

ISSN 1425-204X



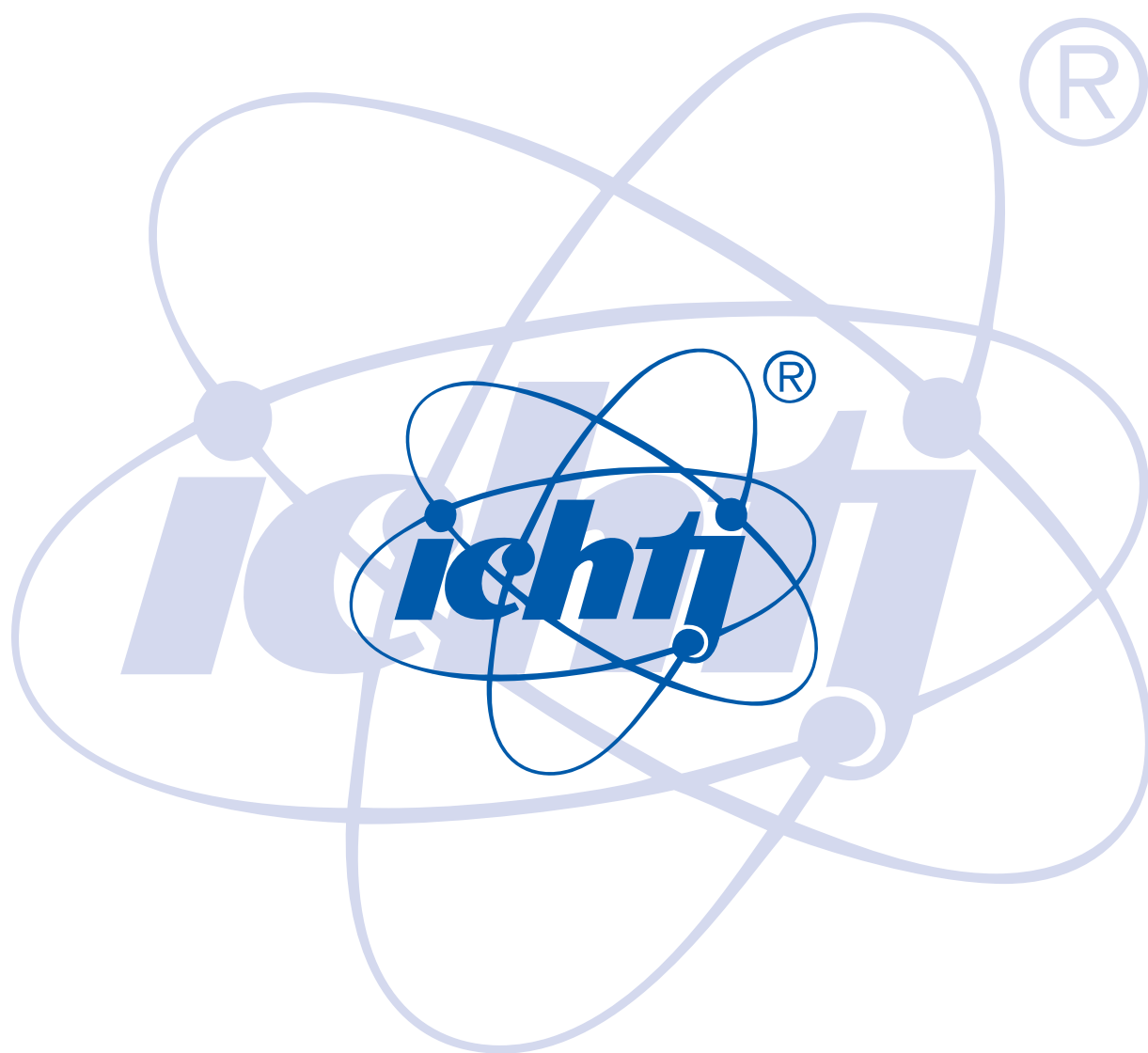
ANNUAL REPORT 2017



INSTITUTE OF NUCLEAR CHEMISTRY AND TECHNOLOGY

ANNUAL REPORT

2017



INSTITUTE
OF NUCLEAR CHEMISTRY
AND TECHNOLOGY

EDITORS

Prof. Jacek Michalik, Ph.D., D.Sc.

Ewa Godlewska-Para, M.Sc.

CONTENTS

GENERAL INFORMATION	7
MANAGEMENT OF THE INSTITUTE	9
MANAGING STAFF OF THE INSTITUTE	9
HEADS OF THE INCT DEPARTMENTS	9
SCIENTIFIC COUNCIL (2015-2017)	9
SCIENTIFIC COUNCIL (2017-2021)	10
ORGANIZATION SCHEME	12
SCIENTIFIC STAFF	13
PROFESSORS	13
SENIOR SCIENTISTS (Ph.D.)	13
CENTRE FOR RADIATION RESEARCH AND TECHNOLOGY	15
PARAMAGNETIC DEFECTS IN GRAPHENE OXIDE IRRADIATED WITH AN ELECTRON BEAM <i>G. Przybytniak, J. Sadło, M. Dąbrowska, B. Sartowska</i>	17
RADIATION MODIFIED ELASTOMERIC COMPOSITES FOR EMC MICROWAVE ABSORBER <i>W. Głuszewski, M. Rajkiewicz, R. Kubacki</i>	19
A CONTINUOUS, NON-INTERFERING LINAC ELECTRON BEAM ENERGY MEASUREMENT SYSTEM FOR RADIATION PROCESSING INSTALLATION <i>S. Bułka, Z. Zimek</i>	20
CENTRE FOR RADIOCHEMISTRY AND NUCLEAR CHEMISTRY	23
⁶⁸ Ga- AND ¹⁷⁷ Lu-RADIOPHARMACEUTICALS BASED ON NEUROKININ-1 RECEPTOR ANTAGONIST SPANTIDE I (5-11) PEPTIDE FOR GLIOBLASTOMA MULTIFORME TREATMENT <i>P.K. Halik, E. Gniazdowska, P. Koźmiński, A. Majkowska-Pilip</i>	25
PREPARATION OF MICROSPHERES OF CARBON BLACK DISPERSION IN URANYL-ASCORBATE GELS AS PRECURSORS OF URANIUM CARBIDE <i>M. Brykała, M. Rogowski, T. Olczak</i>	27
RECOVERY OF URANIUM AND ACCOMPANYING METALS FROM SECONDARY RAW MATERIALS <i>K. Kiegiel, D. Gajda, G. Zakrzewska-Kołodziej</i>	30
NOVEL MAGNETIC COBALT CYANOFERRATE NANOPARTICLES AS A POTENTIAL SORBENT FOR SOLID PHASE EXTRACTION OF RADIONUCLIDES FROM AQUEOUS SAMPLES <i>L. Fuks, D. Wawrzczak, I. Herdzik-Koniecko, T. Smoliński</i>	31
APPLICATION OF ADVANCED MEMBRANE SYSTEMS IN NUCLEAR DESALINATION AS AN EFFECTIVE USE OF COGENERATION <i>G. Zakrzewska-Kołodziej, A. Miśkiewicz, K. Kiegiel, D. Gajda</i>	37
CENTRE FOR RADIOBIOLOGY AND BIOLOGICAL DOSIMETRY	41
STUDIES OF THE NITROSYLATION REACTION OF A PHOSPHINE COMPLEX MODELLING THE IRON CENTRE OF PROTEINS FROM THE CUPIN FAMILY <i>H. Lewandowska, J. Sadło, T. Stepkowski, A. Lankoff, K. Łyczko</i>	42
IMPACT OF NANOPARTICLES ON TOXIC PROPERTIES OF OXIDIZED LOW DENSITY LIPOPROTEIN <i>S. Męczyńska-Wielgosz, M. Wojewódzka, S. Sommer, I. Grądzka, B. Sochanowicz, I. Buraczewska, M. Kruszewski, H. Lewandowska</i>	44
LABORATORY OF NUCLEAR ANALYTICAL METHODS	47
APPLICATION OF IONIZING RADIATION FOR DECOMPOSITION OF BISPHENOL A IN ENVIRONMENTAL SAMPLES <i>A. Bojanowska-Czajka, E. Fornal, T. Szreder, M. Trojanowicz</i>	48

PROFICIENCY TEST ON THE DETERMINATION OF ACTIVITY CONCENTRATIONS OF ²²⁶ Ra, ²⁴¹ Am, ²³⁹ Pu AND ³ H IN FOOD AND ENVIRONMENTAL SAMPLES <i>H. Polkowska-Motrenko, L. Fuks, P. Kalbarczyk, J. Dudek, I. Herdzik-Koniecko, K. Kulisa</i>	52
RECERTIFICATION OF THE POLISH REFERENCE MATERIALS; MODAS-2 BOTTOM SEDIMENT (M-2 BotSed), MODAS-3 HERRING TISSUE (M-3 HerTis), MODAS-4 CORMORANT TISSUE (M-4 CormTis) AND MODAS-5 COD TISSUE (M-5 CodTis) <i>Z. Samczyński, H. Polkowska-Motrenko, R.S. Dybczyński, I. Zuba, E. Chajduk</i>	54
LABORATORY OF MATERIAL RESEARCH	59
STUDIES ON HIGH TEMPERATURE OXIDATION RESISTANCE OF ZIRCONIUM SILICIDE COATINGS ON A ZIRCONIUM ALLOY <i>W. Starosta, V.K. Semina, J. Smolik, L. Waliś, M. Rydzewski, B. Sartowska</i>	61
ACCIDENT TOLERANT MATERIALS: IDEAS AND RESEARCH DIRECTIONS <i>B. Sartowska, W. Starosta, L. Waliś</i>	64
THE USE OF TRACE ELEMENT ANALYSIS ON IRON ARTEFACTS FROM THE PRZEWORSK CULTURE <i>E. Pańczyk, W. Orliński, W. Weker, L. Waliś</i>	67
ANALYSIS OF HISTORIC GLASS USING MICROSAMPLING TECHNIQUES: LA-ICP-MS AND EPMA <i>E. Bakowska, S. Kuenzli, J.J. Kunicki-Goldfinger, J.W. Singer, P. Dzierżanowski</i>	69
POLLUTION CONTROL TECHNOLOGIES LABORATORY	71
NUMERICAL SIMULATION OF NO _x REDUCTION IN AQUEOUS SOLUTION <i>Y. Sun, A. Dobrowolski, O. Roubinek, E. Zwolińska, A. Pawelec, A.G. Chmielewski</i>	73
STABLE ISOTOPE LABORATORY	75
ISOTOPIC AND TRACE ELEMENTS COMPOSITION FOR DIARY PRODUCTS AUTHENTICITY CONTROL <i>R. Wierchnicki, R. Adamska, Z. Samczyński</i>	76
ISOTOPIC STUDY OF APPLE DRINKS <i>R. Wierchnicki, R. Adamska</i>	77
LABORATORY FOR MEASUREMENTS OF TECHNOLOGICAL DOSES	79
LABORATORY FOR DETECTION OF IRRADIATED FOOD	81
INVESTIGATION OF LOW DOSE IRRADIATED DRIED FRUITS BY A STANDARDIZED ELECTRON PARAMAGNETIC RESONANCE DETECTION METHOD <i>G.P. Guzik, M. Miłkowska</i>	83
LABORATORY OF NUCLEAR CONTROL SYSTEMS AND METHODS	87
PUBLICATIONS IN 2017	88
ARTICLES	88
BOOKS	94
CHAPTERS IN BOOKS	95
THE INCT PUBLICATIONS	96
CONFERENCE PROCEEDINGS	97
CONFERENCE ABSTRACTS	99
SUPPLEMENT LIST OF THE PUBLICATIONS IN 2016	108
NUKLEONIKA	109
POSTĘPY TECHNIKI JĄDROWEJ	112
THE INCT PATENTS AND PATENT APPLICATIONS IN 2017	114

PATENTS	114
PATENT APPLICATIONS	114
CONFERENCES ORGANIZED AND CO-ORGANIZED BY THE INCT IN 2017	115
Ph.D./D.Sc. THESES IN 2017	117
Ph.D. THESES	117
D.Sc. THESES	117
EDUCATION	118
Ph.D. PROGRAMME IN CHEMISTRY	118
TRAINING OF STUDENTS	118
MASTER'S, BACHELOR'S AND ENGINEERS'S THESES	119
RESEARCH PROJECTS AND CONTRACTS	121
RESEARCH PROJECTS GRANTED BY THE NATIONAL SCIENCE CENTRE IN 2017	121
PROJECTS GRANTED BY THE NATIONAL CENTRE FOR RESEARCH AND DEVELOPMENT IN 2017	122
IAEA RESEARCH CONTRACTS IN 2017	122
PROJECTS WITHIN THE FRAME OF EUROPEAN UNION PROGRAMME HORIZON 2020	123
OTHER INTERNATIONAL RESEARCH PROGRAMMES IN 2017	123
ERASMUS+ PROGRAMME	124
ANALYSES FOR THE MINISTRY OF ENERGY	124
LIST OF VISITORS TO THE INCT IN 2017	125
THE INCT SEMINARS IN 2017	126
LECTURES AND SEMINARS DELIVERED OUT OF THE INCT IN 2017	127
LECTURES	127
SEMINARS	129
AWARDS IN 2017	131
INDEX OF THE AUTHORS	134

GENERAL INFORMATION

The Institute of Nuclear Chemistry and Technology (INCT) is Poland's leading research institution in the fields of nuclear and radiation chemistry, and radiobiology. Scientific activities of the INCT are dedicated to a wide range of nuclear topics, involving basic and applied research. Basic research is focused on separation processes of actinides and lanthanides, novel radiopharmaceuticals, radiation effects in molecules of biological importance, cells and polymers. With its six electron accelerators, the Institute is one of the most advanced centres in the field of electron beam applications. The various types of accelerators are used for radiation sterilization of medical devices and transplantation grafts, modification of polymers, removal of SO₂ and NO_x from flue gases, and for food irradiation.

The INCT Scientific Council has the right to confer D.Sc. and Ph.D. degrees in the field of chemistry. In 2017, one D.Sc. and six Ph.D. theses were defended in the INCT.

The Institute's expertise and infrastructure made possible the participation in numerous international and domestic projects. In 2017, the INCT started research activity in four projects of the EU programme Horizon 2020, in which leading European institutes and industrial companies participate:

- ARIES: Accelerator research and innovation for European science and society;
- GENIORS: GEN IV integrated oxide fuels recycling strategies;
- TeamCABLES: European tools and methodologies for an efficient ageing management of nuclear power plant cables;
- CHANCE: Characterization of conditioned nuclear waste for its safe disposal in Europe.

Besides, four large projects of the National Centre for Research and Development (NCBR) were carried out, including the specially important for environmental protection project TANGO 2 "Plasma technology for removal nitrogen oxides from flue gases".

There were also 14 projects of the National Science Centre (NCN) led by the INCT researchers, majority of them dedicated to the development of new radiopharmaceuticals for medical diagnosis and therapy.

As the Collaborating Centre in Radiation Technology and Industrial Dosimetry of the International Atomic Energy Agency (IAEA), the Institute coordinated a large-scale inter-comparison test on alanine dosimetry measurements for electron beam and gamma irradiations in which 10 European countries participated. Under the framework of the IAEA Coordinated Research Programme, the INCT researchers took part in 10 IAEA projects cooperating with scientists from numerous countries all over the world. Together with the IAEA, in the framework of ARIES project, the INCT organized the conference "Summer School on Advanced Application of Electron Beam Accelerators" in which 40 scientists from 14 countries participated. The other conferences or seminars organized in 2017 concerned developments and applications of nuclear technologies (together with AGH University of Science and Technology, Kraków, Poland) and radiation modifications of polymers.

For the Ministry of Energy, the INCT prepared two reports important for development of Polish nuclear energy programme:

- the analysis of nuclear waste and burnt fuel treatment in Poland,
- the analysis of ionizing radiation applications in Polish industry together with recommendations for Polish enterprises.

In 2017, the INCT scientists published 80 papers, including 60 publications in scientific journals with an impact factor (IF).

MANAGEMENT OF THE INSTITUTE

MANAGING STAFF OF THE INSTITUTE

Director

Prof. **Andrzej G. Chmielewski**, Ph.D., D.Sc.

Deputy Director for Research and Development

Prof. **Jacek Michalik**, Ph.D., D.Sc.

Deputy Director of Finances

Wojciech Maciąg, M.Sc.

Deputy Director of Maintenance and Marketing

Roman Janusz, M.Sc.

Accountant General

Maria Małkiewicz, M.Sc.

HEADS OF THE INCT DEPARTMENTS

- Centre for Radiation Research and Technology
Zbigniew Zimek, Ph.D.
- Centre for Radiochemistry and Nuclear Chemistry
Prof. **Grażyna Zakrzewska-Kołtuniewicz**, Ph.D., D.Sc.
- Centre for Radiobiology and Biological Dosimetry
Prof. **Marcin Kruszewski**, Ph.D., D.Sc.
- Laboratory of Nuclear Control Systems and Methods
Jacek Palige, Ph.D.
- Laboratory of Material Research
Wojciech Starosta, Ph.D.
- Laboratory of Nuclear Analytical Methods
Halina Polkowska-Motrenko, Ph.D., D.Sc., professor in INCT
- Stable Isotope Laboratory
Ryszard Wierzchnicki, Ph.D.
- Pollution Control Technologies Laboratory
Yongxia Sun, Ph.D., D.Sc., professor in INCT
- Laboratory for Detection of Irradiated Food
Grażyna Liśkiewicz
- Laboratory for Measurements of Technological Doses
Anna Korzeniowska-Sobczuk, M.Sc.

SCIENTIFIC COUNCIL (2015-2017)

1. Prof. **Aleksander Bilewicz**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology
2. Prof. **Krzysztof Bobrowski**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology
3. Prof. **Ewa Bulska**, Ph.D., D.Sc.
University of Warsaw
4. **Sylwester Bułka**, M.Sc.
Institute of Nuclear Chemistry and Technology
5. Prof. **Andrzej G. Chmielewski**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology
6. **Tomasz Ciach**, Ph.D., D.Sc., professor in WUT
Warsaw University of Technology
7. Prof. **Jan Czesław Dobrowolski**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology
8. Prof. **Rajmund Dybczyński**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology

- | | |
|---|---|
| <p>9. Prof. Zbigniew Florjańczyk, Ph.D., D.Sc.
(Chairman)
Warsaw University of Technology</p> <p>10. Prof. Zbigniew Galus, Ph.D., D.Sc.
University of Warsaw</p> <p>11. Prof. Janusz Gołaszewski, Ph.D., D.Sc.
University of Warmia and Mazury</p> <p>12. Prof. Henryk Górecki, Ph.D., D.Sc.
Wrocław University of Technology</p> <p>13. Edward Iller, Ph.D., D.Sc., professor in NCBJ
National Centre for Nuclear Research</p> <p>14. †Michał Jamróz, Ph.D., D.Sc., professor
in INCT
Institute of Nuclear Chemistry and Technology</p> <p>15. Prof. Marek Janiak, Ph.D., D.Sc.
Military Institute of Hygiene and Epidemiology</p> <p>16. Rafał Kocia, Ph.D.
Institute of Nuclear Chemistry and Technology</p> <p>17. Prof. Marcin Kruszewski, Ph.D., D.Sc.
(Vice-chairman)
Institute of Nuclear Chemistry and Technology</p> <p>18. Krzysztof Kulisa, Eng.
Institute of Nuclear Chemistry and Technology</p> <p>19. Prof. Anna Lankoff, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology</p> <p>20. Prof. Marek Wojciech Lankosz, Ph.D., D.Sc.
AGH University of Science and Technology</p> <p>21. Prof. Jacek Michalik, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology</p> <p>22. Wojciech Migdał, Ph.D., D.Sc., professor
in INCT
Institute of Nuclear Chemistry and Technology</p> | <p>23. Prof. Jarosław Mizera, Ph.D., D.Sc.
Warsaw University of Technology</p> <p>24. Prof. Jan Namieśnik, Ph.D., D.Sc.
Gdańsk University of Technology</p> <p>25. Prof. Jerzy Ostyk-Narbutt, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology</p> <p>26. Andrzej Pawlukojeć, Ph.D., D.Sc., professor
in INCT
Institute of Nuclear Chemistry and Technology</p> <p>27. Halina Polkowska-Motrenko, Ph.D., D.Sc.,
professor in INCT
(Vice-chairman)
Institute of Nuclear Chemistry and Technology</p> <p>28. Marek Pruszyński, Ph.D.
Institute of Nuclear Chemistry and Technology</p> <p>29. Grażyna Przybytniak, Ph.D., D.Sc., professor
in INCT
Institute of Nuclear Chemistry and Technology</p> <p>30. Prof. Janusz Rosiak, Ph.D., D.Sc.
Technical University of Łódź</p> <p>31. Yongxia Sun, Ph.D., D.Sc., professor in INCT
Institute of Nuclear Chemistry and Technology</p> <p>32. Prof. Marek Trojanowicz, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology</p> <p>33. Lech Waliś, Ph.D.
Institute of Nuclear Chemistry and Technology</p> <p>34. Maria Wojewódzka, Ph.D.
Institute of Nuclear Chemistry and Technology</p> <p>35. Prof. Grażyna Zakrzewska-Kołtuniewicz, Ph.D.,
D.Sc.
(Vice-chairman)
Institute of Nuclear Chemistry and Technology</p> |
|---|---|

HONORARY MEMBERS OF THE INCT SCIENTIFIC COUNCIL (2015-2017)

- | | |
|--|--|
| <p>1. Prof. Sławomir Siekierski, Ph.D.</p> <p>2. Prof. Zbigniew Szot, Ph.D., D.Sc.</p> | <p>3. Prof. Irena Szumiel, Ph.D., D.Sc.</p> |
|--|--|

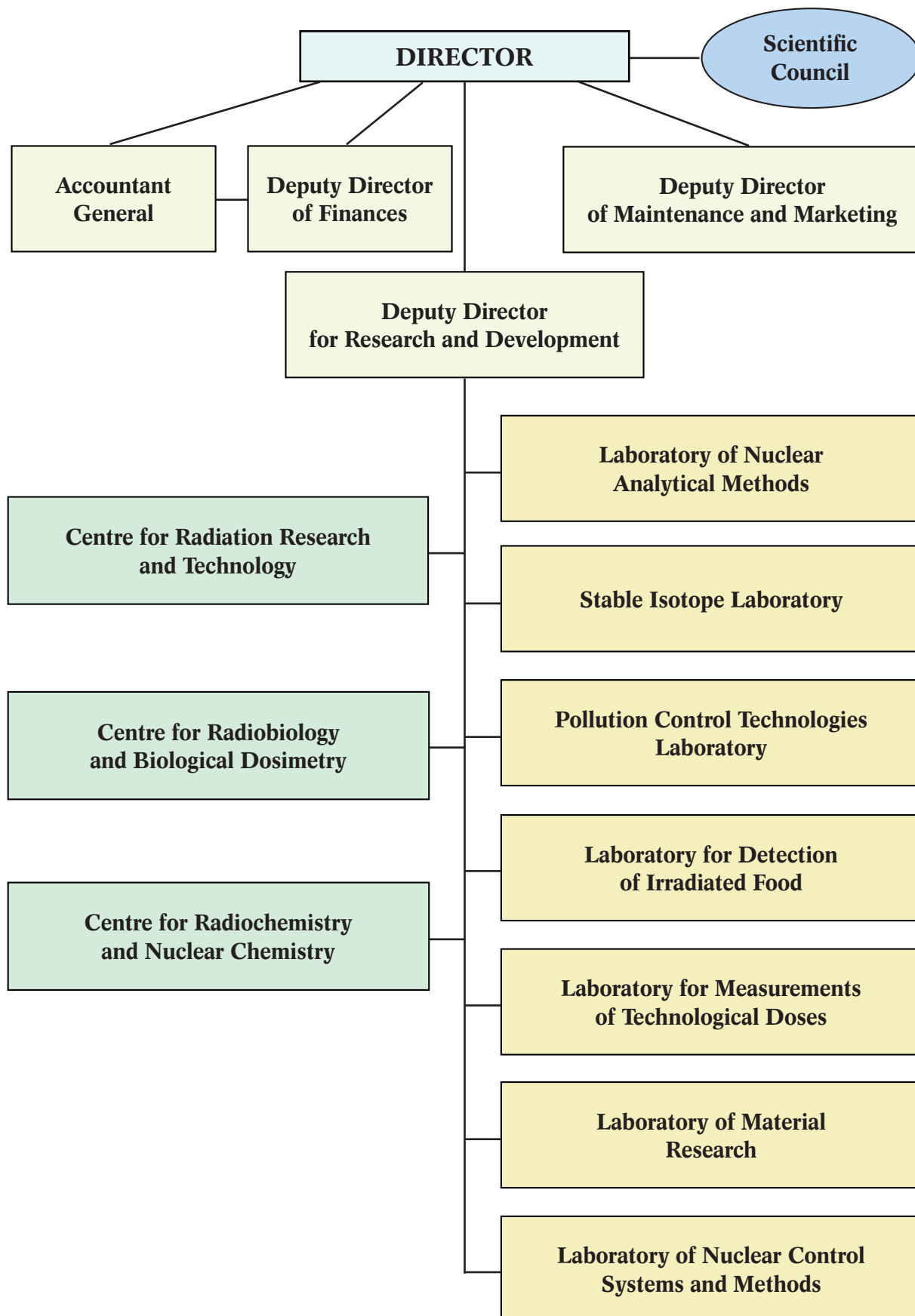
SCIENTIFIC COUNCIL (2017-2021)

- | | |
|---|--|
| <p>1. Krzysztof Bajdor, Ph.D.
Institute of Industrial Organic Chemistry</p> <p>2. Prof. Aleksander Bilewicz, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology</p> <p>3. Prof. Krzysztof Bobrowski, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology</p> <p>4. Prof. Ewa Bulska, Ph.D., D.Sc.
University of Warsaw</p> | <p>5. Prof. Andrzej G. Chmielewski, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology</p> <p>6. Andrzej Cholerzyński, M.Sc.
ZUOP Radioactive Waste Management Plant</p> <p>7. Danuta Ciechańska, Ph.D., D.Sc., professor
IBWCh
Institute of Biopolymers and Chemical Fibres</p> <p>8. Prof. Jan Czesław Dobrowolski, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology</p> |
|---|--|

9. Prof. **Rajmund Dybczyński**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology
10. Prof. **Zbigniew Florjańczyk**, Ph.D., D.Sc.
(Chairman)
Warsaw University of Technology
11. **Ewa Gniazdowska**, Ph.D., D.Sc., professor
in INCT
Institute of Nuclear Chemistry and Technology
12. **Edward Iller**, Ph.D., D.Sc., professor in NCBJ
National Centre for Nuclear Research
13. Prof. **Marek Janiak**, Ph.D., D.Sc.
Military Institute of Hygiene and Epidemiology
14. Prof. **Artur Kamiński**, Ph.D., D.Sc.
Medical University of Warsaw
15. **Rafał Kocia**, Ph.D.
Institute of Nuclear Chemistry and Technology
16. **Paweł Krajewski**, Ph.D.
Central Laboratory for Radiological Protection
17. Prof. **Marcin Kruszewski**, Ph.D., D.Sc.
(Vice-chairman)
Institute of Nuclear Chemistry and Technology
18. **Krzysztof Kurek**, Ph.D., D.Sc., professor in NCBJ
National Centre for Nuclear Research
19. Prof. **Anna Lankoff**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology
20. Prof. **Marek Wojciech Lankosz**, Ph.D., D.Sc.
AGH University of Science and Technology
21. Prof. **Andrzej Marcinek**, Ph.D., D.Sc.
Łódź University of Technology
22. Prof. **Tomasz Matulewicz**, Ph.D., D.Sc.
University of Warsaw
23. Prof. **Jacek Michalik**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology
24. **Wojciech Migdał**, Ph.D., D.Sc., professor
in INCT
Institute of Nuclear Chemistry and Technology
25. Prof. **Jarosław Mizera**, Ph.D., D.Sc.
Warsaw University of Technology
26. Prof. **Eugeniusz Molga**, Ph.D., D.Sc.
Warsaw University of Technology
27. Prof. **Jan Namieśnik**, Ph.D., D.Sc.
Gdańsk University of Technology
28. Prof. **Jerzy Ostyk-Narbutt**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology
29. **Dariusz Pogocki**, Ph.D., D.Sc., professor
in INCT
Institute of Nuclear Chemistry and Technology
30. **Halina Polkowska-Motrenko**, Ph.D., D.Sc.,
professor in INCT
Institute of Nuclear Chemistry and Technology
31. **Grażyna Przybytniak**, Ph.D., D.Sc., professor
in INCT
Institute of Nuclear Chemistry and Technology
32. Prof. **Krzysztof Rusek**, Ph.D., D.Sc.
University of Warsaw
33. **Józef Sobolewski**, Ph.D.
Ministry of Energy, Department of Nuclear Energy
34. **Yongxia Sun**, Ph.D., D.Sc., professor in INCT
Institute of Nuclear Chemistry and Technology
35. Prof. **Marek Trojanowicz**, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology
36. Prof. **Krzysztof Walczak**, Ph.D., D.Sc.
Silesian University of Technology
37. Prof. **Grażyna Zakrzewska-Kołtuniewicz**, Ph.D.,
D.Sc.
(Vice-chairman)
Institute of Nuclear Chemistry and Technology
38. Prof. **Krzysztof Zaremba**, Ph.D., D.Sc.
Warsaw University of Technology

HONORARY MEMBERS OF THE INCT SCIENTIFIC COUNCIL (2017-2021)

1. Prof. **Sławomir Siekierski**, Ph.D.
2. Prof. **Irena Szumiel**, Ph.D., D.Sc.

ORGANIZATION SCHEME

SCIENTIFIC STAFF

PROFESSORS

1. **Bilewicz Aleksander**
radiochemistry, inorganic chemistry
2. **Bobrowski Krzysztof**
radiation chemistry, photochemistry, biophysics
3. **Chmielewski Andrzej G.**
chemical and process engineering, nuclear chemical engineering, isotope chemistry
4. **Cieśla Krystyna**, professor in INCT
physical chemistry
5. **Dobrowolski Jan Cz.**
physical chemistry
6. **Dybczyński Rajmund**
analytical chemistry
7. **Gniazdowska Ewa**, professor in INCT
chemistry
8. **†Jamróz Michał**, professor in INCT
chemistry, physics
9. **Kruszewski Marcin**
radiobiology
10. **Lankoff Anna**
biology
11. **Lipkowski Janusz**
physical chemistry
12. **Michalik Jacek**
radiation chemistry, surface chemistry, radical chemistry
13. **Migdał Wojciech**, professor in INCT
chemistry, science of commodities
14. **Ostyk-Narbutt Jerzy**
radiochemistry, coordination chemistry
15. **Pawlukojć Andrzej**, professor in INCT
chemistry
16. **Pogocki Dariusz**, professor in INCT
radiation chemistry, pulse radiolysis
17. **Polkowska-Motrenko Halina**, professor in INCT
analytical chemistry
18. **Przybytniak Grażyna**, professor in INCT
radiation chemistry
19. **Siekierski Sławomir**
physical chemistry, inorganic chemistry
20. **Sun Yongxia**, professor in INCT
chemistry
21. **Trojanowicz Marek**
analytical chemistry
22. **Zakrzewska-Kołodziej Grażyna**
process and chemical engineering

SENIOR SCIENTISTS (Ph.D.)

1. **Bartłomiejczyk Teresa**
biology
2. **Bartosiewicz Iwona**
chemistry
3. **Bojanowska-Czajka Anna**
chemistry
4. **Brykała Marcin**
chemistry
5. **Brzóška Kamil**
biochemistry
6. **Chajduk Ewelina**
chemistry
7. **Danilczuk Marek (Ph.D., D.Sc.)**
chemistry
8. **Dobrowolski Andrzej**
chemistry
9. **Dudek Jakub**
chemistry
10. **Fuks Leon**
chemistry
11. **Głuszewski Wojciech**
chemistry
12. **Grądzka Iwona**
biology
13. **Guzik Grzegorz**
chemistry
14. **Herdzik-Koniecko Irena**
chemistry

-
- | | |
|--|---|
| 15. Kciuk Gabriel
chemistry | 36. Rode Joanna
chemistry |
| 16. Kiegiel Katarzyna
chemistry | 37. Roubinek Otton
chemistry |
| 17. Kocia Rafał
chemistry | 38. Sadło Jarosław
chemistry |
| 18. Kornacka Ewa
chemistry | 39. Samczyński Zbigniew
analytical chemistry |
| 19. Koźmiński Przemysław
chemistry | 40. Sartowska Bożena
material engineering |
| 20. Kunicki-Goldfinger Jerzy
conservator/restorer of art | 41. Sochanowicz Barbara
biology |
| 21. Latek Stanisław
nuclear physics | 42. Sommer Sylwester
radiobiology, cytogenetics |
| 22. Lewandowska-Siwkiewicz Hanna
chemistry | 43. Starosta Wojciech
chemistry |
| 23. Łuczyńska Katarzyna
chemistry | 44. Sterniczuk Macin
chemistry |
| 24. Łyczko Krzysztof
chemistry | 45. Szreder Tomasz
chemistry |
| 25. Łyczko Monika
chemistry | 46. Waliś Lech
material science, material engineering |
| 26. Majkowska-Pilip Agnieszka
chemistry | 47. Walo Marta
chemistry |
| 27. Męczyńska-Wielgosz Sylwia
chemistry | 48. Wawszczak Danuta
chemistry |
| 28. Miśkiewicz Agnieszka
chemistry | 49. Wierzchnicki Ryszard
chemical engineering |
| 29. Nowicki Andrzej
organic chemistry and technology,
high-temperature technology | 50. Wiśniowski Paweł
radiation chemistry, photochemistry, biophysics |
| 30. Ostrowski Sławomir
chemistry | 51. Wojewódzka Maria
radiobiology |
| 31. Palige Jacek
metallurgy | 52. Wójciuk Grzegorz
chemistry |
| 32. Pawelec Andrzej
chemical engineering | 53. Wójciuk Karolina
chemistry |
| 33. Pruszyński Marek
chemistry | 54. Zimek Zbigniew
electronics, accelerator techniques, radiation
processing |
| 34. Ptaszek Sylwia
chemical engineering | 55. Zwolińska Ewa
chemistry |
| 35. Rafalski Andrzej
radiation chemistry | |

CENTRE FOR RADIATION RESEARCH AND TECHNOLOGY

The electron beams (EB) offered by the Centre for Radiation Research and Technology located at the Institute of Nuclear Chemistry and Technology (INCT) are dedicated to basic research, R&D study, and practical applications of radiation technology.

The Centre, in collaboration with the universities from Poland and abroad, applies EB technology to fundamental research on electron beam-induced chemistry and the transformation of materials. Research in the field of radiation chemistry includes studies on the mechanism and kinetics of radiation-induced processes in liquid and solid phases by the pulse radiolysis method. The pulse radiolysis experimental set up allows for direct time-resolved observation of short-lived intermediates (typically within the nanosecond to millisecond time domain), and is complemented by steady-state radiolysis, stopped-flow absorption spectrofluorimetry, and product analysis using chromatographic methods. Studies on radiation-induced intermediates are dedicated to the processes of energy and charge transfer, to radical reactions in model compounds of biologically relevant aromatic thioethers, peptides and proteins, and also to the observation of atoms, clusters, and radicals by electron paramagnetic resonance (EPR) and electron nuclear double resonance (ENDOR). Further, these studies are also focused on research problems in nanophase chemistry and the radiation-induced crosslinking of selected and/or modified polymers and copolymers.

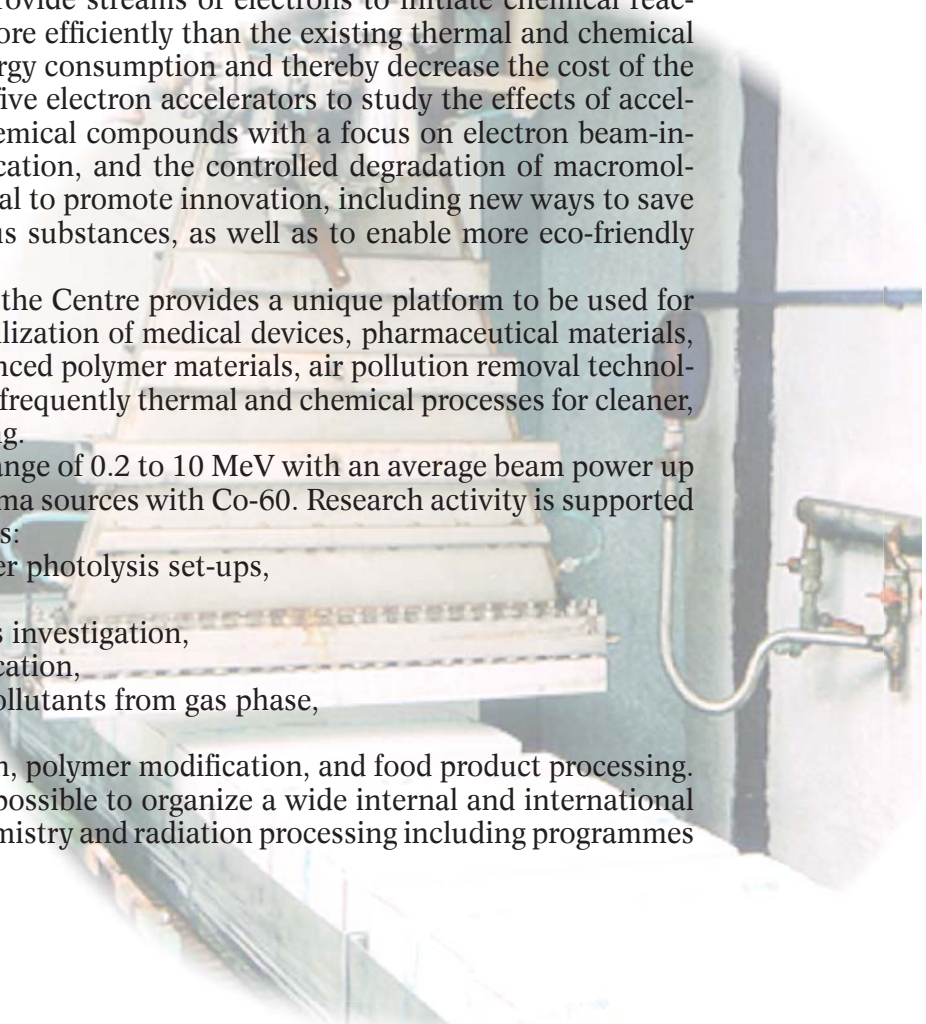
This research has a wide range of potential applications, including creating more environmentally friendly and sustainable packaging, improving product safety, and modifying material properties. Electron accelerators provide streams of electrons to initiate chemical reactions or break down chemical bonds more efficiently than the existing thermal and chemical approaches, thus helping to reduce energy consumption and thereby decrease the cost of the processes. The Centre currently offers five electron accelerators to study the effects of accelerated electrons on a wide range of chemical compounds with a focus on electron beam-induced polymerization, polymer modification, and the controlled degradation of macromolecules. EB technology has great potential to promote innovation, including new ways to save energy and reduce the use of hazardous substances, as well as to enable more eco-friendly manufacturing processes.

Advanced EB technology offered by the Centre provides a unique platform to be used for some of the following applications: sterilization of medical devices, pharmaceutical materials, shelf-life extension food products, advanced polymer materials, air pollution removal technology, and others. EB accelerators replace frequently thermal and chemical processes for cleaner, more efficient, lower cost manufacturing.

The Centre offers EB in the energy range of 0.2 to 10 MeV with an average beam power up to 20 kW and three laboratory-size gamma sources with Co-60. Research activity is supported by unique laboratory equipment such as:

- nanosecond pulse radiolysis and laser photolysis set-ups,
- stopped-flow experimental set-up,
- EPR spectroscopy for solid materials investigation,
- pilot installation for polymer modification,
- experimental stand for removal of pollutants from gas phase,
- polymer characterization laboratory,
- pilot facility for radiation sterilization, polymer modification, and food product processing.

The unique technical core makes it possible to organize a wide internal and international cooperation in the field of radiation chemistry and radiation processing including programmes



supported by the European Union and the International Atomic Energy Agency (IAEA). It should be noted that currently there are no other suitable European experimental platforms for the study of radiation chemistry, physics and radiation processing in a full range of electron energy and beam power.

Since 2010, at the INCT and based on the Centre for Radiation Research and Technology, an IAEA Collaborating Centre for Radiation Processing and Industrial Dosimetry is functioning. That is the best example of the capability and great potential of concentrated equipment, as well as of the employed methods and staff working towards the application of innovative radiation technology.

PARAMAGNETIC DEFECTS IN GRAPHENE OXIDE IRRADIATED WITH AN ELECTRON BEAM

Grażyna Przybytniak, Jarosław Sadło, Małgorzata Dąbrowska, Bożena Sartowska

Studies on graphene and its derivatives are objects of interest for many researchers representing various disciplines. Radiation chemistry provides the specific tools that are able to enhance our current understanding of the features of these unique materials, answering questions about the nature of the interactions between high energy electrons and the layered structure of graphene.

So far, the issue of whether high energy electrons decrease or increase the order in the structures of graphene (G) or graphene oxide (GO) remains unresolved [1, 2]. Previous studies on

carbon nanotubes showed that the effect might be a function of temperature, as in the range of 200-300°C a reduction in the number of the lattice defects was confirmed, whereas at ambient temperature their population was raised significantly [3]. Similar phenomena might be expected in G and GO. These problems are important because irradiation might influence electron transfer and heat conductivity throughout GO lattices, as well as the content of chemical groups.

The general objective of the research was to determine the effects initiated by ionizing radiation in GO with regards to the qualitative and quantitative changes in the population of paramagnetic defects. Graphene oxide was synthesized at the Institute of Electronic Materials Technology (ITME) using a modified Hummers' method [4]. Changes induced by a 10 MeV electron beam generated in an Elektronika accelerator (Institute of Nuclear Chemistry and Technology, INCT) were monitored by electron paramagnetic resonance (EPR) spectroscopy, scanning electron microscopy (SEM) and thermogravimetric analysis (TGA) methods.

The SEM images presented in Fig. 1 reveal the morphology of graphene oxide. The porous structure was constructed from thin GO flakes. The multilayered structures of large, wrinkled surfaces had a thickness which depended on the number of stacked sheets. As seen from the SEM images, the GO flakes showed a thickness of about 20 nm. The wrinkles on the surfaces were probably formed during synthesis of the carbon nanostructures. The images of the material did not change noticeably upon electron beam irradiation with doses up to 1200 kGy, which indicated a negligible influence of electrons on the morphology of GO.

During heating in an air atmosphere, GO decayed showing three characteristic stages (Fig. 2). At temperatures below 150°C, water and weakly bound functional groups were emitted. The second step, around 200°C, was attributed to the release

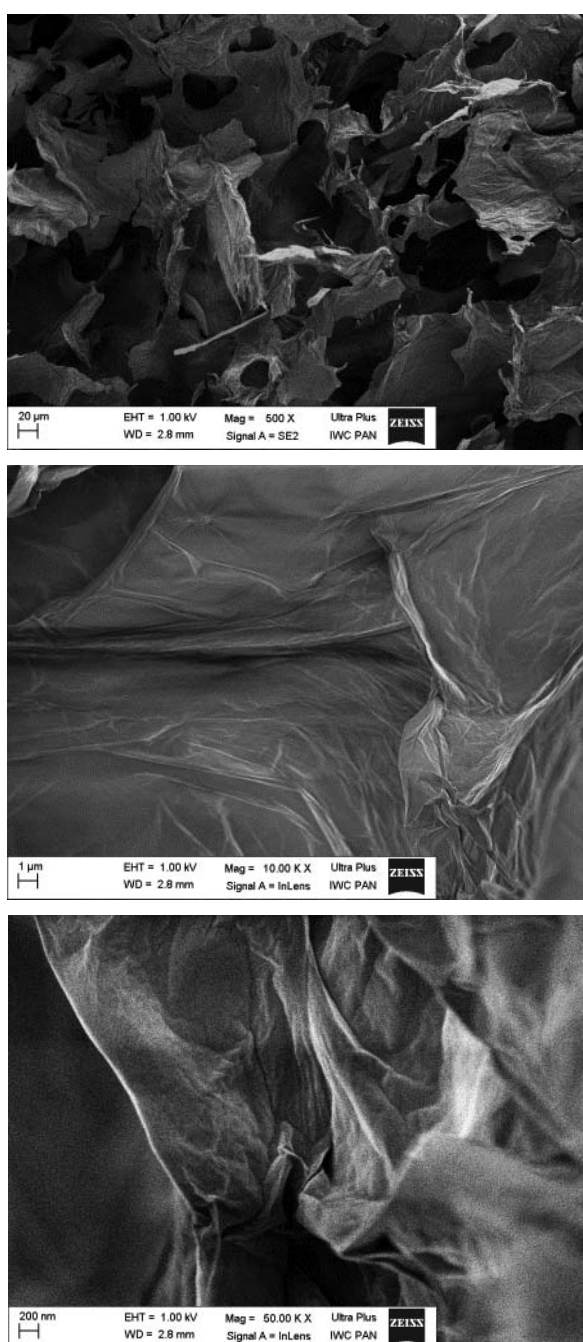


Fig. 1. SEM images of graphene oxide with different magnifications.

