activities with the static method. Instant samples can provide simultaneously ^{14}C activity and $\delta^{13}C$ values. Both ^{14}C activity and $\delta^{13}C$ data will be used to differentiate carbon of global origin and carbon from local fossil fuel combustion.
Mean ^{14}C activity ($\delta^{14}C$) at Zagreb is lower than that in Cvetković due to fossil fuel combustion in the city of Zagreb. This is especially pronounced during winter.

Keywords: atmospheric CO_2, Central Croatia, ^{14}C, $\delta^{13}C$,sampled method comparison, origin of carbon

TALOŽENJE KALIJA U OKOLIŠU

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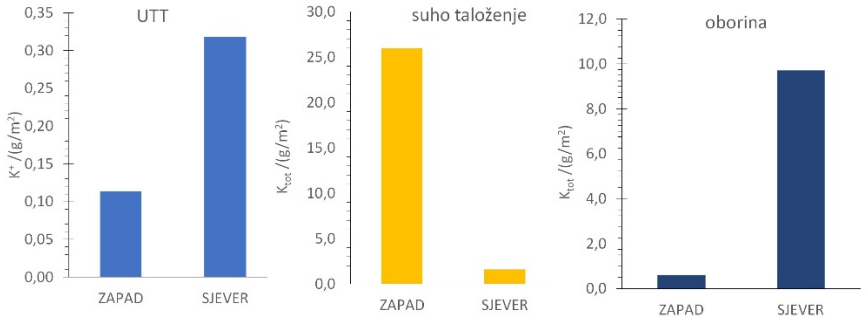
Sažetak

Kalij se u okoliš može taložiti iz više izvora - morske soli, prašine iz tla, biogenih emisija i izgaranja biomase[1–3]. Glavni cilj rada je bio odrediti i usporediti razine kalija i njegovog prirodnog radionuklida ^{40}K u različitim vrstama atmosferskog taloženja (ukupna taložna tvar, suho taloženje i oborine), te procijeniti njegov glavni izvor. Uzorci su sakupljani na dvije lokacije u gradu Zagrebu tijekom 2022. godine. U prvoj polovici 2022. godine uzorci su sakupljeni u zapadnom industrijskom dijelu grada opterećeno prometom, dok su se u drugoj polovici godine sakupljali u sjevernom stambenom dijelu grada. Uzorci suhe depozicije kao i oborina sakupljani su kao tromjesečni uzorci, dok su uzorci ukupne taložne tvari sakupljani na mjesečnoj bazi, ali su ovdje prikazani kao tromjesečni prosjeci radi lakše usporedivosti rezultata s prethodno navedenim metodama. Prirodni radionuklid kalija, ^{40}K, kao i ukupan K određen je visokorezolucijskom gamaspektrometrijom s germanijskim detektorom visoke čistoće (HPGe) u suhoj depoziciji i u oborini, dok je vodotopivi kalij u ukupnoj taložnoj tvari određen ionskom kromatografijom s konduktometrijskim detektorom. U istim uzorcima ukupne taložne tvari određivao se i vodotopivi organski ugljik (WSOC) metodom termičko-optičke transmisije s plamenoionizacijskim detektrom, a u svrhu izračuna omjera K^+ i WSOC, koji može biti pokazatelj određenih izvora onečišćenja.



Slika 1. Taloženje kalija u okolišu

Vidljivo je da su koncentracije kalija u ukupnoj taložnoj tvari kao i u oborinama više na sjeveru grada, dok su kod suhog taloženja više u zapadnom djelu grada Zagreba. Iz omjera K^+ i WSOC vidljivo je da kalij u ukupnom taloženju u gradu Zagrebu dolazi kao produkt sagorijevanja biomase[1,3–5].

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Ključne riječi: kalij, oborine, suho taloženje, ukupna taložna tvar

DEPOSITATION OF POTASSIUM IN THE ENVIRONMENT

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Abstract

Potassium can be deposited into the environment from several sources - sea salt, dust from the soil, biogenic emissions, and biomass burning [1–3]. The main goal of the work was to determine and compare the levels of potassium and its natural radionuclide ^{40}K in different types of atmospheric deposition (total deposition, dry deposition, and precipitation), and to estimate its main source. The samples were collected at two locations in the city of Zagreb in 2022. In the first half of 2022, samples were collected in the western industrial part of the city burdened with traffic, while in the second half of the year, they were collected in the northern residential part of the city. Samples of dry deposition as well as precipitation were collected as quarterly samples, while samples of total deposition were collected on a monthly basis, but are presented here as quarterly averages for easier comparison of results with previously mentioned methods. The natural radionuclide of potassium, ^{40}K, as well as total K was determined by high-resolution gamma spectrometry with a high-purity germanium detector (HPGe) in dry deposition and in precipitation, while water-soluble potassium in the total deposition was determined by ion chromatography with a conductometric detector. In the same samples of total sediment, water-soluble organic carbon (WSOC) was determined using the thermal-optical transmission method with a flame ionization detector, for the purpose of calculating the ratio of K^+ to WSOC, which can be an indicator of certain pollution sources.

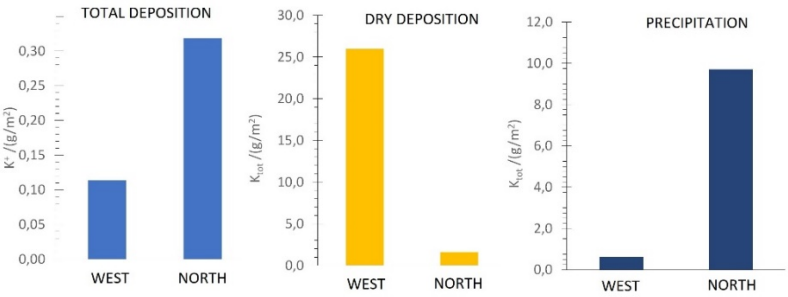

Figure 2. Deposition of potassium in the environment

It was noticed that potassium concentrations in the total deposition as well as in precipitation are higher in the north of the city, while in dry deposition they are higher in the western part of the city of Zagreb. From the ratio of K^+ to WSOC, it is evident that potassium in the total deposition in the city of Zagreb comes as a product of biomass burning[1,3–5].

References

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Keywords: dry deposition, potassium, precipitation, total deposition

MJERENJE TRICIJA U RIJECI SAVI TIJEKOM ČETRDESET GODIŠNJEG RADA NUKLEARNE ELEKTRANE KRŠKO

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Sažetak
Nuklearna elektrana Krško počela je s radom 1983. godine i od tada se provodi kontinuirani monitoring radioaktivnosti u njenoj bližoj i daljnoj okolini. Prije početka gradnje osmišljen je program monitoringa koji je uključivao utvrđivanje nultog stanja radioaktivnosti te praćenje eventualnih promjena tog stanja tijekom rada elektrane. Program monitoringa u početku je obuhvačao opsežana mjerenja radioaktivnosti na području Slovenije i Hrvatske. Tijekom vremena program se je mijenjao tako da su neka mjerenja reducirana, a uvođena neka nova adekvatna trenutnom stanju novih znanstvenih spoznaja iz područja radioekologije. Međutim konstanta programa je praćenje stanja radioaktivnosti rijeke Save od samih početaka što uključuje mjerenja sadržaja radionuklida u vodi, sedimentu i bioti budući da elektrana ispušta određenu količinu radionuklida direktno u Savu. Od ukupne aktivnosti svih radionuklida koje elektrana ispusti u Savu najveći dio odnosi se na aktivnost ^{3}H. Godišnji ispust ^{3}H kreće se između 5 i 20 TBq dok je ispust gama emitera do 100 MBq u posljednjih nekoliko godina. Program monitoringa stoga od samog početka uključuje mjerenje tricija u ispustima te u rijeci Savi na nekolika lokacija. Na dvije lokacije, u Brežicama i Jesenicama na Dolenjskem se provodi kontinuirano mjerenje a u Jesenicama i kontinuirano uzorkovanje vode od samog početka rada elektrane. Stoga je svrha ove prezentacije prikaz rezultata mjerenja tricija u rijeci Savi na obje spomenute lokacije od početka rada elektrane do sada uz osvrt na evoluciju metodologije mjerenja tricija te njenog utjecaja na poboljšanje točnosti mjerenja. Naime kako se tricij određuje tekućinskom scintilacijskom spektrometrijom performanse tekućinskih scintilacijskog brojača vrlo su bitne za točnost rezultata. U razdoblju od prvih nekoliko godina rada elektrane došlo je do velikog poboljšanja performansi scintilacijskih brojača koje su bitno utjecale na povećanje točnosti određivanja. S obzirom da su mjerenja rađena u dva laboratorija, jedan u Sloveniji a drugi u Hrvatskoj, dati će se usporedni prikaza rezultata mjerenja tricija tijekom čitavog vremenskog perioda te će se diskutirati poboljšanje točnosti mjerenja tricija u kontekstu uvođenja nove generacije brojača s vrlo niskim osnovnim zračenjem u rad pojedinog laboratorija. Naime prirodna aktivnost tricija u rijeci Savi manja je od 2 Bq/L pa je na starijim generacijama brojača koji su imali visok nivo osnovnog zračenja, u usporedbi s novim, (>10 vs <2 impulsa/min) dosta teško točno određivanje čak i uz elektrolitsko obogaćenje. Nadalje ispuštanje tricija iz elektrane podiže aktivnost savske vode pa je za mjerenje doprinosa ispusta bitno pouzdano i točno određivanje koje je olakšano na instrumentima nove generacije u usporedbi sa starijima što će se posebno prodiskutirati.

Ključne riječi: tricij, Sava, Nuklearna elektrana Krško, metode mjerenja, rezultati

MEASUREMENT OF TRITIUM IN THE SAVA RIVER DURING FORTY YEARS OF OPERATION OF THE KRŠKO NUCLEAR POWER PLANT

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Abstract
The Krško nuclear power plant began operating in 1983., and since then, continuous monitoring of radioactivity in its immediate and distant surroundings has been carried out. Before the start of construction, a monitoring program was designed that included determining natural level ("zero state") of radioactivity and radioactivity monitoring during the operation of the power plant. The monitoring program initially included extensive measurements of radioactivity in Slovenia and Croatia. The constant of the program is the monitoring of the tritium activity in the Sava River from the very beginning. Of the total activity of all radionuclides released by the power plant into the Sava, the largest part relates to the activity of ^{3}H. The annual release of ^{3}H ranges between 5 and 20 TBq, while the release of gamma emitters is up to 100 MBq in the last few years. Therefore, from the very beginning, the monitoring program includes the measurement of tritium in the discharges and in the Sava River at several locations. At locations, in Brežice and Jesenice on Dolenjske, continuous measurement is carried out, and in Jesenice, continuous sampling of water is carried out from the very beginning of the operation of the power plant. Therefore, the purpose of this presentation is to show the results of tritium measurements in the Sava River at both mentioned locations from the beginning of the operation of the power plant until now, with a review of the evolution of the tritium measurement methodology and its influence on the improvement of measurement accuracy. As tritium is determined by liquid scintillation spectrometry, the performance of liquid scintillation counters is very important for the accuracy of the results. In the period of the first few years of operation of the power plant, there was a great improvement in the performance of the scintillation counters, which significantly influenced the increase in the accuracy of the determination. Given that the measurements were made in two laboratories, one in Slovenia and the other in Croatia, a comparative presentation of the tritium measurement results during the entire time period will be given and the improvement of tritium measurement accuracy will be discussed in the context of the introduction of a new generation of counters with very low basic radiation in the work of an individual laboratory. Namely, the natural activity of tritium in the Sava River is less than 2 Bq/L, so on older generations of counters that had a high level of basic radiation, compared to new ones (>10 vs <2 count/min), accurate determination is quite difficult even with electrolyte enrichment. Furthermore, the release of tritium from the power plant increases the activity of the Sava water, so reliable and accurate determination is essential for measuring the contribution of the discharge, which is facilitated by new generation instruments compared to older ones, which will be discussed separately.

Keywords: Tritium, Sava, Nuclear power plant, measurement methods, results

NADOGRADNJA HPGE SPEKTROMETRIJSKOG SUSTAVA ZA MJERENJE NISKIH AKTIVNOSTI AKTIVNIM ŠTITOM

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Sažetak

U sklopu HrZZ projekta RiChFALL, provodi se analiza radionuklida u dječjoj hrani i sirovinama za njenu pripremu. Kvantitativno određivanje radionuklida koji su gama emiteri vrši se metodom gama spektrometrije korištenjem visoko čistih germanijskih detektora (HPGe). Budući da se u navedenim uzorcima očekuju niske aktivnosti prirodnih i antropogenih radionuklida, u sklopu projekta vrši se nadogradnja postojećeg spektrometrijskog sustava kako bi bio prikladniji za mjerenje vrlo niskih aktivnosti smanjenjem utjecaja pozadinskog zračenja. Za smanjenje utjecaja okolnog zračenja prilikom gama-spektrometrijskog mjerenja, germanijski detektor (HPGe) zajedno je s uzorkom zatvoren u olovni štit. Prostor oko detektora također se isplahuje korištenjem pretlaka tekućeg dušika, kako bi se iz prostora unutar olovne zaštite istisnuo zrak koji sadrži radon, čiji su potomci gama emiteri. Dodatne komponente u spektru okolnog zračenja dolaze zbog utjecaja kozmičkog zračenja, uglavnom od miona, međudjelovanjem sa materijalom samog štita, detektora i okoline. Pasivni olovni štit nije dovoljan kao zaštita od prodornog kozmičkog zračenja, zbog čega se sustavi za mjerenje niskih aktivnosti smještaju duboko pod zemlju. Budući da to nije moguće u našem slučaju, uveden je aktivni štit. Aktivni štit sastoji se od plastičnih scintilatora (ploče polivinil toulena, 70×70×5 cm), vezanim na fotomultiplikatorske cijevi. Kozmičko zračenje prolaskom kroz materijal scintilatora pobuđuje atome te se prilikom njihove deeksitacije emitira svjetlost. U nastavku, kozmičko zračenje prodire kroz olovni štit i materijale u okolini HPGe detektora. Pri interakciji s materijalom posredno može doći do produkcije gama zraka koje detektirane HPGe detektorom popunjavaju spektar pozadinskog zračenja. Gotovo istovremena detekcija signala u scintilatorima i germanijskom detektoru omogućuje odbacivanje događaja nastalih djelovanjem kozmičkog zračenja mjerenjem u antikoincidenciji. Realizacija antikoincidencijskog mjerenja postignuta je korištenjem multikanalnog analizatora s vremenskom koordinatom detektiranih događaja (Caen DT5781 Quad Digital Multi Channel Analyzer).

Promatranjem razlike vremena događaja u scintilatorima i germanijskom detektoru, zaključeno je da većina koincidentnog signala u germanijskom detektoru nastaje unutar 2 μs nakon detekcije miona, dok su koincidentni događaji vidljivi i do 15 μs kasnije. Optimizacijom ostalih postavki, elektroničkih i geometrijskih, te uporabom 3 scintilatorske ploče, uklonjeno je preko 50% ukupnih događaja iz pozadinskog spektra. Nadograđenim sustavom ponovno su snimljen spektri dijela uzoraka iz RiChFALL projekta kako bi se osiguralo da kvaliteta mjerenja (rezolucija i efikasnost) nije degradirana. Sustav aktivnih štitova integriran je u postojeći sustav, te je zadržana jednostavnost mjerenja.

Ključne riječi: gama spektrometrija, niske aktivnosti, kozmički veto, mioni, aktivni štit

UPGRADE OF THE HPGE SPECTROMETRIC SYSTEM FOR MEASURING LOW ACTIVITIES WITH AN ACTIVE SHIELD

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Abstract
As part of the Croatian Science Fundation project RiChFALL, the analysis of radionuclides in children food and raw materials for its production is performed by the gamma spectrometry using high purity germanium detectors (HPGe). Since low activities of natural and anthropogenic radionuclides are expected in the mentioned samples, the existing spectrometric system is being upgraded to make it more suitable for measuring very low activities by reducing the background radiation signal.
To reduce the influence of background radiation during gamma-spectrometric measurement, the germanium detector (HPGe) is enclosed in a lead shield together with the sample. The space around the detector is flushed using liquid nitrogen overpressure, in order to expel air containing radon, whose progenies emit additional gamma rays. Additional components in the background spectrum are a result of cosmic radiation, mainly muons, interacting with the material of the shield, the detector and the environment. A passive lead shield is not sufficient as protection against highly penetrating cosmic radiation, which is why systems for measuring low activity are placed deep underground. Since this is not possible in our case, an active shield was introduced. The active shield consists of plastic scintillators (polyvinyl toluene plates, 70×70×5 cm) with photomultiplier tubes. Cosmic radiation excites the atoms of the scintillator material, producing the light during their deexcitation. Cosmic rays continue to penetrate the lead shield and materials surrounding the HPGe detector. In interaction with the material, gamma rays can be produced indirectly, and populate the spectrum if detected by HPGe. The almost simultaneous detection of signals in the scintillators and the germanium detector gives the opportunity to reject the events caused by cosmic radiation by measuring in anticoincidence mode. Realization of anti-coincidence measurement was achieved using a multichannel analyzer with the time coordinate of detected events (Caen DT5781 Quad Digital Multi Channel Analyzer).
By observing differences of event time stamps in scintillators and the germanium detector, it was concluded that most of the coincident signal in the germanium detector occurs within 2 μs after muon detection, while coincident events are observable up to 15 μs later. By optimizing other settings, electronics and geometry, and using 3 scintillator plates, over 50% of the total events were removed from the background spectrum. With the upgraded system, several samples from the RiChFALL project were remeasured to ensure that the quality of the spectrum (resolution and efficiency) was not degraded. The cosmic veto system was easily integrated into the existing system, while keeping the simplicity of the original setup.

