

NASTAVNO-NAUČNOM VEĆU ELEKTROTEHNIČKOG FAKULTETA UNIVERZITETA U BEOGRADU

Na 737. sednici Nastavno-naučnog veća Elektrotehničkog fakulteta u Beogradu održanoj 11.10.2011. godine, imenovani smo za članove Komisije za ocenu uslova i prihvatanje teme doktorske disertacije **Vladana Ljubenova**, dipl. ing., magistra elektrotehničkih nauka, pod naslovom „**Univerzalne funkcije refleksije fotona od ravne mete određene analizom transporta zračenja metodom sudar po sudar**“. Nakon uvida u dostavljeni materijal podnosimo Nastavno-naučnom veću Elektrotehničkog fakulteta sledeći

I Z V E Š T A J

1. Podaci o kandidatu

Vladan Ljubenov rođen je 08.05.1968. godine u Dimitrovgradu, Republika Srbija, gde je završio osnovnu i srednju školu.

Nakon odsluženja vojnog roka 1986-87. godine upisao je Elektrotehnički fakultet Univerziteta u Beogradu, smer Tehnička fizika. Diplomirao je 1993. godine sa prosečnom ocenom 8.39 i odbranjenim diplomskim radom iz oblasti laserske tehnike sa ocenom 10, čime je stekao stručno zvanje diplomirani inženjer elektrotehnike za tehničku fiziku.

Na istom fakultetu upisao je poslediplomske studije, smer Merenja u elektrotehnici. Magistarsku tezu pod naslovom „Standardizacija polja neutrona u grafitnom bloku sa Ra-alfa-Be izvorom“, pripremljenu pod mentorstvom dr Predraga Marinkovića, van. prof., odbranio je 2001. godine, čime je stekao akademsko zvanje magistra elektrotehničkih nauka - oblast merenja u elektrotehnici.

2001. godine izabran je u istraživačko zvanje istraživač saradnik u Institutu za nuklearne nauke „Vinča“. U ovo zvanje je ponovo izabran 2005. godine.

Nakon diplomiranja, januara 1994. godine zaposlio se u Institutu za nuklearne nauke „Vinča“, gde je u početku radio u Centru za medicinsku zaštitu, u oblasti humane dozimetrije, na instalaciji za kontrolu interne kontaminacije gama radionuklidima (Whole Body Counter).

Oktoobra 1994. godine prelazi u Laboratoriju za nuklearnu energetiku i tehničku fiziku „NET“, koja 2002. godine postaje deo novoformiranog Centra za nuklearne tehnologije „NTI“. Tamo ostaje do kraja 2008. godine, kada odlazi u Međunarodnu agenciju za atomsku energiju (MAAE) u Beču.

U Laboratoriji „NET“ bavio se istraživanjima u oblasti reaktorske fizike i tehnike na reaktoru RB i istraživanjima u oblasti nuklearno-medicinskih SPECT snimanja i rekonstrukcije slike. Nakon formiranja Centra „NTI“ radio je na realizaciji Programa nuklearne dekomisije u Institutu „Vinča“ (Program VIND). Bio je angažovan na projektima uklanjanja isluženog goriva reaktora RA, pripreme za dekomisiju reaktora RA, pogona i održavanja reaktora RB i safeguards kontrola u Institutu „Vinča“ kao rukovodilac nekoliko projekata i aktivnosti i pomoćnik rukovodioca Programa VIND. Od 2004. godine pa do odlaska u MAAE obavljao je funkciju v.d. direktora Centra „NTI“. U periodu 2002-2009. bio je jedan od nosilaca vrlo intenzivne međunarodne saradnje u okviru Programa VIND. Pored angažovanja na realizaciji Programa VIND, u periodu 2003-2009. godine sa grupom istraživača u Institutu „Vinča“ bavio se problemima fotonske refleksije u oblasti niskih energija.

Od 2009. godine radi u MAAE kao stručnjak za sigurnost pri upravljanju radioaktivnim otpadom i dekomisiji nuklearnih postrojenja. Koordinator je nekoliko međunarodnih projekata u oblasti dekomisije i zadužen je za izradu i revizije međunarodnih standarda sigurnosti u ovoj oblasti. Organizuje brojne radionice i trening kurseve u zemljama članicama MAAE i koordinira više nacionalnih i regionalnih projekata u okviru Programa tehničke pomoći MAAE.

Pored srpskog, govori engleski, ruski i bugarski jezik.

U okviru svog profesionalnog usavršavanja u Institutu „Vinča“, pohađao je dvadesetak trening kurseva i radionica na teme u oblasti nuklearne i reaktorske tehnike, sigurnosti nuklearnih

postrojenja, zaštite od zračenja, rukovanja radioaktivnim otpadom i dekomisije, organizovane od strane MAAE, Međunarodnog centra za teorijsku fiziku u Trstu (ICTP), Evropskog istraživačkog centra (EC-JRC) u Petenu i drugih institucija, poput:

- "Monte Carlo Simulation in Medical Physics", Faculty of Organizational Sciences & Yugoslav Society of Biomedical Engineering and Medical Physics (director Radovan Ilić), Belgrade, October 13-31, 1997
- IAEA RER/9/058 Regional Workshop "Extended Shutdown and Decommissioning of Research Reactors", Riga, Latvia, November 26-30, 2001
- "Workshop on Nuclear Reaction Data and Nuclear Reactors: Physics, Design and Safety", IAEA & ICTP "Abdus Salam", Trieste, Italy, February 25 - March 28, 2002
- "Workshop on Nuclear Data for Science and Technology: Material Analysis", IAEA & ICTP "Abdus Salam", Trieste, Italy, May 19-30, 2003
- IAEA Regional Workshop on Experience in Optimization during Decommissioning Activities: Application of the ALARA Principle, IAEA RER/3/005 Project "Support in Planning the Decommissioning of Nuclear Power Plants and Research Reactors", Karlsruhe and Greifswald, Germany, 21-25 April 2008
- IAEA Workshop on Safety Assessment for Decommissioning of Nuclear Power Plants and Research Reactors, TC Project RER/3/005, 23-25 June 2008, Sofia, Bulgaria
- 3D SUNCOP 2008 Seminar, 13 - 31 October 2008 - EC-JRC-IE Petten, The Netherlands (Second Week: Industrial Applications, Coupling Methodologies and Hands-On Training Sessions)