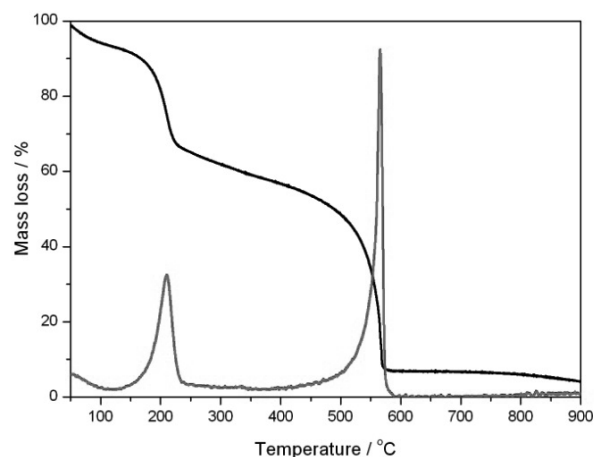


Fig. 2. TGA and DTG (derivative thermogravimetric analysis) relationships of GO determined in an air flow.

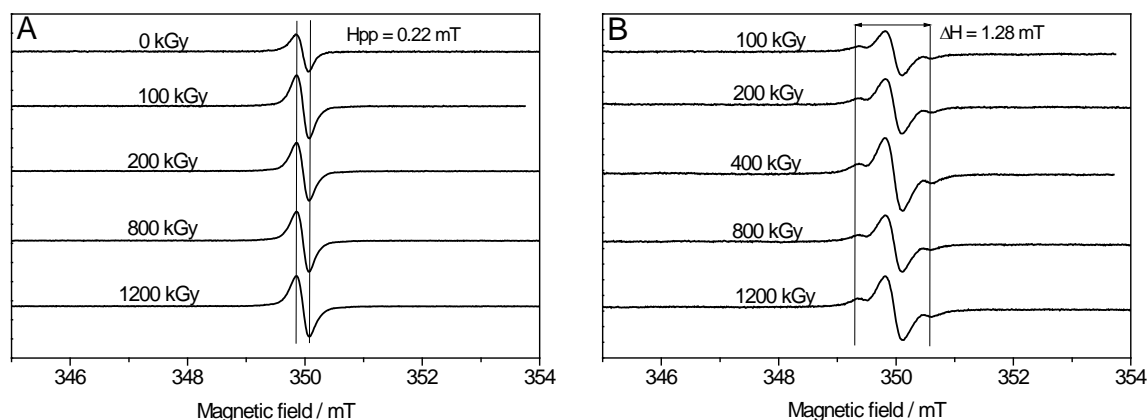


Fig. 3. EPR spectra of graphene oxide measured at two different microwave powers: (A) 1 mW and (B) 100 mW.

of labile oxygen-containing groups, predominantly CO and CO₂. After a mass loss of about 35%, the rest of the functional groups were separated from each other and needed higher temperatures to be removed [5]. They were emitted simultaneously with thermal oxidation of the carbon lattice occurring in the last stage of decomposition. In this case, differences in the thermograms of irradiated and non-irradiated GO were negligible.

EPR spectroscopy of GO disclosed all the paramagnetic defects in graphene oxide (Fig. 3A). At low microwave power (1 mW), only a narrow singlet was observed with a peak-to-peak linewidth of about 0.22 mT and $g = 2.0029$. As shown in Fig. 4, the initial intensity of the spectrum increased with the doses used. The spectral parameters remained almost the same, whereas the height of the signals increased significantly. However, for doses over 200 kGy, the population of paramagnetic defects did not change significantly. When the microwave power was increased up to 100 mW, additional low- and high-field wings separated by $\Delta H = 1.28$ mT appeared, while the central singlet became wider and partly saturated (Fig. 3B).

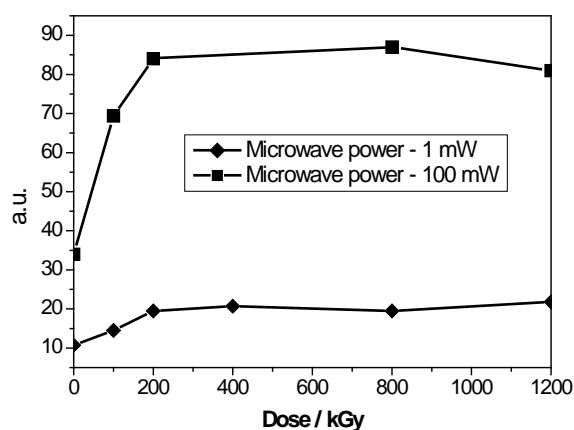


Fig. 4. Relative content of paramagnetic centres in GO irradiated with various doses determined by double integration of the experimental signals.

Based on the analysis of the EPR spectra we concluded that:

- There are at least two types of paramagnetic defects in graphene oxide, situated either at the edges of the GO flakes or on their surfaces.

- The wider signal might be tentatively assigned to defects in which unpaired spin interacts with oxygen atoms. Spectra attributed to such structures are usually broader and insensitive to microwave power saturation.
- Electron beam irradiation initially increases the population of paramagnetic centres. Their nature is similar to the defects existing before exposure to ionizing radiation because although the intensity of the EPR spectra increases, the signal parameters remain unchanged.
- Electrons are presumably trapped by the pre-existing non-paramagnetic defects.
- As seen from EPR spectra, upon absorption of a dose greater than 200 kGy the amount of paramagnetic centres reaches a plateau. It seems that with increasing doses the number of suitable defects playing the role of electron traps is reduced, which results in more efficient recombination of electrons due to a cage effect. The process might be enhanced by repulsion from other captured electrons.

References

- [1]. Banhart, F. (1999). Irradiation effects in carbon nanostructures. *Rep. Prog. Phys.*, 62, 1181-1221. doi.org/10.1088/0034-4885/62/8/201.
- [2]. Banhart, F., Kotakoski, J., & Krasheninnikov, A.V. (2011). Structural defects in graphene. *ACS Nano*, 5, 26-41. DOI: 10.1021/nn102598m.
- [3]. Krasheninnikov, A.V., Lehtinen, P.O., Foster, A.S., & Nieminen, R.M. (2006). Bending the rules: Contrasting vacancy energetics and migration in graphite and carbon nanotubes. *Chem. Phys. Lett.*, 418, 132-136. DOI: 10.1016/j.cplett.2005.10.106.
- [4]. Sobon, G., Sotor, J., Jagiello, J., Kozinski, R., Zdrojek, M., Holdynski, M., Paletko, P., Boguslawski, J., Lipinska, L., & Abramski, K.M. (2012). Graphene oxide vs. reduced graphene oxide as saturable absorbers for Er-doped passively mode-locked fiber laser. *Opt. Express*, 20, 19463-19473. doi.org/10.1364/OE.20.019463.
- [5]. Lavin-Lopez, M.P., Paton-Carrero, A., Sanchez-Silva, L., Valverde, J.L., & Romero, A. (2017). Influence of the reduction strategy in the synthesis of reduced graphene oxide. *Adv. Powder Technol.*, 28, 3195-3203. doi.org/10.1016/j.apt.2017.09.032.

RADIATION MODIFIED ELASTOMERIC COMPOSITES FOR EMC MICROWAVE ABSORBER

Wojciech Głuszewski^{1/}, Maria Rajkiewicz^{2/}, Roman Kubacki^{3/}

^{1/} Institute of Nuclear Chemistry and Technology, Warszawa, Poland

^{2/} Institute for Engineering of Polymer Materials and Dyes, Toruń, Poland

^{3/} Faculty of Electronics, Military University of Technology, Warszawa, Poland

EMC (electromagnetic compatibility) is the branch of electrical engineering concerned with the unintentional generation, propagation and reception of electromagnetic energy, which may cause unwanted effects such as electromagnetic interference (EMI) or even physical damage to operational equipment. The goal of EMC is the correct operation of various types of equipment in a common electromagnetic environment. EMC absorbers tested by the Military University of Technology used elastomer sheets containing magnetic material. They include species targeted to absorb specific frequency bands, as well as components that absorb noise across a wide frequency band.

In some circumstances, there is a need to perform an electromagnetic compatibility investigation not in a specialized anechoic chamber, but in an open space. However, the typical absorbers used in anechoic chambers to absorb the incident radiation and to reduce the reflected rays from walls and floor, such as ferrite tiles and graphite cones, are not suitable for use in open spaces. In this work, the design and investigation of an absorbing material intended to be used to make tents or to produce other light and portable constructions are described. The proposed composite material has good absorbing properties as well as low reflectivity.

Radiation techniques have been used to modify both electronic materials [1] and polymers [2]. In the above example, both processes were combined. The aim of the study was to find new microwave absorbing materials with the following parameters: reduced weight compared to typical ferrites, elasticity, the possibility of being used on the ground outdoors and mechanical resistance to stress and strain, *e.g.* driving with a motor vehicle. Engage™ polyolefin elastomers (POEs) of the ethylene/octene or ethylene/butene type were selected for testing as composite matrices [3]. It was assumed that suitable composite materials would be based on a new generation of compounds containing ferromagnetic components that exhibit very good damping properties for electromagnetic radiation over a wide frequency range. Various compositions of materials were measured, and the following composition was selected as the final one: metallic glass (70%) with graphite admixture (1%) and Engage 8200 elastomer (29%).

A new composite material, based on a nanocrystalline-amorphous alloy based on iron, was used to synthesize a new absorber. Nanocrystalline alloys are very attractive soft magnetic materials. Metallic glass is used as a precursor to produce nanocrystalline alloys. A nanocrystalline alloy with a composition of $\text{Fe}_{73.5}\text{Si}_{13.5}\text{B}_9\text{Nb}_5\text{Cu}_1$

(FINEMET), formed by Yoshizawa *et al.* [4], was the first alloy of this type, and was used as the absorbing material in this work. The quenched, amorphous ribbon was annealed for 1 h at a temperature of 550°C to induce partial crystallization, allowing us to obtain a mean grain size of 10-15 nm. Afterwards, the annealed ribbon was crushed and ball milled to obtain a powder with a particle size of 25-50 μm (Fig. 1).

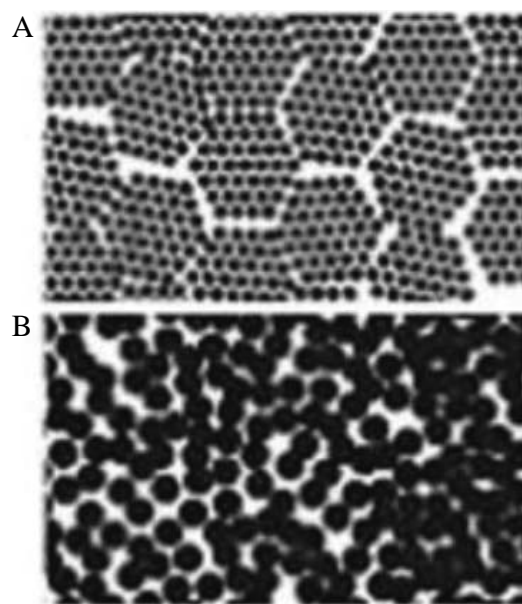


Fig. 1. Comparison of (A) the crystalline structure with (B) the amorphous structure of the metallic glass.

To obtain improved electrical properties, the nanocrystalline alloy powder was mixed with graphite. In addition, in order to improve the absorption properties of the metallic glass, it was radiation modified with a dose of 100 kGy.

Previously, the authors investigated the effect of various crosslinking methods (peroxide, ionizing radiation, ionizing radiation/peroxide and peroxide/ionizing radiation) on the properties of the elastomer.

The properties of Engage 8200 are the following: melt index (190°C/2.16 kg) – 5.0 dg/min; density – 0.870 g/cm³; Mooney viscosity – 8 ML (1 + 4) at 121°C; ultimate tensile strength – 5.7 MPa; ultimate tensile elongation – 1100%; 100% Modulus – 2.3 MPa; hardness, Shore A (1 s) – 66, Shore D (1 s) – 17; tear strength type C – 37.1 kN/m; Vicat softening point – 37°C; DSC melting point, 10°C/min rate – 59°C (Dow method); glass transition temperature – 53°C (Dow method); T_c peak – 4°C (Dow method).

Initial studies on the effect of radiation dose on the elastomer properties were carried out.

Finally, the elastomer was crosslinked with a dose of 50 kGy. The measurements (tensile strength, modulus hardness, Shore A, elongation at break, permanent elongation and compression set) were performed in a certified laboratory at the Institute for Engineering of Polymer Materials and Dyes (PCA accreditation certificate No. AB 147 for the inspection of raw materials, blends and thermoplastic elastomers). The work was performed in accordance with Polish ISO standards. The test results are summarized in Table 1.

Table 1. The impact of radiation dose on the properties of Engage 8200 elastomer.

Measured property	Dose [kGy]				
	0	50	100	200	300
Tensile strength [MPa]	6.7	9.7	9.5	8.4	6.2
Elongation at break [%]	901	869	828	696	509
Modulus 100% [MPa]	2.3	2.2	2.2	2.2	2.2
Modulus 200% [MPa]	2.7	2.7	2.7	2.8	2.8
Modulus 300% [MPa]	3.0	3.0	3.0	3.2	3.4
Hardness Shore A [°ShA]	71	69	68	67	67

To analyse the electrical properties of the absorber, to see whether it fulfils the desired electromagnetic requirements, the constitutive material parameters should be determined. The electromagnetic properties of an isotropic material can be described macroscopically by scalar material properties in term of relative complex permittivity (ϵ) and permeability (μ):

$$\epsilon = \epsilon' - j\epsilon''$$

$$\mu = \mu' - j\mu''$$

where: ϵ' – the electric constant, μ' – the magnetic constant, ϵ'' – the electric loss factor, μ'' – the magnetic loss factor and j – the imaginary number.

The permittivity and permeability broadband measurements of materials are commonly performed using coaxial fixtures. The basic measurements are based on the scattering parameters of the sample. Coaxial line technique allows the constitutive parameters of materials to be measured over a wide frequency band. In a typical configuration of a solid material for measurement of its permittivity and permeability in a coaxial line, the sample completely fills the cross-section of the holder (Fig. 2).

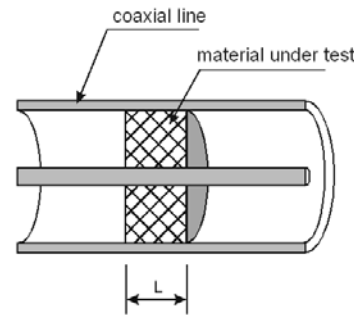


Fig. 2. Schematic configuration of the sample in the coaxial line.

Measurements of electrical and magnetic permeability were made in a coaxial line using a modified measurement method. An electron beam (an Elektronika 10/10 accelerator with a dose rate of 15,000 kGy/h) and gamma radiation (cobalt source GC 5000 with a dose rate of 3.5 kGy/h) were used in the polymer studies. The best absorption properties of the composite were at 1 GHz, where the material did not exhibit electromagnetic field reflections. From the measurements and results obtained, it can be concluded that the composite is a promising absorbing material for solving problems concerning the ability of an electrical or electronic device to work properly in specific electromagnetic environments, such as in antenna systems [5]. Developing an optimal composite requires further research.

References

- [1]. Mroczynski, R., Szymańska, M., & Głuszewski, W. (2015). Reactive magnetron sputtered hafnium oxide layers for nonvolatile semiconductor memory devices. *J. Vac. Sci. Technol. B*, 33, 1, 01A113, 1-5.
- [2]. Głuszewski, W., Zagórski, Z.P., & Rajkiewicz, M. (2015). The comparison of radiation and a peroxide crosslinking of elastomers. *KGK – Kautschuk, Gummi, Kunststoffe*, 15, 11/12, 46-49.
- [3]. Głuszewski, W., Zagórski, Z.P., & Rajkiewicz, M. (2014). Synergistic effects in the processes of crosslinking of elastomers. *Radiat. Phys. Chem.*, 94, 36-39.
- [4]. Yoshizawa, Y., Oguma, S., & Yamauchi, K. (1988). New Fe-based soft magnetic alloys composed of ultrafine grain structure. *J. Appl. Phys.*, 64(10), 6044-6046.
- [5]. Kubacki, R., Głuszewski, W., Laskowski, D., Rudyk, K., & Kuchta, M. (2018). EMC microwave absorber for outdoor applications. *Int. J. Microw. Wirel. Technol.* <https://doi.org/10.1017/S1759078718000223>.

A CONTINUOUS, NON-INTERFERING LINAC ELECTRON BEAM ENERGY MEASUREMENT SYSTEM FOR RADIATION PROCESSING INSTALLATION

Sylwester Bułka, Zbigniew Zimek

Continuous electron energy measurement is currently obligatory for accelerator installations intended for radiation sterilization. This is one of several values, such as dose rate, beam current, transporter speed and the sweep parameters, which must be recorded in accordance with the conditions listed in the accelerator validation requirements code.

While determining the energy of electrons in electrostatic accelerators is relatively simple and leads to the measurement of the accelerating voltage, in the case of RF linear accelerators it cannot be done by means of a simple and direct measurement.

Some accelerator installations have an integrated magnetic electron energy analyser, but

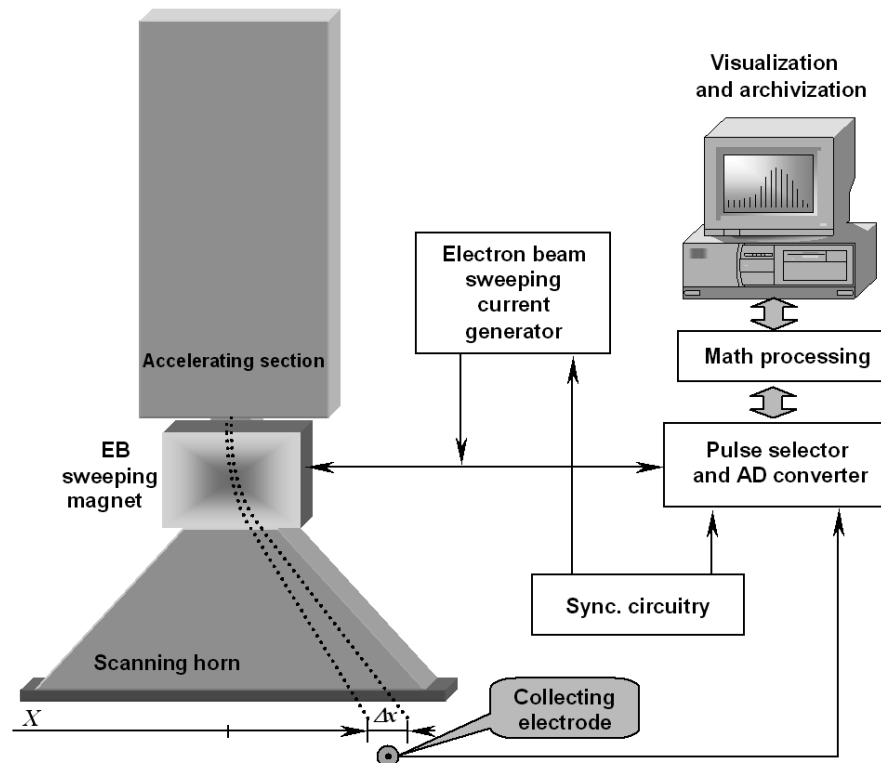


Fig. 1. Essential components of the measurement system.

such a measurement procedure cannot be carried out during sterilization. Also, the use of an aluminium wedge does not meet the requirements for an on-line measurement.

A typical solution is indirect energy estimation based on the knowledge of certain parameters, such as microwave power level and beam current, which affect the output energy of the electron beam. These parameters can be measured on an ongoing basis, and energy can be calculated using known relationships and calibration curves.

Unfortunately, this method does not give a result with satisfactory accuracy, mainly due to the necessary simplification of the computational model and the inability to measure many other physical parameters that this model would have to take into account.

One of the possible solutions [1] is the use of a sensor located directly under the window of the scanned electron beam in such a way that it does not interfere with the distribution of the dose in the irradiation area and provides data to determine the energy of electrons in the beam and the spectral distribution of this energy.

The measurement method based on the use of a secondary electron-collecting electrode was tested in an electron beam scanned installation, typically used for radiation sterilization. The concept of the measurement is shown in Fig. 1. The collecting electrode can be made of a strip of thin metal (Al) or wire. The high energy electrons passing through the electrode material knock out a number of secondary electrons, some of which are able to leave the electrode. This is recorded as the flow of a small, positive current from the electrode, and it is directly proportional to the intensity of the primary electron stream.

For different energies, the magnitude of the deflection will also be different, and therefore the trajectory of electron passage will be different. If there are components with various energies in the beam, then it will be split and stretched over a certain section of Δx . When analysing the intensity

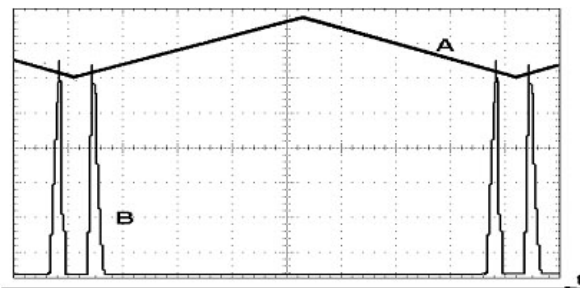


Fig. 2. Waveform oscillogram: A – current in sweeping magnet coil, B – current from the collecting electrode.

of the passing electron stream at subsequent points along Δx , the energy spectrum of the electron beam can be obtained.

The physical movement of the electrode along Δx is unnecessary, because the sweeping current

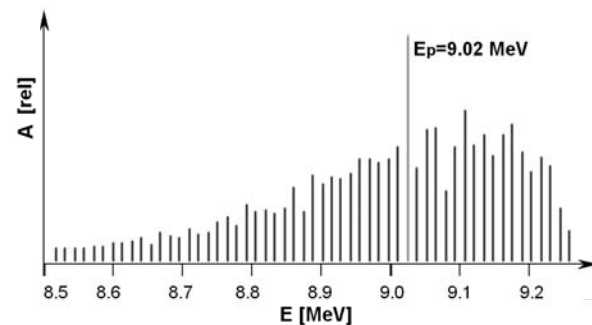


Fig. 3. Visualization of electron beam energy spectrum.

causes the beam to move linearly along the X-axis, thus all points of the Δx section will move over the electrode at some time. As a result, the current collected by the electrode is in the form of a pulse with an amplitude modulated by the instantaneous intensity of the stream (Fig. 2).

The data delivered *via* the interface is stored in the computer operating memory. After applying the error elimination procedures and averaging, the data are normalized and sent for visualization, as shown in Fig. 3.

provide information on the working conditions of various accelerator components, including their alignment and wear level.

The developed and tested system, after calibration using other methods of energy determination, currently works in a continuous mode at the accelerator installation at the Sterilization Station in the Institute of Nuclear Chemistry and Technology (INCT). The current control of the distribution of the electron beam energy spectrum and the automated measurements of other parameters are re-

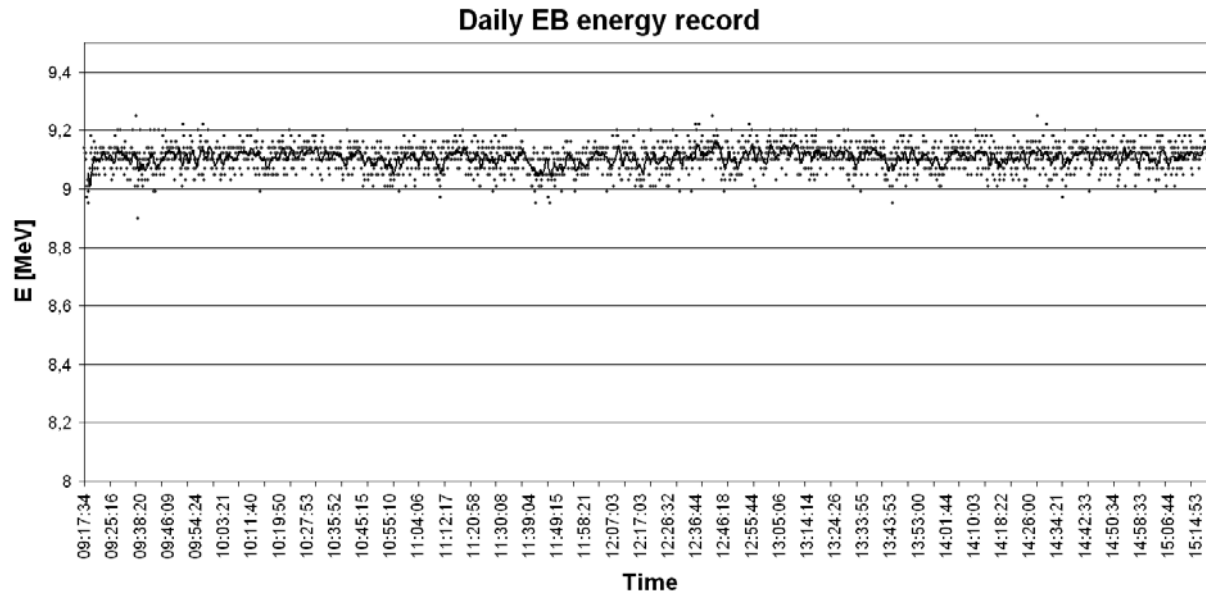


Fig. 4. An example of electron beam energy recorded over the facility workday.

In addition to the requirement of archiving of electron energy results of measurement during the sterilization process (as shown in Fig. 4), knowledge of the distribution of the electron beam energy spectrum allows the operator to set up the accelerator device in such a way that the machine performs the process at its optimum efficiency. During repair or maintenance works, such measurements are a very important diagnostic tool. They

recorded in accordance with the applicable requirements and enable multi-parameter optimization of the irradiation process.

References

- [1]. Zimek, Z. (1989). *Dozymetria wiązki elektronów. Pomiarzy elektryczne*. Warszawa: Centrum Informatyki Energetyki.

CENTRE FOR RADIOCHEMISTRY AND NUCLEAR CHEMISTRY

Chemical issues of nuclear power and radiopharmaceutical chemistry are the main research areas of the Centre for Radiochemistry and Nuclear Chemistry. In 2017, the Centre worked on research projects financed in the form of grants from the National Centre for Research and Development (NCBR) and the National Science Centre (NCN), as well as in the form of founding the Institute's statutory research and development and international cooperation from by Ministry of Science and Higher Education.

International collaboration was focused on the development of the European Commission (FP7 Euratom, Fission) and other (IAEA, COST) projects. The individual projects of young scientists funded under the specific subsidy of the Ministry of Science and Higher Education were important elements for the development of the human resources of the Centre.

The teams of three Centre laboratories (Radiochemical Separation Methods, Membrane Processes and Technologies, and Sol-Gel Technology) continued their studies on radioactive waste management, reprocessing of spent nuclear fuel, and on special nuclear materials. In this respect, the Sol-Gel Technology team continued research on the synthesis of potential nuclear fuel for future reactor systems based on uranium oxides and carbides, as well as mixed thorium-uranium dioxide, in the form of microspheres. The sol-gel method was also applied for preparation of phosphate glasses with potential use for radioactive waste stabilization.

The team of Radiochemical Separation Methods Laboratory continued the research on actinide/lanthanide separation by solvent extraction, which was focused on the verification of hypotheses previously set during the European Collaborative Project SACSESS implementation, regarding the formation of heteroleptic complexes of actinides with TODGA and $\text{SO}_3\text{-Ph-BTP}$ ligands. The present Euratom project in this field, namely GENIORS (GEN IV integrated oxide fuels recycling strategies, Horizon 2020), focuses on future multiple recycling strategies for spent fuel from the GEN IV reactors. In 2017, the research work of the Centre team concerned the study on new extraction systems for the separation of americium(III) from light lanthanides. Advanced quantum chemical calculations were continued, which allowed explaining the reason of actinide selectivity of some ligands used for solvent extraction separation of actinides from lanthanide fission products. The knowledge based on molecular modelling is crucial for design and synthesis of novel, more selective ligands for An/Ln separations.

Experimental and computational design of chiral molecules for applications in medicine and manufacturing of conductive polymers were performed within the frame of the grant financed by the National Science Centre for research executed in a few Polish universities and research institutes, and supervised by the Spectroscopy and Molecular Modelling group of our Centre.

Recovery of uranium and accompanying metals from various types of industrial wastes like phosphogypsum or waste from flotation of copper ores was studied in the scope of the IAEA CRP. Various aspects related to the management and storage of spent nuclear fuel and radioactive wastes formed in the course of exploitation of nuclear power plants (NPPs), with a special emphasis on the Polish Nuclear Power Programme, were studied.

The team of the Centre participated in the consortium of six Polish institutions working on the development of a safety assessment methodology and indication of the optimal location for shallow storage of low- and intermediate-level radioactive waste. At the request of the Ministry of Energy, the team prepared in collaboration with ZUOP an expert report "Management of radioactive waste and spent nuclear fuel in Poland – current status and prospects". Radioactive waste aspects concern the new Euratom Horizon 2020 CHANCE project (Char-

acterisation of conditioned nuclear waste for its safe disposal in Europe) in which the Centre participates. The project carried out by the international consortium, commenced in 2017, is focused on development of new non-destructive methods of radioactive waste characterization, such as muon tomography, calorimetry and innovative techniques based on laser spectroscopy for gaseous radioactive emissions monitoring. Applications in the field of radioactive waste management are complemented by the studies on new sorbents of radionuclides, among others, novel magnetic cobalt cyanoferrate nanoparticles, sufficiently stable for practical application in the treatment of the radioactive effluents.

Novel methods were examined by the Membrane Processes group, for the treatment of “problematic” nuclear waste, based on integrated processes (membrane filtration combined with sorption, advanced oxidation-membrane process), as the basis for further technological advancement in radioactive waste processing field. The application of membrane systems in nuclear desalination was tested within the frame of another IAEA CRP. The possibility of the application of such methods as reverse osmosis and membrane distillation, for desalination as well as radioactive waste treatment within nuclear power plants, was proved.

Basic research on the phenomena occurring in membrane units was continued in the scope of the NCN research project on the development of sensitive methods for studying concentration polarization and membrane fouling. The combination of radiotracers with optic techniques like SEM (scanning electron microscopy), FTIR/PAS (Fourier-transform infrared/photoacoustic spectroscopy) has brought data for the future elaboration of the methodology of testing membrane units.

Social and socio-economic effects of implementation of the Polish Nuclear Power Programme with the development of macroeconomical tools for assessment were studied within the frame of the IAEA CRP in cooperation with the governmental institutions.

Research on radiopharmaceutical chemistry (Laboratory of Radiopharmaceuticals Synthesis and Studies) was focused on obtaining and studying novel potential radiopharmaceuticals, both diagnostic and therapeutic. Novel biomolecules, derivatives of tacrine, agonists (*e.g.* substance P) or antagonists (*e.g.* aprepitant, Spantide I (5-11)) of NK-1 receptor, as well as antibiotics used in medical treatment of bacterial infections, were labelled with ^{99m}Tc or ^{68}Ga , resulting in potential diagnostic tools for Alzheimer’s disease, glioma brain tumours, breast cancer and diabetic foot, respectively. A part of the research was carried out in cooperation with the Department of Pharmaceutical Chemistry and Drug Analyses, Medical University of Łódź and with the Department of Nuclear Medicine, Medical University of Warsaw. New methods for cyclotron productions of diagnostic radionuclides, both SPECT (^{99m}Tc) and PET (^{45}Sc , ^{44}Sc , ^{72}As) were developed in cooperation with the Heavy Ion Laboratory of the University of Warsaw, and the National Centre for Nuclear Research – POLATOM, within two projects awarded by the NCBR.

The development of new cyclotron method for ^{47}Sc production was continued in the scope of a new IAEA Research Contract. Also potential therapeutic radiopharmaceuticals were obtained and studied. Peptides and proteins were labelled with alpha emitters (^{211}At , ^{225}Ac and ^{223}Ra) *via* functionalized soft-metal chelates (metal bridge), and by the use of functionalized nanoparticles such as nanozeolites and gold nanoclusters.

Multifunctional nanoparticles for magnetic hyperthermia and indirect radiation therapy were studied in cooperation of the international consortium in the frame of COST project and in the scope of NCN OPUS project.

The teams of the Centre were awarded with the Director’s prize for publications presented in 2015-2016 and the Director’s award for application achievements in the same period.

The international and national scientific cooperation of the Centre was successfully continued and enhanced making the Centre teams desired partners not only on the national scale, but also over the European research area.

The Centre participated in the organization of several meetings, conferences, seminars and trainings of students.

The scientists of the Centre were involved in the activities of a large number of organizations, societies, and editorial boards of scientific journals in the country and abroad.

⁶⁸Ga- AND ¹⁷⁷Lu-RADIOPHARMACEUTICALS BASED ON NEUROKININ-1 RECEPTOR ANTAGONIST SPANTIDE I (5-11) PEPTIDE FOR GLIOBLASTOMA MULTIFORME TREATMENT

Paweł Krzysztof Halik, Ewa Gniazdowska, Przemysław Koźmiński, Agnieszka Majkowska-Pilip

Gliomas are extremely serious and aggressive brain tumours in adults. For patients with the most malignant glioma – glioblastoma multiforme (GBM, glioblastoma) the prognosis for survival is 9-12 months. All malignant gliomas are primary brain tumours associated with a high morbidity and mortality due to very difficult treatment regimens. It is caused by the fact that tumour cells are relatively resistant to chemo- and radiotherapy, which is highly damaging to healthy brain tissue. Moreover, an accurate surgical treatment is also ineffective and leads to cancer resumption due to the infiltrating and diffusive character of glioblastoma cells spreading beyond the primary tumour area [1]. Therefore, novel therapeutic strategies are needed for the effective management of GBM.

In the past two decades, targeted glioma therapy has become the subject of extensive scientific reflection and study. The development of biomolecular techniques has allowed the recognition of characteristic tumour cell markers, showing potential for treatment. Many published reports have indicated the participation of the Substance P (SP)-Neurokinin 1 receptor (NK-1R) system in the evolution and metastasis of various neoplasm, including malignant gliomas [2-4].

NK-1R is a seven transmembrane helix protein receptor belonging to the family of G-protein coupled receptors (GPCRs). Its endogenous ligands are tachykinins, from which Substance P shows the highest affinity to the receptor. SP is undeca-neuropeptide (sequence Arg-Pro-Lys-Pro-Gln-Gln-Phe-Gly-Leu-Met-NH₂) distributed mainly in the nervous system, but also in peripheral tissues. Both SP and NK-1R are responsible for cell proliferation, vasodilation, transmission of pain, endocrine secretion, immune system inflammatory response and modulation of neuronal sensory transmission related to stress, emesis and anxiety. SP is also a mitosis and haematopoiesis regulatory agent [5].

In pathological conditions the NK-1 receptor is upregulated. This fact makes SP with its recep-

tor system a potential target for recognition and diagnosis of many diseases related with an excessive NK-1R stimulation. However, to date, clinical studies have confirmed application effectiveness of one NK-1R antagonist only against nausea and vomiting induced by chemotherapy. NK-1R overexpression is widely presented in a variety of tumour cell lines, also in glioma cancer lines [4, 6]. Preclinical trials proved the feasibility of targeted local radiotherapy based on the SP/NK-1R system. For GBM treatment, studies have been performed using a labelled SP derivative (²¹³Bi-DOTA-[Thi⁸,Met(O₂)¹¹]-Substance P) proposed in 2010 by Cordier *et al.* [7]. Such treatments were also applied at the Department of Nuclear Medicine, Central Clinical Hospital, Warszawa, in cooperation with the Institute for Transuranium Elements (JRC-ITU, Karlsruhe), where ²¹³Bi/²²⁵Ac-DOTA-[Thi⁸,Met(O₂)¹¹]-Substance P radiopharmaceuticals were examined in patients diagnosed with recurrent critically located GBM. The results of this experiment showed good toleration of the preparation without acute or serious side effects. Although the disease was stabilized, applied radiobioconjugates showed poor migration into the marginal tumour area and instability in blood presence conditions.

To eliminate these disadvantages, we propose a change of biological vector in applied radiopharmaceuticals to the shorter peptide NK-1R antagonist, Spantide I (5-11), SPE (5-11), (sequence Gln-Gln-D-Trp-Phe-D-Trp-Leu-Leu-NH₂). Spantide I is a SP analogue, (D-Arg¹, D-Trp^{7,9}, Leu¹¹)SP(1-11) with similar affinity to NK-1 receptor [8]. The shorter peptide was chosen according to our experience with fragments of SP [9], where the radiobioconjugate ¹⁷⁷Lu-DOTA-SP(5-11) has showed the highest log P value from analysed compounds. Moreover, Spantide I is more resistant to blood peptidases than SP, because of the replacement of L-amino acids with D-isomers.

In this work we have focused on the labelling of the peptide NK-1R antagonist Spantide I (5-11)

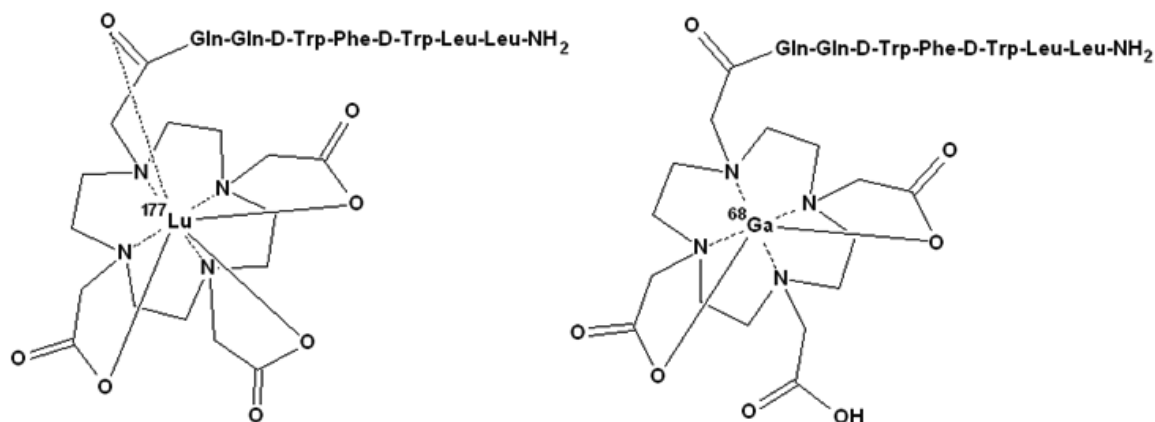


Fig. 1. Structures of the ¹⁷⁷Lu-DOTA-SPE (5-11) and ⁶⁸Ga-DOTA-SPE (5-11) radiobioconjugates.

Table 1. Physicochemical properties of ^{68}Ga -DOTA-SPE (5-11) and ^{177}Lu -DOTA-SPE (5-11) radiobioconjugates.

Radiobioconjugate	log P	Human serum stability [%] (after certain time)	Radiobioconjugate bound to the biomatrix components [%] (after certain time)		
^{68}Ga -DOTA-SPE (5-11)	-0.56 ± 0.02	> 99 (4 h)	8.7 (1 h)	-	11.9 (4 h)
^{177}Lu -DOTA-SPE (5-11)	-0.19 ± 0.03	> 99 (7 d)	5.3 (1 h)	8.3 (2 d)	9.1 (7 d)

with two radioisotopes – ^{68}Ga and ^{177}Lu (Fig. 1), using a macrocyclic chelator DOTA (1,4,7,10-tetraazacyclododecane-1,4,7,10-tetraacetic acid) in the form of active mono-N-hydroxysuccinimide ester (NHS) – DOTA-NHS (1,4,7,10-tetraazacyclododecane-1,4,7,10-tetraacetic acid mono-N-hydroxysuccinimide ester). Our aim was to obtain a novel peptide radiobioconjugate, elaborate on the conditions for effective labelling and examine the stability parameters of the obtained radiobioconjugates.

SPE (5-11) was coupled with DOTA-NHS with addition of Et_3N in DMF at 50°C over night (the molar ratios of reagents were 1 : 1.3 : 4, respectively). Crude DOTA-SPE (5-11) product was purified on a semi-preparative HPLC and lyophilized giving a yield of 60%. MS of DOTA-SPE (5-11): calculated – 1405.63 m/z, found – 1405.73 m/z $[\text{M}+\text{H}^+]$. The labelling reactions of the obtained

Then the stability studies were performed, where the percentage of the unchanged form of each radiobioconjugate in certain time periods was determined. Experiments included analysis of the stability in human serum verified by the HPLC method with radiometric detection.

All examined radiobioconjugate parameters are presented in Table 1. The lipophilicity values of both molecules of interest are slightly negative (-0.56 and -0.19 for ^{68}Ga and ^{177}Lu , respectively). These values, compared to the lipophilicity parameters of radiobioconjugates based on SP and its fragments [9], are significantly higher; this is promising from a pharmacokinetic point of view. Moreover, the presented radiobioconjugates showed total stability in human serum for the entire duration of the experiments (4 h and 7 d for ^{68}Ga and ^{177}Lu , respectively), verified by the radiometric chromatograms (Fig. 2).

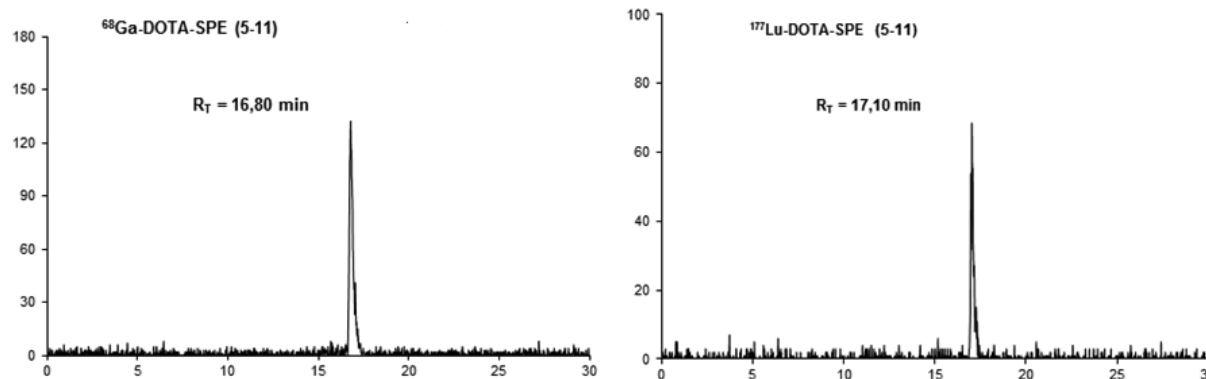


Fig. 2. Radiometric chromatograms of liquid phases of ^{68}Ga -DOTA-SPE (5-11) and ^{177}Lu -DOTA-SPE (5-11) radiobioconjugates in human serum solution after 4 h and 7 d, respectively. HPLC conditions: Phenomenex Jupiter Proteo semi-preparative column ($4\ \mu\text{m}$, $90\ \text{\AA}$, $250\ \text{mm} \times 10\ \text{mm}$), γ detection; elution conditions: solvent A – water with 0.1% TFA (v/v); solvent B – acetonitrile with 0.1% TFA (v/v); gradient: 0-20 min 20 to 80% of B, 20-35 min 80% solvent B; 2 ml/min.

bioconjugate were performed according to the following procedures: to the vial containing about $50\ \mu\text{g}$ of lyophilized DOTA-SPE (5-11) in $300\ \mu\text{L}$ of acetate buffer ($\text{pH} = 5.0$), about $100\ \mu\text{L}$ of concentrated $^{68}\text{GaCl}_3$ solution (80-100 MBq) from $^{68}\text{Ge}/^{68}\text{Ga}$ generator or about $20\ \mu\text{L}$ of $^{177}\text{LuCl}_3$ solution in $0.04\ \text{M}$ HCl (10-15 MBq) were added. In the ^{68}Ga labelling reaction mixture pH was strictly set below 4.0. Both reactions were performed at 95°C for 30 min and 60 min, respectively, with progress HPLC verification. The radiochemical yield of the synthesized radiobioconjugates was higher than 97%.

The lipophilicity parameters for both radiobioconjugates were determined as the log P values, which are the logarithms of the partition coefficients of each molecule in a biphasic mixture of n-octanol and phosphate buffered saline ($\text{pH} 7.40$).

Considering ligand exchange, reactions with amino acids or other strongly competing natural ligands present in human serum did not take place. In the case of stability studies in human serum, we have measured the radioactivity of precipitated matrix proteins (using ethyl alcohol) and the supernatant fractions. A few percent of $^{68}\text{Ga}/^{177}\text{Lu}$ -DOTA-SPE (5-11) molecules were shown to be bound by the biomatrix components, while the rest of the studied radiobioconjugates remained in the liquid phase in an unchanged form.

In conclusion, we have obtained novel ^{68}Ga - and ^{177}Lu -radiobioconjugates based on peptide antagonist of NK1 receptor. Both examined molecules showed promising physicochemical properties for further consideration as potential radiopharmaceuticals for glioblastoma multiforme treat-

ment, competitive to presently applied methods in oncology.

The presented work was financially supported by the statutory activity of the Institute of Nuclear Chemistry and Technology (INCT).