Keywords: gamma spectrometry, low level activity, cosmic veto, muons, active shield

UTJECAJ DONOSA PUSTINJSKOG PIJESKA NA AMBIJENTALNI DOZNI EKVIVALENT, UKUPNU BETA AKTIVNOST I RAZINE ONEČIŠĆUJUĆIH TVARI U ZRAKU

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Sažetak

Donos pijeska i prašine iz pustinja prirodna je pojava koja može štetno djelovati na ljudsko zdravlje i okoliš. Pustinjski pijesak sastoji se od čestica minerala koji potječu iz sušnih područja te može putovati na velike udaljenosti i pritom akumulirati razne onečišćujuće tvari antropogenog porijekla. Područje južne i jugoistočne Europe naročito je pogođeno takvim događajima, zbog donosa pijeska i prašine iz Afrike i Azije. Između 26. i 30. ožujka 2020. godine na području Hrvatske zabilježena je vrlo intenzivna epizoda donosa pustinjskog pijeska iz pustinje Karakum u središnjoj Aziji, koja je uslijedila neposredno nakon donosa iz Sahare. U ovom istraživanju promatran je utjecaj ovog događaja na brzinu ambijentalnog doznog ekvivalenta, ukupnu beta aktivnost i razine pojedinih onečišćujućih tvari u zraku. Brzina ambijentalnog doznog ekvivalenta pratila se u Zagrebu, Zadru i Slavonskom Brodu. Ukupna beta aktivnost zraka mjerena je u Zadru i na dvije lokacije u Zagrebu. Izmjerene su uobičajene vrijednosti za svaku lokaciju. Na mjernim postajama za trajno praćenje kvalitete zraka na kojima mjerenja provodi Institut za medicinska istraživanja i medicinu rada (u Zagrebu, Sisku i Slavonskom Brodu) u navedenom razdoblju zabilježene su izrazito povišene koncentracije frakcije lebdećih čestica PM_{10} (čestice ekvivalentnog aerodinamičkog promjera < 10 µm), koje ujedno predstavljaju i godišnji maksimum na tim lokacijama. Najviši 24-satni prosjeci masenih koncentracija PM_{10} kretali su se između 134 i 219 µg/m^3 u Zagrebu te do 235 µg/m^3 u Sisku i Slavonskom Brodu. Koncentracije frakcije lebdećih čestica $PM_{2,5}$ (čestice ekvivalentnog aerodinamičkog promjera < 2,5 µm) nisu bile značajno povišene, što ukazuje na veliku zastupljenost grubih čestica (promjera između 2,5 i 10 µm). U frakciji lebdećih čestica PM_{10} zabilježene su u tom razdoblju i povišene razine arsena, mangana i željeza. Ovi rezultati pokazuju da povremene epizode donosa pustinjskog pijeska mogu bitno utjecati na razine pojedinih onečišćujućih tvari u zraku. U ovom istraživanju nije pronađen značajniji utjecaj na brzinu ambijentalnog doznog ekvivalenta i ukupnu beta aktivnost zraka.

Ključne riječi: brzina ambijentalnog doznog ekvivalenta, PM_{10}, pustinjski pijesak, ukupna beta aktivnost, zrak

INFLUENCE OF DESERT DUST OUTBREAKS ON THE AMBIENT DOSE EQUIVALENT RATE, TOTAL BETA ACTIVITY AND POLLUTANT LEVELS IN THE AIR

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Abstract
Outbreaks of sand and dust from deserts are a natural phenomenon that can have an adverse effect on human health and the environment. Desert sand consists of mineral particles originating from arid areas and can travel long distances accumulating various pollutants of anthropogenic origin. Southern and southeastern Europe is particularly affected by such events due to the outbreaks of sand and dust from Africa and Asia. In the period 26-30 March 2020, a very intense desert sand episode was recorded over Croatia, caused by sand coming from the Karakum desert in central Asia, preceded by sand transport from the Sahara. In this study, the impact of this event on the ambient dose equivalent rate, total beta activity and levels of certain pollutants in the air was studied. The ambient dose equivalent rate was monitored in Zagreb, Zadar and Slavonski Brod, while the total beta activity of the air was measured in Zadar and at two locations in Zagreb. Typical values were observed for all of the locations. At the measuring stations for continuous air quality monitoring where measurements are carried out by the Institute for Medical Research and Occupational Health (in Zagreb, Sisak and Slavonski Brod), extremely elevated concentrations of the PM_{10} particle fraction (particles with an equivalent aerodynamic diameter < 10 μm) were recorded, causing annual maximums at these locations. The highest average 24-hour PM_{10} mass concentrations ranged between 134 and 219 μg/m^3 in Zagreb and up to 235 μg/m^3 in Sisak and Slavonski Brod. Concentrations of the $PM_{2.5}$ particle fraction (particles with an equivalent aerodynamic diameter < 2.5 μm) were not significantly elevated, which indicates a high prevalence of coarse particles (between 2.5 and 10 μm in diameter). Elevated levels of arsenic, manganese and iron were also recorded in the PM_{10} particle fraction during that period. The results show that occasional desert sand outbreaks can affect significantly the levels of certain pollutants in the air. However, in this study, no significant influence on the rate of the ambient dose equivalent and the total beta activity of the air was found.

Keywords: air, ambient dose equivalent rate, desert dust, total beta activity, PM_{10}

KONCENTRACIJA ^{137}CS U LEBDEĆEM BIOPEPELU I NAKON NJEGOVE APLIKACIJE U KISELOM POLJOPRIVREDNOM TLU

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Sažetak
Provedena su preliminarna mjerenja ^{137}Cs u uzorcima jako alkalnog (pH >12) lebdećeg biopepela i jako kiselog (pH 4,0) lesiviranog poljoprivrednog tla nakon aplikacije. Aplicirani biopepeo je nastao u kogeneracijskom postrojenju spaljivanjem certificirane šumske sječke porijeklom iz spačvanskog bazena. Na pokusnoj parceli (okolica Š. Polja, istočna Slavonija) biopepeo je apliciran jednokratno, prema slučajnom bloknom rasporedu u tri repeticije i dozama od: 0 (kontrola); 4,5; 8,6; 13 i 17,2 t/ha. Nakon aplikacije, u naredne dvije vegetacijske sezone na pokusnoj parceli su uzgajane poljoprivredne kulture s uobičajenim agrotehničkim zahvatima. Uzorci biopepela su uzeti u triplikatu neposredno nakon aplikacije, a uzorci tla s pokusnih parcela (kompozitni sa 0-30 cm dubine) su uzeti 54 mjeseca nakon aplikacije. Svi uzorci su osušeni do konstantne mase, usitnjeni, homogenizirani i pohranjeni u Marinelli posude volumena 1 L. Koncentracija aktivnosti ^{137}Cs izmjerena je gamaspektrometrijskim sustavom koji se temelji na ORTEC HPGe detektoru (FWHM 2,24 keV na 1,33 MeV ^{60}Co s relativnom učinkovitosti od 74,2% na 1,33 MeV ^{60}Co), spojenim s višekanalnim analizatorom. Izmjerena vrijednost koncentracije ^{137}Cs u uzorcima biopepela je bila 17,1 ± 0,6 Bq/kg, u uzorcima kontrolnog tla 3,4 ± 0,2 Bq/kg i uzorcima tla s aplikacijom biopepela od 3,30 do 4,47 Bq/kg. Temeljem navedenog možemo zaključiti da aplikacija lebdećeg biopepela čak i u relativno velikim dozama (>10 t/ha) nije značajnije utjecala na povećanja razine radioaktivnosti cezija u poljoprivrednom tlu.

Ključne riječi: lebdeći biopepeo, kisela tla, ^{137}Cs

CONCENTRATION OF ^{137}CS IN FLY BIOASH AND AFTER ITS APPLICATION IN ACIDIC AGRICULTURAL SOIL

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Abstract
We carried out preliminary measurements of ^{137}Cs in samples of highly alkaline (pH > 12) fly bioash and after its application in highly acidic (pH < 4) agricultural luvisol. The applied bioash has been produced in a congregation plant facility fuelled by certified forest wood chips from the Spačva basin. On the experimental field (close to Š. Polje, eastern Slavonia), the bioash was applied once, according to the randomised block design in triplicates at next doses: 0 (control), 4.5, 8.6, 13, and 17.2 t/ha. After the application on the experimental during the next two vegetation seasons a common agricultural crops were grown by using standard agrotechnical operations. The bioash was sampled in triplicates immediately after the application, whereas soil samples (composite, from 0-30 cm depth) from the test plots were taken 54 months after the application. All the samples were dried to constant mass, ground, homogenised, and packed into 1 L Marinelli beakers. The activity concentration of ^{137}Cs was measured using a gamma-ray spectrometry system based on an ORTEC HPGe detector (relative efficiency of 74.2% and FWHM of 2.24 keV, all at 1.33 MeV ^{60}Co) coupled with a multi-channel analyser. Measured activity concentration in the samples of bioash was 17.1 ± 0.6 Bq/kg, in the control soil 3.4 ± 0.2 Bq/kg, and in the soil treated with bioash it ranged between 3.30 and 4.47 Bq/kg. This leads us to a conclusion that the ^{137}Cs concentration in the soil was not affected by the application of fly bioash even at its relatively high (>10 t/ha) applied dosages.

Keywords: airborne bioash, acidic soil, ^{137}Cs

VERTIKALNA DISTRIBUCIJA ^{210}Po U POLJOPRIVREDNIM TLIMA

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Sažetak
Jedan od ciljeva HrZZ projekta RiChFALL je istraživanje prijenosa radionuklida iz tla u razne poljoprivredne kulture uzgojene na lokalnim poljoprivrednim gospodarstvima. ^{210}Po je prirodno prisutni radionuklid koji zajedno s ^{210}Pb znatno doprinosi unutarnjoj izloženosti ionizirajućem zračenju u ljudi. Isto tako, varijacije u količinama ^{210}Pb i ^{210}Po u tlu mogu biti odraz prirodnih biogeokemijskih procesa kao i antropogenih utjecaja različitih industrijskih aktivnosti. I dok aktivnost ^{210}Pb u uzorcima tla može biti direktno izmjerena gamma spektrometrijom, određivanje aktivnosti ^{210}Po zahtijeva radiokemijsku pripremu uzorka prije mjerenja alfa spektrometrom.
Uzorci tla su bili prikupljeni iz različitih hrvatskih regija. Uz pomoć korera uzimani su na dubinama: 0 – 5 cm, 5 – 10 cm, 10 – 20 cm te 20 – 50 cm, a potom sušeni na temperaturi do 65 °C da bi se izbjegli gubici ^{210}Po prilikom zagrijavanja. Posušeni uzorci su homogenizirani te mehanički prosijani na veličinu čestica od 250 µm. Razaranje uzoraka tla je napravljeno uz pomoć mikrovalne pećnice. Uzimajući u obzir volatilnost ^{210}Po, standardna procedura za mirkovalno razaranje tla je bila malo prilagođena. Masa uzorka je bila otprilike 1 g. Neposredno prije mikrovalne digestije u uzorke je dodan *tracer* ^{209}Po, isto alfa emiter. Nakon razaranja, uzorci su profiltrirani te je filtrat pažljivo uparen do suhoga. Preostali talog je otopljen u 0.5 M HCl otopini uz dodatak potrebne količine askorbinske kiseline. U ovoj otopini napravljena je auto-depozicija Po na srebrni disk, uz pomoć zagrijavanja i miješanja. Raspon kemijskog iskorištenja je bio 80 – 95%.
Koncentracije aktivnosti ^{210}Po u uzorcima tla varirale su od nekoliko desetaka pa do nekoliko stotina Bq/kg. Najveće vrijednosti izmjerene su u površinskim slojevima tla (do 10 cm dubine). Međutim, distribucija ^{210}Po između prvog (0 – 5 cm) i drugog sloja (5 – 10 cm) je varirala, a na nekim lokacijama je upravo drugi sloj imao veće koncentracije aktivnosti ^{210}Po od prvog. U trećem sloju (10 – 20 cm) vrijednosti su najčešće bile nešto niže od onih izmjerenih u površinskim slojevima. No zato u najdubljem sloju (20 – 50 cm) je zabilježen najveći pad u koncentracijama aktivnosti ^{210}Po u svim izmjerenim tlima. Isto tako, ^{210}Po nije nužno bio u ravnoteži s ^{210}Pb u svim uzorcima. Daljna elementna analiza i analiza fizikalno-kemijskih parametera prikupljenih uzoraka mogla bi pomoći u identifikaciji onih faktora koji utječu na dinamiku te distribuciju ^{210}Pb i ^{210}Po u tlima.

Ključne riječi: alfa spektrometrija, polonij, tlo, prirodno prisutni radionuklid

^{210}Po IN VERTICAL SOIL PROFILES OF AGRICULTURAL SOILS

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Abstract
One of the aims of the ongoing RiChFALL project funded by Croatian Science Foundation, is to study transfer of radionuclides to various agricultural products grown in local agricultural holdings. ^{210}Po is naturally occurring radionuclide that together with its parent ^{210}Pb contributes significantly to the internal exposure to ionizing radiation in humans. Also, variations in the content of ^{210}Pb and ^{210}Po in soil can reflect natural biogeochemical processes as well as anthropogenic impact of different industrial activities. While activity of ^{210}Pb can be directly determined by gamma spectrometry in soil samples, determination of ^{210}Po activity requires sample pretreatment followed by detection by alpha spectrometry.
Soil samples were collected from different regions in Croatia. Samples were taken by auger from different depths: 0 – 5 cm, 5 – 10 cm, 10 – 20 cm and 20 – 50 cm and dried on the temperatures up to 65 °C to prevent losses of ^{210}Po. Dried samples were homogenized and mechanically sieved using 250 µm mesh. Microwave assisted acid-digestion of soil samples was applied. Considering volatility of ^{210}Po, procedure for soil digestion was slightly adapted. Sample mass was approximatelly 1g. Before microwave digestion, samples were spiked with tracer ^{209}Po, also an alpha emitter. After digestion, samples were filtered and filtrate was carefully evaporated. Remaining residue was disolved in 0.5 M HCl with the addition of adequate amount of ascorbic acid. In this solution, with help of heating and stirring, Po was auto-deposited on silver disc. Alpha activity of sample was analysed by alpha-spectrometer. Chemical recovery of the described radiochemical analysis ranged 80 – 95%.
Activity concentrations of ^{210}Po in soil samples varied from several tens to several hundreds of Bq/kg. The highest activity concentrations were measured in the topsoils (up to 10 cm in depth). However, distribution of ^{210}Po between first (0 – 5 cm) and second layer (5 – 10 cm) varied, at some locations second layer having higher activities of ^{210}Po than the first one. In the third soil layer (10 – 20 cm) ^{210}Po activity concentrations were usually slightly lower than those measured in the topsoils. However, in the deepest sampled soil layer (20 – 50 cm) the most significant decline in ^{210}Po content was observed. Also, ^{210}Po was not necessarilly in equilibrium with the ^{210}Pb in all samples. Further elemental and physicochemical analysis of the sampled soils could help to detect factors that might affect dynamic and distribution of ^{210}Pb and ^{210}Po in soil.