Nakon prelaska u MAAE organizovao je više od 30 trening kurseva i radionica, održanih u periodu 2009-2011 u Austriji, Belgiji, Velikoj Britaniji, Grčkoj, Danskoj, Indoneziji, Jermeniji, Južnoafričkoj Republici, Kuvajtu, Mađarskoj, Nemačkoj, Siriji, Sjedinjenim Američkim Državama, Tajlandu, Uzbekistanu, Filipinima i Francuskoj, za polaznike iz pedesetak zemalja. Koordinirao je više desetina ekspertske misije i studijskih boravaka u inostranim centrima za kandidate iz više od 20 zemalja, na teme upravljanja radioaktivnim otpadom i dekomisije nuklearnih postrojenja (regulatorni, tehnički i sigurnosni aspekti). Za rad u MAAE dobio je „IAEA Merit Award for Outstanding Performance“ (2010).

Tokom svog rada u Institutu za nuklearne nauke „Vinča“, Vladan Ljubenov je učestvovao u realizaciji sledećih projekata:

Naučno-istraživački projekti Ministarstva nauke Republike Srbije:

- Projekat E0812: „Osnovna istraživanja u vezi korišćenja nuklearne energije“, rukovodilac dr Dušan Spasojević (1994-1996)
- Projekat 08M06: „Istraživanja sigurnosti i rizika korišćenja nuklearne energije“, rukovodilac dr Dušan Spasojević (1996-2000)
- Projekat 1958: „Transportni procesi čestica u fisionim i fuzionim sistemima“, rukovodilac dr Milan Pešić (2001 - 2004)
- Projekat 2016: „Fizika zaštite od zračenja“, rukovodilac Prof. dr Marko Ninković (2005)
- Projekat 141041: „Zaštita od zračenja – fundamentalni teorijski i eksperimentalni fizički aspekti“, rukovodilac dr Dragomir Davidović (2005-2008)

Ostali projekti finansirani od Ministarstva nauke Republike Srbije (učešće i rukovođenje):

- Program nuklearne dekomisije u Institutu Vinča (2004-2008), zamenik rukovodioca programa VIND u periodu 2006-2008.
- projekat „Dekomisija istraživačkog reaktora RA“ (2004-2008), rukovodilac u periodu 2004-2006.
- projekat „Uklanjanje isluženog goriva reaktora RA“ (2007-2008, zamenik rukovodioca projekta)
- Pogon i održavanje istraživačkog reaktora RB u Vinči (2007-2008), rukovodilac projekta u 2007.
- Safeguards aktivnosti u Institutu Vinča (2007-2008), rukovodilac projekta

Nacionalni projekti u okviru Programa tehničke pomoći MAAE (IAEA Technical Cooperation Programme):

- Safe Removal of the Vinca RA Reactor Spent Nuclear Fuel (2007-2008), IAEA TCP Project SRB 4002, zamenik rukovodioca projekta 2007-2008.
- Decommissioning of the RA Research Reactor in Vinča Institute (2003-2008), IAEA TCP Projects SCG 4004 and SRB3002, rukovodilac projekta 2003-2006.

Predstavnik Srbije u međunarodnim projektima MAAE:

- IAEA Project "Evaluation and Demonstration of Safety of the Decommissioning of the Nuclear Facilities (DeSa Project)" (2004-2007)
- IAEA Project "Research Reactor Decommissioning Demonstration Project (R2D2P)" (2006-2008)
- IAEA Regional TC Project RER 3005 "Support in Planning the Decommissioning of Nuclear Power Plants

- and Research Reactors" (European region) (2007-2008)
- IAEA International Decommissioning Network (2007-2008)

Ostali projekti (pre odlaska u MAAE januara 2009):

- Projekat »Priprema programa trajnog zatvaranja istraživačkog reaktora RA u Institutu Vinča«, Ugovor sa Saveznim ministarstvom za privredu i unutrašnju trgovinu SRJ (2003), rukovodilac projekta
- Angažovan kao ekspert MAAE za misiju CPR/9/034-01-01, China Institute of Atomic Energy, Beijing, CHINA, 11-14 April 2005
- Organizator/koordinator jednomesečnog MAAE treninga (fellowship) »Decommissioning Planning and Radiological Characterization« za dvoje inženjera iz China Institute of Atomic Energy Institute, Beijing; trening sproveden u Institutu »Vinča«, septembar – oktobar 2005.

Nakon odlaska u MAAE - koordinator / naučni sekretar / tehnički oficir za međunarodne projekte:

- IAEA Project »Use of Safety Assessment in Planning and Implementation of Decommissioning of Facilities Using Radioactive Material (FaSa)« (2009-2011)
- IAEA Project "Research Reactor Decommissioning Demonstration Project (R2D2P)" (2009-2011)
- IAEA Regional TC Project RER 3009 "Support in Planning the Decommissioning of Nuclear Power Plants and Research Reactors (Phase II)" (European region) (2009-2011)
- IAEA Regional TC Project RAS9056 »Strengthening Capabilities for Protection of the Public and the Environment from Radiation Practices« (Asia and the Pacific Region) (2010-2011)
- IAEA International Decommissioning Network (2009-)
- Tehnički oficir MAAE za nacionalne projekte u oblasti dekomisije nuklearnih postrojenja u Ukrajini (nuklearna elektrana Černobilj), Kini (teškovodni istraživački reaktor u Pekingu), Litvaniji (nuklearna elektrana Ignalina), na Filipinima (istraživački reaktor u Manili), uključen u realizaciju programa dekomisije nuklearnih postrojenja u Iraku, bombardovanih tokom Zalivskog rata 1991.
- Naučni sekretar i koordinator izrade međunarodnih standarda i tehničkih publikacija MAAE u oblasti dekomisije.