References

- [1]. Ramirez, Y.P., Weatherbee, J.L., Wheelhouse, R.T., & Ross, A.H. (2013). Glioblastoma multiforme therapy and mechanisms of resistance. *Pharmaceuticals*, *6*, 1475-1506. DOI: 10.3390/ph6121475.
- [2]. Palma, C., Nardelli, F., Manzini, S., & Maggi, C.A. (1999). Substance P activates responses correlated with tumour growth in human glioma cell lines bearing tachykinin NK1 receptors. *Br. J. Cancer*, *79*(2), 236-243. DOI: 10.1038/sj.bjc.6690039.
- [3]. Munoz, M., Covenas, R., Esteban, F., & Redondo, M. (2015). The substance P/NK-1 receptor system: NK-1 receptor antagonists as anti-cancer drugs. *J. Biosci.*, *40*, 441-463. DOI: 10.1007/s12038-015-9530-8.
- [4]. Palma, C., & Maggi, C.A. (2000). The role of tachykinins via NK₁ receptors in progression of human gliomas. *Life Sci.*, *67*, 985-1001. DOI: 10.1016/S0024-3205(00)00692-5.
- [5]. Garcia-Recio, S., & Gascón, P. (2015). Biological and pharmacological aspects of the NK1-receptor. *BioMed Res. Int.*, *2015*, Article ID 495704. DOI: 10.1155/2015/495704.
- [6]. Covenas, R., & Munoz, M. (2014). Cancer progression and substance P. *Histol. Histopathol.*, *29*, 881-890. DOI: 10.14670/HH-29.881.
- [7]. Cordier, D., Forrer, F., Bruchertseifer, F., Morgenstern, A., Apostolidis, C., Good, S., Müller-Brand, J., Mäcke, H., Reubi, J.C., & Merlo, A. (2010). Targeted alpha-radiionuclide therapy of functionally critically located gliomas with ²¹³Bi-DOTA-[Thi⁸,Met(O₂)¹¹]-substance P: a pilot trial. *Eur. J. Nuc. Med. Mol. Imaging*, *37*(7), 1335-1344. DOI: 10.1007/s00259-010-1385-5.
- [8]. Folkers, K., Hakanson, R., Horig, J., Jie-Cheng, X., & Leander, S. (1984). Biological evaluation of substance P antagonists. *Br. J. Pharmacol.*, *83*(2), 449-456. DOI: PMC1987101.
- [9]. Majkowska-Pilip, A., Gniazdowska, E., Koźmiński, P., Wawrzynowska, A., Budlewski, T., & Kostkiewicz, B. (2016). On the syntheses and evaluation of substance P fragments labelled with ^{99m}Tc and ¹⁷⁷Lu as potential receptor radiopharmaceuticals in glioma treatment. In *INCT Annual Report 2016* (pp. 35-39). Warszawa: Institute of Nuclear Chemistry and Technology.

PREPARATION OF MICROSPHERES OF CARBON BLACK DISPERSION IN URANYL-ASCORBATE GELS AS PRECURSORS OF URANIUM CARBIDE

Marcin Brykała, Marcin Rogowski, Tadeusz Olczak

A novel technique to fabricate precursors of carbide-ceramic nuclear fuel *via* the synthesis of spherical particles (with diameters below 150 μm) of carbon black dispersed in uranyl-ascorbate gels by a combination of the complex sol-gel process (CSGP) and the double extraction process was elaborated. The application of ascorbic acid as a complexing agent in the complex sol-gel process allows a stable and uniform dispersion of carbon in a uranyl-ascorbate sol to be obtained. In the double extraction process, a dispersion of carbon black in sols is emulsified by drops in the organic phase consisting of 2-ethylhexanol-1 and 1 vol% of Primene JM-T. The microspheres are created by gelation of droplets, through simultaneous extraction of water with 2-ethylhexanol-1 and nitrate ions with Primene JM-T. The elaboration of the optimal gelation conditions requires the consideration of many issues which are described in this paper.

This paper deals with an extension of the previously described complex sol-gel process to the production of microspheres of carbon black dispersion (without dispersing agent) in uranyl-ascorbate gels which are recommended as precursors in the synthesis of a new type of fuel-like uranium carbide or uranium nitride. The obtained dispersion after carbonization to UO₂-C can be converted by carbothermic reduction to UC (eventually with UO₂) and additionally by the nitrating process to UN. Medium-sized spherical particles of uranium carbide (with diameters of approximately 100 μm) can be used in nuclear fuel technology for spherical TRISO fuel [1-4]. A flowchart of the applied combination of CSGP and the double extraction process to synthesize spherical particles

of carbon black dispersed in uranyl-ascorbate gel is shown in Fig. 1.

The first step was the preparation of concentrated 1 M uranyl-ascorbate sol solutions with

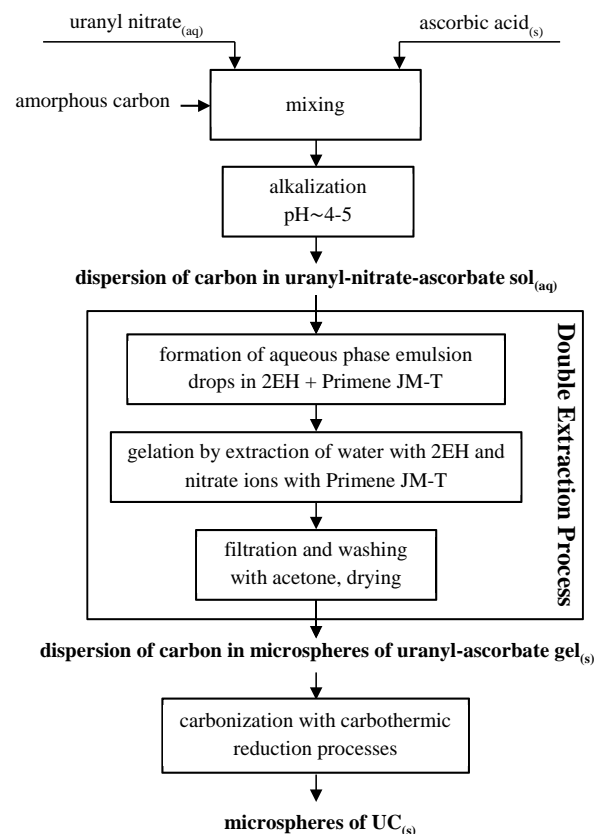


Fig. 1. Flowchart detailing the preparation of uranium carbide microspheres (diameters below 150 μm) by CSGP with gelation by the double extraction processes.

molar ratio (MR) of ASC/U equal to 1, in which carbon black was dispersed with molar ratios of C/U equal to 1, 2 and 3. Carbon black was dispersed in prepared uranyl-ascorbate sol solutions by mixing for 3 h. The as-obtained dispersions have a high degree of homogeneous distribution of the components. Traditionally, the dispersability of carbon black is improved by using dispersing agents (surfactants) which is needless in the complex sol-gel process. As is shown in Fig. 2 and previous works [5], ascorbate sols perfectly wet the carbon black and the formation of agglomerates were not observed. A complexing agent, such as ascorbic acid, also aids dispersion. No crystallization of any added metallic compounds was observed.

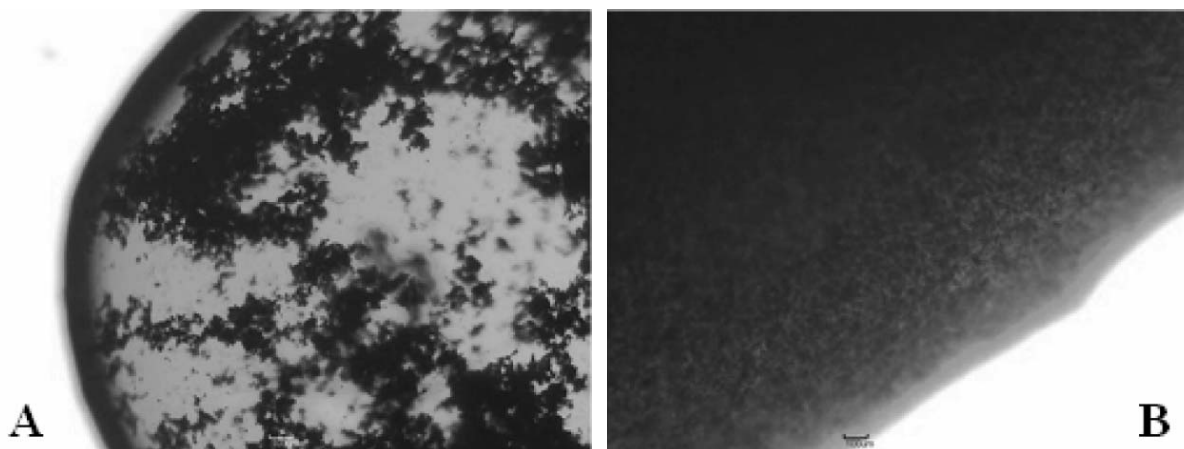


Fig. 2. Optical microscope photographs of a carbon dispersion in 1 M uranyl nitrate solution (A) and in 1 M uranyl-ascorbate sol solution (B).

The second step was gelation of the sols, which is crucial for obtaining the desired average size, size distribution and shape of the microspheres. The gelation of spherical particles requires partial hydrolysis by addition of ammonia solution to pH \sim 4.5 before precipitation. Without ammonia, spherical particles of gel cannot be obtained. With increasing pH an increase in viscosity is observed which additionally has a positive influence on droplet generation. Viscosity seems to be a crucial parameter in determining the stable emulsion droplets' diameters and size distribution.

Medium-sized spherical particles (diameters below 150 μ m) were obtained by applying the double extraction process [6] which is based on the Oak Ridge National Laboratory (ORNL) method of water extraction from sol drops dispersed in an organic solvent [7-9]. The gelation process consists of three steps. The first step was the formation of a sol emulsion in 2-ethylhexanol-1 containing surfactant SPAN-80 and Primene JM-T. SPAN-80 has a low hydrophilic-lipophilic balance (HLB) which prevents coalescence and sticking of sol droplets. The second step was the gelation of droplets by the simultaneous extractions of water, with 2-ethylhexanol-1, and nitrate ions, with Primene JM-T. The gelation process was carried out at room temperature but heated 2-ethylhexanol-1 can also be applied to the internal gelation of acid deficient uranyl nitrate

(ADUN) with hexamethylenetetramine (HMTA) and urea [10]. The last step was the filtration and washing of the microspheres. The gelation process was carried out in a glass-enclosed reactor with very rapid stirring (maximum 1500 rpm) and a volume of 1000 mL.

The size distribution and sphericity were sensitive to the mixing speed of the organic phase when all other experimental parameters were held constant. The size distributions and sphericity of microspheres between the minimum and maximum mixing speeds were considerably different. At low mixing speeds ($<$ 600 rpm), populations of microspheres with diameters greater than 100 μ m, but not greater than 200 μ m, were mainly obtained (82%), with sphericity ($E_q \emptyset$) equal

to 1.092 ± 0.074 . For a given sol, higher stirring speeds (900 rpm) favour the formation of smaller diameter microspheres with good sphericity. If the mixing speed was higher than 1000 rpm, microspheres mainly with diameters below 50 μ m were obtained (89%).

Dried gel microsphere dispersions were analysed using scanning electron microscopy (SEM) with a Zeiss DSM 942. A measuring optical microscope (Motic BA300) was utilized to evaluate the morphological features of microspheres such as shape, diameter and dispersity. An optical analysis

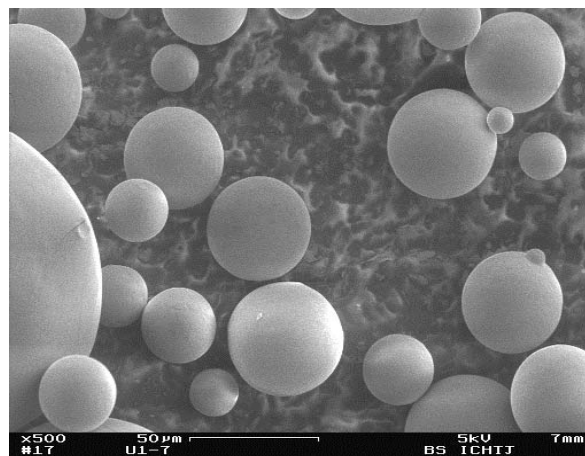


Fig. 3. SEM micrograph of spherical particles of a carbon dispersion in a uranyl-ascorbate gel.

Table 1. Size and sphericity characterization of dried carbon black microsphere dispersions in uranyl-ascorbate gels as a function of molar ratio of C/U.

MR	\varnothing_{\max} [μm]	\varnothing_{\min} [μm]	\varnothing_{av} [μm]	Eq \varnothing
C/U = 1	143.2	33.8	103.4 \pm 29.9	1.007 \pm 0.007
C/U = 2	149.1	46.6	111.2 \pm 26.1	1.009 \pm 0.011
C/U = 3	169.1	49.6	119.0 \pm 24.5	1.011 \pm 0.011

showed a spherical particle shape with good surface integrity (Fig. 3).

As shown in Table 1, the size of the microspheres is directly proportional to the molar ratio of C/U. With the increasing molar ratio of C/U, the proportion of spherical particles with a larger diameter is higher.

This is connected to the higher amount of amorphous carbon in the formed droplet dispersions in the organic solvent and with the higher viscosity. Moreover, the increase in microsphere diameter has an influence on the sphericity of the particles, but to a negligible extent.

The energy dispersive spectrometry (EDS) measurements of quality and quantity of elements in the dried gel microspheres were performed with the use of a Bruker AXS Microanalysis GmbH Berlin operated at 15 keV. The EDS analyses (Fig. 4) were performed to confirm the presence of carbon in the microspheres of gels with molar ratio of C/U equal to 1 and 3. Analyses of elements by the EDS were performed on a dried sample. The results of the EDS confirmed the presence of carbon in the uranyl-ascorbate gel and with an increasing amount of carbon, rising intensity of peaks from C is observed. Additionally, the molar ratio of C/O changes with an increase in the molar ratio of C/U in the obtained gel microspheres.

The last step of the process consists of the thermal treatment and requires some special procedures to preserve the spherical shape. In this step, the conditions should be selected to obtain the desired properties of the final product. A slow heating rate (1-5°C/min) is required to maintain a non-cracked surface of the particles during the carbonization of organic compounds and elimination of nitrates. The whole step should be carried out in an oxygen-free atmosphere to avoid oxida-

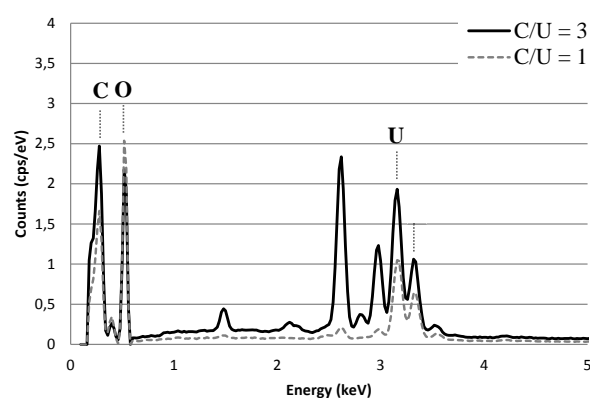


Fig. 4. EDS analysis of carbon black microsphere dispersions in uranyl-ascorbate gels with molar ratio of C/U equal to 1 and 3.

tion of the carbon. The carbonization of gels to a homogeneous mixture of $\text{UO}_{2-x}\text{-C}$ is carried out in an inert gas atmosphere containing hydrogen (95% N_2 + 5% H_2). The last step is the carbonization reaction (1600°C) under reduced pressure to uranium carbide.

The complex sol-gel process can be successfully applied to the preparation of homogeneous amorphous carbon dispersions in sols, using complexation with ascorbic acid, of uranyl nitrate. In the CSGP, a dispersing agent is needless. It was observed that, in contrast to water or pure uranyl nitrate solutions, ascorbate sols perfectly wet the carbon black. It is necessary to point out that the preparation of microspheres of uranyl gels from uranyl nitrate by extraction of water and nitrate ions with the addition of ascorbic acid enabled the gels to be formed. The dispersion can also be gelled into medium-sized microspheres (diameter < 150 μm) by water and nitrate extraction from drops of the dispersion in sols. The size of the microspheres is directly proportional to the molar ratio of C/U. With the increasing molar ratio of C/U, the proportion of spherical particles with a larger diameter is higher. This is connected to the higher amount of amorphous carbon in the formed droplets of dispersion in an organic solvent, and therefore a smaller amount of water and nitrate is extracted during the gelation.

References

- [1]. Vaidya, V.N. (2008). Status of sol-gel process for nuclear fuels. *J. Sol-Gel Sci. Technol.*, 46, 369-381.
- [2]. Pouchon, M.A., Ledergerber, G., Ingold, F., & Bakker, K. (2012). Sphere-pac and Vipac fuel. In R.J.M. Konings, T.R. Allen, R.E. Stoller, S. Yamanaka (Eds.), *Comprehensive nuclear materials* (pp. 275-312). Elsevier.
- [3]. Brähler, G., Hartung, M., Fachinger, J., Grosse, K.H., & Seemann, R. (2012). Improvements in the fabrication of HTR fuel elements. *Nucl. Eng. Des.*, 251, 239-243.
- [4]. Hunt, R.D., Silva, C.M., Lindemer, T.B., Johnson, J.A., & Collins, J.L. (2014). Preparation of $\text{UC}_{0.07-0.10}\text{N}_{0.90-0.95}$ spheres for TRISO coated fuel particles. *J. Nucl. Mater.*, 448, 399-403.
- [5]. Deptula, A., Lada, W., Olczak, T., Sartowska, B., Ciancia, A., Giorgi, L., & Di Bartolomeo, A. (1997). Preparation of Pt/WO_3 powders and thin coatings on carbon black and metal supports by the complex sol gel process (CSGP). *Mater. Res. Soc. Symp. Proc.*, 498, 237-242.
- [6]. Brykala, M., Deptula, A., Rogowski, M., Lada, W., Olczak, T., Wawszczak, D., Smolinski, T., Wojtowicz, P., & Modolo, G. (2014). Synthesis of microspheres of triuranium octaoxide by simultaneous water and nitrate extraction from ascorbate-uranyl sols. *J. Radioanal. Nucl. Chem.*, 299, 651-655.

- [7]. CNEN. (1968). *I Processi sol-gel per la produzione di combustibili ceramici : atti del Simposio Nucleare Internazionale di Torino / organizzato dal Comitato Nazionale per l'Energia Nucleare con la collaborazione del XVII Salone Internazionale della Tecnica, Torino, 2-3 Ottobre 1967*. Rome: Comitato Nazionale Energia Nucleare.
- [8]. IAEA. (1968). *Sol-Gel Processes for Ceramic Nuclear Fuels. Proceedings of a panel, Vienna 6-10 May 1968*. Vienna: IAEA.
- [9]. IAEA. (1973). *Sol-Gel Processes for Fuel Fabrication. Proceedings of a Panel on Sol-Gel Processes for Fuel Fabrication organized by the International Atomic Energy Agency and held in Vienna, 21-24 May 1973*. Vienna: IAEA.
- [10]. Hunt, R.D., Hickman, R.R., Ladd-Lively, J.L., Anderson, K.K., Collins, R.T., & Collins, J.L. (2014). Production of small uranium dioxide microspheres for cermet nuclear fuel using the internal gelation process. *Ann. Nucl. Energy*, 69, 139-143.

RECOVERY OF URANIUM AND ACCOMPANYING METALS FROM SECONDARY RAW MATERIALS

Katarzyna Kiegiel, Dorota Gajda, Grażyna Zakrzewska-Kołodziej

The development of nuclear energy in the world causes an increase in the demand for uranium. Presently, the exploitation of rich uranium ores is profitable when the cost of production of uranium is lower than 130 USD/kg U_3O_8 . According to the OECD-NEA Red Book (2016) [1], such deposits of uranium in the world are estimated at about 5.7 million tonnes of metal. An increase in research on uranium recovery from secondary resources has also been observed. In this investigation, industrial waste and by-products from the copper and phosphorous fertilizer industries, as well as phosphate rocks, were examined as sources of uranium. During the recovery of uranium from secondary sources, which are assumed to be poor quality, the economy of the process can be improved by the simultaneous extraction of accompanying metals such as rare earth elements or other valuable metals present in the processed material.

Before selecting a method of extracting uranium and other selected metals from the available secondary raw material, it is important to adequately characterize this material and determine the type and content of the metallic components of interest. The compositions of the examined materials were determined with the use of ICP-MS (inductively coupled plasma mass spectrometry) analysis. The results are shown in Table 1.

Table 1. The concentration of selected metals in the examined materials: copper flotation tailings, phosphogypsum and phosphates.

Sample	Metals [ppm]								
	U	Th	V	Fe	Co	Ni	Cu	Zn	La
Copper waste 1	15	5	788	nd*	558	330	27 500	1 217	21
Copper waste 2	16	5	833	nd*	589	269	25 000	987	21
Copper waste 3	5	2	55	4 750	79	31	12 225	237	8
Phosphogypsum	2	4	5	2 758	6	14	5	17	40
Syria phosphate	61	1	134	2 911	13	36	13	307	26
Morocco phosphate	117	4	250	3 880	13	69	39	332	90
Tunisia phosphate	32	5	53	3 398	14	20	5	142	64

* nd – not determined.

The efficiencies of uranium leaching from copper flotation tailings with 10% sulphuric acid were not high (Fig. 1). Satisfying results (uranium leach-

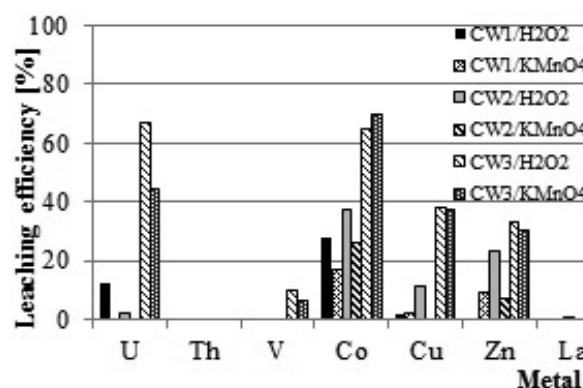


Fig. 1. The leaching efficiencies of metals from copper wastes with various oxidizing agents: CW1 – copper waste 1, CW2 – copper waste 2, CW3 – copper waste 3. Process conditions: 10% H_2SO_4 , 60°C, 2 h.

ing efficiency of 40-67%) were obtained only for copper waste 3.

Phosphogypsum is a very difficult material to leach because of its complex composition. It was found that this material can be leached using a double-stage procedure. In the first stage phosphogypsum was treated with mixture of 30% NaOH and 30% H_2O_2 and heated at 60°C. The solid residue was separated from the post-leaching solution, washed with distilled water and dried at 105°C.

The obtained solid was leached with 10% HCl in the presence of 30% H_2O_2 , as an oxidizing agent, at 60°C. Uranium and rare earth elements were

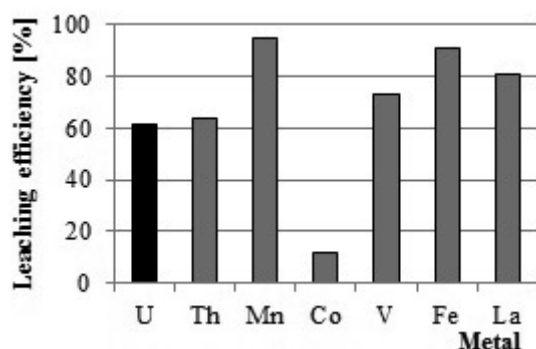


Fig. 2. The leaching efficiencies of metals from phosphogypsum. Process conditions: step one – 30% NaOH, 30% H₂O₂, 22-60°C; step 2 – 10% HCl, 30% H₂O₂, 60°C.

extracted with quite high efficiencies – 61% for uranium and 81% for lanthanum (Fig. 2).

Phosphates were leached using hydrochloric acid, sulphuric acid and alkaline solution. The efficiencies depend strongly on the origin of the phosphate. All three phosphates, from Syria, Morocco and Tunisia, were leached with high efficiencies (40-100%) in acidic conditions; however, only the phosphate from Morocco was leachable in alkaline solution (Fig. 3). It is worth noting that phosphates from Morocco are more easily leached with an alkaline solution than with acid. An interesting

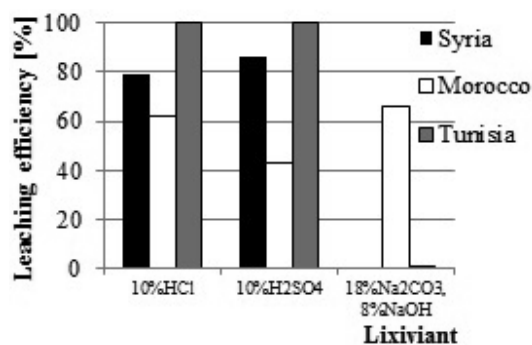


Fig. 3. The leaching efficiencies of uranium from phosphates. Process conditions: 30% H₂O₂, 22°C, 1 day.

result was obtained for the percolation leaching of Tunisia phosphate. A solution of 2.5% Na₂CO₃/NaHCO₃ with 30% H₂O₂ was used as a lixiviant. The solution was recirculated within the phosphate-filled column. The efficiency of uranium leaching reached 19% after 2 h.

Phosphogypsum and flotation tailings from the copper industry are very difficult materials to leach because of their complexity; however, the obtained results are very promising and these studies will be continued. The uranium leaching efficiency of phosphogypsum reached 60%. Moreover, it should be noted that phosphogypsum could be an interesting and valuable source of lanthanides.

The acidic leaching of phosphates was very efficient. In some cases, the leaching efficiency reached 100%.

The isolation of uranium from post-leaching solutions can be obtained by liquid-liquid extraction [2] or ion exchange chromatography [3].

These studies were supported by the financial resources for science in the years 2017-2018 granted for the implementation of the co-financed international project 3643/IAEA/16/2017/0 and the IAEA Research Contract No. 18542.

References

- [1]. NEA & IAEA. (2016). *Uranium 2016: Resources, Production and Demand. A Joint Report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency*. OECD. NEA No. 7301.
- [2]. Kiegiel, K., Abramowska, A., Bieluszka, P., Zakrzewska-Kołodziej, G., & Wołkiewicz, S. (2017). Solvent extraction of uranium leach solution obtained in processing of Polish low-grade ores. *J. Radioanal. Nucl. Chem.*, 311, 589-598. DOI: 10.1007/s10967-016-5029-5.
- [3]. Danko, B., Dybczyński, R.S., Samczyński, Z., Gajda, D., Herdzyk-Koniecko, I., Zakrzewska-Kołodziej, G., Chajduk, E., & Kulisa, K. (2017). Ion exchange investigation for recovery of uranium from acidic pregnant leach solutions. *Nukleonika*, 62, 213-221. DOI: 10.1515/nuka-2017-0031.

NOVEL MAGNETIC COBALT CYANOFERRATE NANOPARTICLES AS A POTENTIAL SORBENT FOR SOLID PHASE EXTRACTION OF RADIONUCLIDES FROM AQUEOUS SAMPLES

Leon Fuks, Danuta Wawszczak, Irena Herdzyk-Koniecko, Tomasz Smoliński

Numerous inorganic sorbents at present find increasing use in applied radiochemistry. The most common use is removing caesium and strontium radionuclides from cooling water in a nuclear reactor, as well as water in the storage pools of spent nuclear fuel. The main advantages of using inorganic sorbents are their chemical strength, thermal stability and radiation-chemical resistance [1, 2].

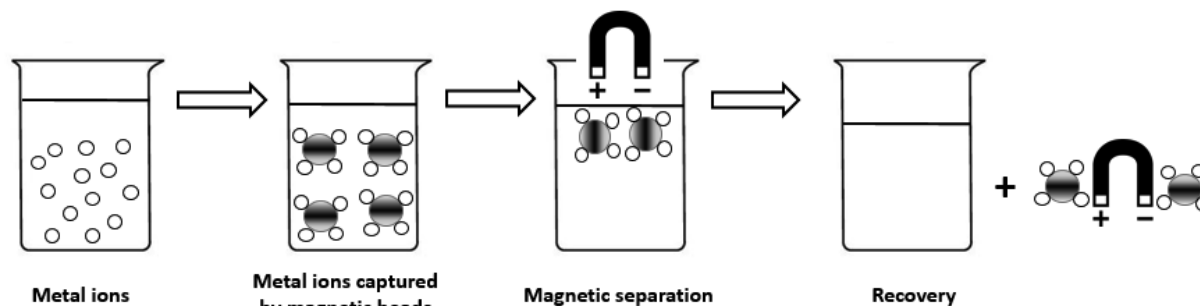
Insoluble hexacyanoferrates of the transition metals are well-known sorbents and ion exchangers [3-8]. They are hardly soluble in a wide acidity interval (*i.e.* in amounts from 10⁻⁶ to 10⁻¹² g cm⁻³), have high mechanical strength, chemical resistance, small specific gravity, good magnetic properties and are cheap to prepare. Their good sorp-

tion properties (distribution coefficients, K_d, often exceed 10⁴ cm³ g⁻¹) depend on their synthesis method as well as on their composition. Inorganic sorbents most frequently occur in the form of fine monocrystals in which the regular arrangement of atoms is cut by a series of channels and free spaces of the size corresponding to those of some ions. Typically, the material is a mixture of hexacyanoferrates containing iron in both the second and third oxidation states [9].

For the prospective use of hexacyanoferrates for the selective removal of *e.g.* Cs-137 from liquid nuclear wastes, a great number of hexacyanoferrates with different transition metals have been studied. An excellent review of the present state of

knowledge was recently published by Vincent *et al.* [10].

In the recent past, magnetic nanoparticles have started to be used as sorbents for the removal of trace metals from aqueous solutions [11-15]. The attractiveness of these materials, besides excellent sorption ability and good mechanical properties, is based on their easy separation from the solution using a magnetic field (Scheme 1) [16-17].



Scheme 1. Schematic representation of the usage of a magnetic sorbent.

In this contribution, being a continuation of research published by Zhao *et al.* [11], we report our studies on the possibilities for the application of the cobalt hexacyanoferrate sorbent containing magnetic iron carbonyl (MHC). Iron carbonyl is a highly pure iron, prepared by the chemical decomposition of purified iron pentacarbonyl. Because of its broad applications in electronics and medicine, the material is extremely cheap and, if bought wholesale, the price is significantly lower than 1.0 USD/kg.

In order to synthesize the magnetic composite material, a co-precipitation method was used, as described by Zhao *et al.* [11]. Magnetic particles of the commercially available iron pentacarbonyl ($\text{Fe}(\text{CO})_5$), solid $\text{K}_4\text{Fe}(\text{CN})_6$ and $\text{Co}(\text{NO}_3)_2$ were used. All studies of the MHC were performed using unfractionated sorbent.

We investigated sorption of Cs(I), Sr(II), Co(II), Eu(III) and Am(III) ions on the magnetic cobalt cyanoferrate nanoparticles (MHC) in batch experiments by analysing decontamination factors of the contaminated water as a function of the main factors important for designing the technological

process. The results published by Zhao *et al.* [11] for a similar magnetic sorbent, $\text{K}_2[\text{CoFe}(\text{CN})_6]$ composite containing magnetite, show that sorption of caesium(I) reaches equilibrium within 2 h. The same contacting time for the contaminated water with MHC was applied in the present work. For each factor, magnetic $\text{K}_2[\text{CoFe}(\text{CN})_6]$ composite with magnetite, studied by Zhao *et al.* [11], was used as the reference material. The aforemen-

tioned studies by Zhao *et al.* have been extended by determining the decontamination factors for Sr(II), Co(II), Eu(III) and Am(III) radionuclides.

Figure 1A reveals that the iron carbonyl MHC completely removes caesium(I) from aqueous solution, the adsorption percentage (E_r) being $99.6 \pm 0.3\%$. This observation corresponds well with our referent sorbent containing magnetite: for this material, E_r value is $98.6 \pm 1.0\%$. So, the proposed MHC sorbent resembles that recommended by Zhao *et al.* [11].

The aim of the presented work was, however, checking the possibility of using the novel sorbent for the recovery of metals other than Cs(I). It was also found that the efficiency of removal of Co(II) and Am(III) is high and the respective E_r values are $99.18 \pm 2.13\%$ and $98.4 \pm 5.27\%$. For the reference composite formed with magnetite, the corresponding values are $92.50 \pm 9.13\%$ and $98.43 \pm 11.42\%$, respectively. However, the proposed sorbent may be applied poorly for the recovery of the other metals. It was found that europium(III), and especially strontium(II), are sorbed below expectations. While the E_r value for the

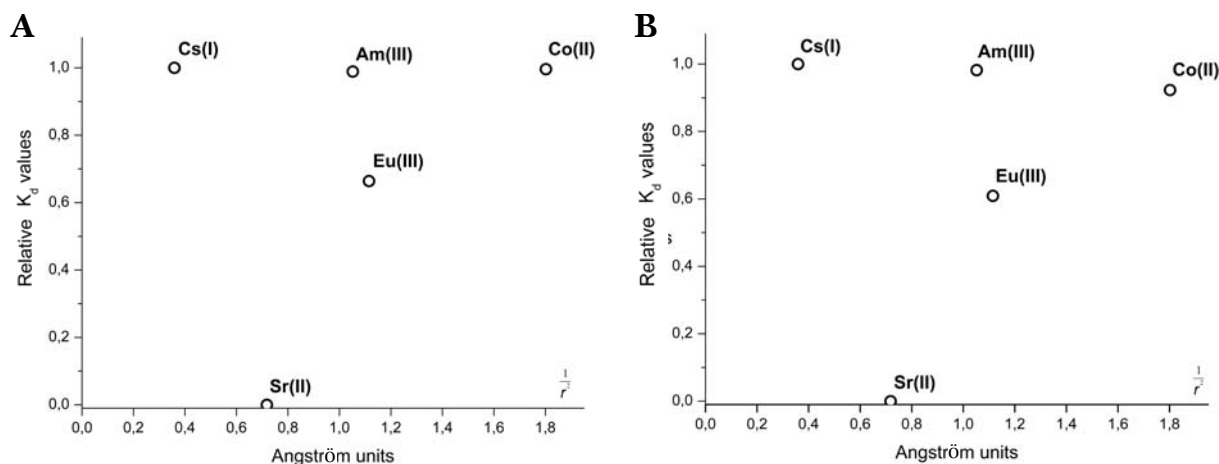


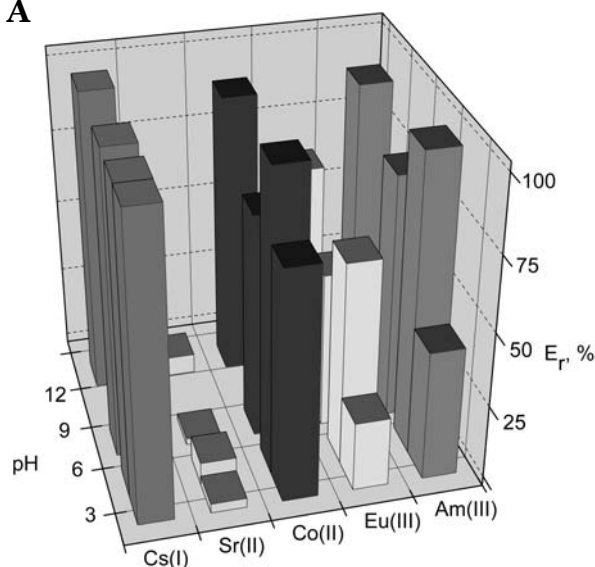
Fig. 1. Dependence of the distribution constants of Cs(I), Sr(II), Co(II), Eu(III) and Am(III) by the MHC nanocomposite with iron carbonyl on the reciprocal of their Shannon ionic radii [18] (A) and the analogue sorbent containing magnetite (B). The data are normalized to the respective values for caesium(I). Acidity of the purified solution – pH 3.5.

former metal was determined as $61.02 \pm 1.39\%$, sorption of strontium(II) appeared to be completely insufficient. The E_r value for this metal does not differ from zero by more than 5%. Results obtained for the magnetite sorbent agree within statistical error with the above values.

It is textbook knowledge that the Gibbs free energy (ΔG°) of the interaction between the investigated metal cation and the counter-ions plays an important role in the interpretation of numerous processes in aqueous solutions. Usually, the well-known Born equation may be used to describe the interactions if they are of pure electrostatic origin. When plotting the results recalculated to the distribution constant values as a function of the reciprocal of the Shannon ionic radii no continuous relationship is observed (Fig. 1). This means that even if metal sorption is governed mainly by the electrostatic cation-anion interactions, certain supplementary phenomena should be taken into account.

Furthermore, acidity of the purified contaminated solutions varied in the range from pH 1.5 to 12. Results of the metal sorption by both magnetic $K_2[CoFe(CN)_6]$ materials are presented in Fig. 2.

A



B

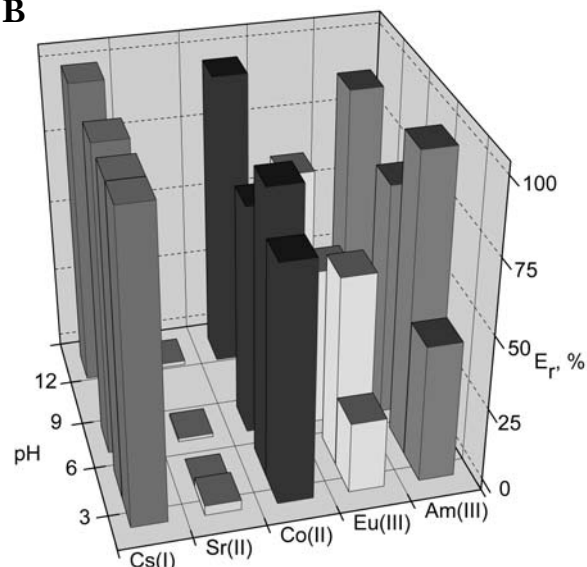


Fig. 2. Effect of pH on adsorption of Cs(I), Sr(II), Co(II), Eu(III) and Am(III) by cobalt cyanoferrate nanocomposites with iron carbonyl (A) and magnetite (B).

It can be seen that Cs(I) may be completely sorbed from both the acidic and basic solutions, meaning that the acidity of the purified solution has no significant influence on the adsorption process of Cs(I). The observation resembles that observed by Zhao *et al.* [11]. On the contrary, sorption of Sr(II) in the whole range of pH is extremely poor, as the efficiency is close to 0%.

Finally, removal of Co(II), Eu(III) and Am(III), metals with smaller radii than the aforementioned cations and with partially filled *d*- and *f*-orbitals, does not exhibit simple dependence on the initial acidity of the solution. This observation may be related to the diverse phenomena appearing for these metals in aqueous solutions. Of primary importance are changes in their speciation.

To check if the sorbents may be used in the purification of real solutions, we decided to compare the aforementioned results obtained for the artificial solutions with the uptake of metals from the solutions of the composition resembling the real radioactive liquid waste. In the available literature, data for this composition are rare and difficult to obtain. To achieve this objective, we have prepared a mixture of Na^+ , K^+ , Mg^{2+} and Ca^{2+} chlorides in concentrations resembling those found in solutions obtained from the National Radioactive Waste Repository, Poland. Results of the comparison are presented in Figs. 3A and 3B. It may be seen that in the case of caesium (to recall, cobalt hexacyanoferrates are dedicated to the selective sorption of this radionuclide), presence of the weighted amounts of salts does not affect sorption in the case of both magnetic components studied. For the other radionuclides, salts present in the solution successfully compete for the sorption sites of the sorbent. So, due to the co-sorption of the salts, one may observe a decrease in the uptake of the radiometals.

Radioactive liquid wastes may also contain certain chelating agents, formerly used for the cleansing of different contaminated items. So, to check

the potential sorbents in processing of the low-level radioactive wastes, we tested them by sorption of the radionuclides from aqueous solutions containing a mixture of popular chelating agents. Composition of the mixture resembled that in CANDEREM (Canadian decontamination and remediation) lotion: about $2 \cdot 10^{-3}$ M of oxalic and citric acids and also Na-EDTA [19]. Then, the obtained results were compared with the data gained previously for the aqueous solution with no chelating agents. As is seen from Figs. 3C and 3D, only for certain radionuclides the E_r values do not differ from each other by more than the experimental errors. So, it may be concluded that the cobalt hexacyanoferrate composites may be successfully applied for the recovery of caesium(I)

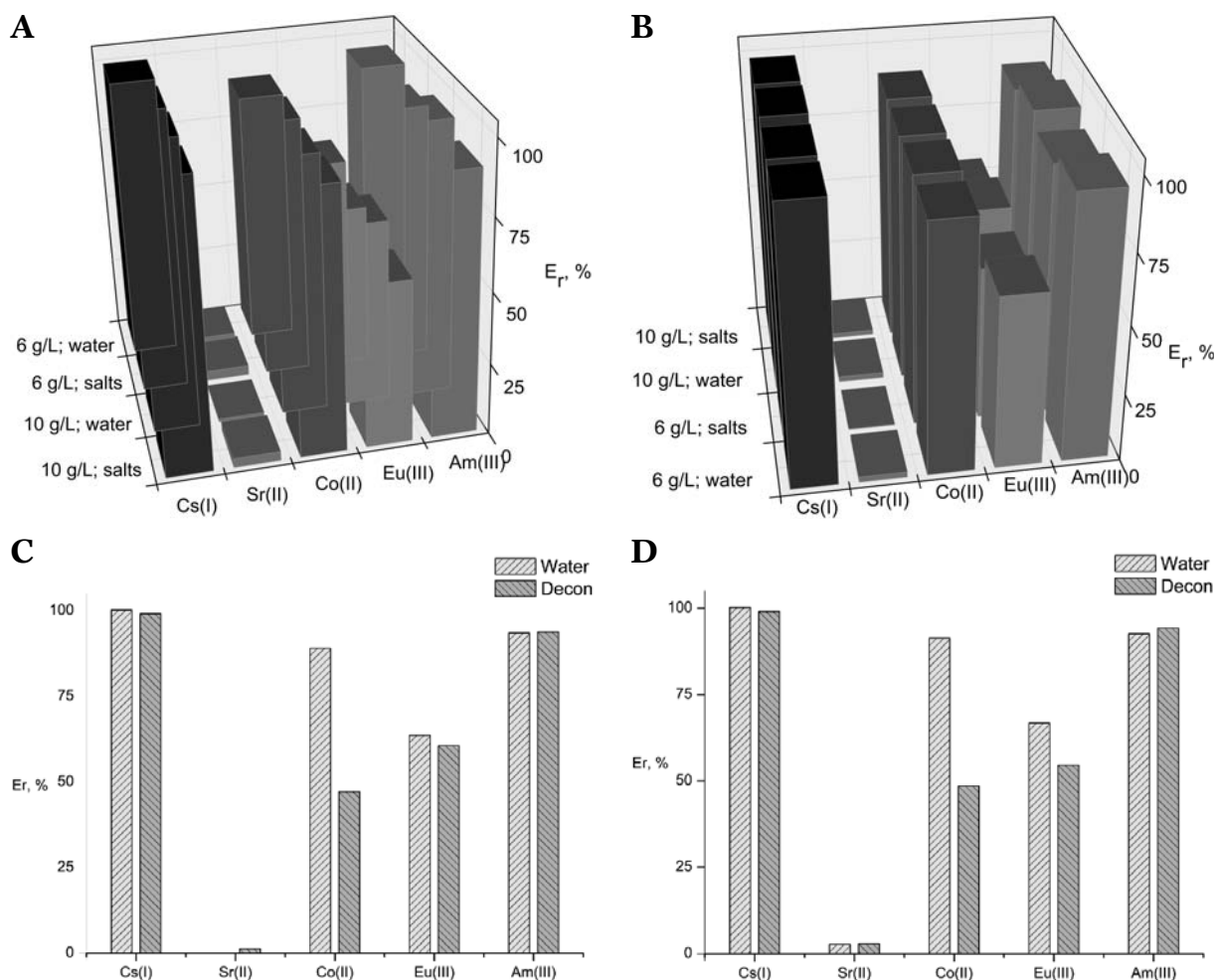


Fig. 3. Effect of the salting: (A) nanocomposite with the iron carbonyl, (B) nanosorbent containing magnetite. Plot (C) presents the effect of the chelating agents present in the solution for the nanocomposite with the iron carbonyl while (D) shows that for the nanosorbent containing the magnetite.

and americium(III), but in the processing of other radionuclides their value is rather limited.

Future applications of both materials for radioactive liquid waste management requires high radiation stability. So, the composites were treated with a radiation dose of 250 kGy and checked to see if their properties had been changed due to the radiation. In the first step, sorption of the radionuclides was studied. It was found that the E_r values are comparable within the experimental error for both pairs: raw materials and the appropriate irradiated sorbents (Fig. 4).

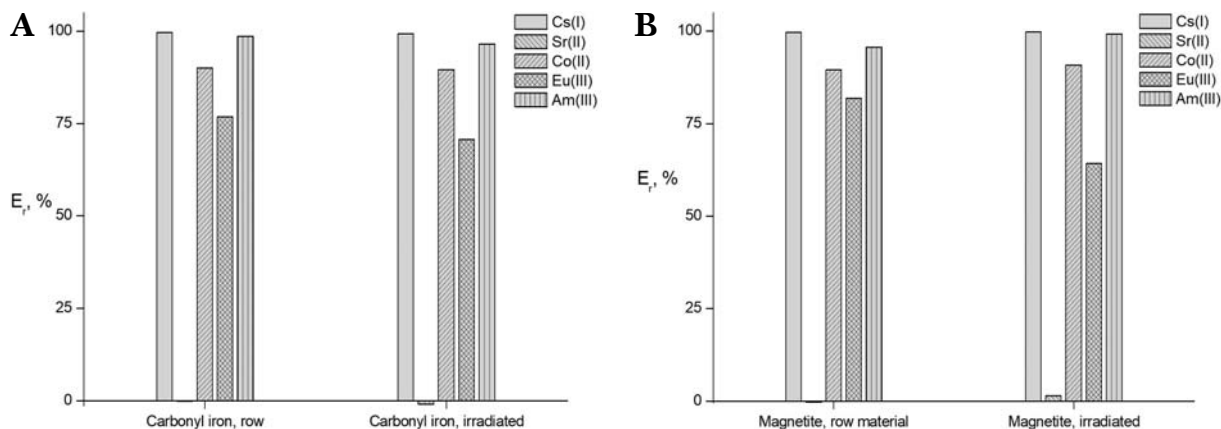


Fig. 4. Stability of sorbent adsorbed with metals: (A) raw MHC material, (B) gamma irradiated MHC material.