Keywords: alpha spectrometry, polonium, soil, naturally occurring radionuclide

ODREĐIVANJE RADIONUKLIDA U POVRŠINSKIM I VODAMA ZA PIĆE TE ATMOSFERSKIM PRECIPITATIMA NA ŠIREM PODRUČJU OPĆINE DVOR

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Sažetak
Kako Republika Hrvatska nema sustavno i trajno riješeno pitanje zbrinjavanja radioaktivnog otpada, donesena je odluka da se krene s izgradnjom Centra za zbrinjavanje radioaktivnog otpada (CRAO) na području općine Dvor, točnije na području bivše vojarne na Čerkezovcu. Sukladno legislativi, u sklopu postupka dobivanja svih potrebnih dozvola za gradnju (CRAO) potrebno je provesti studiju utjecaja na okoliš koja između ostalog traži utvrđivanje postojećeg stanja radioaktivnosti neposredno na lokaciji te u okolici lokacije. Stoga je Fond za financiranje razgradnje NEK-a dao izraditi plan za utvrđivanje postojećeg stanja te je financirao njegovu provedbu. Sukladno planu, Institut za medicinska istraživanja i medicinu rada, Institut Ruđer Bošković i Agronomski faktultet proveli su mjerenja tijekom dvije godine te izradili konačan izvještaj za definiranje postojećeg stanja na lokaciji Centra za zbrinjavanje radioaktivnog otpada i na području općine Dvor s procjenom doze za pojedinca. U sklopu opsežnih mjerenja koja su provedena, Laboratorij za radioekologiju proveo je mjerenja aktivnosti radionuklida prirodnog i antropogenog porijekla u pitkim vodama, površinskim (riječnim) vodama, sedimentima, obraštajima i pčelinjim proizvodima u široj okolici spomenute lokacije te u atmosferskim precipitatima na samoj lokaciji Centra.
U vodama za piće bili su detektirani prirodni radionuklidi (^{238}U, ^{232}Th(^{228}Ra), ^{226}Ra, ^{40}K, ^{7}Be i ^{3}H), te antropogeni ^{137}Cs i ^{90}Sr, dok ostali antropogeni radionuklidi nisu detektirani. Obzirom na različite geološke podloge bunara i izvora, rasponi koncentracija aktivnosti prirodnih radionuklida u nekim bunarskim vodama bili su široki, npr. ^{40}K je izmjeren u rasponu od 6,18 Bq/m^3 do 622 Bq/m^3. Izmjerene koncentracije aktivnosti ^{137}Cs u vodama su u rasponu od 0,145 Bq/m^3 do 1,26 Bq/m^3. Koncentracija aktivnosti ^{90}Sr u vodama iz nekih bunara je ispod granice detekcije, dok je u vodi iz bunara u Paukovcu izmjerena vrijednost 1,85 Bq/m^3. Koncentracije aktivnosti ^{3}H izmjerene su u rasponu od 0,359 Bq/L do 0,664 Bq/L što je usporedivo s vrijednostima u površinskim vodama. U površinskim vodama, prisutni su prirodni radionuklidi te antropogeni ^{137}Cs i ^{90}Sr. Izmjerene koncentracije aktivnosti ^{137}Cs u filtriranim vodama su u rasponu od 0,266 Bq/m^3 do 0,534 Bq/m^3, s nekim iznimkama, dok su u suspendiranoj tvari vrijednosti u rasponu 0,101 - 2,15 Bq/m^3. Raspon izmjerenih koncentracija aktivnosti ^{90}Sr u površinskim vodama je 0,541 Bq/m^3 - 5,17 Bq/m^3, dok su koncentracije aktivnosti ^{3}H izmjerene u rasponu od 0,306 Bq/L do 0,658 Bq/L. U atmosferskim precipitatima detektirani su isključivo prirodni radionuklidi, a koncentracije aktivnosti ^{3}H izmjerene su u rasponu od 0,346 Bq/L do 1,29 Bq/L.
Stoga je cilj prezentacije dati usporedni prikaz rezultata mjerenja prirodnih i umjetnih radionuklida na različitim lokacijama u okolini Centra s osvrtom na metodologiju mjerenja.

Ključne riječi: Centar za zbrinjavanje radioaktivnog otpada, postojeće stanje, vode za piće, površinske vode, atmosferski precipitati, antropogeni radionuklidi, tricij

DETERMINATION OF RADIONUCLIDES IN SURFACE WATER, DRINKING WATER AND RAINWATER IN THE AREA OF DVOR

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Abstract
Disposal of radioactive waste from Nuclear power plant Krško (NPP Krško) still presents an actual problem for the Republic of Croatia. In finding the permanent and systematic solution, the decision of building Radioactive Waste Management Centre was made (RWMC). As the appropriate location which fulfils all of the acquired criteria, the former military base in Čerkezovac, municipality of Dvor, is chosen. However, priori RWMC can be built, an environmental impact assessment must be carried out. This way the current state of radioactivity on the selected location, as well as on the surrounding area, will be determined. Therefore, the Fond for financing the decommissioning of the NPP Krško made a plan to determine current state of radioactivity. In accordance with the plan, during the past two years, several institution (IMI, RBI, AF) conducted different kind of radioactivity measurements. As the result, the current radioactivity situation at the site of the RWMC and in the area of the municipality of Dvor was reported together with the estimation of the dose for an individual. The Laboratory for radioecology carried out the measurements of the activity of both natural and anthropogenic radionuclides in different type of samples: drinking water, surface water, soil, fouling and bee's products. All measurements were carried out in the wider surroundings of Dvor and in the rainwater at the RWMC. The obtained results showed existence of both natural (^{238}U, ^{232}Th(^{228}Ra), ^{226}Ra, ^{40}K, ^{7}Be and ^{3}H) and anthropogenic (^{137}Cs and ^{90}Sr) radionuclides in drinking water. Depending on the geological foundation of wells and springs from which the samples were taken, the activity concentration of the natural radionuclides in well water, varied significantly. For example, the activity concentration of ^{40}K varied between 6.18 Bq/m^3 and 622 Bq/m^3, for ^{137}Cs between 0.145 Bq/m^3 and 1.26 Bq/m^3. The concentration activity for ^{90}Sr in some wells was below detection limit while in Paukovac it reached the value of 1.85 Bq/m^3. The activity concentrations of ^{3}H were measured in the range from 0.359 Bq/dm^3 to 0.664 Bq/dm^3. These values of ^{3}H are comparable with the ones obtained in the surface water where also both natural and anthropogenic radionuclides were detected. The measured activity concentrations of ^{137}Cs, in filtered water, ranged between 0.266 Bq/m^3 and 0.534 Bq/m^3, with few exceptions, while in the suspended matter the range was from 0.101 Bq/m^3 to 2.15 Bq/m^3. In the well water, the activity concentrations of ^{90}Sr varied between 0.541 Bq/m^3 and 5.17 Bq/m^3 while the values for ^{3}H were between 0.306 Bq/dm^3 and 0.658 Bq/m^3. Only natural radionuclides were detected in rainwater where the activity concentration of ^{3}H was in the range from 0.346 Bq/dm^3 to 1.29 Bq/dm^3. Hence, the goal of the presentation is to show the measurement results of natural and anthropogenic radionuclides at different locations in the area of RWMC with accent on the measurement methodology.

Keywords: Radioactive Waste Management Centre, current state, drinking water, surface water, rainwater, anthropogenic radionuclides, tritium

VRETENCA (*ODONATA*) KAO BIOINDIKATORI RADIOAKTIVNOSTI

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Sažetak
Istraživanja faune vretenaca (*Odonata*) i tulara (*Trichoptera*) provedena su u dijelu Rezervata Biosfere Mura-Drava-Dunav, na području Virovitičko-podravske županije. Prikupljeni su uzorci vretenca (*Odonata*) na obali rijeke Drave. Istraživanja su provedena u razdoblju od početka svibnja do kraja kolovoza 2022. godine. Promatrajući vegetacijski pokrov kao i hidrološke uvjete, istraživano područje čini prirodno bogatstvo različitih obilježja te su time i ekološki uvjeti života za vrste koje obitavaju na tom prostoru raznoliki. Uzorci vretenca su liofilizirani, usitnjeni, homogenizirani i mjereni u cilindričnoj geometriji od 100 mL. Koncentracija aktivnosti ^{137}Cs izmjerena je gamaspektrometrijskim sustavom koji se temelji na ORTEC HPGe detektoru (FWHM 2,24 keV na 1,33 MeV ^{60}Co s relativnom učinkovitosti od 74,2% na 1,33 MeV ^{60}Co), spojenim s višekanalnim analizatorom.
Izmjerena vrijednost koncentracije ^{137}Cs u vretencu bila je 7 ± 2 Bq/kg. U usporedbi s prosječnom koncentracijom aktivnosti ^{137}Cs u vodi rijeke Drave to je preko tisuću puta više. Dobivena prosječna vrijednost koncentracije aktivnosti vode rijeke Drave za 2022. godinu je 2,7 ± 0,5 Bq/m^3.
Cilj daljnjih radioloških istraživanja je provesti detaljniju analizu svih radionuklida koji se akumuliraju u ličinkama vretenca. Također, potrebno je detaljnije proučiti ostatak područja Parka Biosfere Mura-Drava-Dunav s radiološke točke gledišta.
Iz dobivenih rezultata izvodi se zaključak da se ličinke vretenca mogu koristiti kao bioindikatori radioaktivnosti u okolišu zbog sposobnosti akumulacije radionuklida.

Ključne riječi: vretenca, bioindikatorski organizmi, ^{137}Cs

DRAGONFLIES (*ODONATA*) AS BIOINDICATORS OF RADIOACTIVITY

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Abstract
We studied the dragonfly (*Odonata*) and Caddisfly (*Trichoptera*) fauna in a part of the Mura-Drava-Danube Biosphere Reserve, located within the Virovitica-Podravina County. Dragonflies (*Odonata*) were sampled on a bank of the Drava River. The research was carried out from May to August 2022. The vegetation and hydrological conditions in the area underlie an abundance of different natural conditions, which results in the variations of the ecological background for the local species. Dragonfly samples were lyophilised, ground, homogenised, and measured in a cylindrical 100 mL geometry. The activity concentration of ^{137}Cs was determined by using a gamma-ray spectrometry system based on an ORTEC HPGe detector (relative efficiency of 74.2% and FWHM of 2.24 keV, all at 1.33 MeV ^{60}Co) coupled with a multi-channel analyser.
The measured activity concentration of ^{137}Cs was 7 ± 2 Bq/kg. This was more than a thousand times higher than in the Drava River water, where the average for 2022 was 2.7 ± 0,5 Bq/m^3.
Our goal for the future is to carry out a detailed analysis of all the radionuclides which accumulate in dragonfly larvae. Moreover, a more detailed radiological study of the Mura-Drava-Danube Biosphere Reserve is required.
We conclude that dragonfly larvae can, due to their ability to accumulate radionuclides, serve as bioindicators of radioactivity.

Keywords: dragonfly, bioindicators, ^{137}Cs

RADON

RADON

STEAM PROJEKT: ZDRUŽENO ISTRAŽIVANJE MIŠLJENJA I STAVOVA STANOVNIŠTVA O RADONU - PRELIMINARNI REZULTATI ZA HRVATSKU

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Sažetak
Tijekom provedbe tehničkog projekta IAEA RER 9153: „*Enhancing the Regional Capacity to Control Long Term Risks to the Public due to Radon in Dwellings and Workplaces*“ uočena je potreba zemalja sudionika za provedbom zajedničkog i harmoniziranog istraživanja javnog mijenja o percepcijama rizika od radona. Dobivene informacije koristit će se u svrhu planiranja strategije komunikacije i njezine provedbe u implementaciji nacionalnih radonskih akcijskih planova prema EU BSS. U tu je svrhu pokrenut STEAM (*Share, Team up, Engage, Analyse, Monitor*) pod-projekt temeljen na iskustvima i rezultatima istraživanja javnog mijenja u Rumunjskoj, a kojem se pridružilo trinaest zemalja: Albanija, Armenija, Austrija, Azerbajdžan, Bugarska, Hrvatska, Estonija, Gruzija, Litva, Moldavija, Rumunjska, Ruska Federacija i Slovačka.
U ovom je višejezičnom i kros-kulturalnom istraživanju javnog mijenja o riziku od radona korišten anketni upitnik koji se sastojao od pet većih blokova pitanja: općenita pitanja o zdravlju – 10 pitanja, radonu – 13 pitanja, percepciji rizika – 2, izvorima informiranja – 2, demografska i socijalna pitanja – 7, što ukupno čini 34 pitanja. Odgovori su kodirani prema Likertovoj skali: „u potpunosti se slažem“, „slažem se“, „niti se slažem niti ne slažem“, „ne slažem se“, „u potpunosti se ne slažem“, „ne znam“ i „radije ne bih odgovorio/la“.
Za određivanje veličine uzorka korišteni su rezultati Popisa stanovništva RH iz 2011. godine kao i uobičajeni parametri nepouzdanosti u društvenim istraživanjima (pogreška od 5% uz interval pouzdanosti od 95%). Kako bi uzorak bi reprezentativan za populaciju korišteno je stratificirano slučajno uzorkovanje u više kategorija (spol, dob, obrazovna skupina, prihod). Prema danim kriterijima potreban broj anketa za RH je 385, a prikupljeno ih je 413.
U ovom će radu biti prikazani rezultati navedenog istraživanja iz kojeg su vidljivi ne samo socioekonomski podaci nego i po prvi put dobiveni podaci o tome koliko uopće prosječan stanovnik zna o radonu, kojim izvorima informiranja najviše vjeruje te koji faktori utječu na njihovo ponašanje kako prilikom odlučivanja o mjerenju radona u kući tako i na aktivnosti usmjerene na smanjenje koncentracije radona u kući kada je to potrebno.
Iako ispitanici smatraju da su dobro i vrlo dobro informirani o rizicima koji utječu na njihovo zdravlje (gotovo 80% ispitanika), njih 68% o radonu ne zna ništa ili vrlo malo, a njih 50% ne zna živi li u područjima u kojima je veća vjerojatnost da će koncentracija radona u njihovim domovima premašiti referentne vrijednosti. Međutim, na hipotetsko pitanje što bi poduzeli da su u njihovim domovima izmjerene povišene vrijednosti radona, njih 85% bi odmah poduzelo mjere za njegovo smanjenje.

Ključne riječi: radon, stratificirano slučajno uzorkovanje, istraživanje mišljenja i stavova

STEAM PROJECT: JOINED RADON POPULATION OPINION SURVEY - PRELIMINARY RESULTS FOR CROATIA

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Abstract
During the implementation of the technical project IAEA RER 9153: "Enhancing the Regional Capacity to Control Long-Term Risks to the Public due to Radon in Dwellings and Workplaces", the need of the participating countries for the implementation of a joint and harmonized survey of public opinion on radon risk perceptions was observed. The obtained information will be used for planning the communication strategy and its implementation in the national radon action plans according to the EU BSS. For this purpose, the STEAM (Share, Team up, Engage, Analyze, Monitor) sub-project was launched based on the experiences and results of public opinion research in Romania, which was joined by thirteen countries: Albania, Armenia, Austria, Azerbaijan, Bulgaria, Croatia, Estonia, Georgia, Lithuania, Republic of Moldova, Romania, Russian Federation and Slovak Republic.
In this multilingual and cross-cultural survey of public opinion on the risk of radon, a questionnaire was used, which consisted of five larger blocks of questions: general questions about health - 10 questions, radon - 13 questions, risk perception - 2, sources of information - 2, socio-demographic data – 7, which makes a total of 34 questions. Answers were coded according to the Likert scale: "strongly agree", "agree", "neither agree nor disagree", "disagree", "strongly disagree", "don't know" and “I prefer to not respond”.
The results of the 2011 Census of the Republic of Croatia were used to determine the sample size, as well as the usual parameters of unreliability in social research (an error of 5% with a confidence interval of 95%). In order to get a representative sample of the population, stratified random sampling was used in several categories (gender, age, educational group, income). According to the given criteria, the required number of surveys for the Republic of Croatia is 385, and 413 were collected.
This paper will present the main results of the mentioned research, from which not only socioeconomic data are visible, but also, for the first time obtained data on how much the average resident of Croatia knows about radon, which sources of information they trust the most, and which factors influence their behavior when deciding about measuring radon in their home as well as which factors influence their decision on reducing the concentration of radon in the home if necessary.
Although respondents believe that they are well or very well informed about the risks that affect their health (almost 80% of respondents), 68% of them know nothing or very little about radon. 50% of the respondents do not know if they live in areas with a higher probability of exceeded radon concentration in their homes above reference value. However, when asked hypothetically what they would do if elevated radon values were measured in their homes, 85% of them would immediately take measures to reduce it.

Keywords: radon, stratified random sampling, opinion survey

A CASE STUDY OF THE FIRST REMEDIATION OF ELEVATED RADON LEVELS IN ONE PUBLIC BUILDING IN CROATIA

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Abstract
Radon concentrations in 117 schools and 87 kindergartens of Istria county were systematically measured by track-etched detectors from November 2013 until February 2015. Detectors were exposed for one year in every playroom in kindergartens and selected classrooms and offices evenly distributed across areas and floors in schools. The obtained average radon concentrations were higher than the reference value (300 Bq/m^3) in 15.5% of kindergartens and 21.0% of schools including this elementary school of interest in Pula. In this school building integrated follow-up radon measurements were performed in 2018-19 by track-etched detectors exposed in every classroom and office. Simultaneously, continuous radon measurements were conducted by TSR3 radon detectors which were exposed for several weeks during the heating season and the time resolution was adjusted to 1-hour. The observed daily variations of radon concentrations show a strong dependence on increased natural ventilation during working hours; a significantly decrease of radon concentrations in the morning and early afternoon and a consequently increase at night and during weekends. However, increased natural ventilation reduce radon concentration in the building during working hours only by 15% and therefore, the design and application of some more effective radon reduction techniques were suggested. The project of radon mitigation has been proposed in September 2021 by one architectural bureau and realized in spring 2022. At six locations around the school building, radon sumps have been created underground beneath the building which serve as the lowest pressure points in the ground to collect radon gas from the soil rather than it being drawn into the building. The pipeworks and inline fans have been installed on the outside walls of the building to continuously exhaust radon from the sump into the atmosphere outside the building. The effectiveness of the installed system has been checked during the IAEA regional workshop on the best practices for reducing radon concentrations in buildings held in Pula in November 2022. During three days, 25 continuous radon monitors (RadonEye Plus 2, Corentium Pro, Tesla TSR4 and AlphaGUARD) were exposed across areas and floors in the school building. Results of this short term measurement show that when the system was fully operable (all fans are switched on) radon concentrations were reduced to levels well below 200 Bq/m^3; when fans were switched off, radon concentrations rapidly increased. Optimization of the installed system for energy-saving purposes was recommended.