Vladan Ljubenov je bio angažovan u nastavi na Elektrotehničkom fakultetu u Beogradu u periodu 1998-2004. godine u okviru računskih i laboratorijskih vežbi iz predmeta Fizika 1, Fizika 2 i Osnove nuklearne tehnike. Organizovao je praktične vežbe za studente Elektrotehničkog fakulteta na reaktoru RB u Vinči, kao i predavanja za polaznike kurseva u okviru „Centra za permanentno obrazovanje“ Instituta Vinča (nekadašnja „Škola za izotope“). Saradivao je u periodu 1999-2001. godine sa Institutom za nuklearnu medicinu Kliničkog Centra Srbije na poslovima kontrole kvaliteta gama kamera.

Učestvovao je u organizaciji 6 međunarodnih konferencija Jugoslovenskog Nuklearnog Društva u periodu 1996-2008. godine i u organizaciji rada sekcije Nuklearna tehnika konferencije ETRAN u periodu 1997-2008. Bio je član Upravnog odbora Jugoslovenskog Nuklearnog Društva (kasnije Nuklearnog Društva Srbije) i Društva za zaštitu od zračenja Srbije i Crne Gore. Član je Uređivačkog odbora i recenzent radova međunarodnog naučnog časopisa „Nuclear Technology and Radiation Protection“ (UDC 621.039+614.876:504.06, YU ISSN 1451-3994).

Nagrade za najbolji rad mladog autora dobio je na konferencijama *Annual Conference of Bulgarian Nuclear Society with the International Participation*, Kozloduy (1999), *Third International Conference of Yugoslav Nuclear Society YUNSC 2000*, Belgrade (2000), *XLVIII Konferencija ETRAN, sekcija Nuklearna tehnika*, Čačak (2004), i *First Meeting of Yugoslav Society for Biomedical Engineering and Medical Physics BIMEF '97*, Beograd (1997).

Tokom svog dosadašnjeg naučno-istraživačkog rada Vladan Ljubenov objavio je, u svojstvu autora i koautora, 18 radova u časopisima međunarodnog značaja, 52 rada na međunarodnim konferencijama (od čega 10 radova po pozivu), 3 rada u časopisima nacionalnog značaja i 49 radova na domaćim konferencijama (od čega 2 rada po pozivu). Autor je više desetina stručnih izveštaja pripremljenih za potrebe realizacije domaćih i međunarodnih projekata (analize i izveštaji o sigurnosti u okviru pogona reaktora RB, uklanjanja isluženog goriva reaktora RA i pripreme za dekomisiju reaktora RA u Vinči).

Spisak publikovanih naučnih i stručnih radova Vladana Ljubanova je sledeći:

- Radovi u časopisima (prvih 6 su ISI reference)

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- [2] S. Marković, V. Ljubenov, O. Ciraj, R. Simović: *Reflected Radiation Assessment in Contrast X-ray Diagnostics*, Radiation Physics and Chemistry, Vol. 71 (2004), Issues 3-4, October-November 2004, pp. 989-990
- [3] J. Vukanic, R. D. Simovic, V. Ljubenov: *Interpolation Formula for Particle Reflection Coefficient of keV Light Ions Obliquely Incident on Heavy Solids*, Nuclear Instruments and Methods in Physics Research B, Vol. 269 (2011), pp. 89-93
- [4] V. Ljubenov, R. Simović, S. Marković R. D. Ilić: *Photon Scattering and Reflection in Diagnostic Energy Domain*, Nuclear Technology & Radiation Protection, Vol. XXIII, No.1, pp. 31-36, 2008.
- [5] V. Ljubenov, R. Simović, S. Marković R. D. Ilić: *Total Reflection Coefficients of Low-Energy Photons Presented as Universal Functions*, Nuclear Technology & Radiation Protection, Vol. XXV, No.2, pp. 100-106, 2010.
- [6] V. L. Ljubenov, R. D. Simović, *Universal Dependence of the Total Number Albedo of the Photons on the Mean Number of Photon Scatterings*, Nuclear Technology & Radiation Protection, Vol. XXVI, No.3, pp. 249-253, 2011.
- [7] V. Stančić, B. Šećerov, V. Ljubenov: *A Unified Approach to Deconvolution Radiation Spectra Measured by Radiochromic Films*, Nuclear Technology & Radiation Protection, Vol. XVII, No.1-2, pp. 37-43, 2002.
- [8] S. Marković, R. Simović, V. Ljubenov: *An Investigation of Low-Energy Photon Reflection from the Iron Target*, Nuclear Technology & Radiation Protection, Vol. XIX, No.1, pp. 39-45, 2004.
- [9] M. Steljić, V. Ljubenov: *Elements of the Record Management System for the RA Research Reactor Decommissioning*, Nuclear Technology & Radiation Protection, Vol. XIX, No.1, pp. 50-58, 2004.
- [10] S. Marković, V. Ljubenov, R. Simović: *A Semiempirical Formula for the Angular Differential Number Albedo of Low-Energy Photons*, Nuclear Technology & Radiation Protection, Vol. XX, No.2, pp. 28-34, 2005.
- [11] S. Marković, R. Simović, V. Ljubenov, R. D. Ilić: *Spectral Albedo of Photons of Initial Energies Below 100 KeV*, Nuclear Technology & Radiation Protection, Vol. XXII, No.1, pp. 40-47, 2007.
- [12] V. Ljubenov, R. Simović, S. Marković R. D. Ilić: *Number Albedo of Low-Energy Photons for Water, Aluminum and Iron*, Nuclear Technology & Radiation Protection, Vol. XXII, No.1, pp. 48-53, 2007.
- [13] S. Marković, V. Ljubenov, R. Simović: *Total Number Albedo and Average Cosine of the Polar Angle of Low-Energy Photons Reflected from Water*, Nuclear Technology & Radiation Protection, Vol. XXII, No.2, pp. 44-47, 2007.
- [14] V. Ljubenov, M. Milošević: *Standard Neutron Fields in Graphite Prism with Ra- α -Be Source*, Nuklearna tehnologija (Journal of the Yugoslav Nuclear Society), Vol. XVI, No.1, pp. 10-15, 2001.
- [15] M. Milošević, M. Pešić, T. Milovanović, V. Ljubenov: *Verification of Void Effect Calculation*, Transactions of ANS 1995 Winter Meeting and Embedded Topical, Vol. 73 (1), pp. 404-406, San Francisco, CA USA (October 29 - November 2, 1995)
- [16] V. Ljubenov, M. Milošević, M. Pešić: *Determination of Neutron Flux in Graphite Block with Ra- α -Be Source*, The 2000 ANS/ENS International Meeting, Transaction, Vol. 83, No. 1, pp. 431-432, Washington DC, USA (November 12-16, 2000)
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- [18] S. Milovanović, M. Pešić, T. Milovanović, V. Ljubenov: *A Method for Determination of Reactivity - Time Function of Safety Rods and Verification of Assumption in Previous Method*, Transactions of the Bulgarian Nuclear Society, Vol. 2, No. 1, pp. 24-27 (July 1997)
- [19] P. Marinković, V. Ljubenov: *SPECT Slice Image Reconstruction by Singular Value Decomposition*, Transactions of the Bulgarian Nuclear Society, Vol. 5, No. 1, pp. 101-104, (2000)
- [20] V. Ljubenov: *MCNP Calculation of Standard Graphite Block*, Transactions of the Bulgarian Nuclear Society, Vol. 5, No. 1, pp. 20-23, (2000), (the best scientific paper of young author at the Annual Conference of the Bulgarian Nuclear Society 1999)
- [21] M. Pešić, P. Marinković, M. Milošević, D. Nikolić, N. Zavaljevski, S. Milovanović, V. Ljubenov: *Verification of Kinetic Parameters of Coupled Fast-Thermal Core HERBE*, Bulletin of the Vinča Institute of Nuclear Sciences, Vol. 2, No. 1, pp.15-23, Vinča (March 1997)
- [22] V. Ljubenov, M. Milošević: *Determination of the Neutron Flux in the Reactor Zones with the Strong Neutron Absorption and Leakage*, Serbian Journal of Electrical Engineering, Vol. 1, No. 3, November 2004, pp. 99-112