Measurement of the zeta potential (ζ_n), which describes the electrostatic potential near the surface of the particle, was determined for both pairs of sorbents. Relatively small changes of the potential occurring upon irradiation may be interpreted as indicating stability of the materials. The already determined ζ_n potential of the $K_2[CoFe(CN)_6]$ composite containing magnetite fluctuates around -30 mV for solutions between pH 4 and pH 10 [11]. Such a value seems to be high enough to produce a significant potential barrier preventing coagulation of the dispersed

nanoparticles. When the acidity of the solution increases to pH 11-12, the negative ζ_n potential reaches values of about -60 mV. Values obtained in the present work are -27 mV and -31 mV for the magnetite nanocomposite and the iron carbonyl material, respectively. Upon gamma irradiation, values of the potential increase only slightly and are -21 mV and -22 mV, respectively. Such a small difference observed for the respective pairs may be assumed as supplementary proof of the chemical stability of both sorbents.

Chemical stability of the proposed sorbents was, in turn, checked by their prolonged equilibration with water and determining the removal of cobalt and iron metals. A ten-day equilibration of sorbent containing the carbonyl iron magnetite

100× magnification reveal that the magnetite MHC is formed of more compact nanoparticles than the iron carbonyl material. The surfaces of both samples viewed with magnification of 5000× exposes, however, more pronounced differences. The sorbent containing magnetite is more uniform when compared with the material formed from iron carbonyl. Agglomerates formed on the surface of the latter material in certain areas are smooth, while in the former they are frayed. The aforementioned dissimilarities may be attributed to the different magnetic materials.

The obtained nanoparticles display large surface areas in both cases of about 32.5 m²/g. Such a large surface area suggests high sorption capacity of the material.

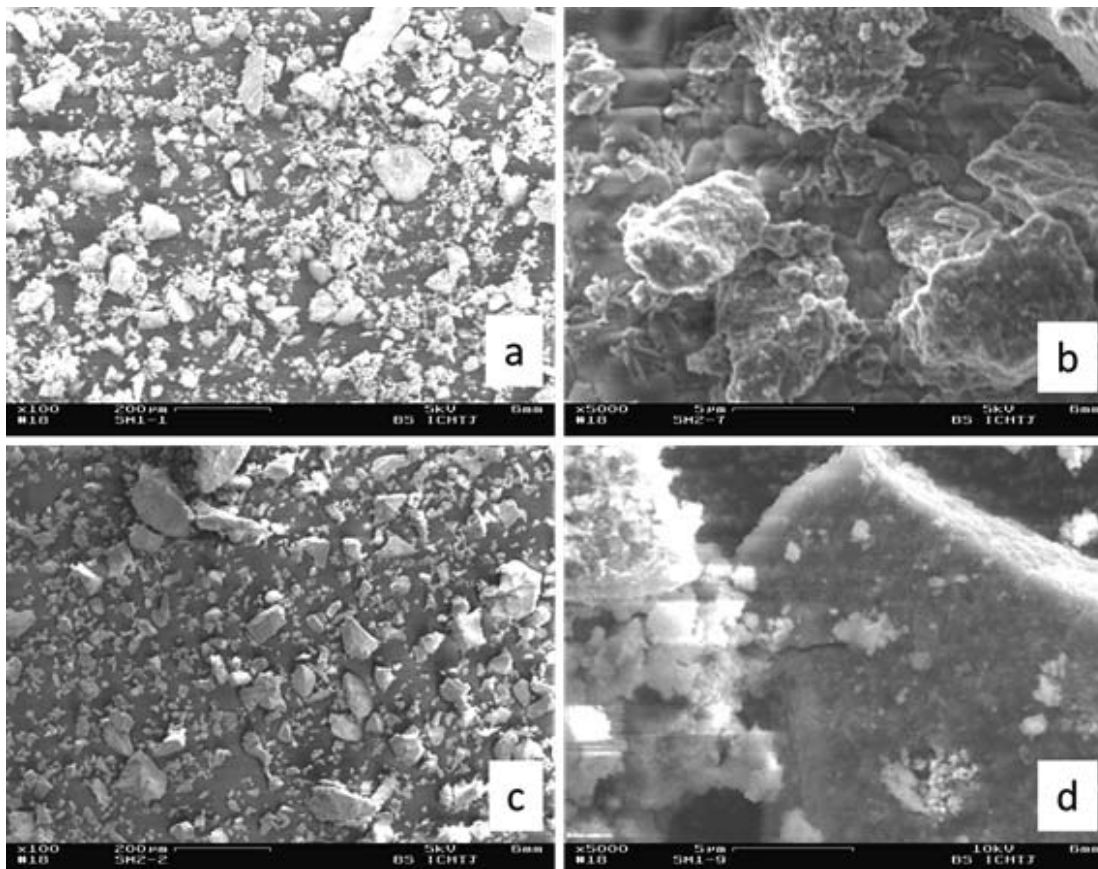


Fig. 5. SEM image of the sorbent surface: (a) 100× magnification of sorbent made with magnetite; (b) 5000× magnification of the same material, (c) 100× magnification of sorbent made with iron carbonyl, (d) 5000× magnification of the same sorbent.

showed the content of both metals in water to be about 30,000 ng/L and 350 ng/L, respectively. When the magnetite nanocomposite was used, these values were slightly lower: about 15,000 ng/L and 250 ng/L, respectively. According to the WHO directive for drinking water quality [20], the concentration of iron should be less than 0.3 mg/L ($3 \cdot 10^5$ ng/L) and there is no recommendation for cobalt. The abovementioned results clearly show that water, purified from radionuclides, should be additionally purified from heavy metals. Among the most prospective methods, nanofiltration/ultrafiltration should be considered.

Figure 5 presents images of the particles of both studied sorbents. Photographs taken with

Diffraction patterns for the iron carbonyl MHC are shown in Fig. 6A. The main reflections are recorded for the similar angles with these for the former material and confirm the presence of the $K_2Co[Fe(CN)]_6$ structure. An additional undefined reflection at 29° most likely comes from the iron carbonyl species.

Results of the X-ray diffraction analysis of the magnetite sorbent are shown in Fig. 6B and confirm the existence of the $K_2Co[Fe(CN)]_6$ structure. One may also see reflections that probably come from other structures, *e.g.* from $CoFe_2O_4$ or $K_2CoFe(CN)_6$. Nevertheless, the main reflections marked with the line indicate that $K_2Co[Fe(CN)]_6$ is the dominant component of the sample.

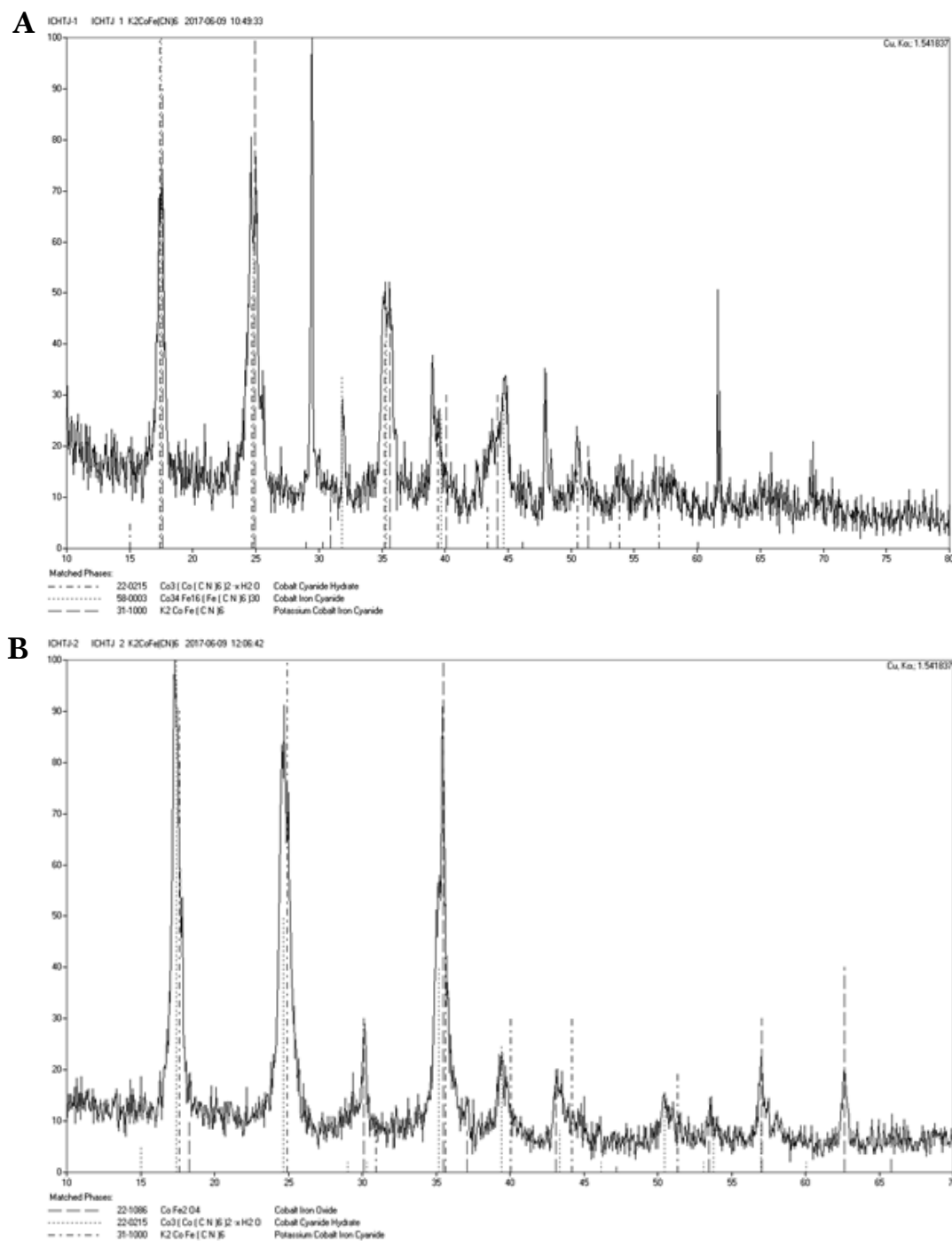


Fig. 6. X-ray diffraction patterns (XRD) of (A) iron carbonyl sorbent, (B) magnetite sorbent.

According to the proposition of Sadlej-Sosnowska *et al.* [21], calculation of the Pearson's correlation coefficient (c.c.) seems to be the most powerful tool for comparing two spectra. The c.c. may range from the value of -1 to 1. A zero value implies a lack of correlation between both spectra, *i.e.* they are totally different. On the contrary, values close to ± 1 indicate a similarity between the compared spectra and, consequently, between the identities of the substances being compared. The calculated correlation coefficient for the powder XRD spectra of both cobalt hexacyanoferrate inorganic-inorganic composites revealed the value of the c.c. to be 0.715, meaning that both materials, even though similar, are not the same at all.

Similarity in sorption properties of the MHC nanocomposites in conjunction with dissimilarities in the structure of both sorbents allows for the conclusion that sorption properties do not depend on the magnetic material used.

In conclusion, decontamination of radioactive wastes with the use of insoluble cobalt hexacyanoferrate nanocomposites (containing the iron hexacarbonyl or magnetite), originally dedicated to the removal of caesium(I) from aqueous solutions, was found to be effective for solutions containing caesium(I), and americium(III) radionuclides. If the concentration of the chelating agents is not too high, cobalt(II) may also be effectively removed from the solution.

The sorbent seems to be sufficiently stable for practical application in the treatment of radioactive wastewaters.

Sorption properties of the transition metal hexacyanoferrate nanocomposites do not depend on the magnetic material used for the synthesis of the sorbent.

References

- [1]. Amphlett, C.B. (1964). *Inorganic ion exchangers*. Amsterdam-London-New York: Elsevier Publishing Company. Series: Topics in Inorganic and General Chemistry, Monograph 2.
- [2]. Kadirvelu, K., & Goel, J. (2005). Ion exchange and inorganic adsorption, physics and chemistry of water. In *Water Encyclopedia* (Chapter 9, pp. 1999-2014). John Wiley & Sons, Inc. DOI: 10.1002/047147844X.pc1506.
- [3]. Streat, M., & Jacobi, D.L. (1995). Complex hexacyanoferrates for the removal of cesium from solution. In A.K. Sengupta (Ed.), *Ion exchange technology: Advances in pollution control* (pp. 193-224). Lancaster: Technomic Publishing Company, Inc.
- [4]. Kubica, B. (2010). Sorption of lead(II) on copper(II) and nickel-potassium hexacyanoferrates and magnetite-loaded resin from inorganic acid solutions. *Nukleonika*, 55, 163-168.
- [5]. Kubica, B., Tuteja-Krysa, M., Misiak, R., Tronh thi Thu My, Kubica, B., Stobiński, M., & Godunova, H. (2003). The behavior of Ba and Sr on inorganic and organic ion-exchangers from sulphuric acid solutions. Preliminary experiments. *J. Radioanal. Nucl. Chem.*, 258, 167-170.
- [6]. Narbutt, J., Siwiniski, J., Bartos, B., & Bilewicz, A. (1986). Studies on new titanium hexacyanoferrate sorbents for radiocesium removal from primary coolant of pressurized water reactors. *J. Radioanal. Nucl. Chem.*, 101, 41-49.
- [7]. Loos-Neskovic, C., Dierkes, M.H., Jackwerth, E., Fedoroff, M., & Garnier, E. (1993). Fixation of palladium on insoluble simple or complex cyano compounds. *Hydrometallurgy*, 32, 345-363.
- [8]. Loos-Neskovic, C., & Pedoroff, M. (1987). Exchange mechanisms of silver on nickel and zinc perrocyanides. *Solvent Extr. Ion Exch.*, 5, 757-780.
- [9]. Szegłowski, Z., Constantinescu, O., Hussonnois, M., Abdul-Hadi, A., & Ardisson, G. (1992). *Continuous purification of ²²³Fr from its decay-products on nickel hexacyanoferrate(II) composite ion exchanger*. Orsay: Institut de Physique Nucléaire. IPNO-DRE Report 92-12.
- [10]. Vincent, T., Vincent, C., & Guibal, E. (2015). Immobilization of metal hexacyanoferrate ion-exchangers for the synthesis of metal ion sorbents—A mini-review. *Molecules*, 20, 20582-20613.
- [11]. Zhao, L., Dudek, J., Polkowska-Motrenko, H., & Chmielewski, A.G. (2016). A magnetic nanosorbent for cesium removal in aqueous solutions. *Radiochim. Acta*, 104, 423-433.
- [12]. Basualto, C., Gaete, J., Molina, L., Valenzuela, F., Yanez, C., & Marco, J.F. (2015). Lanthanide sorbent based on magnetite nanoparticles functionalized with organophosphorus extractants. *Sci. Technol. Adv. Mater.*, 16, 3.
- [13]. Mirabi, A., Dalirandeh, Z., & Rad, A.S. (2015). Preparation of modified magnetic nanoparticles as a sorbent for the preconcentration and determination of cadmium ions in food and environmental water samples prior to flame atomic absorption spectrometry. *J. Magn. Mater.*, 381, 138-144.
- [14]. Sadeghi, S., Azhdari, H., Arabi, H., & Moghaddam, A.Z. (2012). Surface modified magnetic Fe₃O₄ nanoparticles as a selective sorbent for solid phase extraction of uranyl ions from water samples. *J. Hazard. Mater.*, 215-216, 208-216.
- [15]. Das, S., Pandey, A.K., Athawale, A.A., Subramanian, M., Seshagiri, T.K., Khanna, P.K., & Manchanda, V.K. (2011). Silver nanoparticles embedded polymer sorbent for preconcentration of uranium from bio-aggressive aqueous media. *J. Hazard. Mater.*, 186, 2051-2059.
- [16]. Huang, S.-H., & Chen, D.-H. (2009). Rapid removal of heavy metal cations and anions from aqueous solutions by an amino-functionalized magnetic nano-adsorbent. *J. Hazard. Mater.*, 163, 174-179.
- [17]. Grayson, M. (Ed.). (1981). *Kirk-Othmer Encyclopedia of Chemical Technology* (3rd ed.). New York: Wiley, p. 775.
- [18]. Shannon, R.D. (1976). Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides. *Acta Cryst.*, A32, 751-767.
- [19]. Dulama, M., Deneanu, N., Pavelescu, M., & Pașăre, L. (2009). Combined radioactive liquid waste treatment processes involving inorganic sorbents and micro/ultrafiltration. *Rom. J. Phys.*, 54, 851-859.
- [20]. World Health Organization. (2006). *Guidelines for drinking-water quality. First addendum to third edition. Vol.1: Recommendations*. WHO Press. Retrieved December 28, 2017, from http://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf.
- [21]. Sadlej-Sosnowska, N., Ocios, A., & Fuks, L. (2006). Selectivity of similar compounds' identification using IR spectrometry: β -Lactam antibiotics. *J. Mol. Struct.*, 792-793, 110-114.

APPLICATION OF ADVANCED MEMBRANE SYSTEMS IN NUCLEAR DESALINATION AS AN EFFECTIVE USE OF COGENERATION

Grażyna Zakrzewska-Koltuniewicz, Agnieszka Miśkiewicz, Katarzyna Kiegiel, Dorota Gajda

Cogeneration or combined heat and power (CHP) is a highly efficient form of energy conversion and a most efficient use of fuel, since in addition to producing electricity it allows the utilization of waste heat, which can be used for various purposes. Cogeneration in nuclear power plants brings many benefits: it saves energy by recovering waste heat that can be used for numerous industrial applications, e.g. district heating or cooling, production of hydrogen, desalination, etc. Such an approach brings environmental benefits, reducing

CO₂ emissions and the amount of radioactive waste created. The fuel in cogeneration nuclear power plants (NPPs) is used efficiently, in consequence these facilities produce cheap energy, and as a result fossil fuels valuable for the chemical industry are saved.

The successful introduction of nuclear cogeneration into industrial practice is a task set by the International Atomic Energy Agency (IAEA) and the European Nuclear Cogeneration Industrial Initiative (NC2I), in which Poland actively partici-

pates, recognizing the benefits of this approach. Commencing the nuclear programme in Poland gives an opportunity to develop completely new designs and processes, leading to the achievement of maximum reactor efficiency by the effective use of the energy and heat generated in the fission process.

One of the possible ways to simultaneously increase reactor efficiency and the safety of nuclear power plants is to furnish the future NPP with advanced desalination systems, which could be helpful in regular plant operation and in emergency situations. Such industrial application of cogeneration, both in the case of energy production in pressurized water reactors (PWRs) and in the development of high temperature reactors (HTRs), increases the safety of nuclear systems.

Intensive development of desalination technologies around the world has resulted in a significant decrease in the cost of the water that is produced by desalination plants. Traditional distillation processes are being replaced by novel, more economic methods. In recent years, membrane processes have become very attractive methods of desalination. With rapid progress in the production of cheap, robust membrane materials, reverse osmosis (RO) can compete with energy-intensive distillation techniques. These membrane-based processes offer numerous advantages over the conventional evaporation and distillation technologies used for desalination. They are characterized by a lower energy to product ratio because the energy supplied to membrane installations is consumed only for pumping liquid through the system. Since the primary equipment in such installations is membrane modules and pumps, which are easy to replace, they need less maintenance than evaporators. The apparatus does not have moving parts; therefore it is reliable and easy to operate. Membrane devices use less expensive construction materials, since the processes operate at room temperature, reducing corrosion. Low process temperatures also decrease scaling, which is a common problem with evaporators.

When talking about the benefits of using membrane processes, environmental issues cannot be ignored. The emissions released by fuel-fired evaporation and distillation processes are eliminated in such cases.

In recent years, reverse osmosis has become a common desalination technique. According to the International Desalination Association, in 2011 it accounted for 66% of the installed capacity of all desalination systems. Membrane distillation (MD), however, originally developed for seawater desalination [1, 2], has not yet found full implementation in this field. MD is a separation process involving a porous hydrophobic membrane, which is the only contact surface of two phases remaining at different temperatures. The driving force of MD is a temperature gradient across the membrane that results in a vapour pressure difference.

Apart from desalination, many other applications of MD have been considered, such as waste-

water treatment [3], the treatment of the water produced in oilfields [4], groundwater purification [5], milk, whey and lactose concentration, as well as the concentration of juices [6]. At the Institute of Nuclear Chemistry and Technology (INCT), membrane distillation was developed both for water purification [7] and radioactive waste processing [8-11]. Extensive research conducted with the use of different experimental systems confirmed the usefulness of membrane distillation for

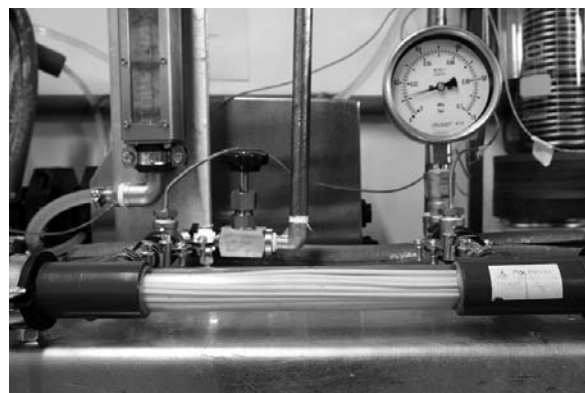


Fig. 1. The module with capillary porous membranes used in MD.

liquid radioactive waste treatment. Several membrane configurations were tested, including the most applicable capillary modules (Fig. 1). The experiments have demonstrated that in addition to the desalination capacity of membranes made of hydrophobic polymers (polytetrafluoroethylene – PTFE, polypropylene – PP), their radionuclide retention was highly effective. In the MD process, radionuclides were concentrated in the retentate, and the distillate was completely purified water, with an activity at the natural background level (Figs. 2 and 3).

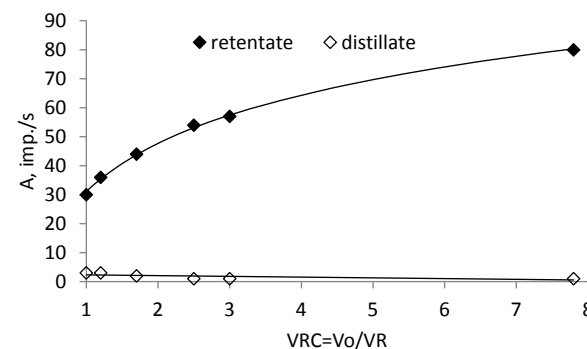


Fig. 2. Concentration of ^{157}Cs in aqueous solution.

It has been revealed by numerous experiments and analyses that the MD process could be used in a nuclear power plant in the systems that allow on-site processing of low-activity liquid waste, while also producing clean water for the needs of the power plant. The feed water for an MD plant can be seawater or water from any other suitable source.

An example scheme of a power plant combining the production of electricity with water desalination is shown in Fig. 4. It generates electricity for the needs of the electric grid in a system

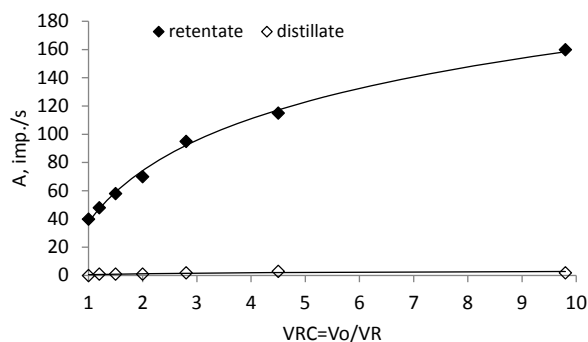


Fig. 3. Concentration of ^{85}Sr in aqueous solution.

consisting of a generator connected to a high-pressure turbine. The low-pressure steam from the turbine transfers the heat to the water in the

emergency they can facilitate the handling of any waste generated.

Both RO and MD are usable methods for water and wastewater treatment. They can be combined with nuclear reactors and used in power plants for various purposes: production of clean water and deionized water, as well as for the treatment of liquid radioactive waste. Membrane distillation that can be driven by the heat from the secondary cooling circuit seems economic for conventional power plants and in nuclear power facilities. This method is advantageous because it has the lowest ratio of energy input to the amount of produced water, high salt retention and allows easy processing and equipment servicing. The MD process can use waste heat because it works at low temperatures.

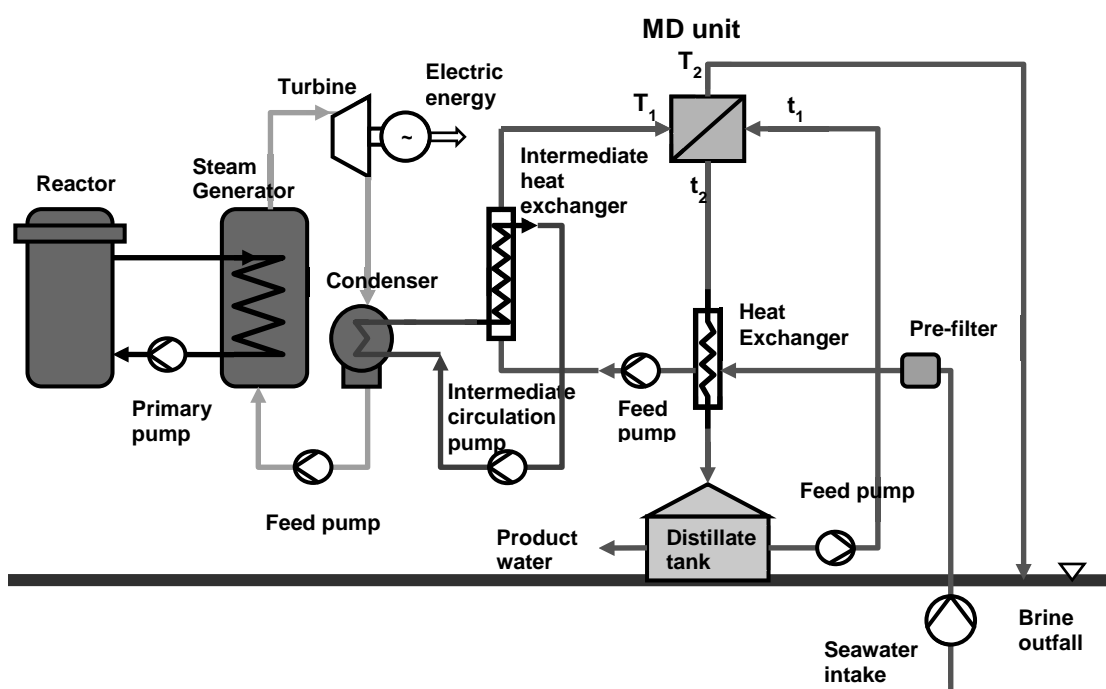


Fig. 4. Membrane distillation process applied to nuclear desalination.

condenser, which heats the seawater in the intermediate heat exchanger. This system constitutes an additional loop separating the nuclear reactor from the desalination plant and securing the desalinated stream against any radioactive impurities coming from the nuclear reactor.

A more economical desalination process associated with a nuclear reactor could be the MD/RO hybrid process, which allows for the better use of the heat generated by nuclear power plants and the recovery of energy. An additional RO unit powered by electricity could use water pre-heated with waste heat, resulting in higher product yields.

It seems that membrane units could be a very important part of the water management system of an NPP. Low temperature systems, such as RO and MD, can be used for the treatment of low-level radioactive effluents created in the power plant and to produce pure water for the different needs of the NPP. Such integrated water management systems can enhance the safety of NPPs, allowing them to work seamlessly, and in times of

The use of membrane techniques for radioactive waste processing gives various water recycling possibilities, decreasing the impact of an NPP on the environment.

References

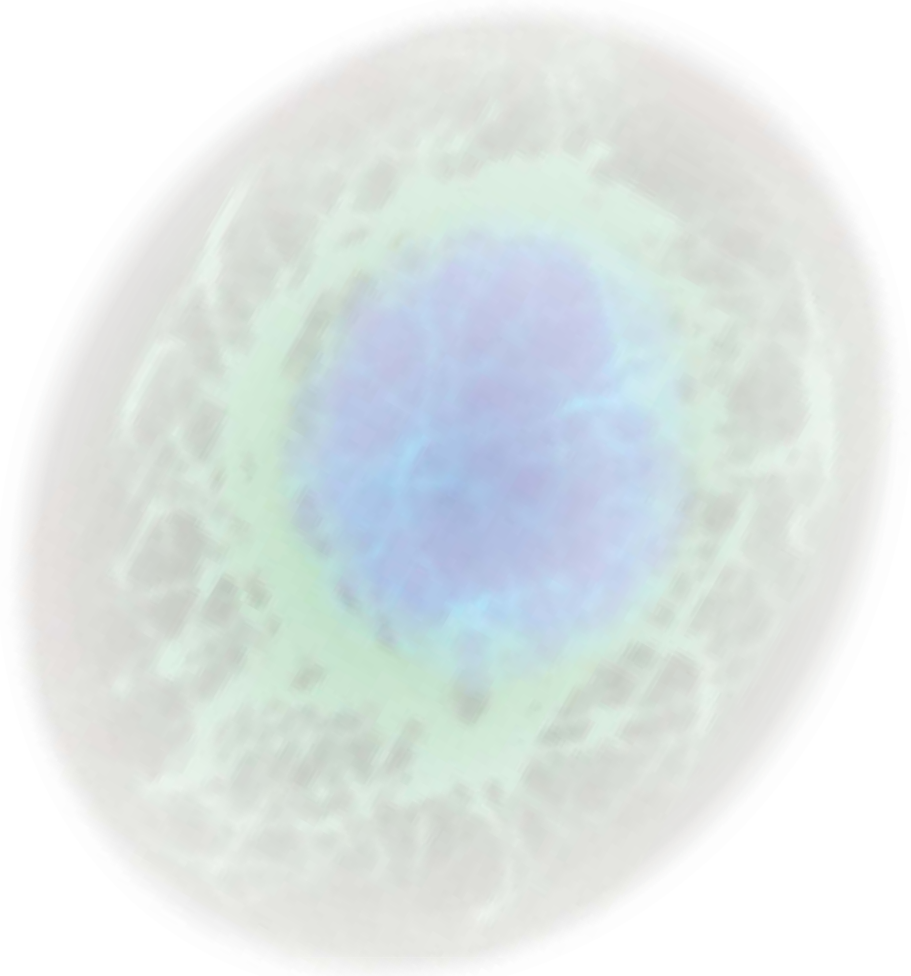
- [1]. Al-Obaidani, S. Curcio, E., Macedonio, F., Di Profio, G., Al-Hinai, H., & Drioli, E. (2008). Potential of membrane distillation in seawater desalination: Thermal efficiency, sensitivity study and cost estimation. *J. Membr. Sci.*, 323, 1, 85-98.
- [2]. Qtaishat, M.R., & Banat, F. (2013). Desalination by solar powered membrane distillation systems. *Desalination*, 308, 186-197.
- [3]. Gryta, M., Tomaszewska, M., & Karakulski, K. (2006). Wastewater treatment by membrane distillation. *Desalination*, 198(1), 67-73.
- [4]. Macedonio, F., Ali, A., Poerio, T., El-Sayed, E., Drioli, E., & Abdel-Jawad, M. (2014). Direct contact membrane distillation for treatment of oilfield produced water. *Sep. Purif. Technol.*, 126, 69-81.
- [5]. Hou, D.Y., Wang, J., Wang, B.Q., Luan, Z.K., Sun, X.C., & Ren, X.J. (2010). Fluoride removal from

- brackish groundwater by direct contact membrane distillation. *Water Sci. Technol.*, 61, 3178-3187.
- [6]. Ashoor, B.B., Mansour, S., Giwa, A., Dufour, V., & Hasan, S.W. (2016). Principles and applications of direct contact membrane distillation (DCMD): A comprehensive review. *Desalination*, 398, 222-246.
- [7]. Zakrzewska-Koltuniewicz, G. (2017). Water management in nuclear power plant using advanced low-temperature systems. *Eur. Water*, 58, 345-350.
- [8]. Zakrzewska-Trznadel, G., Harasimowicz, M., & Chmielewski, A.G. (1999). Concentration of radioactive components in liquid low-level radioactive waste by membrane distillation. *J. Membr. Sci.*, 163, 257-264.
- [9]. Zakrzewska-Trznadel, G., Harasimowicz, M., & Chmielewski, A.G. (2001). Membrane processes in nuclear technology – application for liquid radioactive waste treatment. *Sep. Purif. Technol.*, 22-23, 617-625.
- [10]. Zakrzewska-Koltuniewicz, G. (2015). Advancement in membrane methods for liquid radioactive waste processing: current opportunities, challenges, and the global scenario. In A.K. Pabby, S. S.H. Rizvi, A.M. Sastre (Eds.), *Handbook of membrane separations, chemical, pharmaceutical, food and biotechnological applications* (second edition, pp. 665-708). CRC Press Taylor & Francis Group.
- [11]. Zakrzewska-Trznadel, G. (2013). Advances in membrane technologies for the treatment of liquid radioactive waste. *Desalination*, 321, 119-130.

CENTRE FOR RADIOBIOLOGY AND BIOLOGICAL DOSIMETRY

Studies carried out in 2017 focused on the implementation of new biodosimetric tools that have been developed in the frame of the strategic research project “Technologies supporting development of safe nuclear power engineering” from the National Centre for Research and Development (SP/J/6/143 339/11). Accreditation No 1577 for the retrospective radiation dose estimation by dicentric chromosome measurements in peripheral blood lymphocytes given to the Laboratory for Biological Dosimetry by the Polish Centre for Accreditation in 2016 was sustained for next two years. The Centre participated in the interlaboratory comparison of methods in biological dosimetry, organized by the operational network established in the frame of Coordination Action project RENEb founded within the 7th EU Framework Programme EURATOM – Fission. In addition, new, high throughput methods for biological dosimetry, based on gene expression analysis are being developed.

An important research topic during the last few years has been the nanotoxicology and nanomedicine. Mechanism of toxicity of silver nanoparticles was studied in rat model in respect to their influence on brain functions, including long- and short-term memory. The Centre has also two ongoing projects on radium bearing nanozeolite radiopharmaceuticals against prostate and breast cancer.



STUDIES OF THE NITROSYLATION REACTION OF A PHOSPHINE COMPLEX MODELLING THE IRON CENTRE OF PROTEINS FROM THE CUPIN FAMILY

Hanna Lewandowska, Jarosław Sadło, Tomasz Stępkowski, Anna Lankoff, Krzysztof Łyczko

Dinitrosyl iron complexes (DNIC) with a general formula $\text{Fe}(\text{NO})_2(\text{L})_2$ have been observed in many organisms over a wide spectrum of physiological conditions. The composition of these complexes vary, as they are formed from different ligands containing imidazole or sulfhydryl groups [1, 2].

Pirin is a recently identified eukaryotic iron centre-containing protein from the cupin family, which is involved in transcriptional activation and apoptosis. The homologues of pirin are highly conserved in both prokaryotic and eukaryotic cells, but their function remains poorly understood [3]. Both bacterial and human pirins have quercetinase enzyme activity, which is inhibited by the addition of typical inhibitors of quercetin 2,3-dioxygenase. The pirin iron centre is based on a system of three histidyl ligands, the so-called trihistidyl facial triad (3-His facial triad) [3].

The symmetry of the metallic centre, which is referred to as the facial triad, is typical of the enzymes in the cupin family; the ligands forming the "flat" coordinating environment can be three histidine imidazole rings or two histidines and one carboxylic group [4, 5]. A number of papers have modelled the coordination system of 3-His facial triads typical of non-haem iron dioxygenases using scorpionate ligands, *e.g.* substituted tris(pyrazolyl)methane [6] or tris(imidazolyl)phosphine [7, 8]. Imidazole moieties in these types of tridentate ligands can be bound at C2 [9] or at a C4 with a blocked NH nitrogen [7, 10]. Studies analysing structures of this type are aimed at developing methods of bioinspired catalysis.

Literature data indicate that nitric oxide can interact with the iron centre of proteins, resulting in the disintegration of this centre and a change in the proteins' enzymatic activities [11]. Nitric oxide is often used as an unreactive analogue of diatomic oxygen in structural studies of metallic enzyme centres. Another advantage is its paramagnetic character, which allows researchers to identify and determine the symmetry of its complexes with transition metals, such as iron(II) [2], ruthenium(II) [12], copper(I) [13], *etc.* Therefore, obtaining synthetic complexes is very useful for modelling the histidyl iron centre with nitric oxide. This will help in determining a number of steric parameters and the distribution of electron charge density in similar centres.

Synthesis of $[\text{Fe}(\text{4-TIP}^{\text{Ph}})(\text{OAc})(\text{MeOH})]\text{BPh}_4$

The synthesis was performed according to the modified method published in [7]. In a 5 mL round bottom flask equipped with a stopper and magnetic stirrer, $\text{Fe}(\text{OAc})_2$ (48.5 mg), 4-TipPh (128 mg) and MeOH (1.3 mL) were placed. The mixture was stirred for 30 min at low speed under a nitrogen atmosphere. The mixture was then filtered into a second 5 mL flask, a Pasteur pipette packed with cotton wool being used for the filtration. To the

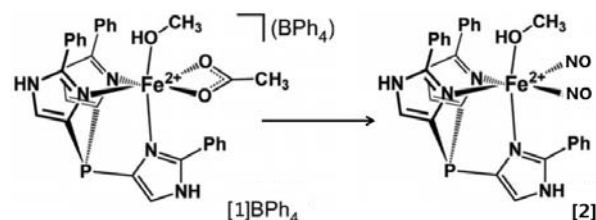
clear filtrate (which was a light brown colour), NaBPh_4 (96.5 mg in 0.2 mL MeOH) was added dropwise; thereupon a thick precipitate formed. The flask was left on the stirrer for 1 h and then transferred to the refrigerator. After 24 h the solution was decanted from the crystals, and the product was dried under vacuum for 5 h. The obtained dry product had a brown shade (complex 1).

Recrystallization

Twice the amount of MeOH was used relative to the total amount of dry product obtained from the reaction; this mixture was stirred for 3 h and then allowed to stand for 24 h in the refrigerator. Decantation and drying gave a light yellow powder. Despite attempts to recrystallize it from various mixtures of methanol and acetonitrile, it was not possible to obtain crystals of crystallographic quality. Spectroscopic, IR and UV-VIS measurements were made.

Nitrosylation of complex 1

NO was bubbled through 600 μL of a saturated solution of complex 1 in acetonitrile under anaerobic conditions. The mixture turned a brown-green colour. After 10 min the reaction was completed. The mixture was allowed to stand for the next 2 h in order to allow its complete saturation with NO .



Scheme 1. Nitrosylation of 1.

The resulting complex 2 was vacuum-dried (dark green complex) and used for analysis (Scheme 1).

Examination of the structure of complex 2

EPR spectra were measured at 100-294 K, a modulation amplitude of 3 G and a microwave power of 1 mW. The spectral parameters were determined by fitting a curve in EPRsim32 [14].

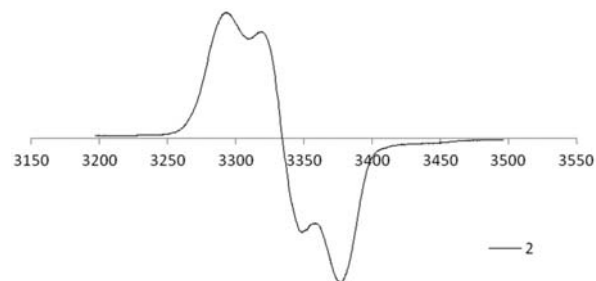


Fig. 1. The EPR signal of 2.

The obtained complex 2, in contrast to the initial complex 1, was characterized by an EPR signal in the range characteristic for nitrosyl iron complexes. The shape of the signal indicated the

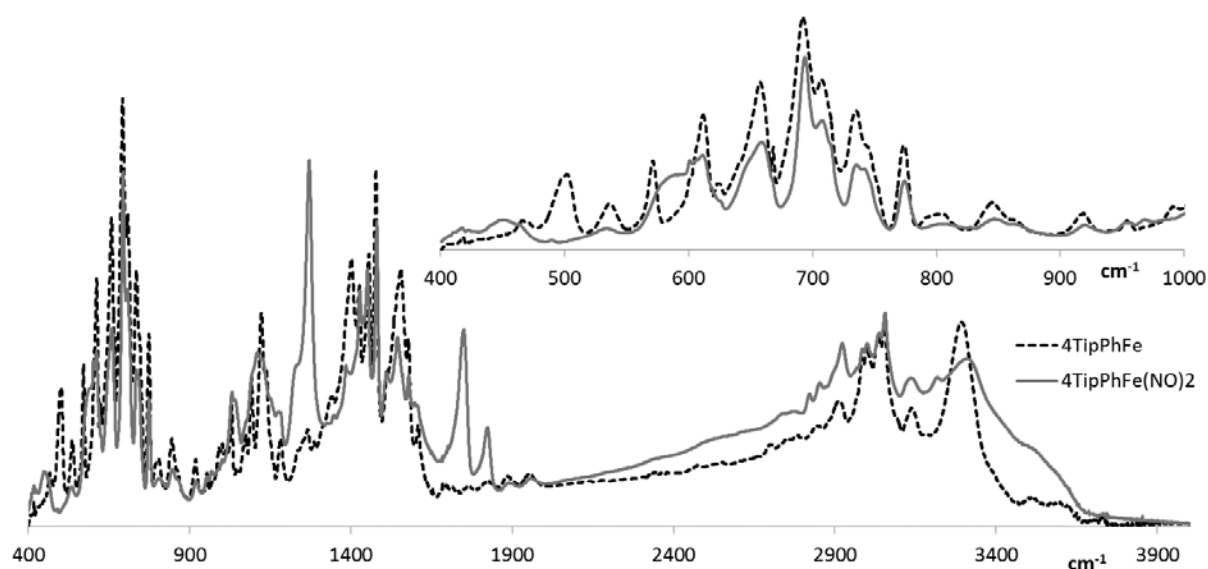


Fig. 2. The IR spectrum of **1** compared to that of **2**. The band at 500 cm^{-1} in the spectrum of **1**, disappearing for **2**, can be assigned to the $\nu(\text{Fe-O})$ between the iron and the leaving acetate ligand. New $\nu(\text{NO})$ vibrations at 1749 cm^{-1} and 1821 cm^{-1} can be seen for **2**; the weak bands at 447 cm^{-1} and 585 cm^{-1} can be attributed to (Fe-N) vibrations [15, 16].

anisotropic symmetry of the paramagnetic centre. The g -values were: 2.0655, 2.0396, 2.0130 (Fig. 1).

The absorption spectra of the compounds were recorded at room temperature with a Bruker Equinox 55 FT-IR spectrometer. Spectra in the range $400\text{--}4000\text{ cm}^{-1}$ at a resolution of 1 cm^{-1} were recorded using KBr pellets, and in the range $200\text{--}600\text{ cm}^{-1}$ at a resolution of 4 cm^{-1} using CsI pellets.

The two bands at 1749 cm^{-1} and 1821 cm^{-1} that appear in the spectrum of the nitrosylated 4-TipPhFe(NO)₂ (Fig. 2) were assigned to the two stretching vibrations of the non-equivalent $-\text{NO}$ groups. The non-equivalence of the two stretching vibrations [15], along with a considerable difference in band intensity [16], are typical for most of the dinitrosyl iron complexes. The disappearing band at 500 cm^{-1} can be assigned to the $\nu(\text{Fe-O})$ between the iron and the leaving acetate ligand, in accordance with other reported stretching bands of that type [17–19]. In turn, very weak bands at 448 cm^{-1} and 585 cm^{-1} can be attributed to the stretching and bending vibrations of the Fe-N bond within the Fe-NO moiety [20].

Conclusions

The obtained 3-His facial triad-mimicking complex was nitrosylated to form a paramagnetic iron(II) dinitrosyl complex. Spectroscopic spectra confirmed the anisotropic nature of the paramagnetic centre and indicated the non-equivalence of the two nitrosyl ligands. The obtained spectroscopic data can be used to analyse the nitrosylation reaction of 3-His facial triad iron centres.

This work was supported by the statutory grant from the Ministry of Science and Higher Education to the INCT (020-605).