Keywords: radon concentration, remediation, public building

UTJECAJ PROJEKTA POBOLJŠANJA ENERGETSKE UČINKOVITOSTI NA KONCENTRACIJE RADONA U PROSTORIJAMA ODJELA ZA FIZIKU I ODJELA ZA MATEMATIKU SVEUČILIŠTA J. J. STROSSMAYERA U OSIJEKU

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Sažetak

Poboljšanje energetske učinkovitosti zgrada zadnjih je godina sve učestalije. Kako je konvekcija jedan od glavnih mehanizama gubitka topline u zgradama, izmjenom stare stolarije i postavljanjem toplinske ovojnice oko zgrade može se smanjiti strujanje zraka i tako postići željeno smanjenje toplinskih gubitaka. Međutim, smanjenjem strujanja zraka olakšava se nakupljanje radona u prostorijama unutar zgrade što može predstavljati potencijalnu opasnost za zdravlje ljudi jer je radon drugi po redu (odmah nakon pušenja) uzročnik karcinoma pluća u svijetu.

Ovaj rad uspoređuje rezultate mjerenja koncentracije radona u zgradi Odjela za fiziku i Odjela za matematiku Sveučilišta u Osijeku iz 2014. godine [D. Stanić i sur., HDZZ, 2015, str. 187-192], kada je zgrada imala staru drvenu stolariju, s novim mjerenjima iz 2021. godine, nakon što je postavljena nova PVC stolarija u sklopu projekta povećanja energetske učinkovitosti zgrade.

Koncentracija radona u zraku mjerena je pasivnom metodom korištenjem odvojivih (engl. strippable) detektora nuklearnih tragova LR-115 tip II. Detektori se postavljaju na nosač detektora RadonOS-Z (cilindrična plastična posuda promjera 11 cm i visine 7 cm). Nakon izlaganja, detektori su jetkani u 10% vodenoj otopini NaOH na 50 °C u trajanju od 150 minuta, a potom su tragovi alfa čestica brojani pomoću brojača iskri, AIST-2V. Koeficijent osjetljivosti K određen je kalibracijom filmova u radonskoj komori i iznosi: $K = 65 \pm 23$ Bq m^{-3} / tr cm^{-2} d^{-1}. Detektori su izlagani u trajanju od 6 mjeseci (studeni 2020. – svibanj 2021.) u istim prostorijama u kojima je vršeno prethodno istraživanje iz 2014. godine.

Rezultati su sljedeći: na Odjelu za fiziku srednje koncentracija radona povećana je s 44 ± 16 Bq/m^3 na 143 ± 51 Bq/m^3, dok je na Odjelu za matematiku također zabilježeno povećanje s 81 ± 29 Bq/m^3 na 263 ± 94 Bq/m^3. Zanimljivo je da je na oba Odjela faktor povećanja isti i iznosi 3,5 puta. Međutim, dok je na Odjelu za fiziku koncentracija radona u svim prostorijama bila ispod preporučene vrijednosti od 300 Bq/m^3 [Pravilnik o granicama ozračenja, preporučenom doznom ograničenju i procjenjivanju osobnog ozračenja, NN 38/18, članak 15. i 16.], na Odjelu za matematiku uočeno je čak pet prostorija s koncentracijom radona iznad preporučene vrijednosti. Ovaj rezultat upućuje na daljnji monitoring radona u navedenim prostorijama, ali i na potrebu ovakvog kontrolnog mjerenja koncentracije radona u svim zgradama nakon završetka projekta energetske obnove zgrade.

Ključne riječi: radon, detektor nuklearnih tragova

THE EFFECT OF THE ENERGY EFFICIENCY IMPROVEMENT PROJECT ON RADON CONCENTRATIONS IN THE ROOMS OF THE DEPARTMENT OF PHYSICS AND THE DEPARTMENT OF MATHEMATICS OF J. J. STROSSMAYER UNIVERSITY OF OSIJEK

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Abstract
Improvements in the energy efficiency of buildings have become more frequent in recent years. Since convection is one of the main mechanisms of heat loss in buildings, by replacing old woodwork and installing a thermal envelope around the building, air flow can be reduced and thus the desired reduction in heat loss can be achieved. However, the reduction of air flow facilitates the accumulation of the indoor radon, which can pose a potential danger to human health, since radon is the second leading cause of lung cancer in the world (right after smoking). This paper compares the results of radon concentration measurements in the building of the Department of Physics and the Department of Mathematics of the University of Osijek from 2014 [D. Stanić et al. CRPA, 2015, pp. 187-192], when the building had old wooden windows, with new measurements from 2021, after new PVC windows were installed as part of the project of increasing the energy efficiency of the building.
Integrated measurements of radon concentrations in the air were performed by means of passive, strippable, nuclear track etched detectors LR-115 type II (Kodak-Pathé, France). The LR-115 detectors were exposed in the air for one year and then etched in 10% NaOH aqueous solution at 50 °C for 150 minutes. Afterwards, the detector tracks were automatically counted using the AIST-2V spark counter (V.G. Khlopkin Radium Institute, St. Petersburg, Russia).
The results are as follows: at the Department of Physics, the mean radon concentration increased from 44 ± 16 Bq/m^3 to 143 ± 51 Bq/m^3, while at the Department of Mathematics an increase was also recorded from 81 ± 29 Bq/m^3 to 263 ± 94 Bq/m^3. It is interesting that in both Departments the increase factor is the same and amounts to 3.5 times. However, while in the Department of Physics the radon concentration in all rooms was below the recommended value of 300 Bq/m^3 [The ordinance on dose limits, recommended dose limits and assessment of personal doses, NN 38/18, Article 15.and 16. (in Croatian)], in the Department of Mathematics as many as five rooms with radon concentration above the recommended value were observed. This result points to further monitoring of radon in the mentioned rooms, but also to the need for such control measurement of radon concentration in all buildings after the completion of the energy efficiency improvement project.

Keywords: radon, nuclear track detector

COMPARISON OF RADON ADSORPTION ON HEMATITE AND ACTIVATED CARBON

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Abstract
Radon is a gas without color, taste and smell from the group of noble gases, so it is chemically almost completely inert. However, radon is also a radioactive gas which makes it dangerous to health if it accumulates in spaces that people use for work and stay. Increased radon concentrations are attempted to be reduced by airing and adsorption on suitable adsorbents such as activated carbon, i.e. more recently silica-gel and various forms of zeolite. The aim of this study was to investigate the properties of hematite (α-Fe_2O_3) as an adsorbent for radon in the air as well as the properties of activated carbon in the same conditions (Figure 1). The results were analyzed using models of adsorption isotherms (Langmuir, Freundlich, Temkin and Dubinin-Radushkevich) and adsorption kinetics (pseudo-first order, pseudo-second order, intra-particle diffusion and Elovich). Hematite has been shown to have very similar characteristics in radon adsorption compared to activated carbon, but a more significant efficiency over a longer period of time which is 97% versus 56% on activated carbon. Based on the results obtained, it can be concluded that hematite is also a possible effective radon adsorbent in the air.

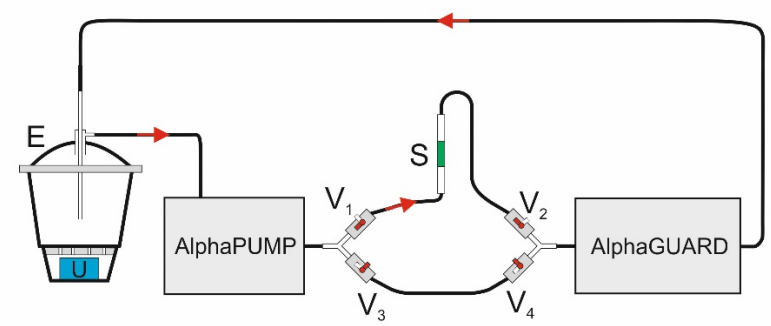

Figure 1: Experimental setup for adsorption of radon in the air.

Keywords: radon, hematite, activated carbon, adsorption

MJERENJE KONCENTRACIJA RADONA U PODZEMNOM ISTRAŽIVAČKOM OBJEKTU

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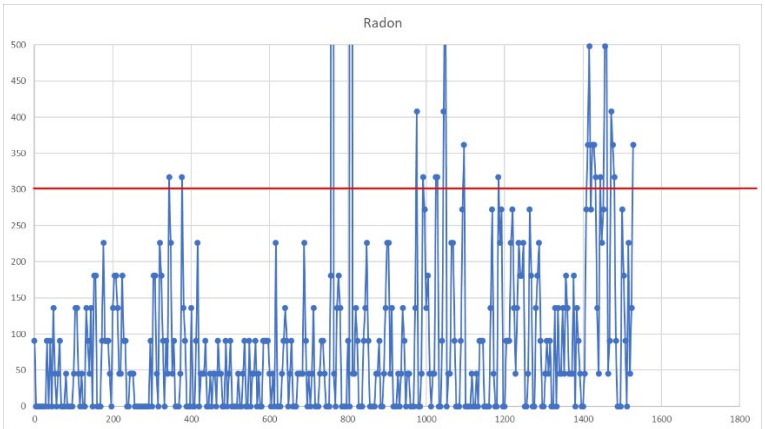
Sažetak
U skladu s Pravilnikom o praćenju stanja radioaktivnosti u okolišu (NN 40/2018) i podacima iz Akcijskog plana za radon za razdoblje 2019. – 2024. (NN 118/2018), nužno je provesti mjere zaštite radnika na mjestima gdje se pojavljuje radon i obavljati periodička mjerenja, a u svrhu zaštite radnika. Mjerenja koncentracija radona provedena su u neaktivnom rudniku sveta Barbara u Rudama, koji predstavlja podzemni objekt turističke, nastavne i znanstvene namjene. Mjerenja su provedena detektorima Radon Scout Home tvrtke Sarad ponovljenim mjerenjima u nekoliko navrata u periodima po dva mjeseca na dvije mjerne točke (Slika 1) te povremenim višesatnim mjerenjima koncentracije radona u rudniku te mjerenjem koncentracije radona u zraku tla u neposrednoj blizini ulaza u rudnik uređajem RTM 2200 SG za mjerenje radona i potomaka tvrtke Sarad. Mjerenja su pokazala da su koncentracije radona većinom niže od vrijednosti 300 Bq/m^3, referentne vrijednosti za radon u zatvorenim prostorima i na radnim mjestima. U slučaju povišenih koncentracija, uređaj za vjetrenje rudnika i održavanje mikroklimatskih uvjeta u rudniku bi se palio i u kratkom vremenu smanjio vrijednosti koncentracije radona na niže od referentne. Povećane koncentracije radona u rudničkoj atmosferi povezane su s periodima nižeg atmosferskog tlaka i kišnim razdobljima. U skladu s Pravilnikom, radnici koji prime godišnju efektivnu dozu veću od 1 mSv, a manju od 6 mSv smatraju se izloženim radnicima kategorije A. U skladu s ICRP, 2014 (ICRP, 2014. Radiological Protection against Radon Exposure. ICRP Publication 126. Ann. ICRP 43(3), prema provedenim mjerenjima kroz godinu dana i usklađivanjem prosjeka s realnim brojem radnih sati provedenih u objektu, zaključeno je kako je efektivna doza za radnike kroz radnu godinu (416 sati) 0,67 mSv/god.



Slika 1: Rezultati dvomjesečnog mjerenja (kolovoz/rujan 2020.) koncentracija radona na mjernom mjestu 1 – uvećano mjerilo s označenom referentnom razinom.

Ključne riječi: radon, podzemni objekt, mjerenje, doza

MEASUREMENT OF RADON CONCENTRATIONS IN AN UNDERGROUND RESEARCH FACILITY

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Abstract
In accordance with the Regulation on monitoring radiation levels in the environment (NN 40/2018) and data from the Action plan for radon for the period 2019-2024 (OG 118/2018), it is necessary to implement measures to protect workers in places where radon appears and to perform periodic measurements for worker protection. Measurements of radon concentrations were carried out in the inactive St. Barbara mine in Rude, which is an underground facility for tourism, education, and scientific purposes. Measurements were carried out using Radon Scout Home detectors from Sarad, with repeated measurements several times every two months at two measurement points (Figure 1), occasional multi-hour measurements of radon concentrations in the mine, and measurements of radon concentrations in the soil air near the mine entrance using the RTM 2200 SG device for measuring radon and its progeny from Sarad. The measurements showed that radon concentrations were mostly lower than the reference value of 300 Bq/m^3 for radon in enclosed spaces and workplaces. In case of elevated concentrations, the mine ventilation and microclimate maintenance device would be turned on and the radon concentration values would be reduced to below the reference value in a short time. Increased radon concentrations in the mine atmosphere were associated with periods of lower atmospheric pressure and rainy periods. In accordance with the Regulation, workers who receive an annual effective dose greater than 1 mSv but less than 6 mSv are considered exposed workers in category A. According to ICRP 2014 (ICRP, 2014. Radiological Protection against Radon Exposure. ICRP Publication 126. Ann. ICRP 43(3), based on measurements taken over the course of a year and adjusting the average for the actual number of working hours spent in the facility, it was concluded that the effective dose for workers over the work year (416 hours) was 0.67 mSv/year.

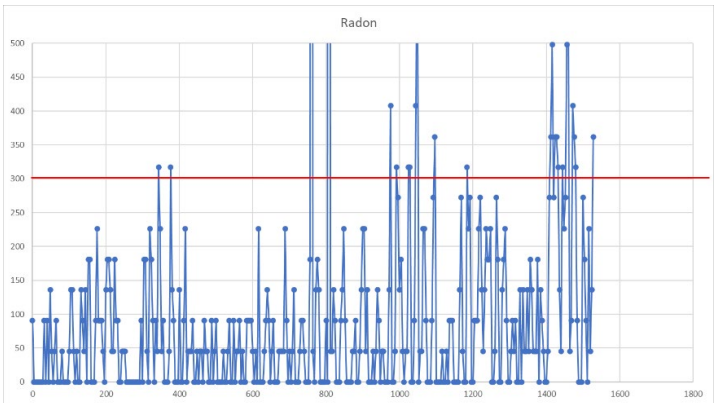

Figure 1: Results of a two-month measurement (August/September 2020) of radon concentration at measuring point 1 – enlarged scale with marked reference level.

Keywords: radon, underground facility, measurmenet, dose

traceRadon - RADON METROLOGY FOR USE IN CLIMATE CHANGE OBSERVATION AND RADIATION PROTECTION AT THE ENVIRONMENTAL LEVEL

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Abstract

The European traceRadon project (http://traceradon-empir.eu/) is ongoing project which brings together 18 institutions from 13 EU countries, including European Commission Joint Research Centre and two institutes representing ICOS thematic centres.

The overall aim of this project is the development of metrological capacity (reference monitors, transfer standards and robust methodology) to measure low levels of radon in the environment, which can be used to determine emission reduction strategies of GHG and improve radiation protection of the general public.

The project consists of six work packages (WP) with five main objectives:

1. To develop traceable methods for the measurement of outdoor low-level radon activity concentration in the range of 1 Bq/m^3 to 100 Bq/m^3, with uncertainties of 10% (k=1), to be used in climate monitoring and radiation protection networks.
2. To develop the capability for traceable radon flux measurements in the field for use in the radon tracer method (RTM) and retrieval of greenhouse gas fluxes at atmospheric climate gas monitoring stations and for identification of Radon Priority Areas (RPA).
3. To validate current radon flux models and inventories by the new traceable measurements of radon activity concentration and radon flux, and to improve process-based radon flux maps that can be used in the RTM, atmospheric dispersion modelling and radiation protection.
4. To provide easy to use dynamic radon and radon flux maps for climate change research and radiation protection in line with Council Directive 2013/59/EURATOM, including their use to identify RPA and radon wash-out peaks.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations and end users in GHG monitoring and European radiological early warning networks.

The traceRadon project will have significant impact through results and outputs dissemination, exchange of gained knowledge between partners and external bodies. The project will support the harmonisation of procedures and methods for the measurement of low levels of radon in the environment and hence their inclusion into European and international standardisation.

Keywords: radon, metrology, radon priority areas, radon flux, GHG

Acknowledgement

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RADON POTENTIAL OF THE KARSTIC LOCATIONS IN THE WESTERN PART OF THE NIKŠIĆ MUNICIPALITY (MONTENEGRO)

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Abstract

Radon concentrations in Montenegrin dwellings and schools are the highest in the western, rural part of the Nikšić municipality, which is a typical high karst region. In this region, during the national radon surveys, radon was measured in ground-floor rooms of 9 houses and 16 schools, at 25 locations that belong to an area of 800 km^2. The radon concentrations in them were found to be in the range (219 – 2494) Bq/m^3, with a mean value AM = 977 Bq/m^3.

In order to investigate the geogenic radon potential of these 25 karstic locations, as a probable cause of the high indoor radon levels, the following soil parameters were measured in the immediate vicinity of the mentioned houses and schools: humidity (*H*), electrical conductivity (*EC*), *pH*, activity concentrations of ^{226}Ra, ^{238}U, ^{235}U, ^{232}Th and ^{40}K, radon activity concentration (*c*), permeability (*k*) for radon gas, and gamma dose rate (*D*) in the air 1 m above the soil. The geogenic radon potential of the location (*GRP*) was calculated from *c* and *k* values. Quantities that characterize radon in soils of the investigated area are found to have high values: c – range (8.9 – 390) kBq/m^3, AM = 115 kBq/m^3; *k* – range (3.9 – 180) · 10^{-13} m^2, AM = 153 10^{-13} m^2; *GRP* – range (11 – 419), AM = 129. Also, concentrations of ^{226}Ra, as ^{222}Rn parent, are elevated (range (48 – 326) Bq/kg, AM = 167 Bq/kg), probably because of traces of bauxite presence at some of the investigated locations. Nine of the 25 investigated locations have a radon index (*RI*) which is categorized as *extremely high*, and the other 9 locations have *very high RI*.