- Radovi na konferencijama

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- [24] K. Subotić, M. Pešić, V. Ljubenov, O. Šotić, I. Plećaš, M. Milošević, A. Perić, R. Pavlović: *Towards "Green Vinča" - Vinča Nuclear Decommissioning Program*, Proceedings of the 4th Yugoslav Nuclear Society International Conference - YUNSC 2002 (CD ROM Edition, ed.: D. Antić), pp. 23-34, Belgrade, (September 30 -October 4, 2002), invited paper, Book of Abstracts (ed.: D. Antić), pp. 24, Belgrade, FRY (September 2002), Vinča Bulletin, Vol. 8, Supplement 2 (October 2003)
- [25] V. Ljubenov, M. Pešić, O. Šotić: *RA Research Reactor in Vinča Institute - Approach to the Decommissioning*, Proceedings of the 4th Yugoslav Nuclear Society International Conference - YUNSC 2002, (CD ROM Edition, ed.: D. Antić), pp. 373-382, Belgrade, (September 30 -October 4, 2002), invited paper, Book of Abstracts (ed.: D. Antić), pp. 26, Belgrade, FRY (September 2002), Vinča Bulletin, Vol. 8, Supplement 2 (October 2003)
- [26] V. Ljubenov: *Decommissioning Planning for the RA Research Reactor in Vinča Institute*, Proceedings of the "International Conference on Lessons Learned from Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities", Athens, 11-15 Decembar 2006, Session 3: Planning for Decommissioning, Invited keynote presentation, p. 161-178
- [27] M. Milošević, V. Ljubenov, M. Pešić: *50 Years of RB Reactor Operation*, 6th International Conference of Nuclear Society of Serbia (CoNuSS 2008), Belgrade, Serbia, September 22-25, 2008 (invited paper, to be published in the Proceedings), Book of Abstracts, p.??
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- [29] V. Ljubenov, E. Warnecke, M. Hannan: *IAEA Decommissioning Safety Activities*, Proceedings of the 12th International Conference on Environmental Remediation & Radioactive Waste Management / Nuclear Decommissioning ICEM'09 / DECOM'09, October 11-15, 2009, Liverpool, UK, ICEM2009-16397
- [30] J. Rowat, V. Ljubenov, D. Draper: *New IAEA Guidance Pertaining to Monitoring for Compliance with Exemption and Clearance Levels*, 56th Annual Meeting of the Health Physics Society HPS 2011, 26-30 June, West Palm Beach, Florida, USA (to be published)
- [31] M. Wong, V. Ljubenov, J. Rowat: *Revision of the IAEA Safety Standards for Decommissioning - Progress and Issues*, International Decommissioning Seminar, Studsvik, Sweden, September 14-16, 2010
- [32] P. Dinner, V. Ljubenov, M. Laraia, A. Junger: *Highlights of the IAEA Decommissioning Activities*, UK Decommissioning & Waste Management Conference, Penrith, Cumbria, UK, November 2010
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- [36] S. Avdić, P. Marinković, V. Ljubenov: *Evaluation of Neutron Spectrum Based on the EM Algorithm for Maximum Likelihood Estimation*, Proceedings of the Yugoslav Nuclear Society Conference - YUNSC'96, pp. 311-314 (ed. D. Antić) (1997), Belgrade, FRY (October 7-9, 1996), Book of Abstract ISBN: 86-80055-94-8, p. 50 (October 1996)
- [37] Z. Žunić, J. McLaughlin, M. Kovačević, D. Veličković, R. Benderać, V. Gordanić, D. Nikezić, S. Perović, R. Simović, B. Radak, M. Spasić, Đ. Bek-Uzarov, S. Pavlović, M. Demajo, G. Bogdanović, T. Jovanović, D. Aleksić, R. Kljajić, S. Jovanović, I. Avramović, V. Ljubenov, M. Mandić, R. Lučić, D. Alavantić: *Research Proposal for National Radon Programme in Yugoslavia*, Proceedings of the Yugoslav Nuclear Society Conference - YUNSC'96, pp. 521-530 (ed. D. Antić) (1997), Belgrade, FRY (October 7-9, 1996), Book of Abstract ISBN: 86-80055-94-8, p. 81 (October 1996)
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2. Predmet i cilj istraživanja