References

- [1]. Borodulin, R.R., Dereven'kov, I.A., Burbaev, D.S., Makarov, S.V., Mikoyan, V.D., Serezhenkov, V.A., Kubrina, L.N., Ivanovic-Burmazovic, I., & Vanin, A.F. (2014). Redox activities of mono- and binuclear

- forms of low-molecular and protein-bound dinitrosyl iron complexes with thiol-containing ligands. *Nitric Oxide*, *40*, 100–109. doi: 10.1016/j.niox.2014.06.005.
- [2]. Lancaster, J.R., Langrehr, J.M., Bergonia, H.A., Murase, N., Simmons, R.L., & Hoffman, R.A. (1992). EPR detection of heme and nonheme iron-containing protein nitrosylation by nitric oxide during rejection of rat heart allograft. *J. Biol. Chem.*, *267*, 10994–10998.
- [3]. Adams, M., & Jia, Z. (2005). Structural and biochemical analysis reveal pirins to possess quercetinase activity. *J. Biol. Chem.*, *280*, 28675–28682. doi: 10.1074/jbc.M501034200.
- [4]. Leitgeb, S., & Nidetzky, B. (2008). Structural and functional comparison of 2-His-1-carboxylate and 3-His metallocentres in non-haem iron (II)-dependent enzymes. *Biochem. Soc. Trans.*, *36*, 1180–1186.
- [5]. Koehntop, K., Emerson, J., & Que Jr, L. (2005). The 2-His-1-carboxylate facial triad: a versatile platform for dioxygen activation by mononuclear non-heme iron(II) enzymes. *JBIC J. Biol. Inorg. Chem.*, *10*, 87–93. doi: 10.1007/s00775-005-0624-x.
- [6]. Edwards, P.G., Harrison, A., Newman, P.D., & Zhang, W. (2006). Trispyrazolylmethane piano stool complexes of iron(II) and cobalt(II). *Inorg. Chim. Acta*, *359*, 3549–3556. doi: 10.1016/j.ica.2005.12.034.
- [7]. Bittner, M.M., Baus, J.S., Lindeman, S.V., & Fiedler, A.T. (2012). Synthesis and structural characterization of iron(II) complexes with tris(imidazolyl)phosphane ligands: A platform for modeling the 3-histidine facial triad of nonheme iron dioxygenases. *Eur. J. Inorg. Chem.*, *2012*, 1848–1856. doi: 10.1002/ejic.201101282.
- [8]. Liang, S., Wang, H., Deb, T., Petersen, J.L., Yee, G.T., & Jensen, M.P. (2012). Structural and spectroscopic trends in a series of half-sandwich scorpionate complexes. *Inorg. Chem.*, *51*, 12707–12719. doi: 10.1021/ic301409s.
- [9]. Brown, R., Zamkane, M., & Cocho, J. (1984). Tris(imidazole)-containing phosphine: M₂⁺ complexes as biomimetic catalysts. Importance of a L: M₂⁺-OH in the catalyzed bimolecular hydrolysis of p-nitrophenyl picolinate. *J. Am. Chem. Soc.*, *106*, 5222–5228.
- [10]. Ibrahim, M.M., & Mersal, G.A. (2010). Zinc (II) tweezers containing artificial peptides mimicking the active site of phosphotriesterase: The catalyzed

- hydrolysis of the toxic organophosphate parathion. *J. Inorg. Biochem.*, 104, 1195-1204.
- [11]. Drapier, J.C., & Bouton, C. (1996). Modulation by nitric oxide of metalloprotein regulatory activities. *BioEssays*, 18, 549-556.
- [12]. Andreasen, L.V., Lorkovic, I.M., Richter-Addo, G.B., & Ford, P.C. (2002). Kinetics studies of the reaction of the ruthenium porphyrin Ru(OEP)(CO) with the S-nitrosothiol N-acetyl-1-amino-2-methylpropyl-2-thionitrite. *Nitric Oxide*, 6, 228-235. doi: 10.1006/niox.2001.0403.
- [13]. Periyasamy, G., Sundararajan, M., Hillier, I.H., Burton, N.A., & McDouall, J.J. (2007). The binding of nitric oxide at the Cu (I) site of copper nitrite reductase and of inorganic models: DFT calculations of the energetics and EPR parameters of side-on and end-on structures. *Phys. Chem. Chem. Phys.*, 9, 2498-2506.
- [14]. Spalek, T., Pietrzyk, P., & Sojka, Z. (2005). Application of the genetic algorithm joint with the Powell method to nonlinear least-squares fitting of powder EPR spectra. *J. Chem. Inf. Model.*, 45, 18-29.
- [15]. Lewandowska, H. (2013). Spectroscopic characterization of nitrosyl complexes. *Struct. Bond.*, 153, 115-166.
- [16]. Saratovskikh, E.A., Psikha, B.L., & Sanina, N.A. (2013). The reaction of the iron thiosulfate-nitrosyl complex with adenosine triphosphoric acid. *Nat. Sci.*, 5, 800-810.
- [17]. D'Antonio, M.C., Wladimirsky, A., Palacios, D., Coggiola, L., González-Baró, A.C., Baran, E.J., & Mercader, R.C. (2009). Spectroscopic investigations of iron (II) and iron (III) oxalates. *J. Brazil. Chem. Soc.*, 20, 445-450.
- [18]. Simaan, A.J., Döpner, S., Banse, F., Bourcier, S., Bouchoux, G., Boussac, A., Hildebrandt, P., & Girerd, J. (2000). FeIII-hydroperoxo and peroxo complexes with aminopyridyl ligands and the resonance raman spectroscopic identification of the Fe–O and O–O stretching modes. *Eur. J. Inorg. Chem.*, 2000, 1627-1633.
- [19]. Das, T.K., Couture, M., Ouellet, Y., Guertin, M., & Rousseau, D.L. (2001). Simultaneous observation of the O–O and Fe–O2 stretching modes in oxyhemoglobins. *Proc. Natl. Acad. Sci.*, 98, 479-484.
- [20]. Alben, J.O., Choi, S., Adler, A.D., & Caughey, W.S. (1973). Infrared spectroscopy of porphyrins. *Ann. NY Acad. Sci.*, 206, 278-295.

IMPACT OF NANOPARTICLES ON TOXIC PROPERTIES OF OXIDIZED LOW DENSITY LIPOPROTEIN

Sylvia Męczyńska-Wielgosz, Maria Wojewódzka, Sylwester Sommer, Iwona Grądzka, Barbara Sochanowicz, Iwona Buraczewska, Marcin Kruszewski, Hanna Lewandowska

Nanoparticles (NPs) and nanomaterials are defined as substances with at least one dimension less than 100 nm. Due to their high surface area and small volume, coupled to other physicochemical properties, NPs possess properties substantially different from bulk materials of the same composition. The increasing use of nanomaterials of various physicochemical properties in different industrial applications has greatly enhanced human exposure to NPs. Thus, it seems necessary to duly investigate the potential interactions of NPs with living organisms in order to identify potential threats that NPs may pose for human health and to reliably estimate the risk of their use [1, 2].

The aim of the present study was to investigate the combined toxicity of NPs and oxidized low-density lipoprotein (oxLDL) on HepG2 cells. OxLDL has been shown to play a major role in atherosclerosis [3]. Macrophages in the arterial wall are able to accumulate oxLDL, forming foam cells. OxLDL increases the activity of the foam cells, while also stimulating the replication of macrophages and their migration into the atherosclerotic plaque. OxLDL is also a toxic and pro-inflammatory agent [4, 5].

OxLDL is eliminated from the blood stream by hepatocytes in the liver by means of the oxLDL-specific receptor CD36. However, NPs can absorb proteins forming an NP-protein corona, a process that may change the conformation of the adsorbed protein and its biological properties [6]. Thus, in the context of the increasing exposure of humans to NPs, it seems interesting to examine the interaction of NPs and oxLDL in terms of their potential toxicity to human hepatocytes.

In this study we examined the impact of selected NPs on the toxic properties of oxLDL to HepG2 cells. We used two types of NPs (approximately 20 nm in size) widely used in industry:

- silver nanoparticles (AgNPs), which are the most commonly used in commercial products. Because of their well-known antimicrobial properties, AgNPs are present in many consumer goods and are able to penetrate the human body *via* multiple paths [7, 8].
- titanium dioxide nanoparticles (TiO₂NPs), which are widely used in industrial and consumer products due to their strong catalytic activity (such as antibiotics and antifungal agents, aerospace materials or optical filters) [9, 10].

Experiments were performed on human hepatoma HepG2 cells purchased from the American Type Culture Collection (ATCC, Rockville, MD, USA). HepG2 cells were cultured in DMEM high glucose (Gibco, Thermo Fischer Scientific, USA) supplemented with 10% fetal calf serum (FCS, Biological Industries, Israel). The cells were incubated in a 5% CO₂ atmosphere at 37°C. To assess the effect of NPs on oxLDL toxicity, an MTT assay was used. Cells were seeded in 96-well microplates (TPP, Switzerland) at a density of 1 · 10⁴ cells/well in 100 µL of culture medium. Twenty four hours after cell seeding, the cells were treated with AgNPs (10 µg/mL, 25 µg/mL) or TiO₂NPs (10 µg/mL, 50 µg/mL) for 2 h. The medium containing the nanoparticles was then removed, and the cells were washed with PBS. The oxLDL solution (50 µg/mL) was added to the culture medium with 1% FCS; the cells were incubated for 24 h in the resulting medium. The oxLDL-containing

medium was then removed, the cells were washed with 150 μL /well of PBS and incubated for 3 h with 100 μL /well of MTT solution (3 mg/mL) at 37°C. After this time, the dye solution was re-

NPs can potentially be used in the future in the treatment of atherosclerosis, which is one of the main causes of death in Poland and other industrialized countries.

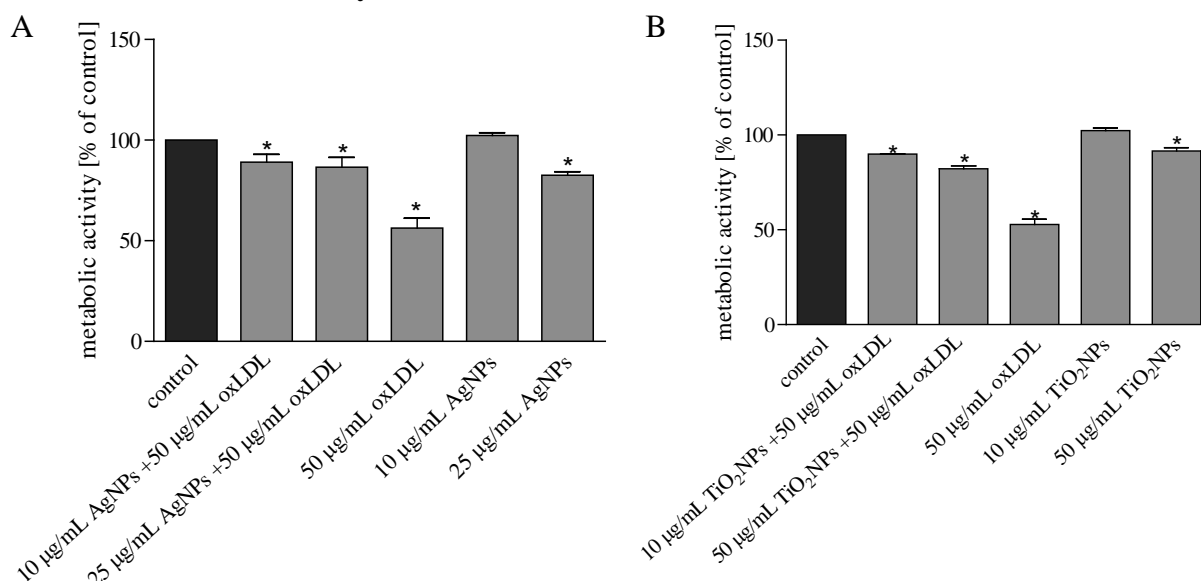


Fig. 1. Metabolic activity of HepG2 cells treated with the mixture of AgNPs (A) or TiO₂NPs (B) and oxLDL. The cells were treated with AgNPs (10 $\mu\text{g/mL}$ or 25 $\mu\text{g/mL}$) or TiO₂NPs (10 $\mu\text{g/mL}$ or 50 $\mu\text{g/mL}$) for 2 h at 37°C and then with oxLDL (50 $\mu\text{g/mL}$) for another 24 h at 37°C. Data are expressed as a percentage of the control value \pm SD from three independent experiments.

moved, and the remaining insoluble formazan crystals were dissolved in 100 μL /well of DMSO. The absorbance was measured at 570 nm in an Infinite M200 plate reader spectrophotometer (Tecan, Austria). At least three independent experiments in six technical replicates were conducted for each experimental point. Significant differences between the treated samples and the control sample were evaluated by a Student's t-test using GraphPad Prism 5.0 software (GraphPad Software Inc., USA).

As shown in Fig. 1A, pretreatment with AgNPs caused a significant decrease in the toxicity of oxLDL. Treatment with AgNPs (25 $\mu\text{g/mL}$) prior to the treatment with oxLDL (50 $\mu\text{g/mL}$) reduced the metabolic activity (viability) of the HepG2 cells to 84% of the control value, while incubation of the cells with oxLDL alone reduced their metabolic activity to 52% of the control value. As presented in Fig. 1B, preincubation with TiO₂NPs prior oxLDL also resulted in a significant reduction of the toxicity of oxLDL. Treatment of the cells with TiO₂NPs (50 $\mu\text{g/mL}$) and oxLDL (50 $\mu\text{g/mL}$) significantly decreased the metabolic activity of HepG2 cells to 82% of the control value, in comparison to incubation of the cells with oxLDL alone, which reduced their metabolic activity to 52% of the control value.

To conclude, the results of this study clearly show that NPs significantly altered the toxicity of oxLDL towards HepG2 cells. Therefore, a systematic study of the effects of NPs on the uptake and biological properties of oxLDL is needed to provide more information about the nature and mechanisms of the interactions between NPs and oxLDL. The study will help to determine whether

This work was supported by the statutory grant from the Ministry of Science and Higher Education to the INCT (020-606).

References

- Sharifi, S., Behzadi, S., Laurent, S., Forrest, M.L., Stroeve, P., & Mahmoudi, M. (2012). Toxicity of nano-materials. *Chem. Soc. Rev.*, 41(6), 2323-2343.
- Re, F., Gregori, M., & Masserini, M. (2012). Nanotechnology for neurodegenerative disorders. *Nanomedicine*, 8, Suppl. 1, S51-S58.
- Matsuura, E., Hughes, G.R., & Khamashta, M.A. (2008). Oxidation of LDL and its clinical implication. *Autoimmun. Rev.*, 7(7), 558-566.
- Dhaliwal, B.S., & Steinbrecher, U.P. (2000). Cholesterol delivered to macrophages by oxidized low density lipoprotein is sequestered in lysosomes and fails to efflux normally. *J. Lipid Res.*, 41, 1658-1665.
- Heinecke, J.W. (2006). Lipoprotein oxidation in cardiovascular disease: chief culprit or innocent bystander? *J. Exp. Med.*, 203(4), 813-816.
- Hellstrand, E., Lynch, I., Andersson, A., Drakenberg, T., Dahlbäck, B., Dawson, K.A., Linse, S., & Cedervall, T. (2009). Complete high-density lipoproteins in nanoparticle corona. *FEBS J.*, 276, 3372-3381.
- Kruszewski, M., Grądzka, I., Bartłomiejczyk, T., Chwastowska, J., Sommer, S., Grzelak, A., Zuberek, M., Lankoff, A., Dusinska, M., & Wojewódzka, M. (2013). Oxidative DNA damage corresponds to the long term survival of human cells treated with silver nanoparticles. *Toxicol Lett.*, 219(2), 151-159.
- Kruszewski, M., Brzoska, K., Brunborg, G., Asare, N., Dobrzynska, M., Dusinska, M., Fjellsbø, L., Georgantzopoulou, A., Gromadzka-Ostrowska, J., Gutleb, A., Lankoff, A., Magdolenová, Z., Pran, E.R., Rinna, A., Instanes, C., Sandberg, W.J., Schwarze, P., Stępkowski, T., Wojewódzka, M., & Refsnes, M. (2011). Toxicity of silver nanomaterials in higher eukaryotes. *Adv. Mol. Toxicol.*, 5, 179-218.

-
- [9]. Shi, H., Magaye, R., Castranova, V., & Zhao, J. (2013). Titanium dioxide nanoparticles: a review of current toxicological data. *Part. Fibre Toxicol.*, 10, 15.
- [10]. Long, T.C., Tajuba, J., Sama, P., Saleh, N., Swartz, C., Parker, J., Hester, S., Lowry, G.V., & Veronesi, B. (2007). Nanosize titanium dioxide stimulates reactive oxygen species in brain microglia and damages neurons in vitro. *Environ. Health Perspect.*, 115, 1631-1637.

LABORATORY OF NUCLEAR ANALYTICAL METHODS

The research programme of the Laboratory of Nuclear Analytical Methods is focused on the development of nuclear and nuclear-related analytical methods for application in nuclear chemical engineering, radiobiology and environmental problems associated with the use of nuclear power and other specific fields of high technology. New procedures of chemical analysis for various types of materials are also being developed. The main areas of activity of the Laboratory include inorganic trace analysis, as well as analytical and radiochemical separation methods. The Laboratory cooperates with the centres and laboratories of the INCT and provides analytical services for them and for the outside institutions. The Laboratory produces certified reference materials (CRMs) for the purpose of inorganic trace analysis and provides proficiency testing schemes on determination of radionuclides and trace elements in food and environmental samples.

The main analytical techniques employed in the Laboratory comprise: neutron activation analysis with the use of a nuclear reactor (instrumental and radiochemical modes), inductively coupled plasma mass spectrometry (together with laser ablation and HPLC), atomic absorption spectrometry, HPLC including ion chromatography, as well as gamma-ray spectrometry and alpha- and beta-ray counting.

In 2017, the Laboratory of Nuclear Analytical Methods conducted a proficiency test (PT) regarding the determination of ^3H , ^{226}Ra , ^{241}Am and ^{239}Pu contents in waters, food and environmental samples. PT was provided at the request of the National Atomic Energy Agency (PAA), Poland. Nine laboratories took part in the PT, including six laboratories forming a radiation monitoring network in Poland (at the request of the PAA) and three other laboratories. The proficiency tests were provided in accordance with the requirements of ISO/IEC 17043:2010, ISO 13528:2015 and the IUPAC International Harmonized Protocol (2006).

In 2017, the Food and Environmental Laboratory (FEL) provided services to municipal and private customers. The Laboratory specializes in the determination of radionuclides in waters and foodstuffs, as well as in environmental samples. Applied analysis methods have been approved by the State Sanitary Inspection.



APPLICATION OF IONIZING RADIATION FOR DECOMPOSITION OF BISPHENOL A IN ENVIRONMENTAL SAMPLES

Anna Bojanowska-Czajka^{1/}, Emilia Fornal^{2/}, Tomasz Szreder, Marek Trojanowicz^{1/}

^{1/} Institute of Nuclear Chemistry and Technology, Warszawa, Poland

^{2/} II Faculty of Medicine with English Language Division, Medical University of Lublin, Poland

Bisphenol A (BPA) (Fig.1) is a well-known hazardous endocrine disruptor that exhibits hormone-like properties. It has also been found that BPA shows mutagenic effects and acute toxicity to various organisms [1].

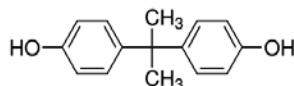


Fig. 1. Structure of bisphenol A (4,4'-(propane-2,2-diyl)diphenol).

It is widely used in many polymers, epoxy resins and paper products. The worldwide annual production of BPA is estimated at about 3 million tons, and is still increasing due to the strong demand for polymers and epoxy resins [2, 3]. BPA is water soluble (about 300 mg/L), and therefore BPA-containing waste can readily release BPA into the aquatic environment. It has already been proved that BPA is ubiquitously distributed in the natural environment and surface waters [4].

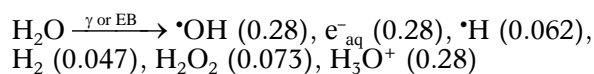
The aim of these studies was further investigation of the decomposition of BPA, and the formation of by-products, during the application of ionizing radiation for the treatment of its solution in deionized water, as well as in real samples of river water. Earlier results obtained from studies on the application of ionizing radiation to BPA for environmental purposes have been promising [5-9].

Generally, it is known that BPA's percentage decomposition increases with an increase in the absorbed dose, and decreases with increasing initial concentration, for both gamma and electron beam (EB) irradiation. It was also found that for aerated solutions containing BPA at an initial concentration of 50 mg/L and pH 4.0, the chemical oxygen demand (COD) was decreased after gamma irradiation by 40% for an absorbed dose of 600 Gy, and by 60% for an absorbed dose of 1.0 kGy [6]. Greater BPA removal was observed, however, in more acidic conditions [8]. It means that BPA removal by radiolytic processes was mainly controlled by $\cdot\text{OH}$ radical-induced oxidation. The second-order reaction rate constants with e_{aq}^- and $\cdot\text{OH}$ were determined when EB irradiation was applied to decompose BPA [7]. Their values were found to be $1.85 \cdot 10^{10} \text{ M}^{-1} \text{ s}^{-1}$ for BPA's reaction with $\cdot\text{OH}$, and $1.8 \cdot 10^9 \text{ M}^{-1} \text{ s}^{-1}$ for its reaction with e_{aq}^- . The rate constant of BPA's reaction with $\cdot\text{OH}$ is about ten times higher than that with e_{aq}^- , which indicates that although both $\cdot\text{OH}$ and e_{aq}^- can react with BPA, $\cdot\text{OH}$ radicals are more efficient reagents for the radiolytic decomposition of BPA.

In the conducted experiments, aqueous solutions of BPA were gamma-irradiated using a ^{60}Co source Gamma Chamber 5000 with a dose rate

3.85 kGy/h. The samples were irradiated in closed 10 mL conical glass flasks, and dosimetry was carried out with Fricke solution. The monitoring of the decomposition of BPA and the identification of its products were carried out with the use of liquid chromatography-mass spectrometry (LC-MS) analysis, employing an Agilent 1290 Infinity HPLC instrument with an Agilent 6530 Q-TOF mass spectrometer with electrospray ionization (ESI). HPLC separations were carried out using an Agilent Bonus-RP column (2.1 \times 50 mm, 1.8 μm) and gradient elution, with eluent A being 5 mM ammonium acetate and eluent B methanol; the flow rate was 0.4 mL/min, the concentration of B was increased from 0 to 95% between 0 and 8 min, and at 10 min the concentration of A was 100%. The MS conditions were as follows: dual AJS ESI ion polarity – negative, drying gas – 8 L/min, sheath gas temperature – 200°C, sheath gas flow – 11 L/min, fragmentor voltage – 110 V, skimmer voltage – 65 V, and examined mass range – 100-1700 m/z. The solid-phase pre-concentration of the analytes was carried out with Oasis HLB columns (Waters), which were conditioned by flushing with 3 mL methanol and 3 mL water at 5 mL/min; 500 mL of sample was then loaded. The bed was next rinsed with 1 mL 5% methanol, and the analytes were eluted with 2 mL methanol.

Generally, the radiolysis of water in deaerated solutions leads to the formation of various products according to the scheme [10]:



In air-saturated solutions, however, the reactive species are the $\cdot\text{OH}$ radicals, as hydrated electrons and $\cdot\text{H}$ are scavenged by dissolved oxygen. The numbers in parentheses in the above equation indicate the radiation chemical yields (G-values) expressed in $\mu\text{M J}^{-1}$ units. The G-values also correspond to the number of molecules consumed or produced in a given reaction per 100 eV of energy absorbed as a result of radiation.

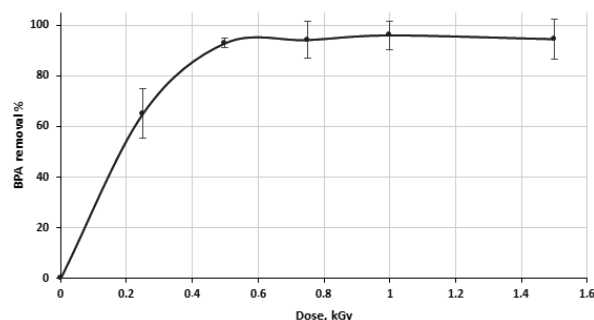


Fig. 2. The yield of BPA removal in gamma irradiation process from 10 mg/L BPA aerated solution of pH 7.0.

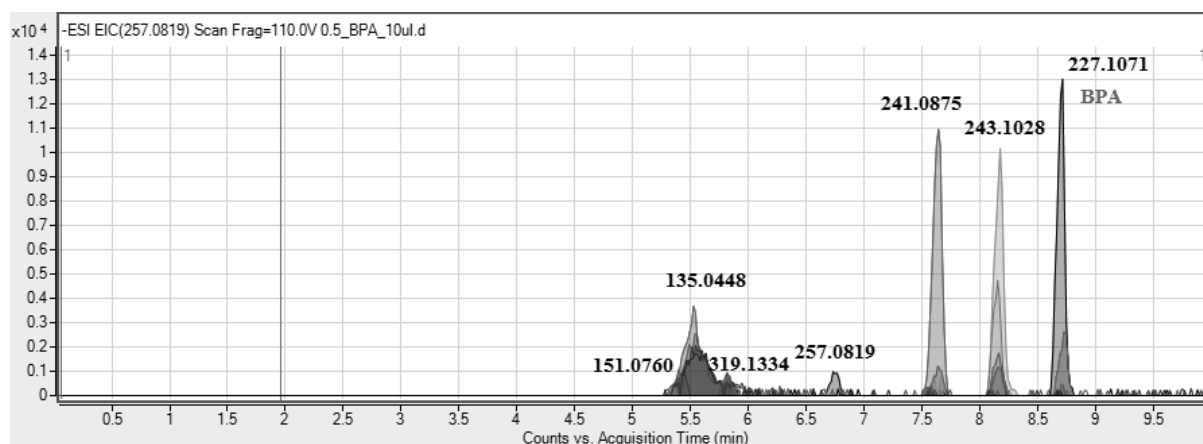


Fig. 3. Extracted ion chromatograms (EIC) obtained for 10 mg/L BPA aerated solution of pH 7.0 after gamma irradiation with absorbed dose 1.5 kGy. For identification of measured species, see Table 1.

After gamma irradiation of aqueous aerated solutions of BPA at an initial concentration of 10 mg/L, chromatographic analysis with quadrupole time of flight (Q-TOF) detection was carried out for solutions irradiated with different doses. It was found that practically complete decomposition of this initial amount of BPA was achieved after the absorption of a 0.5 kGy irradiation dose (Fig. 2). These results are in agreement with our earlier studies [5]. The decomposition products of BPA at dose range up to 1 kGy were identified using LC-Q-TOF measurements (Fig. 3). The available literature data on radiolytic degradation of BPA indicate that the main degradation products are monohydroxylated BPA and dihydroxylated BPA

[6, 8]. It was postulated that the main chemical process in the decomposition of BPA was hydroxylation, which results in the formation of different aromatic hydroxylated derivatives. The formation of these species can be explained based on the stabilization of the aromatic radical generated after the loss of an $\cdot\text{H}$ promoted by $\cdot\text{HO}$. Peller *et al.* [9] suggested that subsequent formation of the hydroxylated product takes place only in pure water or very highly treated wastewater. In our experiment, monohydroxylated BPA ($m/z = 243.1026$) and a small amount of dihydroxylated BPA ($m/z = 259.0976$) were also found after irradiation with the 1 kGy dose. Additionally, the following species were identified in solution after irradiation

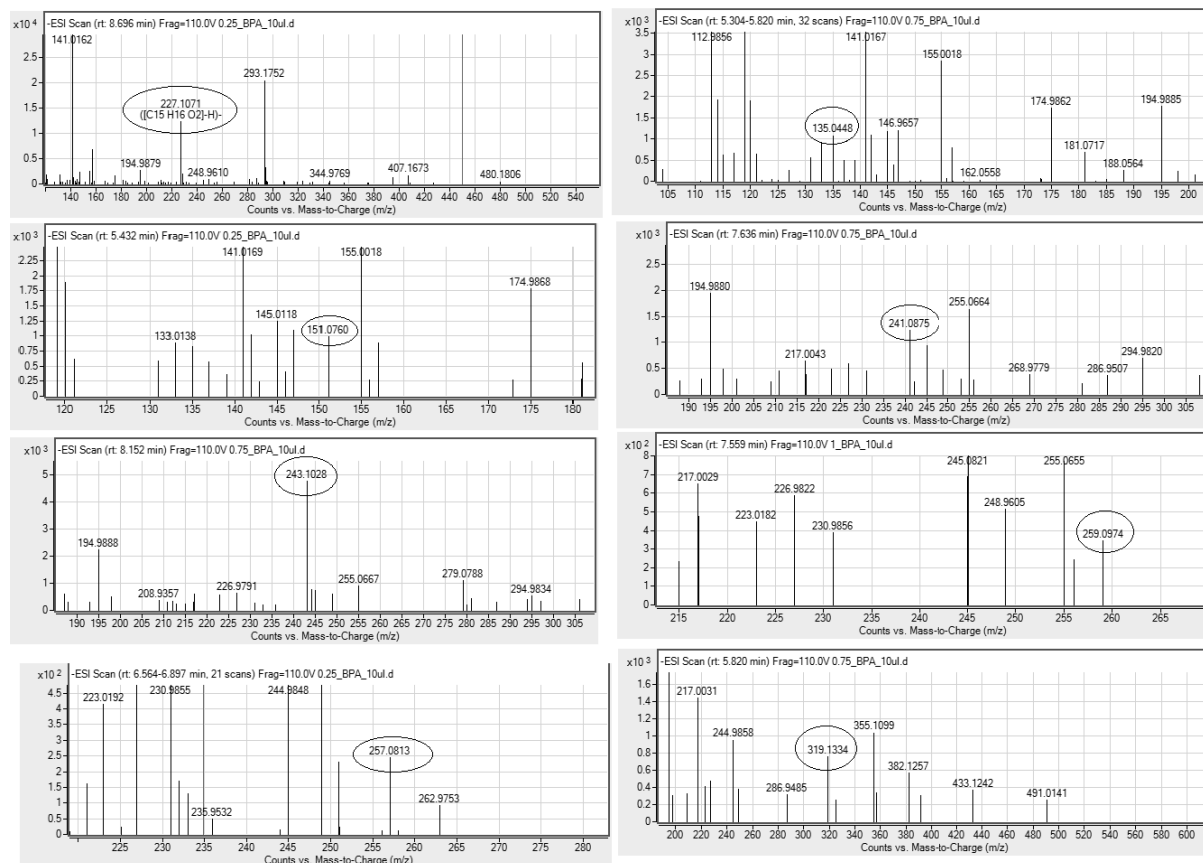
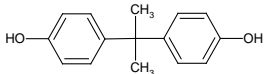
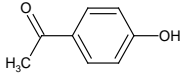
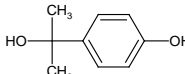
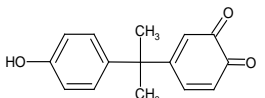
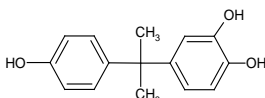
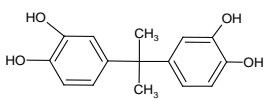
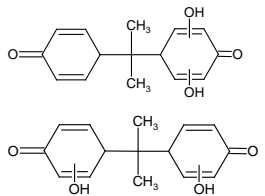
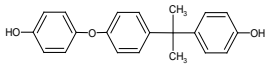


Fig. 4. Mass spectra of products identified in 10 mg/L BPA solution of pH 7.0 after gamma irradiation with absorbed dose 0.75 kGy. For identification of products identified in 10 mg/L BPA solution of pH 7.0 after gamma irradiation with absorbed dose 0.75 kGy. For identification of measured species with m/z values indicated in circles, see Table 1.

Table 1. Products of radiolytic decomposition of BPA identified by LC/MS with indicated m/z values measured (exp.) and theoretical (calc.).

Compound	Molecular structure	m/z (exp.)	m/z (calc.)	Error [ppm]	Found in another AOPs [Reference]
BPA		227.1071	227.1078	0.7	photolytic [11] ozone/persulphate [12] H ₂ O ₂ /persulphate [13]
p-Hydroxyacetophenone		135.0448	135.0451	0.3	H ₂ O ₂ /persulphate [13] UV-C/peroxymonosulphate [14]
4-(1-Hydroxypropan-2-yl)catechol		151.0760	151.0764	0.4	ozone/persulphate [12] photo-Fenton [15]
Quinone of monohydroxylated BPA		241.0875	241.0870	-0.5	photolytic [11] H ₂ O ₂ /persulphate [13] TiO ₂ photocatalytic/photolytic [16] UV-C/peroxymonosulphate [14]
Monohydroxylated BPA		243.1028	243.1026	-0.2	gamma irradiation [6, 8] photolytic [11] H ₂ O ₂ /persulphate [13] UV-C/peroxymonosulphate [14]
Dihydroxylated BPA		259.0974	259.0976	0.2	gamma irradiation [6, 8] photolytic [11]
Quinone of dihydroxylated BPA		257.0813	257.0819	0.6	H ₂ O ₂ /persulphate [13] UV-C/peroxymonosulphate [16]
Coupling product		319.1334	319.1339	0.5	UV-C/peroxymonosulphate [16]

tion: a quinone of monohydroxylated BPA ($m/z = 241.0870$), p-hydroxyacetophenone ($m/z = 135.0451$), 4-(1-hydroxypropan-2-yl)catechol ($m/z = 151.0764$), a quinone of dihydroxylated BPA ($m/z = 257.0819$) and also a coupling product with $m/z = 319.1339$ (Figs. 3 and 4). The concentration of these compounds decreased with an increase in the absorbed dose. Other compounds identified by us (Table 1) were previously found as products of other advanced oxidation processes (AOPs), such as photodegradation [11], an ozone/persulphate process [12] or photooxidation with hydrogen peroxide and sodium persulphate [13]. The main route of BPA decomposition in these processes was also postulated to be hydroxylation followed by dehydration, coupling and ring-opening reactions.

The radiolytic decomposition of BPA was also investigated in real environmental matrices made up of river water from various regions of Poland. The pH values and the content of organic compounds, expressed by total organic carbon (TOC) values, for the examined samples are presented in Table 2. The 250 mL river water samples used for

irradiation were spiked with 1.0 $\mu\text{g/L}$ (4.4 pM) BPA prior to irradiation with doses up to 100 Gy. The irradiated samples were analysed, employing the solid-phase extraction pre-treatment that had been developed earlier [5]. As shown in Fig. 5, the dose needed for practically complete decomposition of 1 $\mu\text{g/L}$ BPA in deionized water was 30 Gy. The effect of the matrices of river water on the decomposition yield, in spite of their low loading with organic substances as shown by TOC values,

Table 2. Characteristics of river water samples used as natural matrices for radiolytic decomposition of BPA.

River (place of sampling)	pH	Total organic carbon [mg/L]
Vistula (Cracow)	7.82	5.43
Odra (Opole)	7.64	5.26
Brda (Bydgoszcz)	7.66	4.97

was quite substantial. For samples of water from the Vistula and Brda rivers, about 90% decomposition of 1 $\mu\text{g/L}$ BPA required an absorbed dose of 100 Gy, while in the case of samples from the

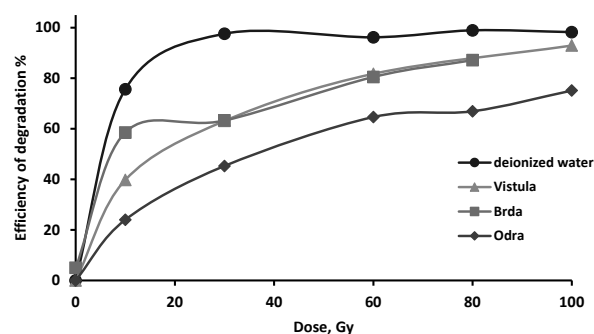


Fig. 5. The yield of radiolytic decomposition of BPA at initial level 1 $\mu\text{g/L}$ (4.4 pM) in aerated distilled water and in spiked river water.

Odra river, for an absorbed dose of 100 Gy about 70% decomposition was observed. These data indicate a quite substantial scavenging effect of other matrix components or other organic pollutants present in treated river water samples. In Table 3 there are listed G-values calculated for the smallest applied dose and the values of rate constants for pseudo-first order decomposition reactions of BPA under the applied conditions for

Table 3. The values of pseudo-first order reaction rate constants, k , and G-values calculated from experimental data obtained from gamma irradiation of 1 $\mu\text{g/L}$ BPA solution in deionized water and in river water samples spiked with 1 $\mu\text{g/L}$ BPA. G-values were calculated for the smallest applied dose – 10 kGy.

Sample	G-value [$\mu\text{M J}^{-1}$]	k [s^{-1}]
Solution in deionized water	0.00033	0.15
Vistula river	0.00017	0.40
Odra river	0.00010	0.23
Brda river	0.00024	0.40

radiolytic decomposition of samples containing 1.0 $\mu\text{g/L}$ BPA. The obtained pseudo-first order rate constant for radiolytic decomposition of BPA indicates that it is a much faster process compared to many other investigated AOPs. For instance, for photolytic decomposition the corresponding rate constants were 0.010 min^{-1} [11] and 0.0186 min^{-1} [14], for photolysis carried out in the presence of persulphate – 0.0118 min^{-1} [13], with persulphate and ozone – 0.0149 min^{-1} [12], or with peroxymonosulphate – 0.025 min^{-1} [14], while for photocatalytic processes with TiO_2 – 0.032 min^{-1} [11] and 0.0973 min^{-1} [16], and then for the photo-Fenton process – 0.0087 s^{-1} [15].

Compared to many other environmental pollutants, the decomposition of which has been examined with the use of ionizing radiation [17], BPA can be very efficiently and practically removed from aerated natural waters due to its high reactivity with $\cdot\text{OH}$ radicals, without any additional chemical adjustment of the treated samples.

References

- Petrie, B., Barden, R., & Kasprzyk-Hordern, B. (2015). A review on emerging contaminants in wastewaters and the environment: Current knowledge, under-
- studied areas and recommendations for future monitoring. *Water Res.*, 72, 3-27.
- Staples, C., Dorn, P., Klecka, G., O'Block, S., & Harris, L. (1998). A review of the environmental fate, effects, and exposures of bisphenol A. *Chemosphere*, 36, 2149-2173.
- Zhang, W., Yin, K., & Chen, L. (2013). Bacteria-mediated bisphenol A degradation. *Appl. Microbiol. Biotechnol.*, 97, 5681-5689.
- Tijani, J., Fatoba, O., Babajide, O., & Petrik, L. (2016). Pharmaceuticals, endocrine disruptors, personal care products, nanomaterials and perfluorinated pollutants: a review. *Environ. Chem. Lett.*, 14, 27-49.
- Bojanowska-Czajka, A., Kciuk, G., Gumiela, M., Borowiecka, S., Nałęcz-Jawecki, G., Koc, A., Garcia-Reyes, J.F., Solpan Ozbay, D., & Trojanowicz, M. (2015). Analytical, toxicological and kinetic investigations of decomposition of the drug diclofenac in waters and waste using gamma radiation. *Environ. Sci. Pollut. Res.*, 22, 20255-20270.
- Rivera-Utrilla, J., Abdel deiem, M.M., Sánchez-Polo, M., Ocampo-Pérez, R., López-Peñalver, J.J., Velo-Gala, I., & Mota, A.J. (2016). Removal of compounds used as plasticizers and herbicides from water by means of gamma irradiation. *Sci. Total Environ.*, 569-570, 518-526.
- Xu, G., Ren, H., Wu, M.-H., Liu, N., Yuan, Q., Tang, L., & Wang, L. (2011). Electron-beam induced degradation of bisphenol A. *Nucl. Sci. Tech.*, 22, 277-281.
- Guo, Z., Dong, Q., He, D., & Zhang, C. (2012). Gamma radiation for treatment of bisphenol A solution in presence of different additives. *Chem. Eng. J.*, 183, 10-14.
- Peller, J.R., Mezyk, S.P., & Cooper, W.J. (2009). Bisphenol A reactions with hydroxyl radicals: diverse pathways determined between deionized water and tertiary treated wastewater solutions. *Res. Chem. Intermed.*, 35, 21-34.
- Buxton, G., Greenstock, C., Helman, W.P., & Ross, A.B. (1988). Critical review of rate constants for reactions of hydrated electrons, hydrogen atoms and hydroxyl radicals (OH/O^-) in aqueous solution. *J. Phys. Chem. Ref. Data*, 17, 513-886.
- Cardoso da Silva, J.C., Reis Teodoro, J.A., Alonso, R.J., Aquino, S.F., & Augusti, R. (2014). Photodegradation of bisphenol A in aqueous medium: Monitoring and identification of by-products by liquid chromatography coupled to high-resolution mass spectrometry. *Rapid Commun. Mass Spectrom.*, 28, 987-994.
- Yang, Y., Guo, H., Zhang, Y., Deng, Q., & Zhang, J. (2016). Degradation of Bisphenol A using ozone/persulfate process: kinetics and mechanism. *Water Air Soil Pollut.*, 227, 53.
- Sharma, J., Mishra, I.M., & Kumar, V. (2016). Mechanistic study of photo-oxidation of Bisphenol-A (BPA) with hydrogen peroxide (H_2O_2) and sodium persulfate (SPS). *J. Environ. Manage.*, 166, 12-22.
- Sharma, J., Mishra, I.M., Dionysiou, D.D., & Kumar, V. (2015). Oxidative removal of Bisphenol A by UV-C/peroxymonosulfate (PMS): Kinetics, influence of co-existing chemicals and degradation pathway. *Chem. Eng. J.*, 276, 193-204.
- Katsumata, H., Kawabe, S., Kaneco, S., Suzuki, T., & Ohta, K. (2004). Degradation of bisphenol A in water by the photo-Fenton reaction. *J. Photochem. Photobiol. A*, 162, 297-305.
- Kondrakov, A.O., Ignatev, A.N., Frimmel, F.H., Bräse, S., Horn, H., & Revelsky, A.I. (2014). Formation of genotoxic quinones during bisphenol A degradation by TiO_2 photocatalysis and UV photolysis: a comparative study. *Catal. B-Environ.*, 160-161, 106-114.

[17]. Trojanowicz, M., Bobrowski, K., Szreder, T., & Bojanowska-Czajka, A. (2018). Gamma-ray, X-ray and electron beam processes as an Advanced Oxidation

Processes. In S. Ameta, R. Ameta (Eds.), *Advanced oxidation processes for wastewater treatment* (pp. 257-331). Academic Press – Elsevier.

PROFICIENCY TEST ON THE DETERMINATION OF ACTIVITY CONCENTRATIONS OF ^{226}Ra , ^{241}Am , ^{239}Pu AND ^3H IN FOOD AND ENVIRONMENTAL SAMPLES

Halina Polkowska-Motrenko, Leon Fuks, Paweł Kalbarczyk, Jakub Dudek, Irena Herdzik-Koniecko, Krzysztof Kulisa

The participation of laboratories in interlaboratory comparisons (ILCs) and proficiency tests (PTs) is a unique way to demonstrate the laboratories' abilities to conduct specific measurements in an objective and externally comparable manner. The determination of radioactive isotopes in various food and environmental samples by the radiochemical laboratories forming the radiation monitoring network in Poland is required by a regulation of the Polish government [1]. Following a request by the President of the National Atomic Energy Agency (PAA), in 2017 the Institute of Nuclear Chemistry and Technology (INCT) conducted PT on the determination of ^{226}Ra , ^{241}Am , ^{239}Pu and ^3H in drinking water, ^{241}Am and ^{239}Pu in wheat flour and ^{239}Pu in soil. The PT was carried out according to ISO/IEC 17043:2010 [2], the IUPAC International Harmonized Protocol (2006) [3] and ISO 13528:2015 [4].

Test materials

Test materials and activity concentrations of radionuclides requested by the PAA are shown in Table 1.

Six laboratories from the radiation monitoring network in Poland and three laboratories from outside the network took part in the PT. The activity of raw material candidates for test materials was measured, and materials of appropriate low initial activity concentrations of the aforementioned radionuclides were chosen (Table 1). The test materials were prepared by spiking the chosen raw materials with a certified standard solution of only one radionuclide. All the water test materials and the wheat flour spiked with ^{241}Am were prepared in this way, ensuring their homogeneity. The wheat flour and soil samples spiked with ^{239}Pu were not homogeneous, being prepared individually for each participant. In these cases, work-

Table 1. Test materials to be prepared.

Test material	Nuclide	Activity concentration requested by the PAA
Drinking water 1H1/17	^3H	0.5-5 Bq/L
Drinking water 1H2/17	^3H	15-30 Bq/L
Drinking water 1R1/17	^{226}Ra	0.5-1 Bq/L
Drinking water 1R2/17	^{226}Ra	2-3 Bq/L
Drinking water 1P1/17	^{239}Pu	1-2 Bq/L
Drinking water 1A1/17	^{241}Am	0.5-2 Bq/L
Wheat flour 2A1/17	^{241}Am	5-10 Bq/kg
Wheat flour 2P1/17	^{239}Pu	0.5-1 Bq/kg
Sand 3P1/17	^{239}Pu	0.5-1 Bq/kg

ing solutions of ^{239}Pu were weighed and added to samples of raw materials. Participants were informed that the test samples containing ^{239}Pu were not homogeneous and the total mass of the sample should be taken to analysis. The details of the preparation of test materials have been published earlier [5, 6].

Reference values of the activity concentrations of ^3H , ^{226}Ra , ^{241}Am and ^{239}Pu in drinking water, wheat flour and soil were determined from the formulation details and from the certified activity values given in the certificates, considering the successive dilution steps, the mass of the spiking solutions and the mass of the test material being spiked [3, 4]. The expanded combined standard uncertainty U ($k = 2$, which corresponds to 95% probability) was evaluated in accordance with GUM [7]. The following sources of uncertainty were taken into account: the uncertainty of

Table 2. Reference values of activity concentration of ^3H , ^{226}Ra , ^{241}Am and ^{239}Pu in drinking water and ^{241}Am in wheat flour.

Test material	Nuclide	$X_{\text{ref}} \pm U$ ($k = 2$), reference date
Drinking water 1H1/17	^3H	4.11 ± 0.25 Bq/L on 23 June 2017
Drinking water 1H2/17	^3H	21.02 ± 0.60 Bq/L on 23 January 2017
Drinking water 1R1/17	^{226}Ra	0.837 ± 0.041 Bq/L on 5 February 1998
Drinking water 1R2/17	^{226}Ra	2.48 ± 0.12 Bq/L on 5 February 1998
Drinking water 1P1/17	^{239}Pu	1.01 ± 0.10 Bq/L on 1 May 2015
Drinking water 1A1/17	^{241}Am	1.640 ± 0.049 Bq/L on 11 June 2001
Wheat flour 2A1/17	^{241}Am	9.260 ± 0.444 Bq/kg on 11 June 2001

Table 3. Reference values of activity concentration of ^{239}Pu in wheat flour and soil.