Spearman correlation reveals a strong relationship between *c* and *GRP* ($r_s = 0.906$, $p < 0.001$), moderate relationships of *c* with *D* ($r_s = 0.517$, $p < 0.008$) and ^{226}Ra ($r_s = 0.521$, $p < 0.008$), and *k* with *EC* ($r_s = 0.614$, $p < 0.001$). The relationship between *D* and ^{226}Ra is strong ($r_s = 0.719$, $p < 0.001$).

Pearson correlation shows positive linear relationships of gamma dose rate (*D*) with ^{226}Ra and radon concentration (*c*) in soil and with *GRP* of the location, which means that *D* could be used at karstic terrains as the first, although rough indicator of radium content in the soil, and geogenic radon potential at the location as well.

Keywords: karst region, high indoor radon levels, high geogenic radon potential

INSTRUMENTACIJA I MJERNE TEHNIKE

INSTRUMENTATION AND MEASURING TECHNIQUES

USPOREDBA TEKUĆIH SCINTILACIJSKIH BROJAČA ZA MJERENJE NISKIH AKTIVNOSTI RADIOAKTIVNOG UGLJIKA ^{14}C I TRICIJA ^{3}H

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Sažetak
Prirodni izotop ugljika (^{14}C) čini samo jednu česticu u 10^{12} atoma ugljika. To je niskoenergijski beta emiter, najveće energije $E(^{14}C)_{max}$ = 156 keV, čija se aktivnost određuje izoliranjem ugljika iz uzorka u mjernu matricu (benzen ili CO_2 apsorbiran u scintilacijskom koktelu) na tekućim scintilacijskim brojačima. Prirodne koncentracije ^{14}C često se koriste za analizu prirodnih procesa, praćenje i ^{14}C datiranje. Aktivnost ^{14}C se rutinski određuje u Laboratoriju za niske radioaktivnosti (LNA) na Institutu Ruđer Bošković (IRB). Ugljik iz uzorka se kemijski prevodi u CO_2 i apsorbira u scintilacijski koktel (LSC-A tehnika) ili u benzen (LSC-B tehnika). Tehnika LSC-A ima veću relativnu nesigurnost (~2,6% za uzorak od 100 pMC, engl. *percent modern carbon*) i obično se koristi za geološke uzorke i monitoring okoliša, dok LSC-B (~0,6% za uzorak od 100 pMC) s većom preciznošću se koristi za ^{14}C datiranje. Brojač za mjerenje niskih radioaktivnosti, Quantulus 1220TM ima vrlo niski pozadinski šum (~1 cpm) i omogućuje ^{14}C datiranje do 50 000 godina. Uređaj se koristi i za mjerenje niskih aktivnosti tricija. U Laboratoriju za radioekologiju (LRE) IRB-a redovito se koriste dva tekućinska scintilacijska brojača: TriCarb 3180 TR/SL i Quantulus 6220 GCT za mjerenje aktivnosti tricija. U okviru ovog istraživanja mjerena je aktivnost ^{14}C brojačima na LRE i LNA te su uspoređeni dobiveni rezultati, odbroj slijepe probe, učinkovitost i mjerne nesigurnosti.
Dobiveni rezultati za benzensku matricu (LSC-B tehnika) pokazali su da iako za slijepu probu vrijednosti brojača TriCarb mogu varirati između 1 i 2 cpm, vrijednosti oko 150 pMC mogu se izmjeriti s 0,2% relativne standardne nesigurnosti, što je usporedivo sa standardnom nesigurnošću za Quantulus 1220.
Preliminarni rezultati za Quantulus 6220 GCT imaju slične odbroje za slijepu probu kao i za Quantulus 1220. Relativne standardne nesigurnosti za slijepu probu su 4 – 5% za Quantulus 6220 i 2% za Quantulus 1220, dok su za aktivne uzorke relativne nesigurnosti za oba instrumenta iste, 0,2 – 0,3% za uzorke od 130 i 150 pMC. Iako je potrebno je provesti daljnja ispitivanja, postoje dobre indikacije da za LCS-B tehniku Quantulus 1220 može zamijeniti Quantulusom 6220 GCT.
Tehnika LSC-A je testirana samo na TriCarb brojaču i preliminarni testovi su pokazali dobro slaganje s mjerenjima dobivenim na Quantulusu 1220 za uzorke s višim aktivnostima (~600 pMC) u energijskom rasponu 10 – 110 keV. Potrebno je provesti daljnje testove kako bi se potvrdili rezultati, međutim, ovo je također dobar pokazatelj da se TriCarb može koristiti za LSC-A tehniku.

Ključne riječi: tekućinski scintilacijski brojač, niska radioaktivnost, radiokarbon ^{14}C, TriCarb 3180, Quantulus 1220, Quantulus 6220 GCT

COMPARISON OF LIQUID SCINTILLATION COUNTERS FOR MEASUREMENT OF LOW-LEVEL RADIOCARBON ^{14}C AND TRITIUM ^{3}H ACTIVITIES

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Abstract
Naturally occurring radiocarbon (^{14}C) isotope amounts to only one particle in 10^{12} atoms of carbon. The isotope is a low energy beta emitter, $E(^{14}C)_{max} = 156$ keV, and is (mostly) determined after separation from the sample to measuring matrix (benzene or CO_2 absorbed in a scintillation cocktail) on liquid scintillation counters. Natural-level ^{14}C concentrations are often used for the analysis of natural processes, monitoring and radiocarbon dating. Radiocarbon activity is routinely determined at the Laboratory for Low Level Radioactivities (LNA) at the Ruđer Bošković Institute (RBI). The carbon from a sample is chemically converted to CO_2 and absorbed into a scintillation cocktail (LSC-A technique) or converted to benzene (LSC-B technique). The LSC-A technique has higher relative uncertainties (~2.6% for 100 pMC sample, "percent modern carbon") and is usually used for geological samples and monitoring, while LSC-B (~0.6% for 100 pMC sample) with higher precision is used for radiocarbon dating. The counter for low-level radioactivity measurements, Quantulus 1220™ has a very low background (~1 cpm) and it enables radiocarbon dating up to 50000 years. It is also used for the measurement of low-level tritium activity. At the Laboratory for Radioecology (LRE), RBI, two liquid scintillation counters, TriCarb 3180 TR/SL and Quantulus 6220 GCT, are regularly used for tritium activity measurements. Within this research ^{14}C activity of carbon samples was measured on counters at LRE and LNA and the obtained results, background count rate, efficiency and measuring uncertainties were compared.
The obtained results for the benzene matrix (LSC-B technique) have shown that although for TriCarb counter background values can vary between 1 and 2 cpm, the values around 150 pMC can be measured with 0.2% relative standard uncertainties, which is comparable to standard error for Quantulus 1220.
The preliminary results for Quantulus 6220 GCT have a similar background counting rate as that for Quantulus 1220. Relative standard uncertainties for background sample are 4 – 5% for Quantulus 6220 and 2% for Quantulus 1220, while for active samples the relative errors for both instruments are the same, 0.2 – 0.3% for both 130 and 150 pMC samples. Further tests need to be performed, however, there is a good indication that for LCS-B technique Quantulus 6220 GCT can perform as well as Quantulus 1220.
Technique LSC-A has been tested only on TriCarb counter and preliminary tests had shown a good agreement with measurements obtained on Quantulus 1220 for samples with higher activities (~600 pMC) in the energy range 10 – 110 keV. Further tests need to be performed to confirm the findings, however, this is a good indicator that the TriCarb can be used for the LSC-A technique.

Keywords: liquid scintillation counter, low-level radioactivity, radiocarbon ^{14}C, TriCarb 3180, Quantulus 1220, Quantulus 6220 GCT

RAZVOJ METODE ODREĐIVANJA ^{210}Pb KOMBINACIJOM KROMATOGRAFSKOG ODJELJIVANJA I TEKUĆINSKE SCINTILACIJSKE DETEKCIJE

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Sažetak

Radionuklid ^{210}Pb član je lanca radioaktivnog raspada ^{238}U te zajedno sa svojim potomkom ^{210}Po spada u skupinu najtoksičnijih radioizotopa koji najviše doprinose prirodnom unutarnjem ozračenju jedinke. Da bi se mogao kvantificirati njihov doprinos ukupnoj efektivnoj dozi, potrebno je kvantitativno određivanje koncentracije aktivnosti, za što je potrebno raspolagati odgovarajućim metodama. Radionuklid ^{210}Pb prilikom raspada emitira niskoenergijske beta čestice ($E_{\beta max}$ = 63,5 keV) i gama zračenje ($E_{\gamma max}$ = 46,53 keV, relativni intenzitet emisije ($I\gamma$= 4.25%). Stoga je ponekad potrebna izolacija olova iz uzorka te detekcija ^{210}Pb na odgovarajućem instrumentu što sam postupak određivanja čini kompliciranim i dugotrajnim. Razvoj tehnologije i novih naprednih separacijskih materijala omogućava razvoj metoda određivanja niskih aktivnosti ciljanih nuklida (^{210}Pb i drugih) prisutnih u raznim vrstama uzoraka uz dostizanje vrlo niskih granica detekcije. Stoga se u Laboratoriju za radioekologiju Instituta Ruđer Bošković, u okviru RichFALL projekta, radi na razvoju brze i jednostavne poluautomatizirane metode određivanja ^{210}Pb u različitim vrstama uzoraka iz okoliša i hrane. Razvijena je metoda gdje se olovo iz uzorka koncentrira i odijeli od niza interferirajućih iona korištenjem kolone punjene AnaLig Sr-01 smolom te eluira s 9 mol/L HCl [1]. Potom se ^{210}Pb kvantitativno određuje na tekućinskom scintilacijskom brojaču iz prethodno uparene eluirane otopine, prebačene u scintilacijsku bočicu uz dodatak 5 mL 0,05 mol/L HNO_3 i pomiješane sa scintilacijskim koktelom. U ovom istraživanju, metoda je poboljšana tako da je olovo eluirano s otopinom EDTA direktno u scintilacijsku bočicu i mjereno na LSC-u kako bi se skratilo vrijeme analize. Ispitana je učinkovitost detekcije standarda ^{210}Pb - (^{210}Bi) u različitim medijima; otopini EDTA, HNO_3 i HCl te ovisno o omjeru volumena uzorka i scintilacijskog koktela. Nakon optimiziranja detekcije, određena je optimalna dimenzija kolone kako bi eluiranje u odabranom volumenu bilo što učinkovitije. Metoda je testirana određivanjem ^{210}Pb u interkomparacijskim i realnim uzorcima, a dobiveni rezultati uspoređeni su s referentnim vrijednostima i/ili rezultatima dobivenima gama-spektrometrijskim određivanjem. Prezentirana metoda rezultira kraćim trajanjem analize uz minimalnu potrebu za manipulacijom uzorcima, manjoj količini sekundarnog otpada te većom efikasnošću u odnosu na postojeće metode.

Literatura

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Ključne riječi: ^{210}Pb, tekućinsko scintilacijsko brojenje, kromatografsko odjeljivanje, radiokemija

DEVELOPEMENT OF A METHOD FOR ^{210}Pb DETERMINATION: COMBINATION OF CHROMATOGRAPHIC SEPARATION AND LIQUID SCINTILLATION COUNTING

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Abstract
The radionuclide ^{210}Pb is a member ^{238}U radioactive decay chain. Together with its daughter radionuclide ^{210}Po, belongs to the group of highly toxic radioisotopes and provides the major internal natural radiation dose to an individual. In order to quantify their contribution to the total dose, a quantitative determination is required, for which it is necessary to have appropriate determination methods. ^{210}Pb emits low energy beta particles ($E_{\beta max}$ = 63.5 keV) and gamma rays ($E_{\gamma max}$ = 46.53 keV with the relative emission intensity, I_γ = 4.25%). Therefore, the determination of ^{210}Pb sometimes requires the isolation of lead from the sample and the detection of ^{210}Pb with a suitable instrument, which makes the determination process complicated and time-consuming. The improvement of technology and new advanced separation materials allow the development of methods for the determination of the low activities of target nuclides (^{210}Pb and others), which are present in various types of samples and reach very low detection limits. In the Laboratory for Radioecology at the Ruđer Bošković Institute, a rapid and simple semi-automated method for the determination of ^{210}Pb in different types of environmental and food samples is being developed within the RichFALL project. Previously, a method for separating lead from interfering ions in the sample was developed using a column filled with AnaLig Sr-01 resin. Lead was then eluted with 9 mol/L HCl [1] and ^{210}Pb was quantified on a liquid scintillation counter. Before counting, the sample was evaporated, transferred to the scintillation vial with the addition of 5 mL of 0.05 mol/L HNO_3 and mixed with the scintillation cocktail. In this study, the method was improved and the analysis time was shortened by eluting lead from the column with EDTA solution directly into the scintillation vial. The efficiency of detection of ^{210}Pb - (^{210}Bi) was tested for the different media used (EDTA, HNO_3 and HCl solutions) and with respect to the volume ratio of the sample and scintillation cocktail. After optimizing the detection, the column dimension was optimized to obtain the best recoveries in a given volume. The method was tested by determining ^{210}Pb in intercomparison and real samples, and the obtained results were compared with reference values and/or results obtained by gamma-spectrometry. The presented method results in shorter analysis time and minimal need for sample manipulation, a lower amount of secondary waste and greater efficiency compared to existing methods.

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Keywords: ^{210}Pb, liquid scintillation counting, chromatography separation, radiochemistry

MEĐULABORATORIJSKE USPOREDBE ODREĐIVANJA UKUPNE ALFA I UKUPNE BETA AKTIVNOSTI U VODI – ISKUSTVA I REZULTATI LABORATORIJA ZA RADIOEKOLOGIJU INSTITUTA RUĐER BOŠKOVIĆ I ODSJEKA ZA FIZIKU NISKIH I SREDNJIH ENERGIJA INSTITUTA JOŽEF STEFAN

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Sažetak
Praćenje radioaktivnih tvari u vodi namijenjenoj za ljudsku potrošnju propisano je direktivom EU 2013/51/Euratom. Prema navedenoj direktivi Indikativna doza (ID) ne smije prelaziti 0,1 mSv odnosno određena ukupna alfa aktivnost u vodi za piće ne smije prelaziti 0,1 Bq/L, a ukupna beta aktivnost 1 Bq/L. Obzirom da navedena metoda zahtijeva određivanje koncentracije aktivnosti svih alfa, odnosno beta emitera (isključujući ^{3}H, radon i ^{40}K), sama metoda sadrži mnoge nedostatke. Potreba za umanjenjem navedenih nedostataka, ali i većoj harmonizaciji metoda, svjedoče rezultati međulaboratorijskih usporedbi koje organizira Zajednički istraživački centar (JRC) Europske komisije. Naime 2012. godine organizirana je međulaboratorijska usporedba određivanja ukupne α/β aktivnosti u vodi za piće s ciljem ocjene prikladnosti raspoloživih metoda za navedena određivanja. Analiza rezultata 71 laboratorija je pokazala kako rezultati mnogih sudionika odstupaju za više od dva reda veličine od referentnih vrijednosti, a svega je jedan laboratorij prijavio rezultate za sve analizirane uzorke voda unutar referentnih vrijednosti. Unatoč napretku u harmonizaciji primjenljivih metoda, provjera osposobljenosti održana 2019.-2020., u kojoj je sudjelovalo 145 laboratorija, pokazala je kako metoda i dalje sadrži nedostatke te kako su rezultati mnogih laboratorija neprihvatljivi, što se najviše očituje pri ocjeni rezultata s pridruženom mjernom nesigurnosti.
Stoga su u ovom radu analizirani rezultati određivanja ukupne alfa i ukupne beta aktivnosti dvaju laboratorija (Laboratorij za radioekologiju, IRB i Odsjek za fiziku srednjih i niskih energija, IJS) koji su sudjelovali u spomenutoj međulaboratorijskoj usporedbi. Dodatno su uspoređeni rezultati određivanja ukupne alfa/ukupne beta aktivnosti u uzorcima međulaboratorijskih usporedbi koje organizira ALMERA (IAEA). Od ukupno 29 prijavljenih rezultata, zeta (ζ) vrijednost 25 rezultata je manja od 2, zeta vrijednost 3 rezultata je između 2 i 3, dok je za jedan rezultat zeta vrijednost veća od 3. Iako je većina dobivenih rezultata prihvaćena od strane organizatora, provedena je detaljnija analiza rezultata, izračuni mjernih nesigurnosti, uspoređene su primijenjene metode za pripravu uzoraka, ISO 10704, ISO 11704 i interna metoda razvijena na IJS te korišteni mjerni instrumenti (iMatic – automatski alfa/beta brojač s PIPS detektorom, Tri-Carb 3180 TR/SL, Quantulus 6220 GCT i Quantulus 1220) u svrhu otkrivanja ključnih nedostataka metoda i njihovom poboljšavanju.