Istraživanje refleksije fotona od zaštitnih materijala obrađivano je u klasičnoj literaturi sa naglaskom na inicijalne energije fotona od 100 keV do 10 MeV. Interes za ovo područje energija bio je posledica tadašnjih potreba zaštite od zračenja kod izgradnje i pogona istraživačkih i energetskih nuklearnih reaktora, kao i kod vojnih primena nuklearnih tehnologija i jonizujućeg zračenja. Sa druge strane, interakciji zračenja sa materijalima i fotonskoj refleksiji u oblasti energija inicijalnih fotona ispod 100 keV, značajnoj za mnoge mimodopske upotrebe zračenja, posebno u dijagnostičkim i terapijskim primenama u medicini, nije bila posvećena podjednaka pažnja. Veličine karakteristične za refleksiju fotona u ovoj energetske oblasti (ugaoni i energetski diferencijalni albedo, brojni, spektralni i dozni albedo, kao i totalni albedo koeficijenti) nisu bile detaljno istražene, ili se u literaturi uopšte nisu mogle naći.

Tokom poslednje decenije u Institutu za nuklearne nauke „Vinča“, grupa istraživača, kojoj pripada i kandidat, sistematski je proučavala refleksiju fotona od tipičnih zaštitnih materijala u oblasti niskih energija incidentnih fotona (energije do 100 keV), koje su od posebnog značaja za primene u radiološkoj rendgen-dijagnostici. Rezultati ovih istraživanja saopštavani su redovno na domaćim i međunarodnim konferencijama i publikovani u časopisima. U ovim radovima prikazani su rezultati koji su se odnosili na analitička, semianalitička i numerička istraživanja problema refleksije, sa ciljem da se formulišu jednostavni matematički izrazi kojima se ključni koeficijenti refleksije mogu opisati dovoljno tačno za praktičnu upotrebu.

Na osnovu razmatranja detaljnih proračuna refleksije fotona savremenim Monte Karlo programima, za slučaj normalnog upada fotona, uočene su univerzalne osobine ugaone raspodele normalizovanih koeficijenata refleksije i na osnovu toga formulisani su analitički izrazi za ugaonu zavisnost brojnog, energetskog i doznog albeda u vidu jednostavnih kosinusnih raspodela po polarnom uglu. Ovaj univerzalni opis fotonske refleksije, za slučaj upada inicijalnog snopa na metu pod pravim uglom, primenljiv je za sve proučavane materijale mete i za sve energije u oblasti do 100 keV. Metodom sudar po sudar izvedena su rešenja za refleksiju jednom i dva puta sudarenih fotona u analitičkoj i sažetoj formi. Poređenjem sa rezultatima simulacije refleksije utvrđeno je da ova rešenja mogu supstituisati ukupnu refleksiju u slučajevima kada je ona dominantno određena prvim i drugim sudarom.

Za energije bliske 100 keV i za mete od lakših materijala ova rešenja nisu dovoljna za procenu ukupne refleksije fotona. Zbog toga je potrebno detaljnije proučiti doprinos višestrukih sudara ugaono-energetskoj raspodeli reflektovanih fotona i integralnim koeficijentima refleksije u pokušaju da se ustanove semi-analitički modeli sa parametrima baziranim na rezultatima detaljnih Monte Karlo simulacija, koji bi uspešno rekonstruisali refleksiju fotona u navedenom slučaju. Modele razvijene u prethodnom periodu za doprinose refleksiji od prvog i drugog sudara, kao i nove modele za doprinose ostalih sudara, treba proveriti u energetske oblasti iznad 100 keV i utvrditi granice njihove validnosti.

Cilj disertacije je da se na osnovu analize uticaja broja sudara u materijalu mete na ugaonu i energetsku raspodelu reflektovanih fotona i na integralne koeficijente refleksije, kao i na osnovu dvojno-diferencijalnih parametara refleksije izračunatih detaljnim Monte Karlo proračunima, formulišu semi-analitička rešenja koja sa zadovoljavajućom tačnošću opisuju ugaono-energetsku raspodelu reflektovanih fotona i ukupnu refleksiju od raznih materijala i za različite energije.

Univerzalni karakter koeficijena refleksije biće potvrđen originalnim prikazom refleksije u zavisnosti od ukupnog broja interakcija fotona sa strukturom mete, a pre njihove konačne refleksije. Relevantni bibliografski izvori i ostvareni radovi koji su vezi sa predmetom istraživanja u ovom radu su sledeći:

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- S. Marković, V. Ljubenov, O. Ciraj, R. Simović: *Reflected Radiation Assessment in Contrast X-ray Diagnostics*, Radiation Physics and Chemistry, Vol. 71 (2004), Issues 3-4, October-November 2004, pp. 989–990
- J. Vukanic, R. D. Simovic, V. Ljubenov: *Interpolation Formula for Particle Reflection Coefficient of keV Light Ions Obliquely Incident on Heavy Solids*, Nuclear Instruments and Methods in Physics Research B, Vol. 269 (2011), pp. 89–93
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- S. Marković, V. Ljubenov, R. Simović: *A Semiempirical Formula for the Angular Differential Number Albedo of Low-Energy Photons*, Nuclear Technology & Radiation Protection, Vol. XX, No.2, pp. 28-34, 2005.
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- V. Ljubenov, R. Simović, S. Marković R. D. Ilić: *Number Albedo of Low-Energy Photons for Water, Aluminum and Iron*, Nuclear Technology & Radiation Protection, Vol. XXII, No.1, pp. 48-53, 2007.
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- R. Simović, S. Marković, **V. Ljubenov**: *Models for the Analytic Estimation of Low Energy Photon Albedo*, Proceedings of the XLIX Conference of ETRAN Society, Vol. IV, pp. 40-43 (ed.: M. Milošević), Budva, Montenegro (June 5-10, 2005) (in Serbian)
- S. Marković, R. Simović, **V. Ljubenov**: *An Analysis of Low-Energy Photon Albedo*, Proceedings of the XXIII Symposium of Radiation Protection Association of Serbia and Montenegro (in Serbian), Donji Milanovac, Serbia and Montenegro, September 26-28, 2005, pp. 199-202
- S. Marković, **V. Ljubenov**, R. Simović, R. D. Ilić: *The One-Parameter Universal Formula for the Angular Differential Number Albedo of Low-Energy Photons*, Proceedings of the 50th Conference of ETRAN Society, (ed.: M. Milošević), p. 65-68, Belgrade, Serbia (June 5-10, 2006) (in Serbian, published on CD-ROM only)
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- S. Marković, R. Simović, **V. Ljubenov**: *Spectral Albedo of Low-Energy Photons*, Proceedings of the 51st Conference of ETRAN Society, (ed.: M. Milošević), paper NT2.7, Herceg Novi, Montenegro (June 4-8, 2007) (in Serbian, published on CD-ROM only, ISBN 978-86-80509-62-4)
- S. Marković, **V. Ljubenov**, R. Simović, R. D. Ilić: *Total Number Albedo of Low-Energy Photons*, Proceedings of the XXIV Symposium of Radiation Protection Association of Serbia and Montenegro (in Serbian), Zlatibor, Serbia, October 3-5, 2007, pp. 245-248
- R. Simović, S. Marković, **V. Ljubenov**: *On the Average Cosine of Polar Angle of Photons Reflected from Water*, Proceedings of the XXIV Symposium of Radiation Protection Association of Serbia and Montenegro (in Serbian), Zlatibor, Serbia, October 3-5, 2007, pp. 253-257
- R. Simović, S. Marković, **V. Ljubenov**, R. D. Ilić: *Photon Scattering and Reflection in Diagnostic Energy Domain*, Proceedings of LII Conference ETRAN, paper NT2.7-1-4, Palić, Serbia, June 9-12, 2008, invited paper, (in Serbian, published on CD-ROM only, ISBN 978-86-80509-62-4)
- R. Simović, S. Marković, **V. Ljubenov**, R. D. Ilić: *Total Photon Reflection Coefficients Presented as Universal Functions*, Proceedings of LIV Conference ETRAN, paper NT1.2-1-4, Donji Milanovac, Serbia, June 7-10, 2010 (in Serbian, published on CD-ROM only, ISBN 978-86-80509-65-5)

3. Polazne hipoteze

Analitičke metode opisivanja refleksije fotona od ravne mete uspešno opisuju refleksiju od jednom i dva puta sudarenih čestica. Ovaj doprinos ukupnoj refleksiji dominantan je za inicijalne energije fotona do 100 keV i za materijale mete većih gustina (gvožđe, olovo). U slučaju viših energija inicijalnih fotona i lakših meta, raste doprinos ukupnoj refleksiji od više puta sudarenih fotona. Ovaj doprinos postojeća analitička rešenja ne mogu uspešno da opišu.

Da bi se procenio doprinos ostalih sudara refleksiji fotona od ravne mete u oblasti energija inicijalnih fotona iznad 100 keV, potrebno je izvršiti detaljne analize refleksije pomoću referentnih transportnih metoda koje mogu da opišu sve interakcije fotona sa materijalom mete od interesa i da reflektovane fotone razvrstaju po njihovim energijama i pravcima kretanja nakon refleksije, ali i po broju doživljenih sudara u materijalu mete. Pogodnim metodom treba ispitati raspodele reflektovanih fotona po energiji i pravcu kretanja nakon refleksije u zavisnosti od energije inicijalnih fotona, materijala mete i broja doživljenih sudara u materijalu. Ova disertacija razmatraće oblast energija inicijalnih fotona do 200 keV i materijale od najvećeg interesa za procenu reflektovanog fotonskog zračenja, kao što su voda, beton, aluminijum, gvoždje, bakar i olovo.

Rezultati ovih analiza daće osnovu za uočavanje pravilnosti i univerzalnih osobina fotonske refleksije, što treba da rezultira uspostavljanjem semi-analitičkog modela koji fotonsku refleksiju od ravne mete u širem opsegu inicijalnih energija opisuje univerzalnim funkcijama, validnim za različite materijale i za različite energije upadnih fotona.

U cilju provere rezultata dobijenih ovako razvijenim modelom, biće izvršeno njihovo poređenje sa raspoloživim rezultatima iz literature. Raspoloživi rezultati odnose se uglavnom na integralne parametre fotonske refleksije (ukupni brojni i ukupni energetska albedo), dok su rezultati za diferencijalne parametre (energetske i ugaone raspodele reflektovanih fotona, a posebno doprinosi pojedinih sudara) još uvek nesistematski. Ova disertacija doprineće poboljšanju sistematičnosti ovakvih rezultata.