Wheat flour 2P1/17	$X \pm U (k = 2)$ [Bq/kg] on 1 May 2015	Soil 3P1/17	$X \pm U (k = 2)$ [Bq/kg] on 1 May 2015
2P1/17/A1	0.897 ± 0.045	3P1/17/A1	0.616 ± 0.031
2P1/17/A2	0.922 ± 0.046	3P1/17/A2	0.698 ± 0.035
2P1/17/A3	0.923 ± 0.046	3P1/17/A3	0.836 ± 0.042
2P1/17/C1	0.918 ± 0.046	3P1/17/C1	0.738 ± 0.037
2P1/17/F1	1.014 ± 0.051	3P1/17/F1	0.725 ± 0.036
2P1/17/J1	0.756 ± 0.038	3P1/17/J1	0.756 ± 0.038

the certified values of activity concentration of the certified standard solutions provided in the certificates, weighing of the standard solutions and raw materials, and (in the case of solid materials) uncertainty due to dry mass determination. The assigned values, together with their expanded uncertainties ($k = 2$), are shown in Tables 2 and 3.

Evaluation of results

The performance of each laboratory has been expressed in terms of z and $zeta$ scores [2, 3]:

$$z = \frac{X_{\text{lab}} - X_{\text{pt}}}{\sigma_{\text{pt}}} \quad (1)$$

$$zeta = \frac{X_{\text{lab}} - X_{\text{pt}}}{\sqrt{u_{\text{lab}}^2 + u(X_{\text{pt}})^2}} \quad (2)$$

where: X_{lab} – result reported by the participant, X_{pt} – assigned value, $u(X_{\text{pt}})$ – standard uncertainty of assigned values, u_{lab} – standard uncertainty reported by the participant, σ_{pt} – standard deviation for proficiency assessment.

X_{lab} is the mean of the individual measurement results as reported by the participant or as calculated by the PT organizer when no mean was reported. The z -score value $|z| < 3$ has been set as an acceptance level for this PT [2-4].

The $zeta$ -score provides information on whether the laboratory uncertainty estimation is consistent with its deviation from the reference value. The $zeta$ -score value should be analysed together with the z -score value calculated for the same laboratory result. The interpretation of the $zeta$ -score value is similar to that of the z -score value [2, 3].

The results obtained by the participants were also evaluated according to the criteria for trueness and precision proposed by the International Atomic Energy Agency (IAEA) [8, 9]. The criteria are as follows:

1. Result passes trueness criterion if:

$$|x_{\text{ref}} - x_{\text{lab}}| \leq 2.58 \sqrt{u_{\text{ref}}^2 + u_{\text{lab}}^2} \quad (3)$$

2. Result passes precision criterion if:

$$\sqrt{\left(\frac{u_{\text{ref}}}{x_{\text{ref}}}\right)^2 + \left(\frac{u_{\text{lab}}}{x_{\text{lab}}}\right)^2} \cdot 100\% \leq \sigma_{\text{pt}} \quad (4)$$

where σ_{pt} (in %) denotes the standard deviation for proficiency assessment used in the calculation of the z -score value or the maximum value of uncertainty that can be accepted.

Table 4. Value (percent of assigned value) of standard deviation for proficiency assessment σ_{pt} .

Test material	^3H	^{226}Ra	^{241}Am	^{239}Pu
	σ_{pt} [%]			
Drinking water	1H1/17 – 25 1H2/17 – 5	8	8	20
Wheat flour	-	-	8	12
Soil	-	-	-	12

Measurement results reported as smaller than the limit of detection of the analytical procedure applied by the laboratory ($\leq \text{LOD}$) were assumed to be acceptable if the activity concentration was

Table 5. Summary of the scoring of the results provided by the participants – tests z and $zeta$.

Test material	Number of results provided by the participants	Number of results accepted/unaccepted by test z	Number of results accepted/unaccepted by test $zeta$	Number of qualitative ($\leq \text{LOD}$) results/number of accepted ones
Drinking water 1H1/17	9	3/3	3/3	3/3
Drinking water 1H2/17	10	6/4	7/3	-
Drinking water 1R1/17	7	6/1	6/1	-
Drinking water 1R2/17	7	7/0	7/0	-
Drinking water 1P1/17	5	4/1	2/3	-
Drinking water 1A1/17	8	8/8	7/1	-
Wheat flour 2A1/17	6	6/6	5/1	-
Wheat flour 2P1/17	3	3/3	3/3	-
Soil 3P1/17	3	3/3	3/3	-

Table 6. Summary of the scoring of the results provided by the participants – the IAEA approach.

Test material	Number of results provided by the participants	Number of results passed criteria for trueness	Number of results passed criteria for precision	Number of accepted results (passed both criteria)
Drinking water 1H1/17	6	3	5	2
Drinking water 1H2/17	10	7	9	6
Drinking water 1R1/17	7	6	7	6
Drinking water 1R2/17	7	7	7	7
Drinking water 1P1/17	5	1	5	1
Drinking water 1A1/17	8	6	8	6
Wheat flour 2A1/17	6	5	6	5
Wheat flour 2P1/17	3	3	3	3
Soil 3P1/17	3	3	3	3

below the detection limit of the analytical method applied by the laboratory.

The standard deviation for the proficiency assessment, σ_{pt} , was calculated as the standard deviation of reproducibility equal to the standard deviation of the arithmetic mean of all the laboratory means calculated after rejection of the outliers. The established values for σ_{pt} are shown in Table 4.

The scoring of the results provided by the participants is summarized in Tables 5 and 6. The results of the scoring show good performances of all the laboratories participating in the PT, especially taking into account that low activity concentrations were measured. The results supplied by the laboratories forming the radiation monitoring network in Poland confirm their competency. Even so, the participants have had the opportunity to compare their results with those of other laboratories and improve the quality of their routine analyses.

References

- [1]. Rada Ministrów. (2002). *Rozporządzenie Rady Ministrów z dnia 17 grudnia 2002 r. w sprawie stacji wczesnego wykrywania skażeń promieniotwórczych i placówek prowadzących pomiary skażeń promieniotwórczych* [Decree of Polish Cabinet 2002 concerning early stage of radioactive contamination and the institution leading the radioactive contamination measurement]. Dz.U. z 2002 r. Nr 239, poz. 2030.
- [2]. ISO. (2010). *Conformity assessment – General requirements for proficiency testing*. ISO/IEC Standard 17043:2010.
- [3]. Thompson, M., Ellison, S.L.R., & Wood, R. (2006). The International Harmonized Protocol for the proficiency testing of analytical chemistry laboratories (IUPAC Technical Report). *Pure Appl. Chem.*, 78, 1, 145-196.
- [4]. ISO (2015). *Statistical methods for use in proficiency testing by interlaboratory comparisons*. ISO Standard 13528:2015.
- [5]. Polkowska-Motrenko, H., & Fuks, L. (2010). Proficiency testing schemes on determination of radioactivity in food and environmental samples organized by NAEA, Poland. *Nukleonika*, 55, 149-155
- [6]. Polkowska-Motrenko, H., Fuks, L., Kalbarczyk, P., Dudek, J., Kulisa, K., Oszczak, A., & Zuba, M. (2015). Preparation of water samples for proficiency testing on radionuclides. *Appl. Radiat. Isot.*, 103, 61-64.
- [7]. Ellison, S.L.R., & Williams, A. (Eds.). (2012). *Eurachem/CITAC guide: Quantifying uncertainty in analytical measurement* (third edition). Retrieved December 28, 2017, from <https://www.eurachem.org/index.php/publications/guides/quam>.
- [8]. Shakhshiro, A., Radecki, Z., Trinkl, A., Sansone, U., & Benesch, T. (2005). *Final Report on the Proficiency Test of the Analytical Laboratories for the Measurement of Environmental Radioactivity (ALMERA) Network*. Seibersdorf: IAEA. Report IAEA/AL/152.
- [9]. Shakhshiro, A., Doherty, P., Kožar Logar, J., Vodenik, B., Verheyen, L., & Taggart, M. (2016). New certified reference materials and proficiency test for environmental radioactivity measurements. *Accredit. Qual. Assur.*, 21, 351-360.

RECERTIFICATION OF THE POLISH REFERENCE MATERIALS: MODAS-2 BOTTOM SEDIMENT (M-2 BotSed), MODAS-3 HERRING TISSUE (M-3 HerTis), MODAS-4 CORMORANT TISSUE (M-4 CormTis) AND MODAS-5 COD TISSUE (M-5 CodTis)

**Zbigniew Samczyński, Halina Polkowska-Motrenko, Rajmund S. Dybczyński, Iga Zuba,
Ewelina Chajduk**

The certified reference materials (CRMs) – MODAS-2 Bottom Sediment (M-2 BotSed), MODAS-3 Herring Tissue (M-3 HerTis), MODAS-4 Cormorant Tissue (M-4 CormTis) and MODAS-5 Cod Tissue (M-5 CodTis) – were prepared and certified in 2012-2015 within the scope of the MODAS consortium, consisting of seven

Polish universities and institutes, as well as LGC Standards (Polish branch). The elemental contents of the above-mentioned CRMs were certified by the Institute of Nuclear Chemistry and Technology (INCT) on the basis of a worldwide interlaboratory comparison in which 46 to 54 laboratories from 13 countries (Poland, Argentina, Austria, Bul-

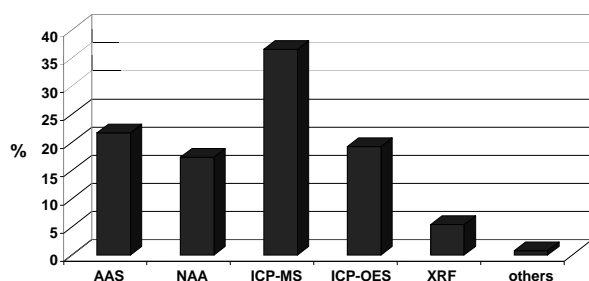


Fig. 1. Frequency of use of analytical methods in the inter-laboratory comparison.

garia, Brazil, Hungary, Indonesia, Italy, Norway, Pakistan, Romania, Russia and Slovenia) participated. The participating laboratories provided the results of the analyses of the candidate CRMs, which were performed mainly by atomic absorption spectrometry (AAS), inductively coupled plasma mass spectrometry (ICP-MS), inductively coupled plasma optical emission spectrometry (ICP-OES) and neutron activation analysis (NAA) methods. The frequency of their use is shown in Fig. 1. As can be seen, mass spectrometry with ionization in inductively coupled plasma was the most frequently applied method. However, comparing the values of the uncertainty of the results obtained

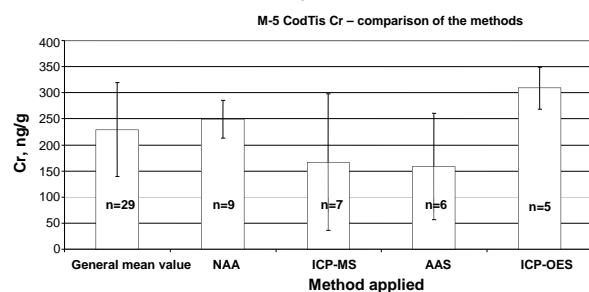


Fig. 2. Uncertainty of the mean results obtained by different analytical methods.

by the individual methods, it can be noted that the uncertainty of the ICP-MS result was, as a rule, the highest among all the results (Fig. 2). It can be seen that the lowest value of uncertainty was seen with the NAA results. This is one of the reasons why NAA plays so important role in the certification of RMs for the purpose of inorganic trace analysis [1, 2].

So, when the participating laboratories provided some new results obtained by NAA after the deadline (April 15, 2014) for supplying analytical results, it was decided to create new databases from all the obtained results and to subject them to statistical analysis in order to establish new certified values. The INCT approach of certification was applied [3]. This approach is based on the outlier rejection procedure, which uses four statistical criteria concurrently, namely those of Dixon (D), Grubbs (G), Skewness (S) and Kurtosis (K), at $\alpha = 0.05$, followed by calculations of the overall means of the results (remaining after the outlier rejection), standard deviations, standard errors, confidence intervals, etc.

The criteria used to decide whether the overall mean can be given the status of the certified value were as follows:

1. The ratio of the one-sided confidence interval and the overall mean:

$$\frac{SD \cdot t_{0.05}}{\bar{X} \cdot \sqrt{N}} \begin{cases} \leq 20\% \text{ (trace elements)} \\ \leq 10\% \text{ (major elements)} \end{cases} \quad (1)$$

or relative standard deviation:

$$\frac{SD}{\bar{X}} \begin{cases} \leq 25\% \text{ (trace elements)} \\ \leq 15\% \text{ (major elements)} \end{cases} \quad (2)$$

For the purpose of this work, elements with concentrations exceeding 5000 mg kg^{-1} (ppm) were considered to be the major elements.

2. The overall mean was calculated on the basis of at least four "accepted" laboratory means ($N \geq 4$) obtained by more than one analytical technique. If results obtained by the use of only one analytical technique are available, the number of "accepted" laboratory averages used for the calculation of the overall mean cannot be smaller than five ($N \geq 5$).
3. If the conditions (1) and (2) are fulfilled, but the number of outliers exceeds 50%, an additional procedure is activated which repeats the process of outlier rejection from the beginning, simultaneously checking the changes in the mean and standard deviation accompanying successive rejections. The process of rejecting of outliers is then stopped when the successive change in both the mean and standard deviation becomes lower or equal to 15%. The condition (1) is then rechecked.
4. If the above criteria are met, but there are indications that after outlier rejection performed on the whole population, the remaining populations of results obtained by various analytical techniques differ significantly, the assignment of certified value is suspended, and its status is described as "information" only.

"Information" values were assigned to those elements for which the results, while not simultaneously fulfilling the conditions (1)-(4), still fulfilled the following condition:

$$\frac{SD \cdot t_{0.05}}{\bar{X} \cdot \sqrt{N}} \begin{cases} \leq 50\% \text{ (trace elements)} \\ \leq 30\% \text{ (major elements)} \end{cases} \quad (3)$$

calculated on the basis of at least three "accepted" laboratory averages; such values are quoted as numbers only, *i.e.* without confidence intervals. The elements for which the obtained values did not fulfil the above criterion were considered to be out of any classification. In the case of some elements (As, Cd, Co, Cr, Fe, Se and U), the correctness of certification was additionally confirmed by definitive methods (primary reference measurement procedures) based on radiochemical neutron activation analysis (RNAA) [4-8] and (in the case of Hg) by isotope dilution mass spectrometry (IDMS) [9, 10]. Traceability to the SI system was maintained because the laboratories, along with the analysis of MODAS samples, also analysed CRMs with a similar matrix. The new certified, as well as the information values, are presented in Tables 1-4.

As additional results obtained by NAA have been taken into account, the uncertainties of the

Table 1. Certified and information values for M-2 SedBot.

Certified values for M-2 BotSed					
macroconstituents		trace elements			
element	concentration [wt%]	element	concentration [mg kg ⁻¹]	element	concentration [ng g ⁻¹]
Al	3.77 ± 0.39	As	7.07 ± 0.67	Bi*	363 ± 94
Ca	6.41 ± 0.56	Ba	266 ± 37	Eu	855 ± 85
Mn	0.102 ± 0.005	Cd	2.17 ± 0.13	Hg	884 ± 53
P	0.175 ± 0.015	Ce	63.1 ± 5.7	Ho*	706 ± 131
Ti	0.325 ± 0.044	Co	7.85 ± 0.72	Lu	337 ± 64
		Cs	4.21 ± 0.29	Sb	955 ± 167
		Cu	32.9 ± 1.8	Tb	693 ± 53
		Dy*	3.66 ± 0.62		
		Er*	2.06 ± 0.40		
		Ga	8.96 ± 1.25		
		Gd*	5.06 ± 0.39		
		La	28.6 ± 3.5		
		Li	27.3 ± 3.7		
		Mo	1.01 ± 0.15		
		Nb	11.2 ± 1.69		
		Nd	27.1 ± 3.3		
		Ni	35.4 ± 2.5		
		Pb	35.9 ± 2.9		
		Pr*	7.00 ± 0.81		
		Rb	71.5 ± 4.1		
		Sc	7.08 ± 0.71		
		Sm	5.23 ± 0.37		
		Sn	3.17 ± 0.65		
		Sr	197 ± 17		
		Th	10.3 ± 0.9		
		U	2.58 ± 0.48		
		V	80.4 ± 10.3		
		Y	20.9 ± 4.0		
		Yb	2.37 ± 0.43		
		Zn	275 ± 14		
Information values for M-2 BotSed					
element	value	unit	element	value	unit
Ag	1.14	mg kg ⁻¹	Na	4273	mg kg ⁻¹
Be	1.23	mg kg ⁻¹	S	2606	mg kg ⁻¹
Br	13.9	mg kg ⁻¹	Se	1.57	mg kg ⁻¹
Cr	68.3	mg kg ⁻¹	Ta	1.01	mg kg ⁻¹
Fe	2.598	wt%	Tl	0.621	mg kg ⁻¹
Hf	11.6	mg kg ⁻¹	Tm	0.294	mg kg ⁻¹
K	1.106	wt%	W	2.43	mg kg ⁻¹
Mg	5695	mg kg ⁻¹	Zr	434	mg kg ⁻¹

* Certified on the basis of results obtained by a single analytical method.

Table 2. Certified and information values for M-3 HerTis.

Certified values for M-3 HerTis					
macroconstituents		trace elements			
element	concentration [wt%]	element	concentration [mg kg ⁻¹]	element	concentration [ng g ⁻¹]
Cl	2.68 ± 0.46	As	9.22 ± 0.79	Ag	36 ± 5
K	1.17 ± 0.12	Ba	2.71 ± 0.28	Cd	325 ± 30
Mg	0.30 ± 0.02	Br	111 ± 11	Co	69 ± 6
Na	1.92 ± 0.17	Cu	3.19 ± 0.22	Cr	919 ± 105
P	2.35 ± 0.39	Fe	190 ± 13	Cs	83.3 ± 7.5
S	0.93 ± 0.10	Mn	5.78 ± 0.61	Hg	227 ± 21
		Rb	2.32 ± 0.19	Li	896 ± 113
		Se	2.62 ± 0.24	Mo	127 ± 20
		Sr	192 ± 15	Ni	316 ± 49
		Zn	111 ± 6	Pb	104 ± 13
				Sb	15.8 ± 3.8
				Sc*	3.2 ± 0.4
				U	75.2 ± 8.2
				V*	782 ± 112
Information values for M-3 HerTis					
element	value	unit	element	value	unit
Ca	3.73	wt%	Y	9.6	ng g ⁻¹
Sm	1.8	ng g ⁻¹			

* Certified on the basis of results obtained by a single analytical method.

Table 3. Certified and information values for M-4 CormTis.

Certified values for M-4 CormTis					
macroconstituents		trace elements			
element	concentration [wt%]	element	concentration [mg kg ⁻¹]	element	concentration [ng g ⁻¹]
K	1.19 ± 0.08	Br	11.1 ± 0.9	As	121 ± 12
Mg	0.10 ± 0.01	Cu	19.5 ± 1.2	Cd	17.2 ± 2.1
Na	0.22 ± 0.02	Fe	281 ± 16	Co	40.4 ± 3.9
P	0.89 ± 0.14	Hg	2.20 ± 0.14	Cs	35.4 ± 4.6
S	1.04 ± 0.11	Mn	2.12 ± 0.18	Sb	66.7 ± 12.2
		Pb	2.33 ± 0.28	V*	7.8 ± 1.2
		Rb	13.3 ± 0.8		
		Se	1.27 ± 0.12		
		Sr	0.24 ± 0.03		
		Zn	63.4 ± 3.5		
Information values for M-4 CormTis					
element	value	unit	element	value	unit
Ag	3.8	ng g ⁻¹	Cr	160	ng g ⁻¹
Ca	258	mg kg ⁻¹	Mo	91	ng g ⁻¹

* Certified on the basis of results obtained by a single analytical method.

Table 4. Certification and information values for M-5 CodTis.

Certified values for M-5 CodTis					
macroconstituents		trace elements			
element	concentration [wt%]	element	concentration [mg kg ⁻¹]	element	concentration [ng g ⁻¹]
Cl	0.41 ± 0.04	As	1.65 ± 0.26	Ba	162 ± 28
K	1.92 ± 0.12	Br	24.8 ± 3.3	Cs	59 ± 5
Mg	0.12 ± 0.02	Cu	1.38 ± 0.09	Hg	310 ± 22
Na	0.34 ± 0.02	Fe	13.3 ± 1.1	Mn	921 ± 75
P	0.96 ± 0.12	Rb	4.54 ± 0.31		
S	1.05 ± 0.16	Se	1.33 ± 0.10		
		Sr	4.07 ± 0.36		
		Zn	20.2 ± 1.1		

Information values for M-5 CodTis					
element	value	unit	element	value	unit
Bi	7.0	ng g ⁻¹	Cr	205	ng g ⁻¹
Ca	0.11	wt%	Li	26	ng g ⁻¹
Cd	5.0	ng g ⁻¹	Ni	136	ng g ⁻¹
Co	19	ng g ⁻¹	Pb	45	ng g ⁻¹

corrected values are lower than before. Analysis of the CRMs by RNAA primary reference measurement procedures (definitive methods) allowed confirmation of the correctness of the certification procedure for the elements for which such procedures were available. In the case of Cr, it was also possible to establish tentative certified values for M-4 CormTis and M-5 CodTis. These values were as follows: for M-4 CormTis 0.147 ± 0.010 mg kg⁻¹ and for M-5 CodTis 0.205 ± 0.018 mg kg⁻¹.

References

- [1]. Dybczyński, R., Danko, B., Kulisa, K., Maleszewska, E., Polkowska-Motrenko, H., Samczyński, Z., & Szopa, Z. (2003). Performance and frequency of use of NAA and other techniques during the certification of two new Polish CRMs prepared by INCT. *Czech J. Phys.*, 53, A171-A179.
- [2]. Polkowska-Motrenko, H., & Dybczyński, R. (2006). Activities of the INCT, Warsaw, in the domain of quality assurance for inorganic trace analysis. *J. Radioanal. Nucl. Chem.*, 269, 339-345.
- [3]. Polkowska-Motrenko, H., Dybczyński, R.S., & Chajduk, E. (2010). Certification of reference materials for inorganic trace analysis: the INCT approach. *Accredit. Qual. Assur.*, 15, 245-259.
- [4]. Samczyński, Z., & Dybczyński, R. (1996). Ion exchange behaviour of cadmium on amphoteric ion exchange resin Retardion 11A8 and its application for the determination of cadmium in biological materials by neutron activation analysis. *Chem. Anal. (Warsaw)*, 41, 873-890.
- [5]. Danko, B., & Dybczyński, R. (1997). Determination of molybdenum and uranium in biological materials by radiochemical neutron activation analysis. *J. Radioanal. Nucl. Chem.*, 216, 51-57.
- [6]. Dybczyński, R., & Danko, B. (1994). A definitive method for the determination of trace amounts of cobalt in biological materials by neutron activation analysis. *J. Radioanal. Nucl. Chem.*, 181, 43-49.
- [7]. Dybczyński, R., Danko, B., Polkowska-Motrenko, H., & Samczyński, Z. (2007). RNAA in metrology: A highly accurate (definitive) method. *Talanta*, 71, 529-536.
- [8]. Dybczyński, R.S., Polkowska-Motrenko, H., Chajduk, E., Danko, B., & Pyszynska, M. (2014). Recent advances in ratio primary reference measurement procedures (definitive methods) and their use in certification of reference materials and controlling assigned values in proficiency testing. *J. Radioanal. Nucl. Chem.*, 302, 1295-1302.
- [9]. Krata, A., Ari, B., & Quetel, C. (2010). *Isotope Dilution Inductively Coupled Plasma Mass Spectrometry applied for establishment of reference value of the total Hg content in a mineral feed test material for IMEP-111*. Geel (Belgium): European Commission – Joint Research Centre – Institute for Reference Materials and Measurements. JRC62101.
- [10]. Fischer, L., Brunner, M., Prohaska, T., & Hann, S. (2012). Accurate quantification of mercury in river water by isotope dilution MC-ICP-SFMS and ICP-QMS detection after cold vapour generation. *J. Anal. At. Spectrom.*, 27, 1983-1991.

LABORATORY OF MATERIAL RESEARCH

The activities of the Laboratory are concentrated on:

- studies of coordination polymers built of s block metals and azine carboxylate ligands,
- synthesis of nanoscale porous metal organic framework (nanoMOF) materials,
- synthesis of functional materials – silver-modified cotton and cellulose fibres using radiation beam techniques,
- improvement of the usable surface properties of special materials applied in nuclear energy technologies (zirconium alloys, steels) using high intensity pulsed plasma beams (HIPPB),
- characterization of art objects.

Porous coordination polymers, also called metal organic framework materials, have become a topical subject in recent years. They exhibit unique pore architecture and a broad range of potential applications. The latter include greenhouse gas removal, storage of gases and the selective separation of components of gaseous mixtures that are of interest for the development of modern energy technologies. In the case of MOFs, the pores' structure and the host-guest molecules' interaction can be tailored relatively easily for a potential application by carefully combining the ligand and the type of metal ion. At present, many potential applications of MOFs require them to be obtained at a nanometre scale. Nanoscopic dimensions are essential to provide MOFs with high surface areas, and for tuning their properties (catalytic, separation, sensing and sorption). One application requiring such dimensions is mixed matrix membrane synthesis, where MOF's particles are used as fillers in a polymer matrix. Others include MOFs with size-dependent properties (optical, electrical and magnetic) and biocompatible materials for biomedical applications, *e.g.* encapsulation and transport of drugs. The integration of nanoscale MOFs onto porous supports would be advantageous for creating thin layer membranes. Studies performed recently in the Laboratory of Material Research concerning the synthesis of nanoscale MOFs are reported. The applied methods include template synthesis in the pores of track-etched membranes with well-defined cylindrical pores, synthesis in microfluidic flow reactors and the synthesis of MOFs on the surface of porous alumina substrates and also on composites with graphene oxide.

Zirconium, due to its good water corrosion and radiation resistance at the normal working conditions of nuclear reactors, is commonly used as cladding material for fuel elements. However, in the case of LOCA (loss-of-coolant accident) conditions, the possible extremely fast oxidation of zirconium in a steam atmosphere, or in an air/steam mixture, at temperatures above 800°C results in intense hydrogen generation and a possible hydrogen-oxygen mixture explosion. These events, despite being very rare, negatively influence the public acceptance for nuclear energy and result in high restoration costs for the accompanying damages. The development of methods to minimize the risk in the case of design-basis and beyond design-basis accidents is urgently needed. Materials with enhanced tolerance to high temperature oxidation have already been proposed for this purpose, such as silicon carbide, Mo-Zr, FeCrAl claddings, MAX phases and multilayer zirconium silicide coatings.

Zirconium silicide or zirconium silicate coatings are known for good resistance in high-temperature conditions and for that reason have been considered for application as environmental barrier coatings for high-temperature gas-turbine components. Up to now, their application as corrosion protective coatings for nuclear fuel pellets has been less explored. However, a review of the existing literature and an analysis of thermodynamic data indicate that silicon-based coatings may offer excellent prospects in this field. In particular, they may provide a more protective barrier than the native ZrO₂ films formed on alloy cladding during routine nuclear reactor operation. Our work in the last year has focused on the development of silicon-based coatings on zirconium alloys claddings and the evaluation of their properties

during accident scenarios, as well as during the regular operation of reactors. Two processes have been considered for coating preparation. The first one is based on the deposition of layers containing zirconium oxide and silicon oxide onto zirconium alloys tubes (and also onto flat samples), followed by densification of the deposited layers. The second one is based on the deposition of gradient layers of zirconium and silicon (and also possibly their oxides) by the physical vapour deposition (PVD) method.

For the deposition of coatings precursors, three methods have been proposed: a dip coating method using mixed zirconium oxide and silicon oxide sols prepared by the sol-gel method, plasma electrolytic oxidation in silicate containing solutions, and electrophoretic deposition from zirconium oxide and silicon oxide containing suspensions, or directly from $ZrSiO_4$ suspension.

For the densification of the prepared porous layers, the unique technique of high intensity pulsed plasma beams will be applied or, alternatively, electron beams operating in scanning mode.

In order to examine, characterize and analyse cultural heritage artefacts or art objects and their component materials, a conservation scientist requires a palette of non-destructive and non-invasive techniques. This type of research improves knowledge concerning the elaboration, evolution and degradation of art objects over time, and provides a basis for their restoration and conservation. Among the various methods used, nuclear techniques are crucial due to their high sensitivity and reproducibility.

The purpose of last year's studies within this cultural heritage framework was the dating and determination of the provenance of a few groups of early medieval lead seals from Czeremno, Gródek, Ruthenian and Russia. Ores from selected sources (Cracow-Silesian and Świętokrzyskie Mountains ore bodies, Poland) were also analysed to determine the provenance of the lead used. SEM-EDS (scanning electron microscopy–energy-dispersive X-ray spectroscopy), X-ray fluorescence analysis (EDXRF, TXRF), PIXE (particle-induced X-ray emission spectroscopy), PGAA (prompt-gamma activation analysis) and INAA (instrumental neutron activation analysis) as non-destructive methods were chosen to study a large number of samples. In addition to the study of the composition of the seals, analyses of the ratios of the lead isotopes were performed by means of a LA-ICP-MS (laser ablation inductively coupled plasma mass spectrometry) method. Interpretation of the results of the statistical methods enabled differentiation of the artefacts according to their various production centres, recipes and raw materials and the methods of purification used. Unique documentation and a database for the different types of seals is the result of these studies.

The investigation into the chemical composition and technologies employed in the manufacture of historical glass using micro-sample techniques was continued in 2017.

STUDIES ON HIGH TEMPERATURE OXIDATION RESISTANCE OF ZIRCONIUM SILICIDE COATINGS ON A ZIRCONIUM ALLOY

Wojciech Starosta^{1/}, Viera K. Semina^{2/}, Jerzy Smolik^{3/}, Lech Waliś^{1/}, Michał Rydzewski^{3/},
Bożena Sartowska^{1/}

^{1/} Institute of Nuclear Chemistry and Technology, Warszawa, Poland

^{2/} Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia

^{3/} Institute for Sustainable Technologies, Radom, Poland

Zirconium alloys are commonly used in pressurized water reactors (PWR) as fuel claddings for the hermetic enclosure of fuel pellets and fission products generated in the course of reactor operation. Zirconium alloys have been selected for their unique properties in reactor environment conditions, particularly for their low thermal neutron absorption, sufficiently good corrosion resistance at working conditions (360°C, 195 bar) and the sufficient stability of their mechanical properties under neutron irradiation. However, the main drawback of zirconium alloys is their completely unsatisfactory resistance to high temperature oxidation in steam atmosphere. Such conditions are expected in the case of a loss-of-coolant accident (LOCA). In this case the exothermic oxidation reaction of zirconium leads to a fast temperature rise and to the generation of large amounts of explosive gaseous hydrogen that may lead to the destruction of the nuclear core. As the safety of nuclear installations is of primary importance, intensive research work is being conducted worldwide on the development of so-called accident-tolerant fuels (ATFs), which will be much less prone to oxidation. Various concepts have been proposed for ATFs. The most revolutionary one is based on replacing zirconium alloys with composites of silicon carbide, another on applying an external oxidation-resistant coating on the surface of the zirconium alloy tubes. Before introducing a new type of material to the market, extensive tests are required in order to fulfil existing regulations, so the somewhat more conservative concept of external coatings seems to have the potential to be implemented in a shorter time. The results of the research work published on this subject in the open literature up to the end of 2016 have been recently reviewed [1].

Recently, a renewed interest in nuclear power has been observed in Poland. The strategic research programme called “Technologies supporting development of safe nuclear power engineering” was established in a response to the expected introduction of nuclear power engineering to Poland. The Laboratory of Materials Research at the Institute of Nuclear Chemistry and Technology joined this programme, focusing their research work on zirconium oxidation mechanisms under normal working conditions and during cases of emergency, as well as on countermeasures that would help to mitigate the catastrophic oxidation of zirconium in the case of an LOCA accident. The technique of high intensity pulsed plasma and ion beam treatment has been applied for the modification of the surface layer of zirconium. Using this

method, the melting of the surface layer and doping with eroded metallic electrode materials, such as Y, Cr and Al, into the molten surface layer was possible. However, the concentration of doped elements was usually at the level of a few percent, which was not high enough for the creation of a protective oxide layer on the surface of the fuel rod in the case of a large increase in temperature. Good results in autoclave tests and in an oxidation test in air at high temperature were obtained in the case of a chromium layer of 3.5 µm deposited by arc plasma discharge [2]. Based on that experience, we finally switched to physical deposition methods as flexible methods of coating synthesis and selected zirconium silicides as possible protective coatings. There are a number of reasons for this choice. Firstly, zirconium and silicon are preferred to chromium due to their lower cross-sections for thermal neutron absorption in comparison to chromium. Other ones are related to the material properties of silicides, particularly to their high melting points and resistance to oxidation. Phase diagrams for the Zr-Si system clearly show the existence of intermetallic compounds with different Zr/Si ratios and stability regions. For example, ZrSi₂ is stable up to 1620°C and ZrSi is stable up to 2210°C, etc. Both zirconium and silicon readily form their respective oxides at high temperatures. According to its Ellingham diagram, ZrO₂'s formation enthalpy is higher than the enthalpy of silicon dioxide formation, and zirconium dioxide should be formed preferentially according to thermodynamic laws. However, kinetic factors also need to be taken into account. In the course of zirconium silicide oxidation, depletion of zirconium should lead to silicon's activity increasing, and the formation of silicon oxide is possible. As a result, ZrO₂, SiO₂ or even ZrSiO₄ may form, depending on the stoichiometry of the zirconium silicide. Moreover, in the case of ZrSi₂, layer depletion of silicon should lead to the formation of ZrSi, which possesses a higher melting temperature. Thus, it seems that zirconium silicide coatings with a stoichiometry of ZrSi₂ offer good prospects for their application as protective layers against oxidation at high temperatures. To check this hypothesis the relevant studies described here have been undertaken.

The commercially available Zr705 grade zirconium alloy supplied by Stanford Advanced Materials was used for sample preparation. Slices of 5 mm thickness were cut from a 25.4 mm diameter rod. The samples were polished with sandpaper and cleaned in an ultrasonic bath. Furthermore, before coating deposition their surfaces were etch-

Table 1. The mass gain of samples due to oxidation in air at 700°C.

Time [h]	Zr alloy – raw sample [g]	Sample coated from ZrSi ₂ target [g]	Sample coated from Zr and Si targets [g]
1	0.0264	0.0096	0.0072
2	0.0325	0.0134	0.0088
3	0.0383	0.0156	0.0126
4	0.0472	0.0195	0.0143
5	0.0585	0.0241	0.0184

ed in a low-pressure glow discharge in argon gas. Zirconium- and silicon-containing coatings were sputter-deposited onto polished samples to a nominal thickness of about 3 μm by the DC magnetron sputtering technique from pure Zr and Si targets or a ZrSi₂-sintered target with a diameter of 100 mm and a thickness of 8 mm, adhesively bonded on a copper washer. Before deposition, the chamber was evacuated to $3 \cdot 10^{-3}$ Pa, and the samples were heated up to about 300°C. The working pressure during deposition was 0.5 Pa, and the distance from the samples to the plasma source was 150 mm. During the process, the temperature was constantly monitored using a pyrometric temperature measurement system. The negative bias of the substrate was -100 V.

Two series of samples were prepared using different combinations of targets. The first one was prepared using two independent zirconium and silicon targets. This allowed for the synthesis of coatings with different stoichiometry by changing the relative sputtering rates of the targets. The second series was prepared using a single target made of the ZrSi₂ compound.

The as-deposited samples were amorphous, as was confirmed by X-ray diffraction (XRD) studies. For the development of crystallinity, thermal treatment in a tube furnace under an argon flow was applied.

For determining the oxidation resistance of the coatings, two types of tests were performed. One of them was aimed at determining the oxidation kinetics and the other at determining the performance under simulated accident conditions. For the oxidation kinetics study, the weight increase of the sample was determined after its oxidation in air at a temperature of 700°C. The sample, which was coated on both faces, was periodically placed into a furnace and removed from there at one-hour intervals up to 5 h maximum. After cooling in air, the weight of the sample was determined using a precision balance. The weight increment data were fitted to a power function. Independently, four samples coated on one side were placed into a furnace warmed to 700°C and were taken out one by one at one-hour intervals for scanning electron microscopy (SEM) studies on their morphologies and the thickness evolution of their coated layers in the course of oxidation.

For the determination of the performance in the case of uncontrolled temperature growth during an LOCA, samples coated on one side were

placed inside a furnace, warmed up to 1100°C for 1000 s in an air atmosphere and then taken out and dropped immediately into water.

At each step of the research, SEM (Ultra plus, Zeiss), XRD (D8 Advance, Bruker) and EDX (energy-dispersive X-ray spectroscopy; Quantax, Bruker) methods were applied for morphological, structural and elemental composition studies.

The results of weight increase from the oxidation in air at a temperature of 700°C are given in Table 1 for the two types of coated samples and for the raw sample. The data were fitted to the power function

$$w^k = \alpha \cdot t$$

or in the logarithmic form

$$\log(w) = 1/k \cdot \log(t) + \log(\alpha)/k$$

where: w – mass gain, t – time.

The results of the linear regression fitting are presented in Table 2.

Table 2. The functional form of linear regression fitting to the mass gain of samples due to oxidation in air at 700°C.

Zr alloy – raw sample	$\log(w) = 0.4738 \cdot \log(t) - 1.6505$
Sample coated from ZrSi ₂ target	$\log(w) = 0.5474 \cdot \log(t) - 2.0327$
Sample coated from Zr and Si targets	$\log(w) = 0.5768 \cdot \log(t) - 2.1754$

An analysis of the data obtained clearly showed smaller mass gain in the case of the coated samples. For the samples coated from two targets, the mass gain for the 5-hour oxidation in air at 700°C was 3.17 times smaller than in the case of the raw sample. Analysis of the regression data confirmed the protective nature of the coatings. The values of exponential factor k of 1.73 (in the case of the two targets) and 1.83 (in the case of one target) obtained are slightly smaller than the ideal value of 2, which corresponds to the case when diffusion of oxygen through the layer is the main mechanism responsible for the mass gain during oxidation. It cannot be excluded that a small amount of porosity exists in the coatings, which is directly related to the columnar microstructure of coatings obtained by magnetron sputtering. It is worth mentioning that the coatings made from the two targets exhibited smaller values of mass increase over the oxidation time. It was also found that the samples prepared from two targets, after treatment at 700°C in an air at-

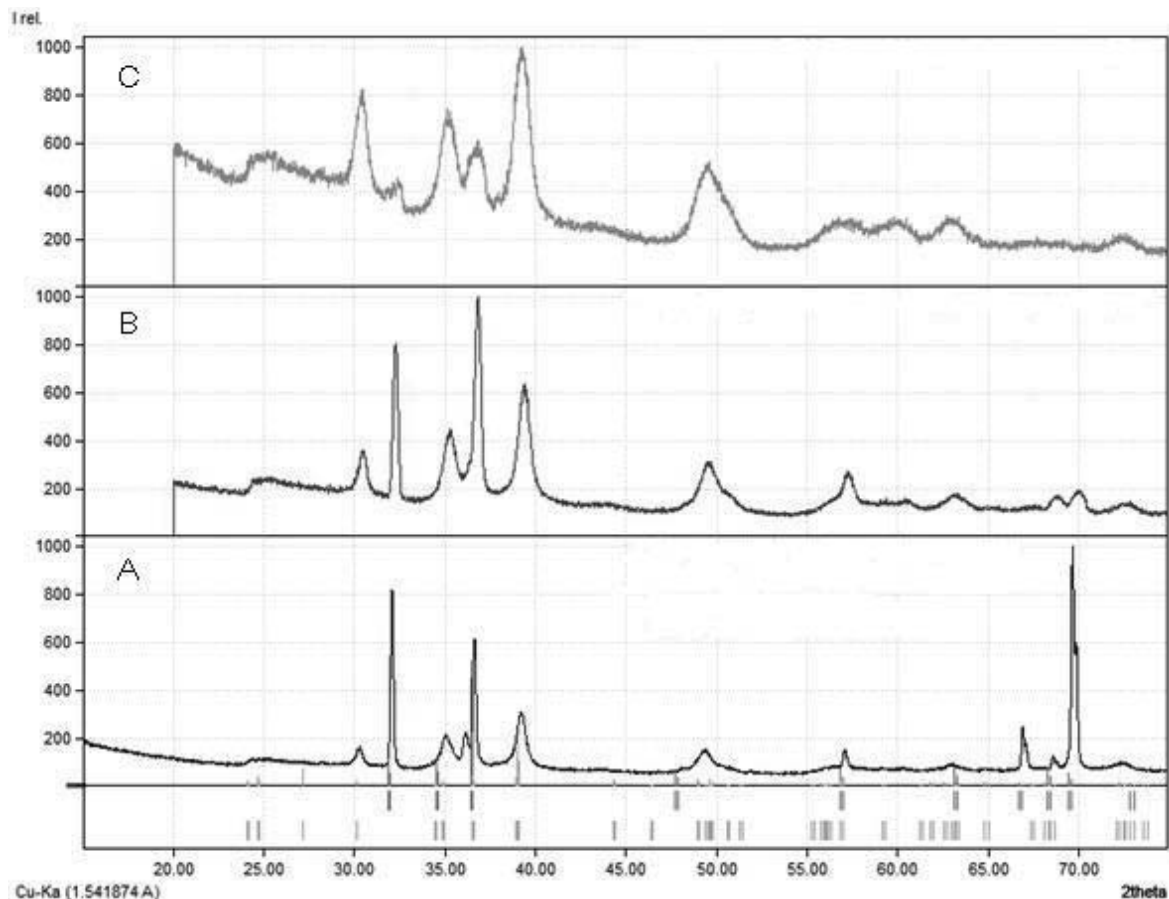


Fig. 1. The XRD spectra of the coating deposited from the two independent targets (Zr, Si) after thermal treatment at a temperature of 800°C in argon neutral atmosphere in normal geometry (A), at a glancing angle of 10° (B) and a glancing angle of 5° (C). The positions of zirconium alloy reflections are shown by the first row and the $ZrSi_2$ reflections by the second row of vertical markers below the spectra.

mosphere for 4 h, exhibited smooth surfaces, free of visible cracks, while in the case of coatings prepared with the application of the $ZrSi_2$ compound target, a network of cracks was clearly visible.

Experiments performed at the higher temperature of 1100°C with fast cooling in water again showed the better performance of the coated samples. The mass gain for the uncoated sample was equal to 0.3039 g, while that for the sample coated from two targets was 0.2216 g and that for the sample coated from the one compound target was 0.2159 g.

As mentioned already, the as-deposited samples were amorphous. The thermal treatment of the samples in argon neutral atmosphere enabled the development of crystallinity. This was confirmed by the XRD measurements presented in Fig. 1, showing the spectra measured at normal Bragg-Brentano geometry and at glancing angles of 5° and 10°.

It can be seen that in the case of normal diffraction geometry, the zirconium substrate reflections are dominant in the spectrum, while in the other two cases, especially at a glancing angle of

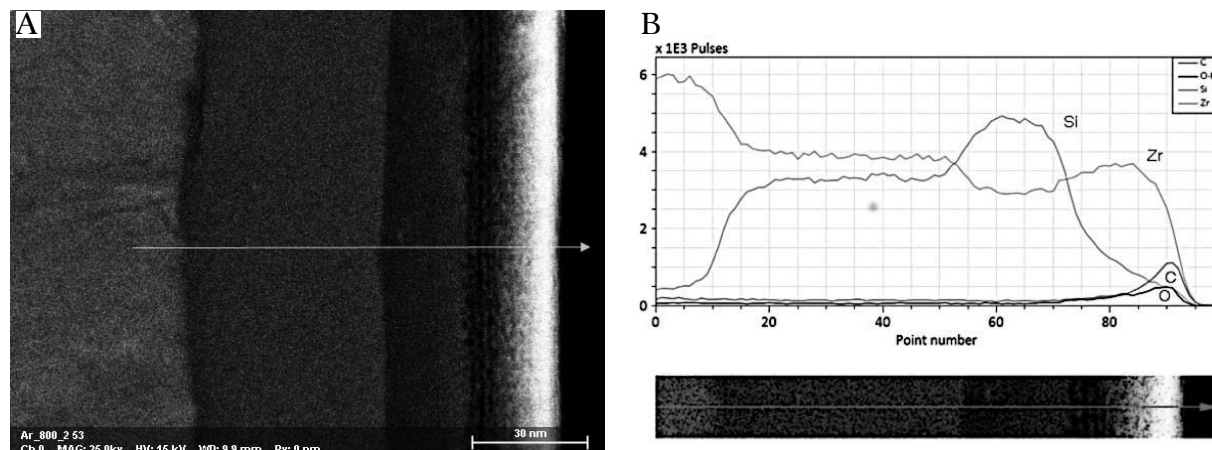


Fig. 2. The SEM view of a cross-section of the coating made from the two independent targets (Zr, Si) (A) and elemental distribution across the coating after treatment in argon neutral atmosphere at a temperature of 800°C for 4 h (B).