Ključne riječi: ukupna alfa aktivnost, ukupna beta aktivnost, tekućinsko scintilacijsko brojenje, interkomparacije

INTERLABORATORY COMPARISONS OF TOTAL ALPHA AND TOTAL BETA ACTIVITY DETERMINATION IN WATER - EXPERIENCES AND RESULTS OF THE LABORATORY FOR RADIOECOLOGY OF THE RUĐER BOŠKOVIĆ INSTITUTE AND THE DEPARTMENT OF LOW AND MEDIUM ENERGY PHYSICS OF THE JOŽEF STEFAN INSTITUTE

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Abstract
The requirements for monitoring levels of radioactive substances in water intended for human consumption are laid down in Council Directive 2013/51/Euratom. According to the Directive, the indicative dose may not exceed 0.1 mSv, i.e. the determined total alpha and beta activity in drinking water may not exceed 0.1 Bq/L and 1 Bq/L, respectively. Since the above method requires the determination of the activity concentration of all alpha and beta emitters (except ^{3}H, radon, and ^{40}K), the method itself has many shortcomings. The results of intercomparisons organized by the Joint Research Center of the European Commission have shown the need for greater harmonization of the methods used and a reduction in the aforementioned deficiencies. Namely, in 2012, the intercomparison measurement of total α/β activity in drinking water was organized to evaluate the suitability of the available methods for the above-mentioned determinations. Analysis of the results from 71 laboratories showed that the results of many participants differed from the reference values by more than two orders of magnitude, and only one laboratory reported results for all analyzed water samples within the reference values. Despite progress in harmonizing the applicable methods, the 2019-2020 interlaboratory comparison, in which 145 laboratories participated, showed that there are still shortcomings in the method and that the results of many laboratories are unacceptable, which is most evident when evaluating the results with the associated measurement uncertainty.
Therefore, this paper analyzes the results of the determination of total alpha and total beta activity from two laboratories (Laboratory for Radioecology, RBI and Department of Medium and Low Energy Physics, JSI) that participated in the mentioned interlaboratory comparison. In addition, the results of the determination of gross alpha/gross beta activity in samples of the proficiency tests organized by ALMERA (IAEA) were compared. Out of the total 29 results reported, the zeta value is less than 2 in 25 results, in 3 results the zeta value is between 2 and 3, while in one result the zeta value is greater than 3. Although most of the results obtained were accepted by the organizers, the results were analyzed in more detail. This includes the analysis of the calculation of measurement uncertainties, the applied methods for sample preparation, ISO 10704, ISO 11704 and the internal method of JSI. In addition, the performances of different detectors were compared (*i*Matic - automatic alpha-beta counter with PIPS detector, Tri-Carb 3180 TR/SL, Quantulus 6220 GCT and Quantulus 1220). The analysis revealed the main weaknesses of each method and recommendations for their performances were given.

Keywords: gross alpha activity, gross beta activity, liquid scintillation counting, intercomparison

DEVELOPMENT OF POSITRON EMISSION TOMOGRAPHY DEMONSTRATOR WITH MEASUREMENT OF GAMMA-RAY POLARIZATION

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Abstract

The measurement of polarization of gamma rays has lately received a growing interest in developing medical physics applications such as the new generation of Positron Emission Tomography (PET) devices. Several simulation studies have shown that it has the potential to improve the image quality, since the polarization provides an additional handle to discriminate signal and noise. In the event of electron-positron annihilation, a pair of 511 keV gamma photons that are created have close to opposite momenta and mutually orthogonal polarizations. The former characteristic of the process has been used in PET, by exploiting the fact that two gammas will travel in a straight-line path. The latter characteristic, the polarization correlation of the created photons, has not yet been utilized in medical imaging, however it offers and opportunity to discriminate spurious random coincidences and body scatter events in PET, since these background events lack such correlation.

A novel PET demonstrator has been developed to measure the gamma-ray polarizations to explore the possibilities of their implementation to improve SNR in PET. The device consists of four detector modules on an aluminum ring which can be rotated around the annihilation source. Each of the modules consists of four smaller detector matrices of 8 × 8 pixels of GaGG:Ce and/or LYSO:Ce with detector pitch of either 2.2 mm or 3.2 mm.

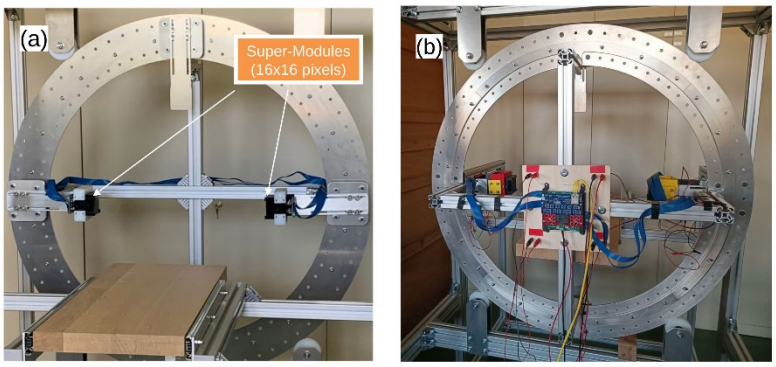

Figure 1: (a) Front view of the PET demonstrator with two modules mounted,
(b) Rear view, showing the mounted modules connected to the data acquisition system.

The modules thus comprise 16 × 16 pixels each and the PET demonstrator has total of 1024 pixels distributed among 16 trans-axial rings. The pairs of identically pitched modules, mounted at opposite sides of the ring are able to identify and reconstruct the correlation of the gamma-ray polarizations by measuring the azimuthal angles of the Compton scattered annihilation quanta inside the module. In the present work, we shall report on the overall performance of the demonstrator using the results obtained from laboratory measurements and report on the progress of tests in clinically relevant environments.

Keywords: Positron Emission Tomography (PET), gamma polarization, Compton Scattering, GaGG:Ce, LYSO:Ce

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Sažetak
Cilja rada je prikazati (r)evoluciju u pristup pojmu „stručnjak za medicinsku fiziku“ hrvatskog (https://narodne-novine.nn.hr) spram europskog (https://eur-lex.europa) zakonodavca i relevantnih europskih dokumenata.
Stručnjak za medicinsku fiziku (medical physics expert - MPE) „means an individual or, if provided for in national legislation, a group of individuals, having the knowledge, training and experience to act or give advice on matters relating to radiation physics applied to medical exposure, whose competence in this respect is recognised by the competent authority.“, od 2013. kao nemijenjana formulacija i bez dodatnih uvjeta. Ta formulacija po hrvatskom zakonodavcu od 2017. glasi „stručnjak za medicinsku fiziku jest pojedinac ili skupina pojedinaca koji imaju znanje, osposobljenost i iskustvo djelovati ili davati savjete u pitanjima povezanima s fizikom zračenja primijenjenom u medicinskom ozračenju i čiju je radnu sposobnost za to priznalo nadležno tijelo“. Međutim, hrvatski MPE mora biti/udovoljavati barem jednom od sljedećih uvjeta: A. specijalist medicinske fizike (2018., 2022.), B. osoba sa završenim preddiplomskim i diplomskim sveučilišnim studijem ili integriranim preddiplomskim i diplomskim sveučilišnim studijem iz područja prirodnih ili tehničkih znanosti (2018.), iz područja prirodnih znanosti (polje fizika) ili poslijediplomskim studijem iz područja medicinske fizike (2022.), koja ima znanje, osposobljenost i iskustvo za djelovanje ili davanje savjeta u pitanjima povezanima s fizikom zračenja primijenjenom u medicinskom ozračenju i koja ima najmanje osam godina kliničke prakse u jednom ili više od sljedećih područja: a) radioterapija, b) nuklearna medicina, c) dijagnostička ili intervencijska radiologija. Pritom je za tu promjenu učinjenu 2022. Ministarstvo unutarnji poslova Republike hrvatske (MUP), unutar čijeg je Ravnateljstva civilne zaštite ustrojena i Služba za radiološku sigurnost, u opisu e-savjetovanja oko novopredloženog pravilnika 2021. navelo samo da se njime prenose „određeni zahtjevi iz Direktive vijeća 2013/59/Euratom.“, a na komentare glede promjena inkriminiranog članka 21. argumentiran vjerodostojnim europskim dokumentima odgovorilo samo s „nije predmet izmjena i dopuna na ovom e-savjetovanju“.
Tijela javne vlasti dužna su na internetskim stranicama objavljivati nacrte zakona i drugih propisa iz svoje nadležnosti o kojima se provodi javno savjetovanje sa zainteresiranom javnošću, u pravilu u trajanju od 30 dana, uz objavu razloga za donošenje i ciljeva koji se žele postići savjetovanjem te izvješća o provedenom savjetovanju i zaprimljenim primjedbama i prijedlozima. Međutim, MUP za neke zakonske akte u vezi radiološke i nuklearne sigurnosti to ne čini primjereno, čime na osebujan način omalovažava civilno društvo i sputava njegov razvoj kroz otvorenu i argumentiranu komunikaciju svekolike zainteresirane javnosti s državnim i javnim institucijama, kao važno uporište suvremene demokracije.

Ključne riječi: stručnjak za medicinsku fiziku, ministarstvo unutarnjih poslova, civilno društvo

MEDICAL PHYSICS EXPERTISE AND CIVIL PROTECTION OF CIVIL SOCIETY

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Abstract
The aim of the paper is to show the (r)evolution in the approach to the term "medical physics expert" by the Croatian (https://narodne-novine.nn.hr) versus the European (https://eur-lex.europa) legislator and relevant European documents.
Medical physics expert (MPE) "means an individual or, if provided for in national legislation, a group of individuals, having the knowledge, training and experience to act or give advice on matters relating to radiation physics applied to medical exposure, whose competence in this respect is recognized by the competent authority.", since 2013 as unchanged wording and without additional conditions. According to the Croatian legislator, since 2017 the definition of the term 'medical physics expert' reads very similar. However, the Croatian MPE must be/meet at least one of the following conditions: A. specialist in medical physics (2018, 2022), B. a person with completed undergraduate and graduate university studies or integrated undergraduate and graduate university studies in the area of natural or technical sciences (2018), in the area of natural sciences (field physics) or postgraduate study in the branch of medical physics (2022), who has knowledge, training and experience in acting or giving advice in matters related to radiation physics applied in medical exposure, and has at least eight years of clinical practice in one or more of the following specialties: a) radiotherapy, b) nuclear medicine, c) diagnostic or interventional radiology . At the same time, for the Regulation's change made in 2022, the Ministry of Internal Affairs of the Republic of Croatia (MIA), within whose Directorate of Civil Protection the Department for Radiological Safety is organized, in the description of the e-consultation regarding the newly proposed Regulation in 2021, stated only that it transfers "certain requirements from the Council Directive 2013/59/Euratom.", and to the comment argued with relevant European documents in regard to the changes to the incriminated Article 21, responded with simply "it is not the subject of changes in this e-consultation".
Public authorities are obliged to publish on their websites draft laws and other regulations from their jurisdiction, on which public consultation is carried out with the interested public (as a rule for a period of 30 days), with the publication of the reasons for the adoption and the goals to be achieved by the consultation, as well as the publication of the reports on conducted consultation and received comments and suggestions. However, the MIA does not do this in appropriate manner in regard to some legal acts on radiological and nuclear safety, which in a peculiar way belittles civil society and hinders its development through open communication with arguments among interested public and state/public institutions, as an important stronghold of modern democracy.

Keywords: medical physics expert, ministry of internal affairs, civil society

USPOSTAVLJANJE NOVOG LABORATORIJA ZA RENDGENSKO OZRAČIVANJE NA INSTITUTU ZA MEDICINSKA ISTRAŽIVANJA I MEDICINU RADA

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Sažetak
Institut za medicinska istraživanja i medicinu rada pri kraju je višegodišnjeg projekta: „Istraživačko-edukacijski centar za zdravstvenu i medicinsku ekologiju i zaštitu od zračenja“ koji uključuje rekonstrukciju i proširenje Instituta. Svrha ovog projekta je povećati i unaprijediti postojeću infrastrukturu Instituta i njegovu istraživačku opremu, te uz prateću organizacijsku reformu uspostaviti Istraživačko-obrazovni centar za zdravlje i medicinsku ekologiju te zaštitu od zračenja. Izgradnjom odgovarajuće prostrane infrastrukture i ulaganjem u suvremenu znanstvenu opremu značajno će se povećati znanstvena izvrsnost i vidljivost Instituta u području postojećih istraživanja. U okviru rada detaljno će se prezentirati proces uspostave i performanse našeg novog laboratorija za rendgensko ozračivanje koji smo instalirali zajedno s PTW Freiburg GmbH, Njemačka i VF Nuclear, a.s. Češka Republika. Laboratorij je opremljen s dvije rendgenske jedinice za proizvodnju pulsnih polja i nepulsnih standardnih kvaliteta zračenja. Laboratorij je opremljen rendgenskim zatvaračem, filterskim kotačem, kalibracijskom klupom, kamerama na daljinsko upravljanje i kompletnim sigurnosnim sustavom. Opremljen je širokim spektrom instrumenata koji uključuju nekoliko ionizacijskih komora, kliničke i istraživačke elektrometre, multimetre visoke preciznosti i nuklearne instrumente za razvoj sljedeće generacije uređaja za napredna radiološka oslikavanja.

Ključne riječi: nove ustanove, instrumentacija i metode, dozimetrija

ESTABLISHMENT OF A NEW X-RAY IRRADIATION LABORATORY AT THE INSTITUTE FOR MEDICAL RESEARCH AND OCCUPATIONAL HEALTH

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Abstract
The Institute for Medical Research and Occupational Health (IMROH) is at the end of multiyear project: "Research and Educational Centre of Environmental Health and Radiation Protection" that includes reconstruction and expansion of the IMROH. The purpose of this project is to increase and improve the current IMROH infrastructure and its research equipment, and with the accompanying organizational reform to establish a Research and Education Center for Health and Medical Ecology and Radiation Protection. Building appropriate spacious infrastructure and investing in modern scientific equipment will significantly increase the scientific excellence and visibility of IMROH in the field of existing research. This contribution gives in depth presentation on the establishment and performance of our new x-ray irradiation laboratory that we have installed together with a PTW Freiburg GmbH, Germany and VF Nuclear, a.s. Czech Republic. Laboratory is equipped with two X-ray units for production of pulsed fields and non-pulsed standard radiation qualities. Laboratory is equipped with X-ray shutter, filter wheel, calibration bench, remote controlled cameras, and complete security system. It is equipped with wide spectrum of instrumentation that include several ionization chambers, clinical and research electrometers, reference level multimeters and nuclear instrumentation for development of next generation advanced radiological imaging.

Keywords: new facilities, instrumentation and methods, dosimetry

RAZVOJ I ISPITIVANJE JEDNOSLOJNE KOMPTONSKE GAMA KAMERE

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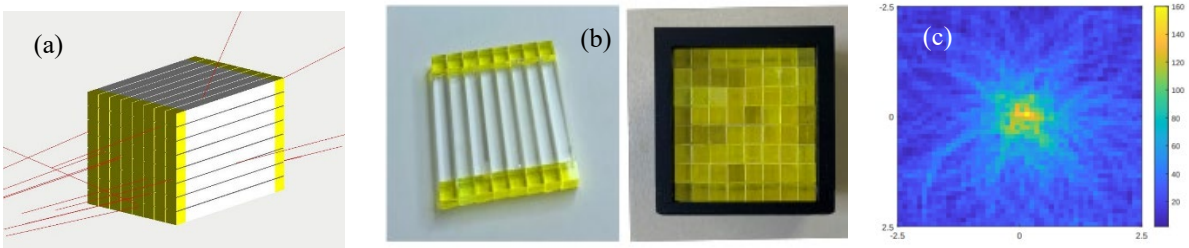
Sažetak

Za uspješnu detekciju ionizirajućeg zračenja iz okoliša potrebni su učinkoviti, kompaktni i isplativi uređaji. Jedan od uređaja za detekciju gama zračenja je komptonska gama kamera (KGK), koja, za razliku od gama kamera s mehaničkom kolimacijom, koristi elektronsku kolimaciju temeljenu na kinematici Comptonovog raspršenja. Razvoj KGK-a započeo je s poluvodičkim detektorima izvrsnog prostornog razlučivanja uz razmjerno veliku složenost uređaja i velike troškove, nastavljen je sa scintilacijskim detektorima, najprije u kombinaciji s fotomultiplikatorskim cijevima, a u novije vrijeme i sa silicijskim fotomultiplikatorima (SiPM). KGK koje se temelje na scintilatorima imaju slabije, ali još uvijek prihvatljivo kutno razlučivanje u usporedbi s kamerama temeljenim na poluvodičima te veću učinkovitost i nižu cijenu. Većinom se dosad konstruirane KGK-e sastoji se od dva odvojena sloja detektora, raspršivača i apsorbera ili pak primjenjuju složene sheme očitavanja dubine međudjelovanja fotona.

Dizajnirali smo i konstruirali novu jednoslojnu KGK-u temeljenu na segmentiranim scintilatorima, koji se očitavaju s jedne strane pomoću SiPM-a. U ovoj koncepciji, element detektora sastoji se od dva identična GAGG:Ce kristala dimenzija 3 × 3 × 3 mm^3, optički povezana svjetlovodom od pleksiglasa veličine 3 × 3 × 20 mm^3. Elementi su razmješteni u matricu 8 × 8 s razmakom od 3,2 mm i odvojeni ESR reflektorom. Prednji kristali elementi u ovoj konfiguraciji djeluju kao raspršivači, a stražnji kao apsorberi. Oba elementa u jednom stupcu očitava isti SiPM na stražnjoj strani matrice, čime se zadržava minimalan broj kanala za očitavanje, ključan za kompaktan i prijenosan uređaj. Mjerenjem je utvrđeno da prosječna energijska razlučivost prednjih odn. stražnjih elemenata iznosi 8,9% odn. 10,8% za gama zračenje energije 662 keV. U laboratorijskom testu rekonstruirana je slika izvora ^{137}Cs (promjer ≈ 3 mm) postavljenog 50 mm ispred detektora pomoću algoritma jednostavne povratne projekcije te pokazuje oblik Gaussovog vrha sa standardnom devijacijom od σ=5,1±0,2 mm. Predstavit ćemo rezultate detaljne karakterizacije svojstava detektora pri energijama gama fotona od 511 keV i 662 keV kao i procjenu njegovih mogućnosti snimanja izvora smještenih na različitim položajima unutar vidnog polja.