Rezultati doktorske disertacije biće, između ostalog, nastavak već publikovanih rezultata u sledećim referencama:

- S. Marković, V. Ljubenov, O. Ciraj, R. Simović: *Calculation of Scattered Radiation Around a Patient Subjected to the X-ray Diagnostic Examination*, First International Meeting on Applied Physics APHYS 2003, Badajoz, Spain, October 13-18, 2003, published in Recent Advances in Multidisciplinary Applied Physics (ed. A. Mendez-Vilas), pp. 751-756. S. Marković, V. Ljubenov, O. Ciraj, R. Simović: *Reflected Radiation Assessment in Contrast X-ray Diagnostics*, Radiation Physics and Chemistry, Vol. 71 (2004), Issues 3-4, October-November 2004, pp. 989-990
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4. Naučne metode istraživanja

Istraživanja će biti bazirana na detaljnim Monte Karlo modelima i simulacijama fotonske refleksije od različitih materijala u širem opsegu energija inicijalnih fotona metodom „sudar po sudar“. Za ovu svrhu biće korišćen referentni Monte Karlo program MCNP. Istraživanja će proširiti prethodno dobijene rezultate za refleksiju fotona u niskoenergetskoj oblasti. Modeli za Monte Karlo simulacije, razvijeni ranije, biće modifikovani da omoguće određivanje doprinosa refleksiji od broja sudara u materijalu mete. Biće razmatrani materijali od najvećeg interesa za praktične primene (voda, beton, aluminijum, gvožđe, bakar i olovo). Fizički procesi interakcije fotona sa materijalom mete biće tretirani egzaktno, bez aproksimacija, koristeći biblioteke efikasnih preseka kontinualne po energiji fotona.

Rezultati Monte Karlo simulacija biće iskorišćeni za analize primenljivosti postojećih analitičkih modela za opisivanje ukupne refleksije preko jedanput i dva puta rasejanih fotona, kao i za uspostavljanje semi-analitičkog modela koji fotonsku refleksiju od ravne mete opisuje univerzalnim funkcijama, validnim za različite materijale i za različite energije upadnih fotona.

5. Očekivani naučni doprinos

Poslednjih godina istraživači u oblasti primenjene transportne teorije različitih čestica, poput jona, elektrona, neutrona i fotona, intenzivno su se bavili proučavanjem mogućnosti predstavljanja

diferencijalnih i integralnih koeficijenata refleksije čestica u obliku univerzalnih funkcija. Primeri ovakvih istraživanja prikazani su u radovima:

- Vicanek, M., Urbassek, N. M., Reflection Coefficient of Low-Energy Light Ions, *Phys. Rev. B*, 44 (1991), 14, pp. 7234-7242
- Luo, Z, Hou, Q., Can the Light Ion Transport in Heavy Targets be Characterized by a Single Parameter, *Nucl. Instr. and Meth. B*, 95 (1995), pp. 1-6
- Simović, R. D., Vukanić, J., Reflection Coefficients of Low-Energy Light Ions for the Power Form of the Interaction Potential, *Radiat. Phys. Chem.*, 80 (2011), 3, pp. 310-317
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Rezultati ovakvih istraživanja od značaja su i u metodološkom smislu i u pogledu praktične primene. Sa teorijske tačke gledišta, potraga za univerzalnom definicijom koeficijenata refleksije usmerena je na pronalaženje zajedničke metodologije za istraživanje i opisivanje tipično heterogenih procesa transporta čestica. Sa praktične tačke gledišta, određivanje univerzalnih koeficijenata refleksije rezultiraće smanjenom potrebom za korišćenjem obimnih tabela podataka koje se trenutno koriste u inženjerskim priručnicima, kao i u pojednostavljenju njihovog korišćenja (Mashkovich, V. P., Ionizing Radiation Shielding – Manual (in Russian), Energoatomizdat, Moscow, 1982).

U domenu fotonskih energija koje se koriste u medicinskoj dijagnostici (do 100 keV), refleksija fotona bila je predmet intenzivnih istraživanja, uglavnom tehnikama Monte Karlo simulacija, koje su imale za cilj da odrede koeficijente refleksije, ali i semi-analitičkim procedurama, koje su primenjivane u analizama opštih karakteristika fizičkog fenomena refleksije (S. Marković, V. Ljubenov, O. Ciraj, R. Simović: *Calculation of Scattered Radiation Around a Patient Subjected to the X-ray Diagnostic Examination*, First International Meeting on Applied Physics APHY 2003, Badajoz, Spain, October 13-18, 2003, published in Recent Advances in Multidisciplinary Applied Physics (ed. A. Mendez-Vilas), pp. 751-756; V. Ljubenov, R. Simović, S. Marković R. D. Ilić: *Photon Scattering and Reflection in Diagnostic Energy Domain*, Nuclear Technology & Radiation Protection, Vol. XXIII, No.1, pp. 31-36, 2008.). U okviru ovih istraživanja, napravljeni su početni koraci u formulisanju koeficijenata refleksije u obliku univerzalnih analitičkih funkcija, primenljivih u širem opsegu energija upadnih fotona i za različite materijale korišćene u zaštiti od zračenja (Marković, S., Backscattered Radiation Field in Diagnostic Radiology Contrast Techniques, Ph. D. Thesis, Faculty of Electrical Engineering, University of Belgrade, Belgrade, 2008; R. Simović, S. Marković, V. Ljubenov, R. D. Ilić: Total Photon Reflection Coefficients Presented as Universal Functions, Proceedings of LIV Conference ETRAN, paper NT1.2-1-4, Donji Milanovac, Serbia, June 7-10, 2010 (in Serbian, published on CD-ROM only, ISBN 978-86-80509-65-5)).

U okviru predložene disertacije, Monte Karlo simulacije fotonske refleksije rezultiraće trostruko diferencijalnim koeficijentima refleksije (po uglu refleksije, energiji reflektovanih fotona i po broju sudara doživljenih u materijalu mete pre konačne refleksije) za različite materijale mete i u širem opsegu inicijalnih energija fotona (do 200 keV). Rezultati simulacija biće prikupljeni u diskretnim ugaono-energetskim intervalima, čiji će broj i širina biti izabrani tako da omoguće dovoljno precizno praćenje fizičkih procesa, kao i dobijanje rezultata sa prihvatljivom statističkom nesigurnošću. Rezultati će sadržati razdvojene doprinose refleksiji fotona za različite brojeve doživljenih sudara u materijalu mete, što će omogućiti uspostavljanje odnosa između doprinosa refleksiji od jednom i dva puta sudarenih čestica, za koji su ranije uspostavljene analitičke aproksimacije, i ukupne refleksije fotona.