5°, the reflections belonging to the $ZrSi_2$ phase are clearly visible. The Rietveld refinement of the XRD spectra based on the model of two contributing phases, Zr and $ZrSi_2$, converged successfully, confirming the validity of the model.

The SEM studies of cross-sections of thermally treated, coated samples allowed interesting observations of the morphology of the coatings to be made. After treatment in a non-oxidizing argon atmosphere, a layered structure inside the coating was developed. Three distinct layers could be distinguished, as shown in Fig. 2. For each of the layers, different elemental contents of zirconium, silicon and oxygen were found using the EDX method.

Starting from the outer region (Fig. 2B) we can observe:

- the thin external layer containing the elements Zr, Si and O. The presence of monoclinic ZrO_2 has already been confirmed by the XRD spectra and this phase is probably present mainly here. The structural form of Si is at present unknown. The XRD diffraction does not give any evidence for the presence of crystalline forms of silicon. The presence of amorphous silicon oxides is possible and need to be confirmed.
- the middle layer with near $ZrSi_2$ stoichiometry. The XRD studies confirm the presence of crystalline $ZrSi_2$.
- the wider, near to the bulk zirconium alloy layer with the stoichiometry $ZrSi$.

The safety of a nuclear installation in the case of beyond design-basis accidents strongly depends on the materials utilized. To avoid catastrophic accidents, such as the one in Fukushima, occurring in the future, high performance materials that can withstand the severe oxidation conditions present in the case of accidents need to be developed. In the studies presented in this paper, a zirconium silicide material was proposed as a pro-

TECTIVE COATING FOR THE ZIRCONIUM ALLOY FUEL TUBES. Preliminary studies confirmed the protective character of this coatings at the temperature ranges investigated. The method of coating deposition from two independent targets allows for the preparation of thin coatings in the range of few micrometres with different stoichiometry. It seems that this variant is preferable over the deposition using one target with definite stoichiometric composition, as usually stoichiometry is not preserved during deposition. Moreover, no cracks were observed in the case of deposition using two elemental targets. The interesting observation of the *in situ* formation of a layered structure with different composition inside the coatings during thermal treatment in argon and in air could be utilized for the development of coatings that are protective against oxidation at high temperatures.

The financial support from the Ministry of Science and Higher Education grant under decision 3787/ZIBJ Dubna/2017/0 is gratefully acknowledged.

References

- [1]. Tang, C., Stueber, M., Seifert, H.J., & Steinbrück, M. (2017). Protective coatings on zirconium-based alloys as accident-tolerant fuel (ATF) claddings. *Corros. Rev.*, 35(3), 141-165. DOI: 10.1515/corrrev-2017-0010.
- [2]. Starosta, W., Barlak, M., Buczkowski, M., Kosińska, A., Sartowska, B., Waliś, L., & Janiak, T. (2015). Analiza mechanizmów tworzenia się oraz właściwości warstw tlenkowych powstających w wyniku rozkładu wody na powierzchni koszulek cyrkonowych oraz zbadanie wpływu modyfikacji struktury warstwy wierzchniej koszulek na procesy generacji wodoru. W *Analiza procesów generacji wodoru w reaktorze jądrowym w trakcie normalnej eksploatacji i w sytuacjach awaryjnych z propozycjami działań na rzecz podniesienia poziomu bezpieczeństwa jądrowego* (s. 55-72). Warszawa: Instytut Chemii i Techniki Jądrowej.

ACCIDENT TOLERANT MATERIALS: IDEAS AND RESEARCH DIRECTIONS

Bożena Sartowska, Wojciech Starosta, Lech Waliś

Introduction

Zirconium, due to its good water corrosion and radiation resistance under the normal working conditions of nuclear reactors, is commonly used as a cladding material for fuel elements. A schematic of a light water reactor (LWR) fuel rod is presented in Fig. 1. The fuel pellets' cladding is a very important part of the rod. The elemental composition of the zirconium alloys used in nuclear reactors is presented in Table 1.

In the case of normal working conditions (a cooling water temperature of 360°C for pressurized water reactors (PWRs)), a slow zirconium oxidation occurs due to the presence of oxygen absorbed at the cladding's surface or that from water radiolysis reactions.

In the case of LOCA (loss-of-coolant accident) conditions, the extremely fast oxidation of zirconium in a steam atmosphere and/or an air-steam

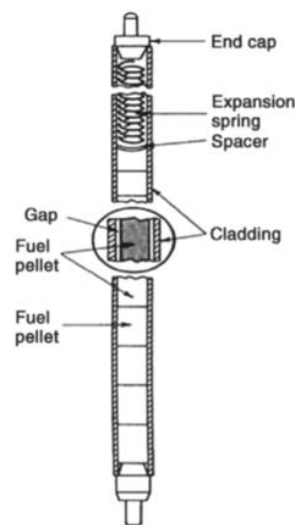


Fig. 1. Schematic of a light water reactor fuel rod [1].

Table 1. Concentration of alloying elements in zirconium alloys used for claddings.

Zirconium alloy	Producer	Alloying element [wt%]					
		Sn	Nb	Fe	Cr	Ni	O
Zry-2	commonly used	1.50	-	0.13	0.1	0.06	0.12
Zry-4	commonly used	1.50	-	0.21	0.1	0.007	0.12
M5	AREVA		0.8-1.2				
ZIRLO	Westinghouse	0.7-1.0	1.0				
E110	Russia	-	0.9-1.1				

mixture at temperatures above 800°C results in intense hydrogen generation and a possible hydrogen-oxygen mixture explosion. The evolution of a fuel rod under LOCA and SBO (station blackout) conditions is connected with: steam oxidation of cladding, cladding ballooning and bursting, cladding internal oxidation, fuel relocation and dispersal, oxide eutectic formation and fuel rod melt [2]. These events, although very rare, negatively influence the public acceptance of nuclear energy. The development of a solution to this problem that will minimize the risk of such accidents is urgently needed. The concept of accident-tolerant fuels (ATFs) and accident-tolerant materials (ATMs) has been developed recently for this purpose [2, 3].

There have been many improvements to the original design and materials used. However, the basic concept of uranium oxide fuel pellets clad with zirconium alloy tubes has reminded the choice for the vast majority of commercial nuclear power plants. Development of a method to minimize the risk related to the design and unforeseeable situations is urgently needed. Four key performance features of the ATF and ATM concepts for improved safety margins proposed by Zinkle *et al.* [2] are: (i) minimize core enthalpy input (reduced steam-cladding oxidation rate and reduced heat of oxidation of cladding), (ii) minimize combustible hydrogen generation (reduced steam-cladding oxidation rate, enhanced hydrogen sequestration and chemical conversion), (iii) improved cladding to maintain core-cooling ability and to retain fission products (improved high-temperature cladding strength and fracture resistance, improved burst margins, thermal shock resistance, increased melting temperature and resistance to hydrogen embrittlement), (iv) improved fuel containment of fission products (enhanced retention of fission products, minimize fuel relocation/dispersal, lower operating temperatures, inhibit cladding's internal oxidation and increased fuel melting safety margin).

The approaches can be grouped into three general categories:

- non-zirconium cladding with high strength and oxidation resistance;
- improved high-temperature oxidation resistance and/or strength of zirconium alloy cladding;
- alternative forms of fuel with improved performance and fission product retention compared to monolithic UO₂.

These are the main research directions in the ATM area.

Non-zirconium cladding with high strength and oxidation resistance

The development of new alloys with special compositions and microstructures, along with the application of new materials resistant to water corrosion, are the main topics here. Challenges and issues to be resolved include: the effect of higher thermal neutron absorption cross-section, the impact of radiation hardening and embrittlement on cladding, pellet-cladding mechanical interaction behaviour, oxidation behaviour in steam at high temperatures, potential enhanced susceptibility to stress corrosion cracking, and potential reductions in the cost of tube fabrication.

Structural alloys

The thermal neutron cross-section of stainless steels is higher than that for zirconium alloys. But this problem with the use of stainless steel cladding can be partially overcome by thinner walled advanced stainless claddings because they are stronger than zirconium alloys. Investigations of this kind of material have covered: austenitic stainless steels (AISI 304, AISI 316 and AISI 347), austenitic nickel-based alloys (Inconel 600 and Incoloy 800) and ferritic steel with chromium (AISI 430). The replacement of the zirconium alloy by a ferritic material containing chromium and aluminium appears to be the nearest to implementation for accident-tolerant fuels [4, 5].

Silicon carbide

Silicon carbide (SiC) composite is used in industrial applications such as turbine components. Silicon carbide fibre reinforced SiC matrix ceramic composites (SiC/SiC) have been proposed as a potential cladding material due to: low thermal neutron absorption cross section, retention of strength up to very high temperatures, good radiation resistance and good oxidation resistance in air and steam up to 1600°C [6, 7].

FeCrAl alloys

FeCrAl alloys are used in industries where high-temperature oxidation resistance is needed (combustion and fossil fuel energy plants) [8]. FeCrAl nuclear grade alloys have important features for nuclear application: good mechanical properties for extended periods at high temperature, oxidation resistance, radiation tolerance, long-term water corrosion resistance and compatibility with the prototypically used UO₂ fuel. Nuclear grade FeCrAl alloys should be formable

as thin-walled tubes. The nominal composition of the model FeCrAl alloys are: Fe – 10-20 wt%, Cr – 3-5 wt% and Al – 0-0.15 wt%. The composition problem is complicated because the elemental composition has to be in a very narrow range. For example, more Cr is better for corrosion and oxidation resistance, but it would increase the potential embrittlement of the materials at relatively lower temperatures, and more Al gives better oxidation resistance at elevated temperatures, but it may raise the ductile-brittle transition temperature [5].

Refractory alloys

Refractory alloys based on Nb, Ta, Mo or W offer the potential for significant improvements in high-temperature strength as compared to zirconium alloys. Refractory alloys exhibit poor behaviour in high-temperature oxidizing environments, but research has identified some alloys (for example Mo₂Si-based) with adequate short-term oxidation resistance. It has been noted that high-temperature oxidation can be significantly different for steam and air [9]. Potential cladding designs for refractory alloys include monolithic and multilayered “sandwich” designs where thin oxidation-resistant layers are applied to the inner and outer surfaces of the refractory alloy [5].

Highly adherent oxidation-resistant coatings

Highly adherent oxidation-resistant coatings on the zirconium alloys can be an alternative to the known bulk materials for cladding. Challenges and issues to be resolved are the following: the coating should be easily regenerated if a small portion is spalled off during fuel assembly handling or during normal reactor operation, the need for careful matching of the coefficients of thermal expansion in order to minimize interfacial stresses and delamination during cycling from room temperature to 300°C (normal operation) or from 300°C up to high temperatures (abnormal operation) and the coating must be compliant enough to withstand the diametrical compression that results from reactor pressurization. The ability of coatings to continuously protect the exposed cladding to a sufficient extent after a burst also needs to be considered, because at this point the inner uncoated surface of the cladding is exposed to steam that causes rapid oxidation.

Chromium coatings

Chromium coatings serve as a protective oxidation barrier by providing the following properties: significantly improved resistance to corrosion under normal conditions in the 360°C water test, reduced corrosion rates in high-temperature steam and improved post-quench mechanical behaviour due to a reduced ingress of oxygen within the metal to form the alpha (O)-Zr phase [5].

MAX phase

MAX phases are a group of ternary ceramic compounds composed of early transition metals (Sc, Ti, V, Cr, Zr, Nb, Mo, Hf and Ta) as M, of elements from the A group (mainly Al, Si, P, S, Ga, Ge, As, In, Cd, Sn, Tl and Pb) as A, and carbon or nitrogen as X. MAX phases have good properties such as: thermal and electrical conductivity,

corrosion resistance and mechanical properties that are maintained at high temperatures [5, 10].

Coatings based on silicon

Zirconium silicide or zirconium silicate coatings are known for good resistance in high temperature conditions and are applied as environmental barrier coatings for high-temperature gas-turbine components. Silicon-based coatings may provide a more protective barrier than the native ZrO₂ films formed on alloy cladding during routine nuclear plant operations and may provide a protective barrier during high-temperature accident scenarios. Phase diagrams for zirconium-silicon systems show the existence of intermetallic compounds with different Zr/Si ratios and stability regions. For example, ZrSi₂ is stable up to 1620°C and ZrSi is stable up to 2210°C [11].

Institute of Nuclear Chemistry and Technology activity

The Institute of Nuclear Chemistry and Technology (INCT) is a partner in the International Atomic Energy Agency (IAEA) coordinated research project (CRP) “Analysis of options and experimental examination of fuels for water-cooled reactors with increased accident tolerance – ACTOF” in the framework of the IAEA programme “Nuclear fuel cycle and materials technologies”. Globally, there is a great deal of experience with the performance of reactor fuel in abnormal conditions. Theoretical studies and experiments have been performed, and there have been excursions forming abnormal operating conditions in a few power reactors. This CRP will explore the potential to design and operate advanced fuel types that are intended to be more tolerant of severe accident conditions, whilst retaining the capability of current fuel designs for safe operation under normal operation and anticipated transient conditions. The participants of the ACTOF project are: Argentina, Brazil, China, Czech Republic, Finland, Germany, India, Italy, Korea, Poland, the Russian Federation and the United States of America.

The INCT is involved in this programme with the subject “Silicide/silicate coatings on zirconium alloys for improving the high temperature corrosion resistance”.

Conclusions

Several potential approaches for development of ATMs exist and could lead to improved accident tolerance in LWR fuel systems. The various options in this paper explore and offer basic guidelines on the attributes of ATM concepts. Accident progression is dominated by the integral system response during such events. ATMs can affect the sequence and rate of this progression, thereby providing enhanced coping time during such events; the safety margins for nuclear power systems can therefore be enhanced.

This work has been partially supported under the IAEA Research Contract No. 19026/R0 and by the Polish Ministry of Science and Higher Education under decisions 3525/IAEA/2016/0 and 3689/IAEA/2017/0.

References

- [1]. Allen, T., Busby, J., Meyer, M., & Petti, D. (2010). Materials challenges for nuclear systems. *Materials Today*, 13(12), 14-23.
- [2]. Zinkle, S.J., Terrani, K.A., Gehin, J.C., Ott, L.J., & Snead, L.L. (2014). Accident tolerant fuels for LWRs: A perspective. *J. Nucl. Mater.*, 448, 374-379.
- [3]. Mariani, R.D., Medvedev, P., Porter, D.L., Hayes, S.L., Cole, J.L., & Bai, X.M. (2013). Novel accident-tolerant fuel meat and cladding. In *LWR Fuel Performance Meeting (Top Fuel 2013) Charlotte, North Carolina, United States, 15-19 September 2013* (pp. 763-770). Idaho Falls, Idaho: Idaho National Laboratory.
- [4]. Terrani, K.A., Zinkle, S.J., & Snead, L.L. (2014). Advanced oxidation-resistant iron-based alloys for LWR fuel cladding. *J. Nucl. Mater.*, 448, 420-435.
- [5]. IAEA. (2016). *Accident tolerant fuel concepts for light water reactors. Proceedings of a Technical Meeting held at Oak Ridge National Laboratories, United States of America, 13-16 October 2014*. Vienna: IAEA. IAEA-TECDOC-1797.
- [6]. Yueh, K., & Terrani, K.A. (2014). Silicon carbide composite for light water reactor fuel assembly applications. *J. Nucl. Mater.*, 448, 380-388.
- [7]. Lee, Y.H., McKrell, T., & Kazimi, M.S. (2014). *Safety of light water reactor fuel with silicon carbide cladding*. Massachusetts Institute of Technology. Advanced Nuclear Power Program. MIT-ANP-TR-150.
- [8]. Ejenstam, J., Halvarsson, M., Weidow, J., Jönsson, B., & Szakalos, P. (2013). Oxidation studies of Fe10CrAl-Re alloys exposed to Pb at 550°C for 10,000 h. *J. Nucl. Mater.*, 443(1-3), 161-170.
- [9]. Nelson, A., Sooby, E., Kim, Y.-J., Cheng, B., & Maloy, S.A. (2014). High temperature oxidation of molybdenum in water vapor environments. *J. Nucl. Mater.*, 448, 441-447.
- [10]. Barsoum, M.W. (2013). *MAX phases: Properties of machinable ternary carbides and nitrides*. Weinheim, Germany: Wiley-VCH Verlag GmbH & KGaA.
- [11]. Chaia, N., Mathieu, S., Rouillard, F., & Vilasi, M. (2015) The ability of silicide coating to delay the catastrophic oxidation of vanadium under severe conditions. *J. Nucl. Mater.*, 457, 124-129.

THE USE OF TRACE ELEMENT ANALYSIS ON IRON ARTEFACTS FROM THE PRZEWORSK CULTURE

Ewa Pańczyk^{1/}, Wawrzyniec Orliński^{2/}, Władysław Weker^{3/}, Lech Waliś^{1/}

^{1/} Institute of Nuclear Chemistry and Technology, Warszawa, Poland

^{2/} Historical Museum, Legionowo, Poland

^{3/} State Archaeological Museum, Warszawa, Poland

The main purpose of the studies presented here is to investigate the La Tène culture's impact on the cultures of ancient Central Europe, especially the Przeworsk culture. The provenance of prehistoric iron is one of the key questions in the archaeology of the Iron Age.

In the literature, it is accepted that three older cultural substrates contributed to the Przeworsk culture: the Cloche Grave, the La Tène, and the Jastorf cultures. Of these three, the La Tène culture had the largest impact on the Przeworsk culture. The influence of the La Tène culture is seen in the economy and crafts of the Przeworsk culture and principally in the spiritual culture that is manifested through their burial sites. The Przeworsk culture was the first culture in this part of the European *Barbaricum* and commonly made use of iron in their tools and weapons. Since the pre-Roman period, the Mazovia region functioned as a hub for metallurgical mass production with its local bog iron ores. Researchers have also discovered iron weapons from this period that were imported from the Celtic territories (the finds from Legionowo, Kraszewo, Kamieńczyk, Dobrzankowo, Oblin, Łęgonice Małe and Dzierżążnia Nowa). These objects, stylistically and structurally, are identical to objects made in the Western Celtic territories (e.g. the finds from the Celtic sanctuary in Gournay-sur-Aronde). For this reason, it is essential to conduct the latest physico-chemical testing methods on objects from the Western *Barbaricum* region as well as the Celtic territories. Such testing would allow an examination of intercultural relations with respect to iron weapons. It

is worth emphasizing that this research will be the first wide-scale interdisciplinary exploration of this type involving objects found in the Western *Barbaricum* region as well as the Celtic territories. Through this research, it will be possible to confirm that objects found in the areas inhabited by the Przeworsk culture are potential imports and will simultaneously provide a new perspective on intercultural relations in Europe. Moreover, it will allow further assessment on the significance of the La Tène culture in shaping the Przeworsk culture.

A prehistoric burial ground of the Przeworsk culture dated between the 1st century BC and 2nd century AD was evacuated near Legionowo. This paper is the first part of our work, being concerned only with iron artefacts from the collection of the Historical Museum at Legionowo.

Samples for analysis were collected from 27 iron artefacts. Table 1 includes a description of the collected samples.

Trace and major elements in the iron objects were analysed by instrumental neutron activation analysis (INAA) without chemical separation, using standards of the analysed elements. The samples were packed together with standards of the following elements: Na, K, Sc, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Zr, Mo, Ru, Ag, Cd, Sn, Sb, Te, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Tb, Dy, Ho, Er, Yb, Lu, Hf, Ta, W, Ir, Au, Hg, Th and ²³⁸U. Also attached were Au and Sc standards evaporated onto a piece of aluminium foil and a sample of the CTA-FFA-1 standard (Institute of Nuclear Chemistry and Technology, INCT).

Table 1. Description of the investigated Przeworsk culture iron artefacts from the collection of the Historical Museum at Legionowo.

Number of sample	Description of iron items	Catalogue number	Number of sample	Description of iron items	Catalogue number
P.1	iron arrow-head.1	w.325/2009	P.15	iron umbo-2	
P.2	iron arrow-head.2	w.325/2009	P.16	iron arrow-head.1	w.346/2009
P.3	iron sword.1	w.324/2009	P.17	iron arrow-head.2	w.346/2009
P.4	iron sword.2	w.324/2009	P.18	iron penknife	w.446/2009
P.5	iron sword.1	w.342/2009	P.19	iron arrow-head.1	
P.6	iron sword.2	w.342/2009	P.20	iron arrow-head.2	
P.7	iron ring-1		P.21	iron arrow-head.1	w.519/2009
P.8	iron ring-2		P.22	iron arrow-head.2	w.519/2009
P.9	iron ring-3		P.23	iron sword.1	w.658/2009
P.10	iron ring-4		P.24	iron sword.2	w.658/2009
P.11	iron ring-5		P.25	iron sword-pin pivot	w.212/35
P.12	iron ring-6		P.26	iron sword-pommel	w.212/35
P.13	iron buckle	w.343	P.28	iron object 'wolf gun'	w.189/2009
P.14	iron umbo-1				

They played the role of the thermal neutron flux monitor [1].

Irradiation of the samples was carried out in the MARIA reactor in Świerk, in a channel with $8 \cdot 10^{13}$ n/cm² s thermal neutron flux. The irradiation time was 2 h with a subsequent 8-hour cooling. The irradiated samples were then unpacked; they were washed in 1 M hydrochloric acid solution and rinsed in alcohol to remove surface contamination.

Measurements of the activity of samples and standards prepared in such a way were carried out using an HP germanium detector with an active volume of 80 cm³ and an energy resolving power of 1.95 keV for a 1333 keV ⁶⁰Co source. The analysis of the complex gamma radiation spectra was carried out using Genie 2000 software. The measurements were repeated six times within three months after irradiation, while the measurement times varied between 300 and 10,000 s.

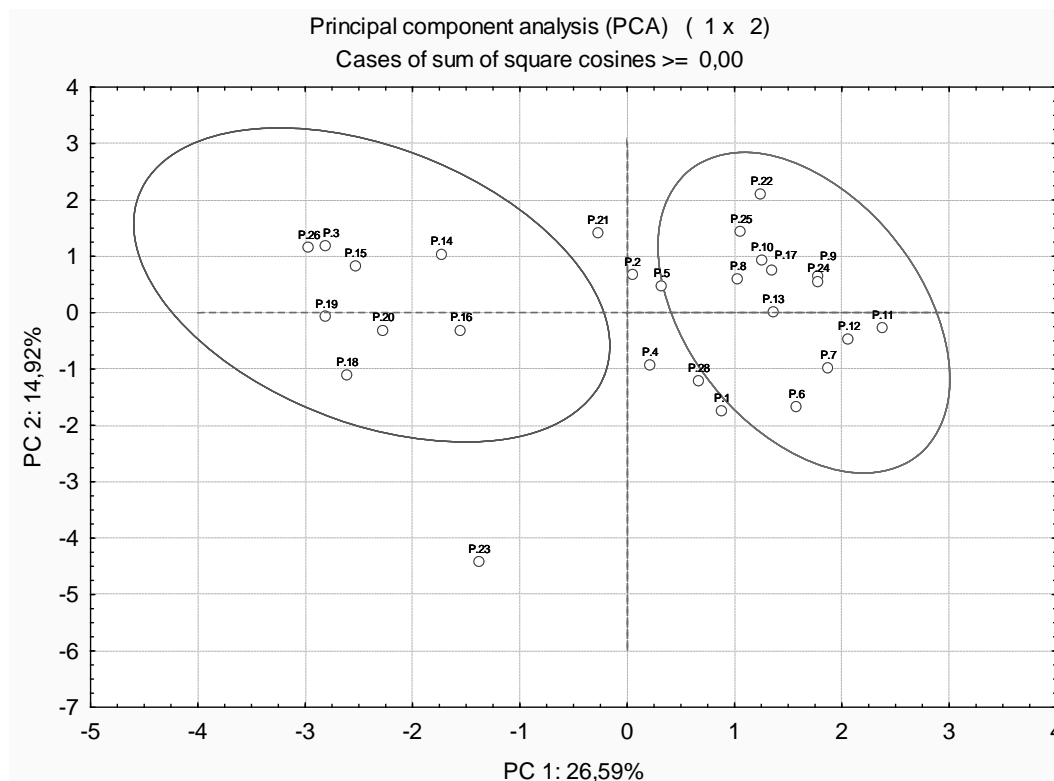


Fig. 1. Principal component analysis of 27 Przeworsk culture iron artefacts from the collection of the Historical Museum at Legionowo carried out on a set defined by 13 variables (Co, Cr, Cu, Eu, La, Mn, Ni, Th, U, Sb, Sm, Zn and Ta). Ellipses are defined by Gaussian distribution, confidence level 0.95.

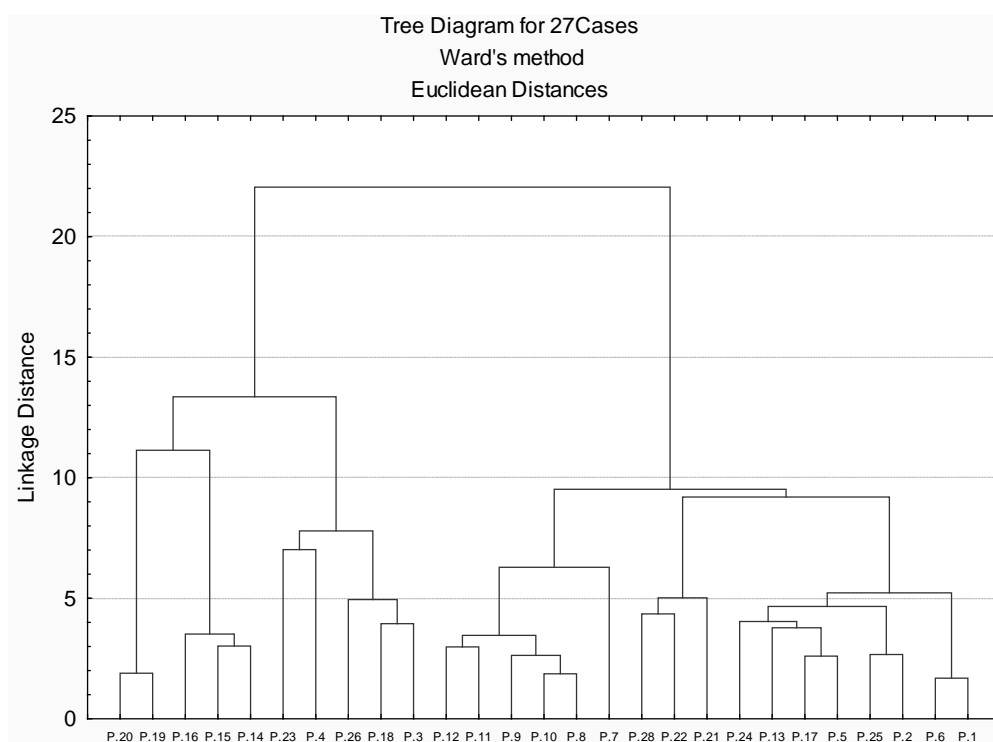


Fig. 2. Cluster analysis of 27 Przeworsk culture iron artefacts from the collection of the Historical Museum at Legionowo describing 13 features (number of features was determined by INAA elements: Co, Cr, Cu, Eu, La, Mn, Ni, Th, U, Sb, Sm, Zn and Ta); standardized and logarithmic variables.

47 elements were identified and determined in the analysed samples. Out of the 47 determined elements, only the elements characteristic for tested samples (Co, Cr, Cu, Eu, La, Mn, Ni, U Th, Sb, Sm, Zn and Ta) were selected for multi-parameter statistical analysis aimed at identifying the degree of similarity of the analysed samples.

Principal component analysis (PCA) and cluster analysis were carried out with the use of STATISTICA (StatSoft) software [2] to identify the degree of similarity of the analysed objects. These multivariate analyses were performed for standardized and logarithmic variables. The results of principal component analysis are presented in Fig. 1, which clearly shows a division into groups closely related to the origin of the tested samples.

The output dendrogram of the cluster analysis is shown in Fig. 2, where the division between the two groups is very similar to the results from the PCA. Such a division suggests that the studied

iron artefacts belonging to these defined groups originated from different sources.

The present study confirms the effectiveness of combined analyses of major and trace elements to characterize iron artefacts.

Our work illustrates the usefulness of multivariate statistical analyses in approaching a problem of this type. The obtained data show that it is not easy to completely and correctly identify or reproduce the materials used in the past and their deterioration processes.

References

- [1]. Pańczyk, E. (2011). *Conservation of paintings. In Nuclear techniques for cultural heritage research* (pp. 17-40). Vienna: IAEA. IAEA Radiation Technology Series No. 2.
- [2]. Stanisław, A. (2007). *Przystępny kurs statystyki z zastosowaniem STATISTICA PL na przykładach z medycyny. Analizy wielowymiarowe*. Kraków: StatSoft.

ANALYSIS OF HISTORIC GLASS USING MICROSAMPLING TECHNIQUES: LA-ICP-MS AND EPMA

Ela Bakowska^{1/}, Stephen Kuenzli^{1/}, Jerzy J. Kunicki-Goldfinger^{2/}, Jared W. Singer^{3/}, Piotr Dzierżanowski^{4/}

^{1/} Corning Research and Development Corporation, Corning, N.Y., USA

^{2/} Institute of Nuclear Chemistry and Technology, Warszawa, Poland

^{3/} Rensselaer Polytechnic Institute, Troy, N.Y., USA

^{4/} Electron Microprobe Laboratory, Faculty of Geology, University of Warsaw, Warszawa, Poland

Historical glass constitutes a part of our material cultural inheritance and can be considered as an important witness of various human activities,

such as trade, economy, culture or even politics. However, our understanding of glass as a material is still severely limited. The main objective of the

project is to determine the provenance of various central European glass vessels dated to the mid-late 17th and 18th centuries. Differences between the compositions of glasses made in different locations are to be anticipated.

153 samples were taken from the selected glass vessels of interest. Most of them were goblets of various forms, made of colourless glass. With a few exceptions, they belonged to the Polish museums' collections. All the samples had already been analysed by the use of electron probe microanalysis (EPMA). Analyses by wavelength dispersive spectrometry in an EPMA system were carried out using a Cameca SX-100 with three simultaneously working spectrometers (PET, LiF, TAP crystals and PC2 for boron) at the Electron Microprobe Laboratory, Faculty of Geology, University of Warsaw, Poland. Corning Museum of Glass reference glasses "A", "B", "C" and "D"; NIST SRMs 610 and 612; as well as CRMs CZ4001, CZ4002 and CZ4003 from the Czech Metrology Institute were used for calibration and/or as controls. All the samples and standards were embedded in resin blocks of 25 mm diameter.

Many recent papers have shown that trace element analysis is even more effective in discriminating between the types and sources of some raw materials [1-2]. For this goal, inductively coupled plasma mass spectrometry with sampling using laser ablation (LA-ICP-MS) was used. The technique is a relatively new tool in glass archaeometry; however, it is of very high importance in such studies [1-2]. The method offers direct micro-sampling and fast multi-elemental capabilities (including Li and B) and is used for the accurate and precise determination of minor and trace elements with very low detection limits down to ng/L [2-6].

In the present study, a subset of these samples was analysed quantitatively, utilizing two LA-ICP-MS systems:

- LSX-213 G2+ Nd:YAG laser at 213 nm (Teledyne/CETAC/Photon Machines, Chromium 2.2b Software, HelEx sample cell) with aurora Elite ICP-MS (Bruker/Aanalytik Jena, Quantum v3.2b1633 software) at the Corning Research and Development Corporation, Sullivan Park campus, Corning, N.Y., USA;
- Analyte G2 excimer laser at 193 nm (Teledyne/CETAC/Photon Machines, Chromium V2011.3.31 Software), laminar-flow "Frames" cell, with Varian 820 ICP-MS (Varian/Aanalytik Jena) at the Rensselaer Polytechnic Institute, Troy, N.Y., USA.

We reused the samples prepared for the EPMA analysis. A narrow laser beam was used for the sampling of a small amount of substance from the surface. This technique is increasingly being used in the direct analysis of solid samples.

The lack of suitable matrix-matched glass samples is still recognized as an important limitation of LA-ICP-MS in data interpretation. The LA-ICP-MS testing of the same glass samples and standards was carried out at both facilities with similar lasing parameters (with the obvious exception of the wavelength). The effects of time resolved analysis (TRA) with either ablation spot or line scan were evaluated and compared with the results from EPMA testing as well as literature data, when applicable.

Data processing was carried out utilizing Quantum software as well as Iolite software's "X_Trace_Elements_IS" data reduction scheme (version 3.5, Iolite Software).

References

- [1]. Cagno, S., Mendera, M., Jeffries, T., & Janssens, K. (2010). Raw materials for medieval to post-medieval Tuscan glassmaking: new insight from LA-ICP-MS analyses. *J. Archaeol. Sci.*, 37, 3030-3036.
- [2]. Gratuze, B. (2017). Glass characterization using laser ablation-inductively coupled plasma-mass spectrometry methods. In L. Dussubieux, M. Golitko, B. Gratuze (Eds.), *Recent advances in laser ablation ICP-MS for archaeology* (pp. 179-196). Berlin Heidelberg: Springer-Verlag.
- [3]. Brill, R.H. (1999). *Chemical analyses of early glasses. Volume 2*. Corning, N.Y.: The Corning Museum of Glass.
- [4]. Wagner, B., Nowak, A., Bulska, E., Hametner, K., & Günther, D. (2012). Critical assessment of the elemental composition of Corning archeological reference glasses by LA-ICP-MS. *Anal. Bioanal. Chem.*, 402(4), 1667-1677.
- [5]. Latkoczy, C., Becker, S., Dücking, M., Günther, D., Hoogewerff, J.A., Almirall, J.R., Buscaglia, J., Dobney, A., Koons, R.D., Montero, S., van der Peijl, G.J., Stoecklein, W.R., Trejos, T., Watling, J.R., & Zdanowicz, V.S. (2005). Development and evaluation of a standard method for the quantitative determination of elements in float glass samples by LA-ICP-MS. *J. Forensic Sci.*, 50(6), 1327-41.
- [6]. ASTM International. (2013). *Standard test method for determination of trace elements in soda-lime glass samples using laser ablation inductively coupled plasma mass spectrometry for forensic comparisons*. ASTM E2927-13.

POLLUTION CONTROL TECHNOLOGIES LABORATORY

The research activities of the Pollution Control Technologies Laboratory concern the concepts and methods of process engineering applicable to the environmental area. In particular, we participate in research on the application of electron accelerators to such environmental technologies as flue gas and water treatment, wastewater purification, the processing of various types of industrial waste, *etc.*

The main aims of the Laboratory's activity are:

- development of new processes and technologies of environmental engineering,
- development of environmental applications of radiation technologies,
- promotion of nuclear methods in the field of environmental applications.

The activities of our group cover both basic and applied research. Among others, the most important research fields are:

- development of electron beam flue gas treatment (EBFGT) technology,
- support for the industrial implementation of the EBFGT process,
- investigation of chemical reaction mechanisms and kinetics in gas phases and aqueous solutions irradiated by electron beams,
- study of the mechanism of removal of volatile organic compounds (VOCs) and other pollutants from flue gas by electron beam irradiation,
- process modelling.

The Laboratory is equipped with research tools such as:

- a laboratory installation for electron beam flue gas treatment;
- Model 40 UV pulsed fluorescent SO₂ analysers and Model 10 A/R chemiluminescent NO/NO_x analysers with molybdenum converters, manufactured by Thermo Electron Corporation (USA);
- GC-17A gas chromatograph with a GCMS-QP5050 mass spectrometer, manufactured by Shimadzu Corporation (Japan);
- Lancom II portable gas analyser type, manufactured by Land Combustion (UK) (NO_x, SO₂, CO, O₂, *etc.*).

The Laboratory is open for any form of cooperation. In particular, we offer such activities as:

- laboratory research on environmental applications of electron accelerators,
- theoretical modelling of chemical processes under electron beam irradiation,
- concept design of electron beam technology implementation,
- process equipment design with the use of CFD methods.

In recent years, the Laboratory cooperated with such institutions as:

- Faculty of Chemical and Process Engineering, Warsaw University of Technology (Poland);
- International Atomic Energy Agency;
- Saudi ARAMCO (Saudi Arabia);
- EB Tech Co., Ltd. (Republic of Korea);
- Technology Centre of Western Pomerania (Germany);
- Leibniz Institute for Plasma Science and Technology (Germany);
- Risø National Laboratory for Sustainable Energy, Technical University of Denmark (Denmark);
- Uppsala University, The Ångström Laboratory (Sweden);
- Kaunas University of Technology (Lithuania);
- Vilnius Gediminas Technical University (Lithuania);
- Robert Szwedowski Institute of Fluid-Flow Machinery, Polish Academy of Sciences (Poland);
- West Pomeranian University of Technology (Poland);

- National Centre for Nuclear Research, Otwock-Świerk (Poland);
- Ukrainian Engineering Pedagogics Academy (Ukraine);
- Tsinghua University (China);
- Xi'an Jiaotong University (China);
- Joint Institute for Power and Nuclear Research – Sosny, National Academy of Sciences of Belarus (Belarus);
- University of Palermo (Italy);
- Institute for Polymers, Composites and Biomaterials (IPCB), National Research Council (CNR) (Italy);
- Hacettepe University (Turkey);
- Institute of Macromolecular Chemistry “Petru Poni” Iasi (Romania);
- University of Reims Champagne-Ardenne (France);
- University Politehnica of Bucharest (Romania);
- Texas A&M AgriLife, Texas A&M University (USA).

NUMERICAL SIMULATION OF NO_x REDUCTION IN AQUEOUS SOLUTION

Yongxia Sun, Andrzej Dobrowolski, Otton Roubinek, Ewa Zwolińska, Andrzej Pawelec,
Andrzej G. Chmielewski

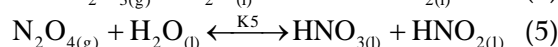
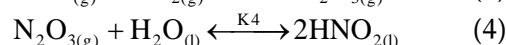
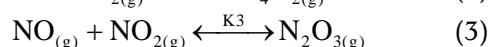
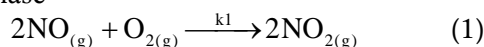
In the process of burning high-sulphur fuels in marine diesel engines used in transoceanic ships, high concentrations of NO_x and SO₂ are emitted to the atmosphere, which significantly exceed the emission limits of both pollutants. Therefore, the application of emission control methods is necessary.

A new hybrid method of SO₂ and NO_x removal from flue gases designed for application in marine conditions was elaborated at the Institute of Nuclear Chemistry and Technology (INCT). The removal of SO₂ and NO_x from flue gases takes place in two stages: in the first stage the gases are irradiated by an electron beam from an accelerator, while in the second stage the off-gas after irradiation is absorbed in a water scrubber.

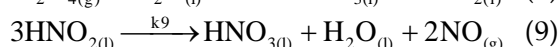
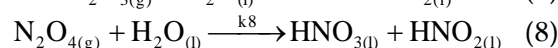
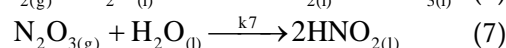
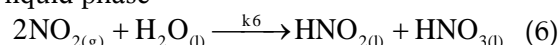
The results of preliminary laboratory research with the use of a 0.6 dm³ scrubber to treat a gas stream with a volumetric flow rate of 150 dm³/h showed high removal efficiency of SO₂ and NO_x. However, the research showed that NO_x removal efficiency strongly depends on the irradiation dose and initial NO_x concentration. As the radiation-induced process had been modelled elsewhere [1], a mathematical model of NO_x removal in the water absorption process was constructed to enable analysis of the process mechanism.

The following reactions in the gas and liquid phases were considered [2]:

• gas phase



• liquid phase



The chemical reaction rates are as given by Loutet *et al.* [2]: $k_1 = 0.0102 \text{ m}^6 \text{ kmol}^{-2} \text{ s}^{-1}$, $k_2 = 10^9 \text{ m}^3 \text{ kmol}^{-1} \text{ s}^{-1}$, $k_3 = 10^9 \text{ m}^3 \text{ kmol}^{-1} \text{ s}^{-1}$, $k_4 = 41,000 \text{ m}^3 \text{ kmol}^{-1} \text{ s}^{-1}$, $k_5 = 250 \text{ m}^3 \text{ kmol}^{-1} \text{ s}^{-1}$, $k_6 = 46,999 \text{ m}^3 \text{ kmol}^{-1} \text{ s}^{-1}$, $k_7 = 17,000 \text{ s}^{-1}$, $k_8 = 93.32 \text{ s}^{-1}$, $k_9 = 0.0468 \text{ atm}^2 \text{ m}^9 \text{ kmol}^{-3} \text{ s}^{-1}$, $k_2' = k_2 \cdot K_2^{-1}$, $K_2 = 0.439 \text{ m}^3 \text{ kmol}^{-1}$, $k_3' = k_3 \cdot K_3^{-1}$, $K_3 = 13,699 \text{ m}^3 \text{ kmol}^{-1}$, $k_4' = k_4 \cdot K_4^{-1}$, $K_4 = 0.2763$, $k_5' = k_5 \cdot K_5^{-1}$, $K_5 = 0.00002191$. For the gas phase the temperature was assumed to be 90°C, while for the liquid phase the temperature was assumed to be 15°C.

The absorption kinetics were described by Eq. (10):

$$r_i = k_L a \cdot (p_i - p_i^*) \quad (10)$$

where: $i = \text{NO}, \text{NO}_2, \text{N}_2\text{O}_3$ or N_2O_4 ; $k_L a$ – the mass transfer coefficient [s^{-1}], in this work the value of $k_L a$ was set as 0.01 s^{-1} [3]; p_i – the partial pressure of component i in the bulk; and p_i^* – the interface pressure of component i in the liquid.

The system of ordinary differential equations, being the mathematical model of the considered process, was solved with the use of the Runge-Kutta procedure in the MATLAB programming language. Simulations were carried out for the following concentrations:

- initial NO concentrations: 200, 500, 1000 and 1271 ppmv;
- NO₂ concentrations: 0, 20 and 50 ppmv.

The following irradiation doses were considered: 3.5, 10.9 and 44.1 kGy. The concentrations of NO and NO₂ at the scrubber inlet were taken from the literature [1, 4]. The calculated results for the NO and NO₂ concentrations are shown in Table 1. The efficiency of NO_x removal in the electron beam process (without absorption) and in the hybrid electron beam process (with absorption) is shown in Table 2.

The obtained modelling results show that application of the hybrid electron beam process in comparison to the electron beam process is the most profitable method for moderate doses of irradiation and high inlet concentration of NO_x. These results make the hybrid electron beam process at-

Table 1. NO and NO₂ concentrations in the hybrid electron beam process.

No.	Dose [kGy]	NO initial concentration [ppmv]	NO ₂ initial concentration [ppmv]	NO at scrubber inlet [ppmv]	NO ₂ at scrubber inlet [ppmv]	NO at scrubber outlet [ppmv]	NO ₂ at scrubber outlet [ppmv]
1	3.5	200.0	0.0	163.0	19.0	161.1	15.1
2	3.5	1000.0	0.0	902.0	78.0	872.2	41.4
3	10.9	1271.0	52.0	940.0	318.0	822.8	204.5
4	10.9	500.0	20.0	200.0	120.0	186.0	107.0
5	44.1	200.0	0.0	82.0	8.0	81.6	6.9
6	44.1	1000.0	0.0	621.0	89.0	594.6	56.0

Table 2. Efficiency of NO_x removal in the electron beam process and hybrid electron beam process.

No.	Efficiency of NO _x removal in the electron beam process [%]	Efficiency of NO _x removal in the hybrid electron beam process [%]
1	9.0	11.9
2	2.0	8.7
3	4.9	22.4
4	38.5	43.7
5	55.0	55.8
6	29.0	34.9

tractive for potential practical application in marine flue gas treatment.

References

- [1]. Zwolińska, E. (2017). *The removal of NO_x and SO₂ from exhaust gases using hybrid electron beam method*. Unpublished doctoral dissertation. Institute of Nuclear Chemistry and Technology, Warszawa, Poland.
- [2]. Loutet, K.G., Mahecha-Botero, A., Boyd, T., Buchi, S., Reid, D., & Brereton, C.M.H. (2011). Experimental measurements and mass transfer/reaction modeling for an industrial NO_x absorption process. *Ind. Eng. Chem. Res.*, 50(4), 2192-2203.
- [3]. Painmanakul, P., Wachirasak, J., Jamnongwong, M., & Hébrard, G. (2009). Theoretical prediction of volumetric mass transfer coefficient ($k_L a$) for designing an aeration tank. *Eng. J.*, 13(3), 13-28.
- [4]. Chmielewski, A.G., Sun, Y., Zimek, Z., Bulka, S., & Licki, J. (2002). Mechanism of NO_x removal by electron beam process in the presence of scavengers. *Radiat. Phys. Chem.*, 65(4-5), 397-403.

STABLE ISOTOPE LABORATORY

Basic activities of the Stable Isotope Laboratory concern the techniques and methods of stable isotope measurements (H, C, N, O, S) by the use of an isotope ratio mass spectrometer (IRMS). Our activity area also concerns the application of IRMS to the environmental area, including determination of the stable isotope composition of hydrogeological, environmental, and food samples.

The main aims of the activity of the Laboratory are:

- preparation and measurement of the stable isotope composition of food and environmental samples;
- establishing new areas of the application of stable isotope compositions for food authenticity control, environmental protection, and origin identification.