Slika 1: (a) Dizajn detektora, (b) Sastavljanje detektora, (c) Rekonstruirana slika izvora ^{137}Cs.

Ključne riječi: detektor zračenja, komptonska kamera, oslikavanje fotonima gama zračenja, GAGG, SiPM

DEVELOPMENT AND RESEARCH OF A SINGLE-PLANE COMPTON GAMMA CAMERA

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Abstract

The detection of environmental radiation is of great importance and efficient, compact and cost-effective instruments are highly needed. One potentially suitable detection tool for gamma-radiation detection is the Compton gamma camera (CGC), which, in contrast to gamma cameras with mechanical collimations, uses electronic collimation based on the kinematics of the Compton scattering. The evolution of CGCs started with semiconductor detectors, which provide excellent spatial resolution, but suffer from complexity and high costs, later shifted to scintillator detectors, initially with photo-multiplier tubes and more recently with Silicon photomultipliers (SiPMs). Scintillator-based CGCs have lower, yet still acceptable angular resolutions compared to the ones based on semiconductors, but higher efficiencies and lower cost. Most CGC realizations comprise two separate detector planes, the scatterer and the absorber or they implement complex depth-of-interaction readout schemes.

We designed and constructed a novel single-plane CGC based on segmented scintillators, read out on one side by SiPMs. In this concept, a detector element consists of two identical GAGG:Ce scintillator crystals of $3 \times 3 \times 3$ mm^3 optically coupled by a plexiglass light guide of $3 \times 3 \times 20$ mm^3. Detector elements are placed in an 8×8 matrix with a 3.2 mm pitch, separated by ESR reflector. In this configuration, the front scintillator layer is acting as the scatterer and the back scintillator layer as the absorber, while both are read out by the same SiPM array coupled to the back side of the matrix read out by the TOFPET2 DAQ. This concept keeps the minimum number of read-out channels, crucial for a compact and portable device. The average energy resolution of the front and the back detector layer was found to be 8.9% and 10.8%, respectively for 662 keV gamma energy. The basic imaging test obtained with a ^{137}Cs source (diam. $\approx$ 3 mm) placed 50 mm in front of the detector using a simple back-projection algorithm, shows a Gaussian peak with a standard deviation of $\sigma = 5.1 \pm 0.2$ mm. In this contribution, we present the results of the detailed characterization of the detector performance at gamma-ray energies of 511 keV and 662 keV as well as the estimate of its imaging capabilities for gamma sources located at various positions within the field-of-view.

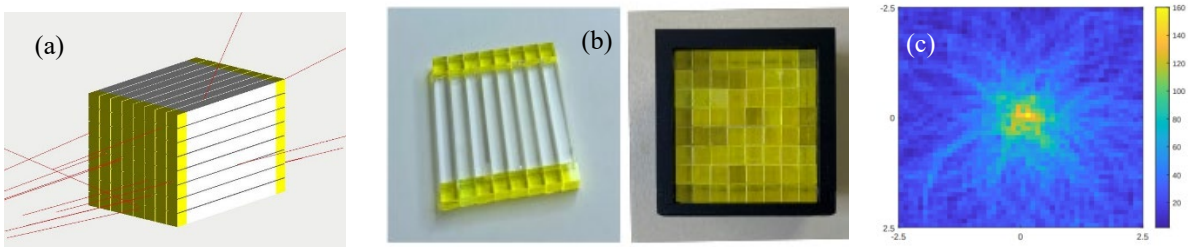

Figure 1: (a) Detector design, (b) Construction of detector, (c) reconstructed image of ^{137}Cs.

Keywords: radiation detection, Compton camera, gamma imaging, GAGG, SiPM

USPOREDBA Sr I AnaLig SMOLE ZA ODREĐIVANJE ^{210}Pb U ORGANSKIM UZORCIMA

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Sažetak

Za određivanje ^{210}Pb u organskim uzorcima malih masa, analiza uporabom beta brojača je često potrebna da bi se postigle željene granice detekcije. Za beta brojanje je pak potrebna radiokemijska separacija ^{210}Pb od intereferirajućih radionuklida. U tu svrhu moguće je koristiti različite smole.

U ovom istraživanju, napravljena je usporedba dviju smola: Sr smola, kao poznati krunasti eter korišten u radiokemijskim analizama više radionuklida te AnaLig®Sr-01, materijal temeljen na molekularnom raspoznavanju, a koji je manje zastupljen u radiokemiji. Obje vrsta smola, incijalno proizvedene za separaciju Sr, čvrsto vežu Pb iz različitih kiselih otopina. Stoga su ove dvije vrste smole ispitane na istoj vrsti organskog uzorka (uzorci gujavica) da bi se usporedile njihove mogućnosti izolacije ^{210}Pb. Separacija ^{210}Pb na Sr smoli je napravljena metodom opisanom u Štrok i Smodiš (2011), a na AnaLig Sr-01 smoli metodom Dulanska et al. (2011) koja je za potrebe ovog istraživanja bila modificirana. Prije radiokemijske separacije uzorcima je dodana poznata količina Pb nosača, a potom su razoreni mješavinom $HNO_3/HCl/H_2O_2$ uz zagrijavanje. Uzorci su na obje smole naneseni u 2 M HCl otopini. Sr smola je korištena samo jednom za svaki uzorak, dok je AnaLig smola regenerirana vodom i alkalnom otopinom EDTA. U obje metode ^{210}Pb je taložen u obliku $PbSO_4$, a kemijsko iskorištenje je određeno gravimetrijski. Dodatno, potencijalni gubitak Pb na AnaLig smoli je popraćen njegovim određivanjem u uzorku prije i poslije kolone uz pomoć atomskog apsorpcijskog spektrometra (AAS). Uzorci su čuvani 30 dana prije brojanja proporcionalnim beta brojačem. Na Sr smoli je analizirano ukupno 18 uzoraka, a na AnaLig smoli 9. Uzorci su bili u rasponu masa 0.04 – 0.62 g suhe tvari.

Na Sr smoli, kemijsko iskorištenje je bilo u rasponu 16 – 35%, s prosječnom vrijednosti od 22%. Na AnaLig®Sr-01 smoli gravimetrijski određeno iskorištenje je bilo u rasponu 16 – 90 %, prosječne vrijednosti 70%. Međutim, iskorištenje određeno AAS-om je bilo u rasponu 63 – 100%, s prosječnom vrijednosti od 87%. Razlike između gravimetrijski i spektrometrijski određenog iskorištenja upućuju na postojanost AnaLig smole prilikom opetovane upotrebe, dok su dodatni gubici Pb mogući tijekom njegove depozicije u obliku sulfata. Osim većih kemijskih iskorištenja, otprilike tri puta manje količine reagensa su bile potrebne za separaciju ^{210}Pb na AnaLig®Sr-01 u odnosu na Sr smolu.

Literatura

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Ključne riječi: olovo, radiokemijska separacija, Sr smola, AnaLig®Sr-01

COMPARISON OF Sr AND AnaLig RESIN FOR THE ^{210}Pb DETERMINATION IN ORGANIC SAMPLES

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Abstract

Radiochemical separation, followed by beta counting, is often necessary for ^{210}Pb determination in organic samples that are limited in quantities to reach desired detection limits. Beta counting requires the separation of ^{210}Pb from interfering radionuclides. A common approach is to use different resins.

In this study, the performance of two resin types was compared: Sr resin, a well-known crown ether resin used in the radiochemical analysis for separation of several radionuclides, and molecular recognition technology product AnaLig®Sr-01, a less known material used in radiochemistry. Initially produced for Sr separation, both resins firmly bind Pb from different acid solutions. Therefore, these materials were tested using the same organic matrix (earthworm samples) to separate ^{210}Pb from the sample. ^{210}Pb was separated on Sr resin using the method described by Štrok and Smodiš (2011). The separation on AnaLig®Sr-01 resin was based on the method described in Dulanska et al. (2020) with slight modifications. Prior to the radiochemical separation of ^{210}Pb, samples were spiked with a known amount of Pb carrier and digested in $HNO_3/HCl/H_2O_2$ mixture on a hot plate. Samples were loaded on Sr and AnaLig resin in 2 M HCl solution. Further, AnaLig resin was regenerated using water and alkaline EDTA solution, while new Sr resin was used for each sample. In both methods, ^{210}Pb was precipitated with $PbSO_4$, weighted to gravimetrically determine radiochemical recovery and stored for 30 days before counting on a gas-flow proportional counter. Additionally, on AnaLig resin, potential Pb losses were followed with an atomic absorption spectrometer (AAS) by measuring Pb in a sample before loading on a column and after Pb elution. The total number of samples was 18 for Sr resin and nine for AnaLig resin. Sample mass ranged 0.04 – 0.62 g dry mass.

For Sr resin, chemical recovery ranged 16 – 35%, with a mean value of 22%. For AnaLig®Sr-01, chemical recovery determined gravimetrically ranged 16 – 90%, with a mean value of 70%. However, recovery determined by AAS ranged 63 – 100%, with a mean value of 87%. Differences between gravimetrically and spectrometrically determined recoveries indicate good stability in the repeated use of AnaLig®Sr-01, while additional losses of Pb could be expected during $PbSO_4$ precipitation. Besides higher separation yields, approximately three times a lower amount of reagents were required for ^{210}Pb radiochemical separation on AnaLig®Sr-01 compared to the Sr resin.

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2. Štrok & Smodiš Levels of ^{210}Po and ^{210}Pb in fish and molluscs in Slovenia and the related dose assessment to the population. Chemosphere 2011;82:970–6.

Keywords: lead, radiochemical separation, Sr resin, AnaLig®Sr-01

NUKLEARNE PRIJETNJE – IZAZOVI

NUCLEAR THREATS - CHALLENGES

RADIOAKTIVNOST U POPULARNOJ KULTURI ILI KAKO MEM MOŽE OBLIKOVATI JAVNO MIŠLJENJE

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Sažetak

Radioaktivnost, i većina ostalih pojmova iz područja znanosti o zračenju, lako unose nemir u širu javnost te se lako mogu zlorabiti.

Kulturni koncept poznat kao mem (eng. *meme*, od grč. *mimema* – oponašan) ima široku uporabu na intenetu te može pomoći u popularizaciji znanosti i osvještavanju javnosti.

Općenito bih memove svrstala u 3 grupe: 1. memove koje su napravili ljudi koji poznaju materiju i žele biti smiješni; 2. memove koji su napravili ljudi koje ne poznaju materiju, ali isto žele biti smiješni; te 3. memove koji su napravili ljudi koji šire paniku, a misle da su upakirali sve u šalu. Dobar primjer je cijeli niz memova kojima su tema štit operatera prilikom rendgenskih pretraga ili događaji vezani uz nesreće u Černobilu i Fukushimi.

Cilj mi je pokazati koje posljedice na oblikovanje javnog mnijenja mogu imati prethodno navedeni memovi.

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Ključne riječi: radioaktivnost, mem, javno mnijenje, popularizacija znanosti

RADIOACTIVITY IN POPULAR CULTURE OR HOW MEME CAN FORM PUBLIC OPINION

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Abstract

The term radioactivity, and most of other terms from the field of radiation sciences, can be easily used and abused for spreading turmoil within general public.

The cultural concept called "meme" (from the Greek *mimema* meaning "imitated") has been in wide usage on the internet. Therefore, it can be a helpful tool for science popularisation and increasing public awareness.

Generally, I sorted memes in three groups: 1. memes made by people who had some knowledge in the field and wanted to be funny; 2. memes made by people who did not have enough knowledge in the field but still wanted to be funny; and 3. memes made by people who eradiated nothing but panic and thought they gave it funny package. For example, series of memes in which the topic was operators shielding during X-ray examination or Chernobyl and Fukushima events.

The implications that these memes can have on shaping public opinion will be discussed and explored during my presentation.

References

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Keywords: radioactivity, meme, public opinion, science popularisation

NUKLEARNA FORENZIKA – SLUČAJ KARASOVIĆI

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Sažetak
Glavna uloga nuklearne forenzike je identifikacija porijekla i povijesti ispitivanog nuklearnog/radioaktivnog materijala na osnovu izotopnih, kemijskih i fizikalnih otisaka kako bi se osigurali dokazi za daljnju kriminalističku istragu vezanu uz diverziju, krijumčarenje ili neovlaštenu uporabu takvog materijala. Nuklearna forenzika uključuje detaljne analize pronađenog materijala kojima se određuje "nuklearno forenzički potpis" tj. "otisak" materijala, trag po kojem je materijal prepoznatljiv. Uspoređivanjem dobivenih otisaka materijala s već postojećim otiscima u bibliotekama nuklearne forenzike, moguće je odrediti potencijalne proizvođače i povijest nuklearnog materijala.
U Hrvatskoj je nedavno zabilježen i razriješen slučaj posjedovanja sumnjivog materijala na području graničnog prijelaza Karasovići gdje je utvrđeno da materijal sadrži povišenu aktivnost ^{226}Ra. Isti je oduzet fizičkoj osobi, a sastojao se od 2 vrste uzorka, crnog praha u plastičnom spremniku i u 3 platnene vrećice, te nakita, 9 ogrlica i narukvica. Materijal je analiziran u Laboratoriju za radioekologiju Instituta Ruđer Bošković.
Gama spektrometrijom visoke razlučivosti (HRGS) utvrđeno je da nakit sadrži značajnu količinu izotopa ^{235}U i ^{238}U te prirodni izotop ^{40}K. U nekim uzorcima detektirano je prisustvo i antropogenog izotopa ^{137}Cs. Utvrđeno je u jednom dijelu nakita izotopni omjer ^{235}U/^{238}U prirodan dok je u drugom dijelu uzoraka narušen u korist ^{238}U. Maseni udio uranija u nakitu kreće se u rasponu od 0,15 do 0,35%. Rendgenskom difrakcijskom analizom utvrđeno je da je nakit izrađen od stakla koje sadrži uranij. Za drugu vrstu uzorka, prah pakiran u 3 platnene vrećice i plastičnom spremniku utvrđeno je HRGS da je sastav praha u oba uzorka identičan s obzirom na detektirane izotope. Na uzorku iz jedne vrećice kvantitativno su određene masene aktivnosti prisutnih radionuklida. Ukupna aktivnost analiziranog praha iznosi 37 kBq/g, utvrđen je prirodni izotopni omjera uranija, određene su pojedinačne aktivnosti ključnih radionuklida ^{238}U, ^{235}U i ^{226}Ra. Rendgenska difrakcijska analiza pokazala je da prah sadrži uranijem bogate faze koje odgovaraju mineralima masuyitu, uranintu i betafitu te minerale koji ne sadrže uranij (kalcit, kvarc, klorit i cerianit). Uraninit i betafit su podređene uranijem bogate faze, a dominira masuyit. Rijetko pojavljivanje minerala masuyita, kao i prisutnost klorita, kalcita i kvarca mogu ukazivati na preradu prirodnog materijala u svrhu obogaćivanja uranijskih faza. Utvrđene mineralne faze do sada nisu pronađene u RH stoga predmetni materijal ne potiče iz RH.
Obzirom na realnu opasnost od neovlaštene uporabe nuklearnog materijala (npr. "prljave bombe") neophodan je daljnji razvoj nuklearne forenzike, uspostava biblioteka nuklearne forenzike te umrežavanje znanstvenih institucija, stručnih tehničkih servisa i regulatornih tijela nadležnih za radiološku i nuklearnu sigurnost.

Ključne riječi: nuklearna forenzika, nuklearni materijal, radioaktivni materijal, uranij, gama spektrometrija visoke razlučivosti

NUCLEAR FORENSICS – THE KARASOVIĆ CASE

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Abstract
The main role of nuclear forensics is to identify the origin and history of the investigated nuclear/radioactive material based on isotopic, chemical and physical fingerprints in order to provide evidence for further criminal investigation related to the diversion, smuggling or unauthorized use of such material. Nuclear forensics includes detailed analysis of the confiscated material, which determines the "nuclear forensic signature", i.e. the "fingerprint" of the material, the trace by which the material is recognizable. By comparison with the nuclear forensics libraries, it is possible to determine potential producers and the history of the nuclear material.
At the Karasovići border crossing in Croatia was recently recorded and resolved a case of illegal possession of suspect material. An increased activity of ^{226}Ra was found in the material. The confiscated material consisted of 2 types of samples, black powder and jewelry. The material was analyzed in the Laboratory for Radioecology of the Ruđer Bošković Institute.
By means of High-resolution gamma-ray spectrometry (HRGS) it was determined that the jewelry in question contains a significant amount of isotopes ^{235}U and ^{238}U and the natural isotope ^{40}K. In some samples, the presence of the anthropogenic isotope ^{137}Cs was also detected. In one part of the jewelry, the ^{235}U/^{238}U isotopic ratio was found to be natural, while in the other part of the samples it was distorted in favor of ^{238}U. The mass ratio of uranium in jewelry ranges from 0.15 to 0.35%. X-ray diffraction analysis determined that the jewelry was made of glass containing uranium. For the second type of sample, powder in 3 cloth bags and in plastic container, it was determined by HRGS that the composition of the powder in both samples is identical. The mass activities of the present radionuclides were quantitatively determined on a sample from one bag. The total activity of the analyzed powder is 37 kBq/g, isotopic ratio of uranium is found to be natural, and the activities of key radionuclides ^{238}U, ^{235}U and ^{226}Ra were determined. X-ray diffraction analysis showed that the powder contains uranium-rich phases corresponding to the minerals masuyite, uraninite and betafite and minerals that do not contain uranium (calcite, quartz, chlorite and cerianite). Uraninite and betafite are subordinate to the uranium-rich phase, and masuyite dominates. The rare occurrence of the mineral masuyite, as well as the presence of chlorite, calcite and quartz may indicate the processing of natural material for the purpose of enriching uranium phases. Identified mineral phases have not been found in Croatia so far, therefore the material in question does not originate from Croatia.
Considering the real danger of unauthorized use of nuclear material (e.g. "dirty bombs"), further development of nuclear forensics, establishment of nuclear forensics libraries and networking of scientific institutions, expert technical services and regulatory bodies responsible for radiological and nuclear safety is necessary.