Ovi rezultati biće polazna tačka da se odrede parametri za pojednostavljen semi-analitički tretman, koji može da reprodukuje Monte Karlo rezultate i eksperimentalne rezultate raspoložive u literaturi.

6. Plan istraživanja i struktura rada

U prvoj fazi rada biće razvijen materijalno-geometrijski model (ulazni fajl) za Monte Karlo simulacije transporta fotona kroz materijanu sredinu i za određivanje fotonske refleksije programom MCNP, koji može da odredi doprinose pojedinih sudara ukupnoj refleksiji. Ovaj model biće verifikovan poređenjem dobijenih rezultata za totalne i dvostruko-diferencijalne koeficijente

refleksije sa rezultatima ranijih proračuna programima MCNP, FOTELP i PENELOPE, gde se nije razdvajao doprinos refleksiji od pojedinih sudara. Verifikacija modela u odnosu na određivanje doprinosa refleksiji od pojedinih sudara biće izvršena poređenjem rezultata sa postojećim rezultatima dobijenim programom FOTELP (V. Ljubenov, R. Simović, S. Marković R. D. Ilić: *Photon Scattering and Reflection in Diagnostic Energy Domain*, Nuclear Technology & Radiation Protection, Vol. XXIII, No.1, pp. 31-36, 2008.).

Ovako verifikovan model biće korišćen za simulacije fotonskog transporta i refleksije od vode, betona, aluminijuma, gvožđa, bakra i olova u opsegu inicijalnih energija upadnih fotona do 300 keV za slučaj normalnog upada u materijalnu sredinu. Opseg inicijalnih energija biće pokriven u najmanje 5-6 tačaka za svaki od materijala.

Dobijeni rezultati biće obrađeni da bi se iz njih odredili ukupni čestični i energetski koeficijenti refleksije (doprinos od svih sudara, kao i doprinosi od pojedinih sudara) i dvostruko-diferencijalni koeficijenti refleksije po energijama reflektovanih fotona i po polarnom uglu refleksije (doprinos od svih sudara, kao i doprinosi od pojedinih sudara), kao i srednji broj sudara pre konačne refleksije za svaki razmatrani slučaj (materijal mete i početna energija upadnih fotona).

Analizom ovih rezultata biće uočene univerzalne karakteristike procesa fotonske refleksije u domenu energija do 200 keV i biće predložene univerzalne analitičke funkcije za opisivanje integralnih koeficijenata refleksije. Biće takođe izvedeni zaključci o ponašanju ugaonih i energetskih raspodela reflektovanih fotona za razmatrane slučajeve.

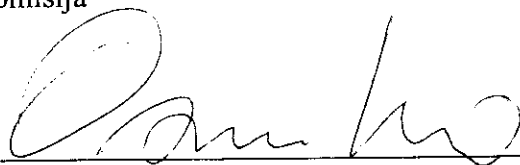
Struktura rada pratiće izloženi plan istraživanja.

7. Zaključak i predlog

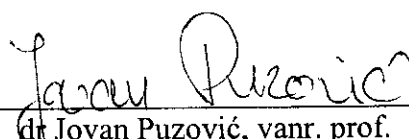
Vladan Ljubenov, dipl. ing., magistar elektrotehničkih nauka, prijavio je svoju doktorsku disertaciju pod naslovom **Univerzalne funkcije refleksije fotona od ravne mete određene analizom transporta zračenja metodom sudar po sudar** u skladu sa Pravilnikom o doktorskim studijama Elektrotehničkog fakulteta Univerziteta u Beogradu, podnevši na uvid sva, pomenutin pravilnikom, predviđena dokumenta. Na osnovu podnesenih dokumenata je konstatovano da je Vladan Ljubenov diplomirao na Elektrotehničkom fakultetu u Beogradu, da je na istom fakultetu završio Postdiplomske studije i odbranio magistarsku tezu, te da ne postoje nikakve zakonske smetnje da prijavi doktorsku disertaciju. Iz dostavljene dokumentacije koja uključuje i bibliografiju do sada objavljenih naučnih i stručnih radova Vladana Ljubenova može se zaključiti da se radi o uspešnom naučnom radniku, te se očekuje da će ciljeve postavljene u prijavi svoje disertacije uspešno obaviti u, za to predviđenom, zakonskom roku. Na osnovu obrazloženja predmeta i cilja istraživanja, polaznih hipoteza istraživanja, očekivanih naučnih doprinosa i plana istraživanja možemo zaključiti da tema prijavljene doktorske disertacije pod naslovom **Univerzalne funkcije refleksije fotona od ravne mete određene analizom transporta zračenja metodom sudar po sudar** omogućava da se u okviru nje ostvare značajni naučni i stručni doprinosi iz oblasti refleksije X i gama zračenja od materijala, kao i iz oblasti zaštite od zračenja reflektovanog unazad. Predloženi mentor prof. dr Predrag Osmokrović je redovni profesor Elektrotehničkog fakulteta Univerziteta u Beogradu sa preko sto objavljenih radova u časopisima sa SCI liste, od kojih i veći broj radova iz oblasti transporta zračenja, a ujedno i rukovodilac fundamentalnih istraživanja Ministarstva za nauku, u kategoriji A1, te u tom smislu smatramo da je kompetentan da obavlja funkciju mentora ove disertacije. Stoga predlažemo Nastavno-naučnom veću da odobri izradu doktorske disertacije kandidata Vladana Ljubenova pod naslovom **Univerzalne funkcije refleksije fotona od ravne mete određene analizom transporta zračenja metodom sudar po sudar**.

U Beogradu,
05.01.2012.

Komisija


dr Predrag Osmokrović, red. prof.


dr Predrag Marinković, red. prof.


dr Jovan Puzović, vanr. prof.
(Fizički fakultet Univerziteta u Beogradu)