Keywords: nuclear forensics, nuclear material, radioactive material, uranium, high resolution gamma spectrometry

NEIONIZIRAJUĆA ZRAČENJA

NONIONISING RADIATION

UČINKOVITE METODE DOZIMETRIJE ZA IZLOŽENOST LJUDI ZRAČENJU 5G MOBILNIH SUSTAVA

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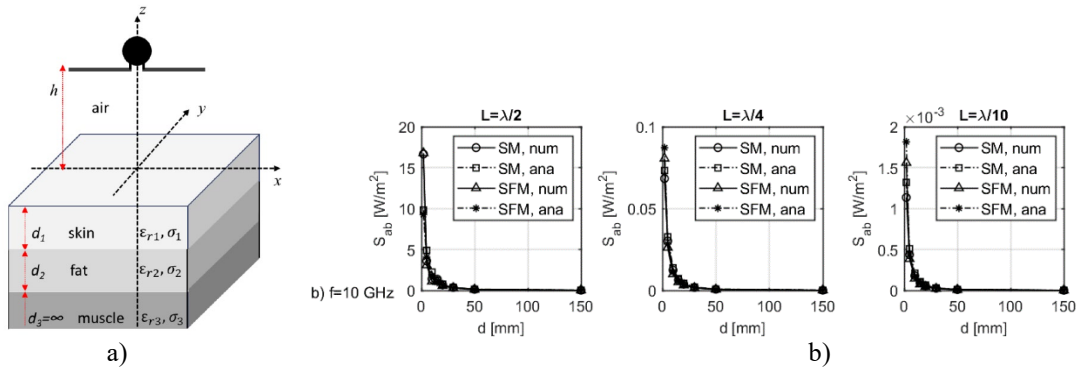
Sažetak

Izloženost ljudi zračenju 5G mobilnih komunikacijskih sustava može uzrokovati lokalni porast temperature na površini tijela, odnosno koži, ušima i očima. Za frekvencije ispod *tranzicijske frekvencije* f = 6 GHz koristi se standardna dozimetrijska veličina: specifična gustoća apsorbirane snage (SAR) u svrhu kvantifikacije volumnog zagrijavanja. Međutim, u skladu s nedavno objavljenim ICNIRP 2020 smjernicama [1], površinsko zagrijavanje iznad 6 GHz se kvantificira preko *gustoće apsorbirane snage* (S_{ab}). Nadalje, *gustoća transmitirane snage* (TPD), alternativna dozimetrijska veličina iznad 6GHz, također je korištena u nekim studijama. U ovom radu daje se pregled nedavno razvijenih metoda unutarnje dozimetrije koje je autor koristio (npr. [2]) za procjenu izloženosti ljudi zračenju 5G mobilnih sustava.

Tako su izložene neke determinističke tehnike unutarnje dozimetrije za analitičku procjenu S_{ab} i TPD u ravnom homogeneom i višeslojnom tkivu (Slika 1), uslijed izloženosti izvoru 5G zračenja u GHz frekvencijskom području. Razmatrana je pobuda u vidu Hertz-ovog dipola i dipol antene konačne duljine.



Slika 1: Dipol antena ispred ravnog višeslojnog tkiva (a), S_{ab} u funkciji udaljenosti antene od tijela

U radu se također obrađuje i stohastičko-deterministička elektromagnetsko-toplinska dozimetrija u donjem dijelu GHz frekvencijskog područja primjenom anatomski zasnovanog realističnog višeslojnog modela ljudske glave izložene zračenju 5G komunikacijskih sustava.

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Ključne riječi: izloženost ljudi, 5G mobilni komunikacijski sustavi, elektromagnetsko-toplinska dozimetrija, gustoća apsorbirane snage, gustoća transmitirane snage

EFFICIENT DOSIMETRY METHODS FOR THE HUMAN EXPOSURE TO RADIATION FROM 5G MOBILE SYSTEMS

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Abstract
Human exposure to 5G mobile communications systems may cause a local temperature increase at the body surface, i.e. skin, ear and eyes. For the frequencies below *transition frequency* of 6 GHz well-established and for decades widely used specific absorption rate (SAR) is used to quantify the volume heating. However, according to recently published ICNIRP 2020 guidelines [1], the surface heating above 6 GHz is quantified by *absorbed power density* (S_{ab}). In addition, *transmitted power density* (TPD), an alternative dosimetric quantity above 6 GHz has been used in some studies, as well. This paper reviews some recently developed internal dosimetry methods used by the author (e.g. [2]) for the assessment of human exposure to radiation from 5G mobile systems.
Thus, some deterministic internal dosimetry techniques for an analytical assessment of S_{ab} and TPD in flat homogeneous and multilayered tissue, Figure 1, due to exposure to 5G radiation sources in GHz frequency range, are presented. The excitation by Hertz dipole and finite length dipole antenna are considered.

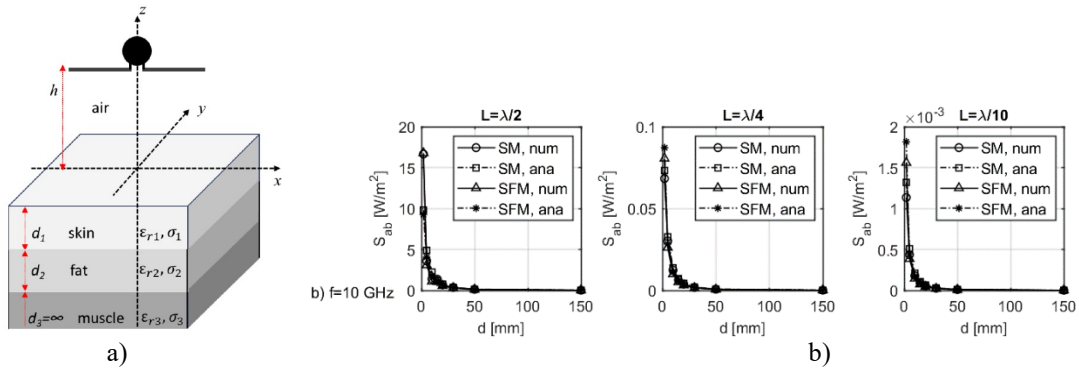

Figure 1: Dipole antenna in front of flat multilayered tissue (a), S_{ab} vs antenna-body distance (b)

This work also addresses a stochastic-deterministic electromagnetic-thermal dosimetry in lower portion of GHz frequency range featuring the use of anatomically based realistic multilayered model of the human head exposed to radiation from 5G communication systems.

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2. Poljak D. et al., Absorbed Power Density in a Multilayer Tissue Model due to Radiation of Dipole Antenna in GHz Frequency Range, Part I and Part II, Proc. SpliTECH 2022.

Keywords: human exposure, 5G mobile communication systems, electromagnetic-thermal dosimetry, absorbed power density, transmitted power density

DOZIMETRIJA ELEKTROMAGNETSKOG ZRAČENJA U PROVEDBI PROJEKATA „e-ŠKOLE“ – RAZVOJ SUSTAVA DIGITALNO ZRELIH ŠKOLA (PILOT I II FAZA)

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Sažetak

Uporaba Wi-Fi radijskih primopredajnika ubrzano raste. Korištenjem takve tehnologije, elektronički uređaji radijski se povezuju s računalnom mrežom putem mikrovalova ili elektromagnetskih (EM) polja radijskih frekvencija (RF) čime se otklanja ili smanjuje potreba za spajanjem mrežnim kabelima. Bežični radijski sustavi pružaju slobodu kretanja s prijamnikom unutar škole (prijenosno računalo, tablet ili pametni telefon) te ih je lakše, a ponekad i jeftinije ostvariti nego žičane mreže. Takve tehnologije postale su dio životne, ali i školske svakodnevice. Najbolji primjer za to je prijenosno računalo koje je spojeno na Internet putem Wi-Fi usmjernika. Wi-Fi radijsko povezivanje prisutno je već duže vrijeme i Wi-Fi pristupne točke nalaze se u mnogim javnim i privatnim prostorima te radi toga treba imati na umu da su ljudi tada povremeno uronjeni u Wi-Fi signal te time izloženi dodatnoj niskoj razini EM polja prilikom korištenja Interneta za poslovne ili privatne svrhe. Kako je izloženost učionica u školama u stvarnosti „nametnuta“ kategorija izloženosti učenika i nastavnika kojima je to i profesionalna izloženost novom agensu, u školama se u sklopu projekata „e-Škole: Uspostava sustava razvoja digitalno zrelih škola (pilot projekt i faza II)” koje Hrvatska akademska i istraživačka mreža – CARNet provodi od 2015. do 2023. g. provodi dozimetrija izloženost RF komunikacijskim EM poljima iz Wi-Fi usmjernika u razredima. Svrha oba projekta „e-Škole“ je uspostaviti mrežu digitalno zrelih škola za 21. stoljeće podizanjem razine digitalne zrelosti svih osnovnih i srednjih škola u RH. U digitalno zrelim školama predviđa se aktivna i svakodnevna uporaba informacijsko komunikacijske tehnologije (IKT) u nastavi i poslovanju škole koja doprinosi: razvoju digitalne kompetencije učenika, razvoju digitalne kompetencije nastavnika i učinkovitom i transparentnom upravljanju školom. Prema dosad prikupljenim objavljenim znanstvenim informacijama (dozimetrijskim podacima, relevantnim studijama i rijetkim dostupnim epidemiološkim podacima) te sveobuhvatnim analizama dobivenim tijekom mjerenja i posebno, simulacijama i modeliranjem izloženosti školskih prostora u sklopu projekata e-Škole, suradnici IMI izveli su zaključak da ne postoje dozimetrijski razlozi zbog kojih se Wi-Fi radijski sustavi ne bi trebali nastaviti koristiti u školama.S obzirom na to da razina emitiranih EM polja (od Wi-Fi tehnologije i ostalih radijskih uređaja) može biti predmet propitivanja ili zabrinutosti kod roditelja, nastavnika i ostalih dionika, CARNet i IMI planiraju u sklopu daljnjih projekta e-Škole nastaviti provoditi relevantna mjerenja EM polja. Uz to, planira se nastaviti i istraživanje mogućih utjecaja koje EM polja od Wi-Fi i drugih radiokomunikacijskih uređaja, koji se koriste ili će se koristiti u redovnim nastavnim procesima u hrvatskim školama, mogu imati na zdravlje oblikovanjem reprezentativnih radiobioloških eksperimenata i epidemioloških metoda. Sve navedeno provodit će se s ciljem prikupljanja sigurnih, pouzdanih, točnih i ažurnih podataka, posebno dozimetrijskih koji su osnova za donošenje zaključaka o stvarnoj izloženosti koji će se potom koristiti za daljnja validacijska mjerenja, posebice u svrhu epidemioloških i socioloških istraživanja te unapređenje nastavnih procesa i izradu velike podatkovne baze svih vrsta podataka vezanih za istraživanja utjecaja RF EM polja na zdravlje kako bi se dosadašnji podaci mogli koristiti u istraživanjima i razvoju moderne tehnologije za borbu protiv karcinoma svih vrsta.

Ključne riječi: Wi-Fi, EM polja, dozimetrija, e-Škole, izloženost, digitalna zrelost

THE DOSIMETRY OF ELECTROMAGNETIC RADIATION IN THE IMPLEMENTATION OF THE PROJECT „e-SCHOOLS“ – ESTABLISHING A SYSTEM FOR DEVELOPING DIGITALLY MATURE SCHOOLS (Pilot and Phase II)

Ivica Prlić[1], Jerko Šiško[1], Luka Pavelić[1], Mihovil Jurdana[1], Silvija Kobeščak[1], Mladen Hajdinjak[2], Zdravko Cerovac[3], Renata Ivanković[4], Hrvoje Mesić[5], Martina Dragičević[1]

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The use of Wi-Fi radio transmitters is growing rapidly. Through this technology, electronic devices are radio-connected to a computer network via microwaves or electromagnetic (EM) radio frequency (RF) fields, eliminating or reducing the need for network cables. Wireless radio systems enable freedom of movement with the receiver within a school (laptop, tablet or smartphone) and are easier and sometimes even cheaper to implement than wired networks. Such technologies have become part of everyday life, as well as everyday schooling. The best example of this is a laptop connected to the internet via a Wi-Fi router. Wi-Fi radio connections have been around for a long time and Wi-Fi access points are located in many public and private spaces, so one should bear in mind that people are therefore occasionally immersed in Wi-Fi signals and thus exposed to an additional low level of EM fields when using the internet for business or private purposes. As exposure in school classrooms is in fact a “forced” category of exposure for students and teachers, for whom this is also occupational exposure to a new agent, the project “e-Schools: Establishing a system for the development of digitally mature schools (Pilot and Phase II)”, conducted by the Croatian Academic and Research Network – CARNet from 2015 to 2023, set out to perform dosimetric measurements of RF communication EM fields from Wi-Fi routers in classrooms. The purpose of both "e-School" projects is to establish a network of digitally mature schools for the 21st century by raising the level of digital maturity of all primary and secondary schools in Croatia. Digitally mature schools imply the active and daily use of information and communication technology (ICT) in teaching and school operations, which contributes to the development of student and teacher digital competence and efficient and transparent school management.
According to data published so far (dosimetric data, relevant studies and rare epidemiological data) and comprehensive analyses obtained during measurements and in particular simulations and modeling of the exposure of school spaces within the e-School projects, experts from IMROH concluded that there were no dosimetry-based reasons why Wi-Fi radio systems should not continue to be used in schools. Given that the level of the emitted EM fields (from Wi-Fi technology and other radio devices) may be the subject of concern among parents, teachers and other stakeholders, CARNet and IMROH plan to continue relevant EM field measurements through further e-School projects. In addition, we plan to continue investigating the possible effects that EM fields from Wi-Fi and other radio communication devices, used in regular teaching processes in Croatian schools, can have on one’s health by designing representative radiobiological experiments and epidemiological methods. This will be carried out with the aim of collecting safe, reliable, accurate and up-to-date data, especially dosimetric data, which are the basis for conclusions about actual exposure, which will then be used for further validation measurements, especially for the purpose of epidemiological and sociological research and the improvement of teaching processes and creation of a large database of all types of data related to research on the impact of RF EM fields on health. This will enable the data collected so far to be used in research and development of modern technologies to fight cancers of all types.

Key words: Wi-Fi, EM fields, dosimetry, e-Schools, exposure, digital maturity

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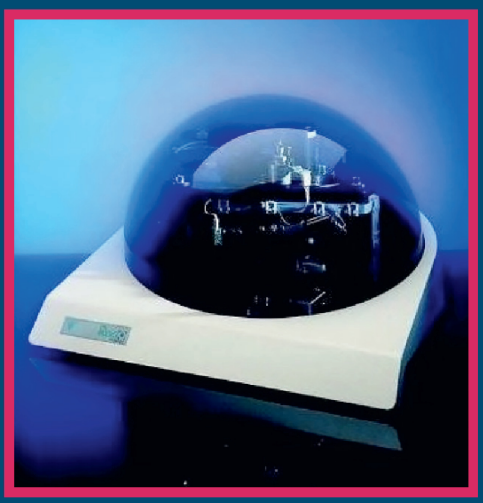

ACCREDITATION FRIENDLY SYSTEM

Traceability
Calibration factor is traced back to BfS and national calibration laboratories

Synchronization
Reference detector set concept to synchronize user system and the factory reference system

Turnkey solution
Including calibration and variety of detectors in ready made format

QC support system
For user labs including watchdog monitor program, which operates locally on the user's system

Accreditation
Growing number of 17025 accredited users labs

10-stage production QC
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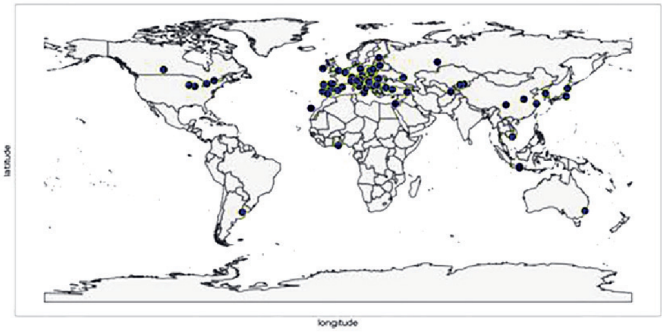

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