The Laboratory is equipped with the following instruments:

- mass spectrometer – DELTA^{plus} (FinniganMAT, Germany);
- elemental analyser Flash 1112NC (ThermoFinnigan, Italy);
- GasBench II (ThermoQuest, Germany);
- H/Device (ThermoQuest, Germany);
- gas chromatograph (Shimadzu, Japan);
- gas chromatograph with a mass spectrometer (Shimadzu, Japan);
- liquid scintillation counter (for ¹⁴C and tritium environmental samples) 1414-003 Guardian (Wallac-Oy, Finland);
- freeze dryer Alpha 1-2 LD plus (Christ, Germany).

The Laboratory research staff is involved in the following projects:

- “The study of the influence of the environmental factors on the isotopic compositions of dairy products”,
- accreditation process (isotopic method for food authenticity control),
- interlaboratory proficiency test FIT-PTS (food analysis using isotopic techniques – proficiency testing scheme).

The Stable Isotope Laboratory is open for any form of cooperation. We are prepared to undertake any research and development task within the scope of our activity. In particular, we offer our measurement experience, precision, and proficiency in the field of stable isotope composition to aid the research of others. In addition, we are open to perform any service regarding the control of food authenticity by stable isotope methods supported by gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS) methods.

Our Laboratory cooperates with the following national partners:

- Agricultural and Food Quality Inspection,
- Polish Association of Juice Producers,
- customs inspections,
- food export-import company,
- food control laboratories,
- private customers

and foreign partners:

- Eurofins Scientific Analytics (France),
- International Atomic Energy Agency (IAEA),
- Joint Research Centre (Ispra, Italy).



ISOTOPIC AND TRACE ELEMENT COMPOSITION FOR DAIRY PRODUCTS' AUTHENTICITY CONTROL

Ryszard Wierzchnicki, Renata Adamska, Zbigniew Samczyński

The different compositions of cow fodder (natural and processed) and drinking water (tap water) are reasons for the seasonal and regional variation of

materials an elemental analyser coupled with a mass spectrometer was used. The measurements of trace element composition (Fig. 3) were performed

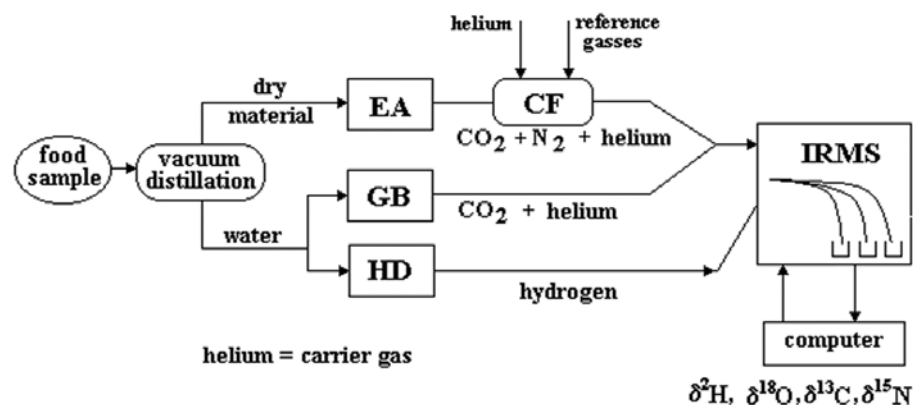


Fig. 1. Sample preparation and measurement by the use of the IRMS technique: EA – elemental analyser, GB – GasBench II, HD – H/Device, CF – ConFlo III, IRMS – isotope ratio mass spectrometer DELTA^{plus}.

the isotopic and trace element composition of fresh milk and, finally, dairy products. The stable isotopic composition of food is strictly related to environmental conditions, such as climate, geographical region and season.

The aim of this study was to demonstrate the regional and seasonal variations of the isotopic and trace element composition of milk. Samples of fresh and commercial milk were obtained from the main regions of milk production in Poland and measured using an isotope ratio mass spectrometer. The measurement of the stable isotope composition (carbon, hydrogen, oxygen, nitrogen and sulphur) of food is a very sensitive method for controlling its origin and authenticity [1-5].

Isotope ratio mass spectrometry (IRMS) is the main method used for the measurement of the stable isotopic content of food and beverages (Fig. 1). A DELTA^{plus} mass spectrometer connected with an H/Device instrument was used to determine the hydrogen isotope ratio. The oxygen isotope ratio was determined in water samples with the use of a GasBench instrument connected with a mass spectrometer. For the determination of carbon, nitrogen (Fig. 2) and sulphur in solid

using inductively coupled plasma mass spectrometry (ICP-MS) for a limited number of dairy products.

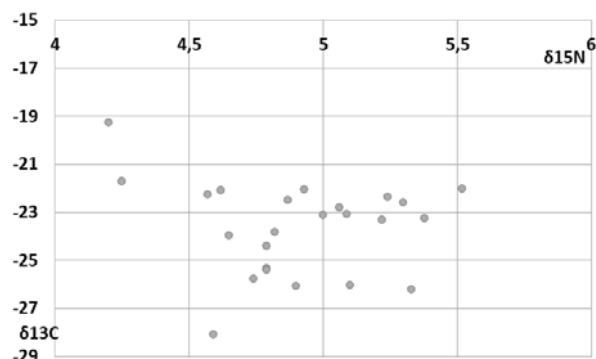


Fig. 2. Carbon ¹³C and nitrogen ¹⁵N isotopic composition of defatted milk.

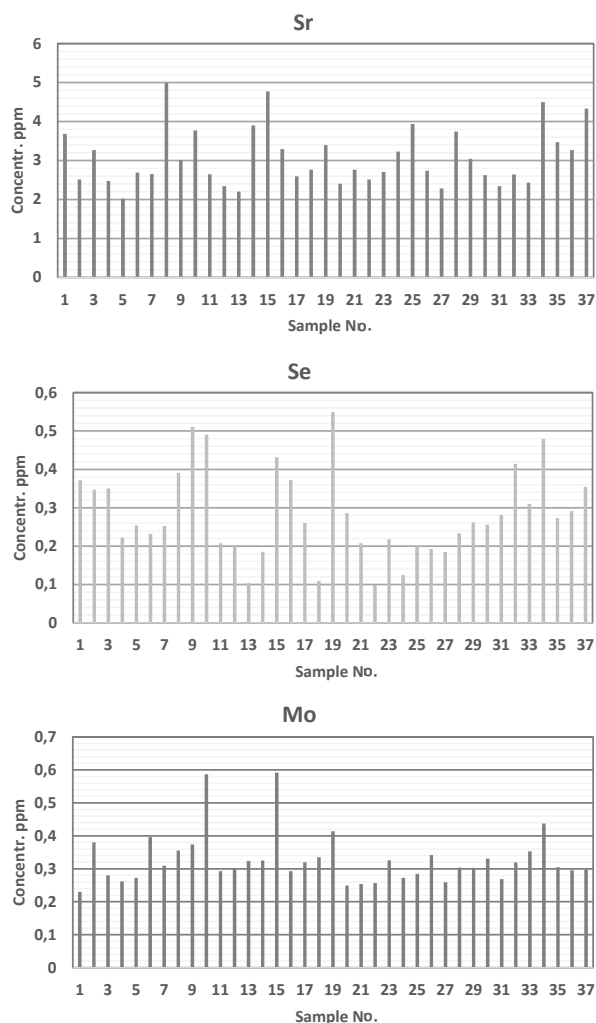


Fig. 3. Concentration of trace elements Sr, Se and Mo in defatted milk.

Finally, application of the multi-element (isotopic and trace element composition) method for the origin control of dairy products requires testing more samples of such products, from both organic and conventional farms. After the construction of a large database of isotopes and trace elements, the method could be used as a standard to control the origin and authenticity of dairy products.

This work was supported by the Polish Ministry of Science and Higher Education under grant W79/FAO/IEAE/2016.

References

- [1]. Knobbe, N., Vogl, J., Pritzkow, W., Panne, U., Fry, H., Lochotzke, H. M., & Preiss-Weigert, A. (2006). C and N stable isotope variation in urine and milk of cattle depending on the diet. *Anal. Bioanal. Chem.*, 386, 104-108.
- [2]. Camin, F., Wehrens, R., Bertoldi, D., Bontempo, L., Ziller, L., Perini, M., Nicolini, G., Nocetti, M., & Larcher, R. (2012). H, C, N and S stable isotopes and mineral profiles to objectively guarantee the authenticity of grated hard cheeses. *Anal. Chim. Acta*, 711, 54-59.
- [3]. Renou, J.-P., Deponge, C., Gachon, P., Bonnefoy, J.-C., Coulon, J.-B., Garel, J.-P., Vérité, R., & Ritz, P. (2004). Characterization of animal products according to geographic origin and feeding diet using nuclear magnetic resonance and isotope ratio mass spectrometry: cow milk. *Food Chem.*, 85, 63-66.
- [4]. Camin, F., Perini, M., Colombari, G., Bontempo, L., & Versini, G. (2008). Influence of dietary composition on the carbon, nitrogen, oxygen and hydrogen stable isotope ratios of milk. *Rapid Commun. Mass Spectrom.*, 22, 1690-1696.
- [5]. Scampicchio, M., Mimmo, T., Capici, C., Huck, C., Innocente, N., Drusch, S., & Cesco, S. (2012). Identification of the origin and process induced changes in milk by stable isotope ratio mass spectrometry. *J. Agric. Food Chem.*, 60, 11268-11273.

ISOTOPIC STUDY OF APPLE DRINKS

Ryszard Wierchnicki, Renata Adamska

Stable isotope analyses have been useful tool for food authenticity control. An important limitation of applying the isotopic method for food authenticity control is a lack of a database comprising the stable isotope compositions of different origin foods. For many years, the Stable Isotope Laboratory of the Institute of Nuclear Chemistry and Technology (INCT) has carried out studies on the isotopic composition of food for elaboration and implementation in new isotope ratio mass spectrometry (IRMS) methods, and also creates a database of isotopic composition of chosen food from the Polish market. Our recent studies concerned the intramolecular isotopic distribution pattern between the components of ciders.

Cider is one of the popular drinks produced by apple juice fermentation (Table 1). The main chemical components of cider are: water, ethanol, sugars, flavours and CO₂. The subject of the study is determination of the stable isotope composition of water, ethanol and CO₂ included in ciders. Accordingly, the study aim is to investigate the stable isotope compositions of these components, as well as identifying their source, in an effort to control the authenticity of the drinks [1-8].

The addition of sugar to the production of ciders is allowed in some countries but forbidden in

the others (e.g. France). During the fermentation of sugars in juice, ethanol and CO₂ are produced. The addition of beet sugar (C₃ plants – Calvin cycle) or cane sugar and corn syrup (C₄ plants – Hatch-Slack pathway) results in different isotopic

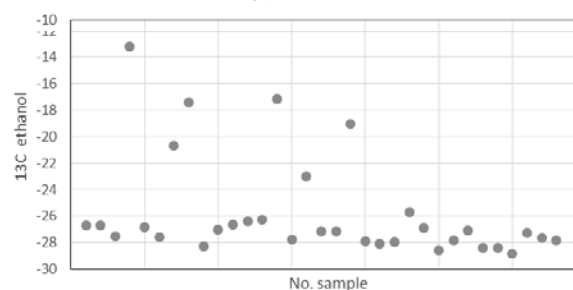


Fig. 1. The measured $\delta^{13}\text{C}$ values of ethanol for tested ciders.

composition of CO₂ and ethanol (Fig. 1). Artificial carbonating ciders, typically using CO₂ from an industrial source, result in a $\delta^{13}\text{C}$ value of CO₂ lower than -40‰ (Fig. 2).

Our method is to look for the range of values of the isotopic composition for authentic ciders. In the study, the stable isotope method for measurement of ethanol and CO₂ bubbles (natural or exogenous carbonation) will be elaborated to control the quality of ciders and their compliance

Table 1. Names of popular apple drinks and concentration of alcohol.

Apple drink	Alcohol [vol%]	Polish market	French market	English market	German market
Juice	0	sok jabłkowy	pomme jus	apple juice	apfelsaft
Cider	1.3-8.0	cydr	cidre	cider	cidre
“Wine”	9-18	“wino jabłkowe”	cidre	cider	apfelwein
Liqueur	18-35	nalewka, likier jabłkowy	eau-de-vie de pommes	apple liqueur	Apfelkorn
Vodka	35-45	wódka jabłkowa	calvados (only region Calvados)	applejack (apple brandy)	Obstwasser

Table 2. Analytical methods used for control of cider (apple drinks) authenticity.

Parameter	Component	Composition	Method
$\delta^{13}\text{C}$	ethanol, CO_2	$^{13}\text{C}/^{12}\text{C}$	IRMS
$\delta^{18}\text{O}$	water	$^{18}\text{O}/^{16}\text{O}$	IRMS
$\delta^{18}\text{O}$	solid residue	$^{18}\text{O}/^{16}\text{O}$	IRMS
$\delta^{87}\text{Sr}$	solid residue	$^{87}\text{Sr}/^{86}\text{Sr}$	MC-ICP-MS, TIMS
Elements	solid residue	trace elements	ICP-MS
Sugars	solid residue	fructose, glucose, sucrose	HPLC

with labelling (authenticity). The basic problem surrounding CO_2 is: Is the CO_2 gas in ciders from a natural source (natural fermentation) or from an industrial (technical) source? For control of cider authenticity, the basic information is the compliance oxygen isotopic composition in cider (water) with the corresponding composition for apple juices from the same geographical region.

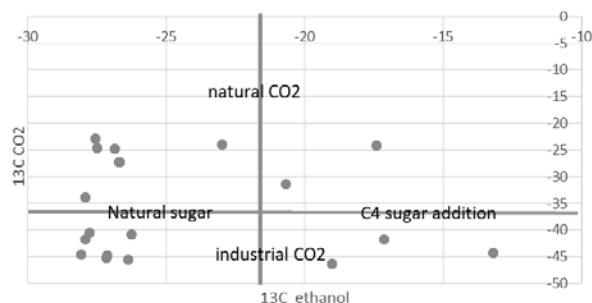


Fig. 2. The measured $\delta^{13}\text{C}$ values of ethanol vs. $\delta^{13}\text{C}$ of CO_2 for the Polish commercial ciders.

Samples of 34 commercial ciders were purchased from the Polish market. We examined their isotopic composition using IRMS methods. Specially, our study concerned the isotopic composition of: carbon $\delta^{13}\text{C}$ in ethanol, oxygen $\delta^{18}\text{O}$ in water and carbon $\delta^{13}\text{C}$ in CO_2 .

The isotopic composition of $\delta^{13}\text{C}$ in CO_2 and ethanol is finally expressed by the following equation:

$$\delta^{13}\text{C}_{\text{vsPDB}} = \frac{\left[\frac{^{13}\text{C}}{^{12}\text{C}} \right]_{\text{SAMPLE}} - \left[\frac{^{13}\text{C}}{^{12}\text{C}} \right]_{\text{STANDARD}}}{\left[\frac{^{13}\text{C}}{^{12}\text{C}} \right]_{\text{STANDARD}}} \cdot 1000\text{‰}$$

The examples of measured isotopic composition values of cider components are presented in Figs. 1 and 2.

The isotopic compositions of water and CO_2 were determined using GasBench (ThermoQuest, Germany) connected in the continuous flow mode to a DELTA^{plus} (FinniganMat, Germany) mass spectrometer. The isotopic composition of ethanol was measured using the same mass spectrometer with the elemental analyser Flash EA1112 (ThermoQuest, Italy). Every sample was measured six times for both the carbon and oxygen isotopic composition. The standard deviation of the values obtained from measurements was 0.2‰ for $\delta^{13}\text{C}$ (ethanol and CO_2) and 0.15‰ for $\delta^{18}\text{O}$ (water).

In conclusion, the work will be continued to characterize components from the bigger population of commercial products (ciders). The main result of the studies will be the formation of a database containing the compositions (Table 2) for all the basic components of apple drinks from different origins. By utilizing the database, employing the methods for the origin control of drinks can be implemented in everyday practice. It will still be necessary to test the sensitivity of the method for each component of apple drinks. Finally, on the basis of the study, the correlations between components of apple drinks will be elaborated.

References

- [1]. Gonzalez-Martin, I., Gonzalez-Perez, C., & Marques-Macias, E. (1997). Contribution to the study of the origin of CO_2 in Spanish sparkling wines by determination of the $^{13}\text{C}/^{12}\text{C}$ isotope ratio. *J. Agric. Food Chem.*, 45, 1149-1151.
- [2]. Gaillard, L., Guyon, F., Salagoity, M.-H., & Medina, B. (2013). Authenticity of carbon dioxide bubbles in French ciders through multiflow-isotope ratio mass spectrometry measurements. *Food Chem.*, 141, 2103-2107.
- [3]. Martinelli, L.A., Moreira, M.Z., Ometto, J.P.H.B., Alcarde, A.R., Rizzon, L.A., Stange, E., & Ehleringer, J.R. (2003). Stable carbon isotopic composition of the wine and CO_2 bubbles of sparkling wines: Detecting C4 Sugar additions. *J. Agric. Food Chem.*, 51, 2625-2631.
- [4]. Cabañero, A.I., San-Hipólito, T., & Rupérez, M. (2007). GasBench/isotope ratio mass spectrometry: a carbon isotope approach to detect exogenous CO_2 in sparkling drinks. *Rapid Commun. Mass Spectrom.*, 21(20), 3323-3328.
- [5]. Carter, J.F., Yates, H.S.A., & Tinngi, U. (2015). Stable isotope and chemical compositions of European and Australasian ciders as a guide to authenticity. *J. Agric. Food Chem.*, 63, 975-982.
- [6]. García-Ruiz, S., Moldovan, M., Fortunato, G., Wunderli, S., & García Alonso, J.I. (2007). Evaluation of strontium isotope abundance ratios in combination with multi-elemental analysis as a possible tool to study the geographical origin of ciders. *Anal. Chim. Acta*, 590, 55-66.
- [7]. Calderone, G., Guillou, C., Reniero, F., & Nautet, N. (2007). Helping to authenticate sparkling drinks with $^{13}\text{C}/^{12}\text{C}$ of CO_2 by gas chromatography-isotope ratio mass spectrometry. *Food Res. Int.*, 40, 3, 324-331.
- [8]. Bizjak Bat, K., Eler, K., Mazej, D., Mozetič Vodopivec, B., & Ogrinc, N. (2016). Isotopic and elemental characterisation of Slovenian apple juice according to geographical origin: Preliminary results. *Food Chem.*, 203, 86-94.

LABORATORY FOR MEASUREMENTS OF TECHNOLOGICAL DOSES

The Laboratory for Measurements of Technological Doses (LMTD) was created in 1998 and accredited as a testing laboratory in February 2004 (Polish Centre of Accreditation, accreditation number: AB 461). The actual accreditation range is:

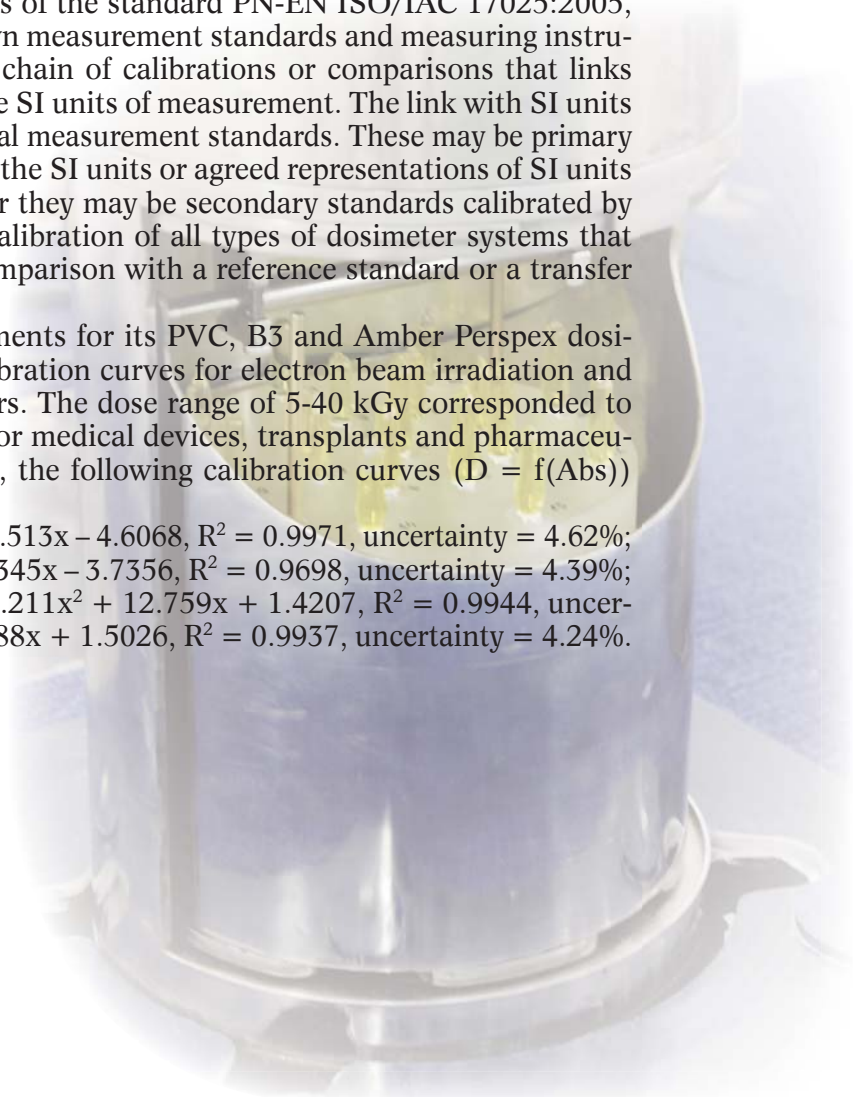
- gamma radiation dose measurement by means of a Fricke dosimeter (20-400 Gy),
- gamma radiation dose measurement by means of a CTA film dosimeter (10-80 kGy),
- electron radiation dose measurement by means of a CTA film dosimeter (15-40 kGy),
- electron radiation dose measurement by means of graphite and polystyrene calorimeters (1.5-40 kGy),
- irradiation of dosimeters or other small objects with ^{60}Co gamma radiation to strictly define doses,
- irradiation of dosimeters or other small objects with 10 MeV electron beams to strictly define doses.

The secondary standard of the dose rate utilized by the LMTD is a ^{60}Co gamma source Issledovatel and a Gamma Chamber 5000. The sources were calibrated in January 2016 and in March 2012, respectively, according to the NPL (National Physical Laboratory, Teddington, UK) primary standard. The uncertainty of the dose rate was estimated to be 3.0% and 3.1% (U, $k = 2$).

In accordance with the recommendations of the standard PN-EN ISO/IAC 17025:2005, a laboratory establishes traceability of its own measurement standards and measuring instruments to the SI by means of an unbroken chain of calibrations or comparisons that links them to the relevant primary standards of the SI units of measurement. The link with SI units may be achieved by referencing to the national measurement standards. These may be primary standards, which are primary realizations of the SI units or agreed representations of SI units based on fundamental physical constants, or they may be secondary standards calibrated by another national metrology institute. The calibration of all types of dosimeter systems that are used routinely should be checked by comparison with a reference standard or a transfer standard dosimeter.

In 2017, the LPDT performed measurements for its PVC, B3 and Amber Perspex dosimeters. These consisted in determining calibration curves for electron beam irradiation and comparing them with the LPDT calorimeters. The dose range of 5-40 kGy corresponded to the routine radiation sterilization process for medical devices, transplants and pharmaceuticals. For the above-mentioned dosimeters, the following calibration curves ($D = f(\text{Abs})$) were obtained:

- for the PVC dosimeter: $Y = -26.236x^2 + 71.513x - 4.6068$, $R^2 = 0.9971$, uncertainty = 4.62%;
- for the B3 dosimeter: $Y = -22.386x^2 + 96.345x - 3.7356$, $R^2 = 0.9698$, uncertainty = 4.39%;
- for the Amber Perspex dosimeter: $Y = 32.211x^2 + 12.759x + 1.4207$, $R^2 = 0.9944$, uncertainty = 5.39%, and $Y = 77.847x^2 + 21.088x + 1.5026$, $R^2 = 0.9937$, uncertainty = 4.24%.



LABORATORY FOR DETECTION OF IRRADIATED FOOD

The Laboratory for Detection of Irradiated Food was created at the Institute of Nuclear Chemistry and Technology in 1994. The adoption of the quality assurance system resulted in accreditation of the Laboratory in 1999 by the Polish Centre for Accreditation (PCA). Since that time, the Laboratory for Detection of Irradiated Food has constantly maintained the status of an accredited R&D unit and is authorized to examine food samples to classify them as being either irradiated or not irradiated. Every four years, the Laboratory accreditation certificate must be renewed after successfully passing the PCA expert audit. The current certificate, which is the 5th, was received on 30th September 2014 and is valid until 24th October 2018.

Professional and well-experienced staff members are working to improve irradiation detection methods adapted in the Laboratory to make them more sensitive and reliable for an extended group of food articles. The Laboratory offers analytical services in this field to domestic and foreign customers for an extended assortment of food articles *via* the use of five appropriate and normalized analytical methods. The *Scope of Accreditation* – an integral part of the accreditation certificate, offers customers five methods suitable to detect radiation treatment in almost all foodstuffs available in the open market.

Nowadays, many food items such as herbal pharmaceuticals, diet supplements, and food extracts are received by the Laboratory for examination of irradiation from our domestic and foreign customers.

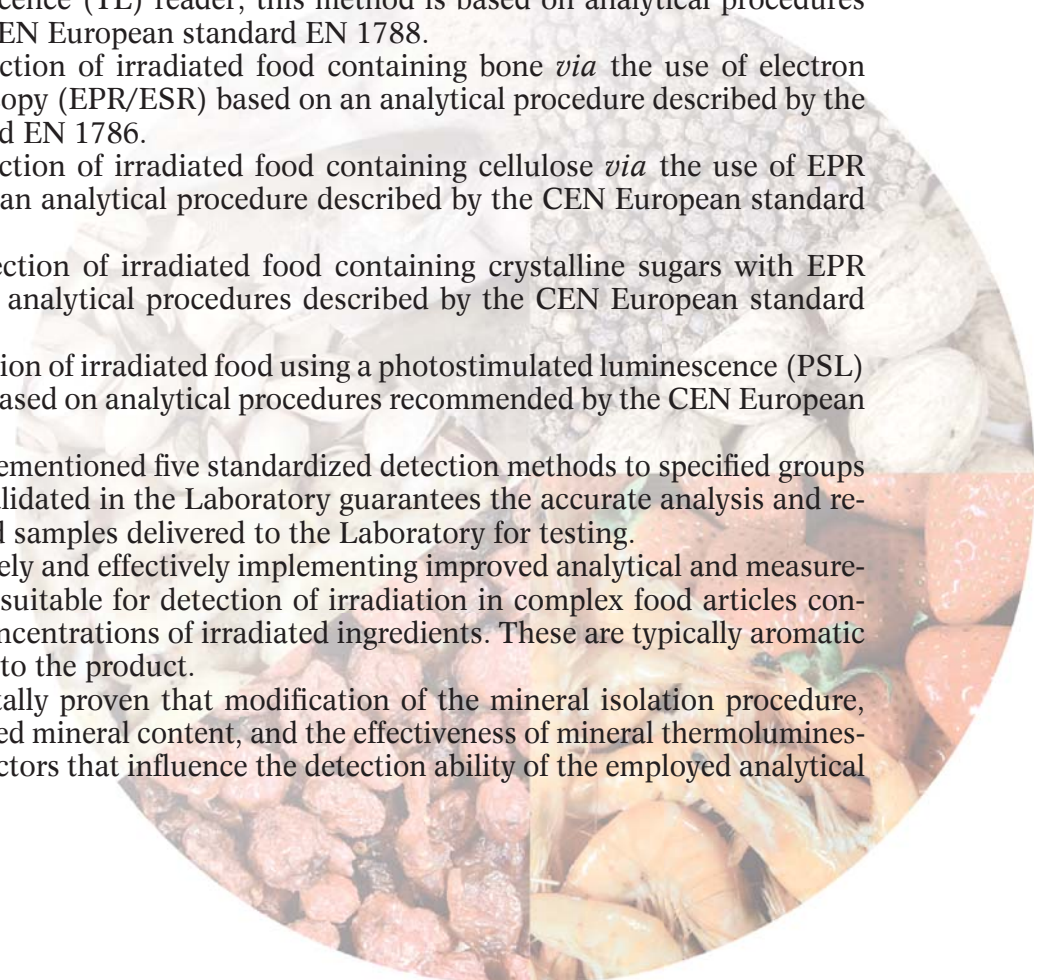
The Laboratory implemented the following detection methods:

- A method for the detection of irradiated food from which silicate minerals can be isolated using a thermoluminescence (TL) reader; this method is based on analytical procedures recommended by the CEN European standard EN 1788.
- A method for the detection of irradiated food containing bone *via* the use of electron paramagnetic spectroscopy (EPR/ESR) based on an analytical procedure described by the CEN European standard EN 1786.
- A method for the detection of irradiated food containing cellulose *via* the use of EPR spectroscopy based on an analytical procedure described by the CEN European standard EN 1787.
- A method for the detection of irradiated food containing crystalline sugars with EPR spectroscopy based on analytical procedures described by the CEN European standard EN 13708.
- A method for the detection of irradiated food using a photostimulated luminescence (PSL) reader; this method is based on analytical procedures recommended by the CEN European standard EN 13751.

The application of the aforementioned five standardized detection methods to specified groups of foods that have been validated in the Laboratory guarantees the accurate analysis and reliable classification of food samples delivered to the Laboratory for testing.

The Laboratory is actively and effectively implementing improved analytical and measurement procedures that are suitable for detection of irradiation in complex food articles containing low or very low concentrations of irradiated ingredients. These are typically aromatic herbs and spices admixed to the product.

It has been experimentally proven that modification of the mineral isolation procedure, the determination of isolated mineral content, and the effectiveness of mineral thermoluminescence are the important factors that influence the detection ability of the employed analytical method.



In 2017, the Laboratory reported a large increase in the number of samples delivered by domestic customers to be analysed; samples were also delivered by foreign customers from Germany, Italy, Denmark, Latvia, Hungary and Spain. The assortment of samples received comprised food extracts, herbal pharmaceuticals, diet supplements, spices, dried vegetables and red fermented rice. In total, 1426 samples were examined. Of these, 1419 samples were examined by the TL method, while the EPR based analytical procedures were applied only three times and the PSL – four times.

From 19th June 2012, the Laboratory has held the status of the reference laboratory in the field of the detection of irradiated food in Poland under the nomination of the Ministry of Health (National Reference Laboratory No. 5). As such, the Laboratory is responsible for organizing control and monitoring irradiated food around the country.

INVESTIGATION OF LOW DOSE IRRADIATED DRIED FRUITS BY A STANDARDIZED ELECTRON PARAMAGNETIC RESONANCE DETECTION METHOD

Grzegorz Piotr Guzik, Magdalena Miłkowska

The dried fruit components of diet supplements and fruit extracts are supposed to positively influence human condition and health. These components are usually dried in a traditional manner and contain many impurities and microbial contaminants, including dangerous pests. For this reason, dried fruits undergo disinfection leading to microbial decontamination.

One of the most effective methods of microbial decontamination of dried and fresh fruits is irradiation [1, 2]. As recommended by a FAO/WHO expert group, the safe dose of ionizing radiation as applied to food is 0.2-10 kGy [3], while in the case of dried spices and fruits it is 5-10 kGy, depending on the content of microbial contaminants. Recently, thermal or high pressure treatment combined with irradiation have been applied for the decontamination of these products. In such combined disinfection processes markedly lower doses of ionizing radiation than those recommended are required.

The aim of the present study was to evaluate the detection limits of such low dose irradiation applied to dried fruits examined after a long period of storage. In other words, the determination of the possibility of the detection of irradiation in dried fruits irradiated with low doses of ionizing radiation and stored for a prolonged period. An analytical procedure based on the CEN European standard EN 13708 was used [4].

The subject of the investigation were ten species of dried fruits used in pharmacy as available on the market. These were: plum, apricot, strawberry, cherry, cranberry, date, raisin, mulberry, fig, and blackcurrant. All the fruits were irradiated with doses of 0.3 kGy and 0.5 kGy (the lowest recommended technological doses in use). For comparison, non-irradiated batches of the tested fruits were investigated in parallel.

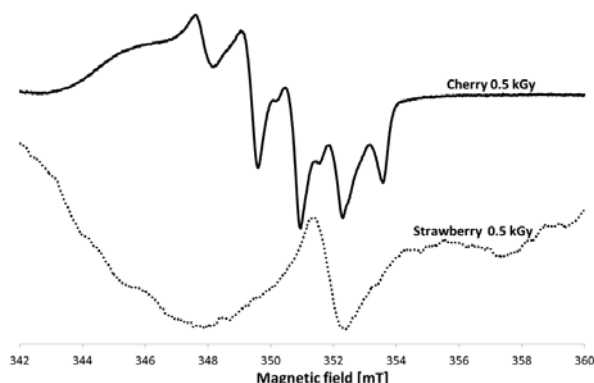


Fig. 1. EPR signals of dried cherry and strawberry irradiated with a 0.5 kGy dose of ^{60}Co gamma radiation and measured 1 day after irradiation at room temperature. The multiline broad signal of dried cherry resembles the signals observed with radiation-treated food products containing crystalline sugar. The characteristic signal of cellulose radicals can be recognized in the dried strawberry's EPR trace.

Depending on the species examined by the EPR (electron paramagnetic resonance) method, the fruit components tested were the peels, stones, skins or pulp/flesh. The samples taken for investigation were dried fruits purchased from the market or fresh fruits dried for 48 h at 40°C in a dryer machine under a flow of dry air. The samples

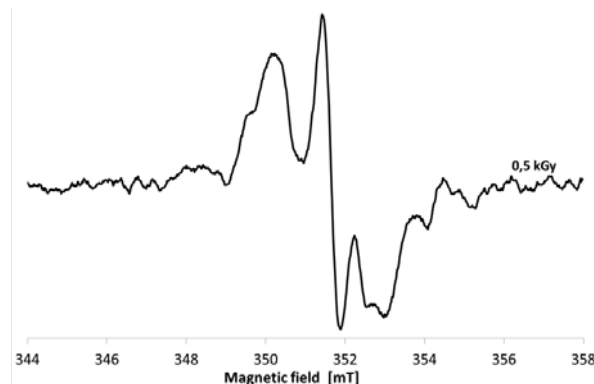


Fig. 2. EPR signal of dried cherry irradiated with a 0.5 kGy dose of ^{60}Co gamma radiation and measured 20 months after irradiation. The multiline broad signal is typical of radiation-treated food products containing crystalline sugar.

were irradiated in a ^{60}Co gamma source (Gamma Chamber 5000) with two doses, 0.3 kGy and 0.5 kGy. A suitable portion of each fruit was placed in a signal-free glass ampoule 4 mm in diameter and subsequently measured with a Bruker EMXplus EPR spectrometer equipped with Xenon software. Representative EPR signals obtained with the investigated fruits are shown in Figs. 1-4, respectively.

The EPR measurements of dried samples were carried out 1 day after the irradiation to avoid the interference of short-lived radicals produced by radiation. The specific signal characteristic for irradiated sugars (Fig. 1) appeared for all fruits, with the exception of plum and apricot (Table 1). However, in the irradiated, dried strawberry's EPR signal only a central line with two weak satellite lines on both sides was noted, proving that radiation-evoked cellulose radicals were involved.

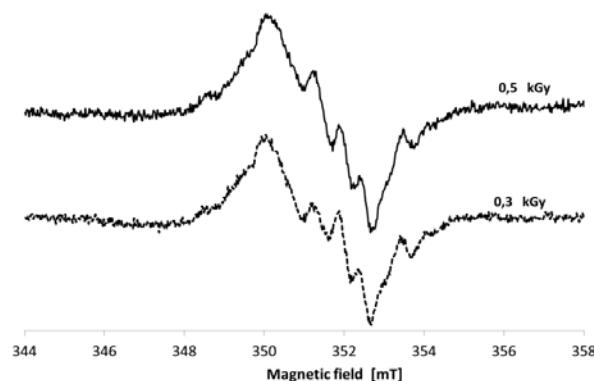


Fig. 3. EPR signals of dried mulberry irradiated with 0.3 kGy and 0.5 kGy doses of ^{60}Co gamma radiation, measured 20 months after irradiation.

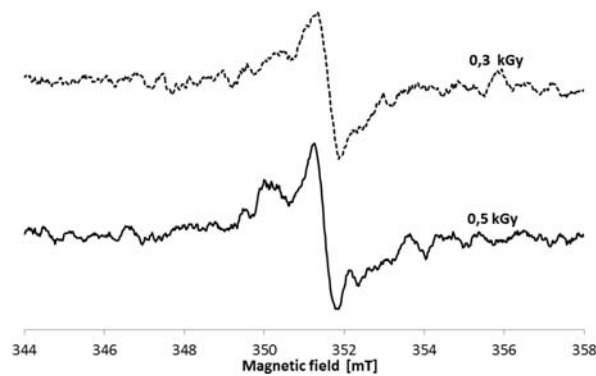


Fig.4. EPR signals of dried cranberries. The multiline, broad signal recorded is like a weak sugar signal. The whole fruit was irradiated with 0.3 kGy and 0.5 kGy doses of ^{60}Co gamma radiation and the signal was measured 20 months after irradiation. Two weak satellite lines on both sides of central line prove that cellulose radiation-evoked radicals were involved.

The samples were then stored in the dark for 20 months to determine the stability of the EPR signals involved. The results of the second EPR examination are shown in Table 2.

diation were markedly higher than those registered after 20 months of storage.

The EPR signal recorded with irradiated cherry was a broad (5.8 mT), multiline spectrum derived from stable radicals trapped in crystalline sugars (Fig.2). This kind of stable EPR signal was recorded with most commercially available dried fruits. However, after 20 months of storage this EPR signal was only seen for three irradiated fruits: cherry, cranberry and mulberry (all treated with a 0.5 kGy dose and also for mulberry treated with a 0.3 kGy dose) [5, 6].

The EPR signal recorded with irradiated mulberry represented a different multiline signal (7.4 mT broad), which could be assigned to a sugar-derived signal (Fig.3).

A different EPR signal was recorded with the sample of irradiated dried cranberries (Fig. 4). In this signal a triplet with a strong central line was seen. The distance between the two weak satellite lines was about 6 mT with $g = 2.004$, evidence that cellulose radicals were involved [7].

The multiline, broad signal that was recorded was like a weak sugar signal. The whole fruit was

Table 1. The results of the EPR study of dried fruits 1 day after irradiation at room temperature.

Dried fruit	Dose [kGy]	EPR result 1 day after irradiation	Dose [kGy]	EPR result 1 day after irradiation
Plum	0.3	no signal	0.5	no signal
Apricot	0.3	no signal	0.5	no signal
Strawberry	0.3	weak cellulose-derived signal	0.5	weak cellulose-derived signal
Cherry	0.3	specific sugar-derived signal	0.5	specific sugar-derived signal
Cranberry	0.3	specific sugar-derived signal	0.5	specific sugar-derived signal
Date	0.3	specific sugar-derived signal	0.5	specific sugar-derived signal
Raisin	0.3	specific sugar-derived signal	0.5	specific sugar-derived signal
Mulberry	0.3	specific sugar-derived signal	0.5	specific sugar-derived signal
Fig	0.3	specific sugar-derived signal	0.5	specific sugar-derived signal
Blackcurrant	0.3	specific sugar-derived signal	0.5	specific sugar-derived signal

The intensities of the central EPR signals recorded for dried samples immediately after irradiated with 0.3 kGy and 0.5 kGy doses of ^{60}Co gamma radiation and measured 20 months after

Table 2. The results of the EPR study of ten fruits after 20 months of storage at room temperature.

Dried fruit	Dose [kGy]	EPR result after 20 months of storage	Dose [kGy]	EPR result after 20 months of storage
Plum	0.3	no signal	0.5	no signal
Apricot	0.3	no signal	0.5	no signal
Strawberry	0.3	no characteristic signal – only central line	0.5	no characteristic signal – only central line
Cherry	0.3	no characteristic signal – only central line	0.5	sugar-derived signal
Cranberry	0.3	no characteristic signal – only central line	0.5	weak sugar-derived signal
Date	0.3	no characteristic signal – only central line	0.5	no characteristic signal – only central line
Raisin	0.3	no satellite lines	0.5	no satellite lines
Mulberry	0.3	weak sugar-derived signal	0.5	weak sugar-derived signal
Fig	0.3	no characteristic signal – only central line	0.5	no characteristic signal – only central line
Blackcurrant	0.3	no characteristic signal – only central line	0.5	no characteristic signal – only central line

irradiation. Two weak satellite lines on both sides of the central line proved that cellulose radiation-evoked radicals were involved.

The EPR spectra of seven species of dried fruits irradiated with 0.3 kGy and 0.5 kGy doses and investigated 1 day after treatment gave well-resolved multiline signals specific for irradiated sugars. No EPR signal was found with the plum or apricot. The characteristic signal of the cellulose radical could be recognized with dried strawberry.

After prolonged storage of the samples for 20 months, the radiation-induced EPR signals survived in the samples of cherry, cranberry and mulberry, giving evidence of the unique stability at room temperature of the EPR signals in these fruits. The remaining seven species of investigated fruits did not give any characteristic signal after prolonged storage, but only a strong single line in the central part of the spectrum. Only for dried cherry, cranberry and mulberry treated with 0.3 kGy or 0.5 kGy doses it was possible to detect irradiation after 20 months of storage at room temperature.

References

- [1]. Directive 1999/2/EC of the European Parliament and of the Council on the approximation of the laws of the Member States concerning foods and food ingredients treated with ionizing radiation.
- [2]. Directive 1999/3/EC of the European Parliament and of the Council on the establishment of a Community list of foods and food ingredients treated with ionizing radiation.
- [3]. FAO/WHO. *General Standard for Irradiated Foods*. Codex Stan 106-1983, Rev.1-2003.
- [4]. European Committee for Standardization. *Foodstuffs – Detection of irradiated food containing crystalline sugar by ESR spectroscopy*. PN-EN 13708:2003.
- [5]. Raffi, J., & Agnel, J.-P. (1989). Electron spin resonance identification of irradiated fruits. *Radiat. Phys. Chem.*, 34, 6, 891-894.
- [6]. Raffi, J., Agnel, J.-P., Buscarlet, L.A., & Martin, C.C. (1988). Electron spin resonance identification of irradiated strawberry. *J. Chem. Soc., Faraday Trans. 1*, 84, 3359-3362.
- [7]. European Committee for Standardization. *Foodstuffs – Detection of irradiated food containing cellulose by ESR spectroscopy*. PN-EN 1787:2001.

LABORATORY OF NUCLEAR CONTROL SYSTEMS AND METHODS

The primary focus of the Laboratory activity in 2017 was the development of methods and equipment, based generally on the application of ionizing radiation and process engineering for both measurements and diagnostic purposes. The research programme of the Laboratory was focused on the following topics:

- development of measuring devices and systems for industry and for protection of the environment;
- development of a new leakage control method for testing industrial installations during their operation;
- identification and optimization of industrial processes using the tracer and radiotracer methods;
- application of membrane processes of biogas separation and their enrichment in methane;
- elaboration and industrial scale implementation of new methods and technology of biogas production by fermentation of agriculture substrates and by-products such as wastewater sediments obtained during wastewater clarification;
- development of new radiotracer and radiometric methods for optimization of hydrometallurgical processes.

In the field of elaboration and construction of nuclear instrumentation, the works were directed towards the detection of radioactive contamination and measurements of the concentration of radon daughter radioisotopes in air.

In the above-mentioned areas of activity, the Laboratory cooperated with the International Atomic Energy Agency (IAEA).



PUBLICATIONS IN 2017

ARTICLES

Journals from Thomson Reuters database JCR

1. **Adamo G., Grimaldi N., Sabatino M.A., Walo M., Dispenza C., Ghersi G.**
E-beam crosslinked nanogels conjugated with monoclonal antibodies in targeting strategies.
Biological Chemistry, 398, 2, 277-287 (2017).
2. **Ainsbury E., Badie C., Barnard S., Manning G., Moquet J., Abend M., Antunes A.C., Barrios L., Bassinet C., Beinke C., Bortolin E., Bossin L., Bricknell C., Brzóška K., Buraczewska I., Castaño C.H., Čemusová Z., Christiansson M., Cordero S.M., Cosler G., Della Monaca S., Desangles F., Discher M., Dominquez I., Doucha-Senf S., Eakins J., Fattibene P., Filippi S., Frenzel M., Georgieva D., Gregoire E., Guogyte K., Hadjidekova V., Hadjiiska L., Hristova R., Karakosta M., Kis E., Kriehuber R., Lee J., Lloyd D., Lumniczky K., Lyng F., Macaeva E., Majewski M., Martins S.V., McKeever W.S., Meade A., Medipally D., Meschinie R., M'kacher R., Monteiro Gil O., Montero A., Moreno M., Noditi M., Oestreicher U., Oskamp D., Palitti F., Palma V., Pantelias G., Pateux J., Patrono C., Pepe G., Port M., Prieto M.J., Quattrini M.C., Quintens R., Ricoul M., Roy L., Sabatier L., Sebastià N., Sholom S., Sommer S., Staynova A., Strunz S., Terzoudi G., Testa A., Trompier F., Valente M., Van Hoey O., Veronese I., Wójcik A., Woda C.**
Integration of new biological and physical retrospective dosimetry methods into EU emergency response plans – joint RENEB and EURADOS inter-laboratory comparisons.
International Journal of Radiation Biology, 93, 1, 99-109 (2017).
3. **Ainsbury E., Higuera M., Puig P., Einbeck J., Samaga D., Barquinero J.F., Barrios L., Brzozowska B., Fattibene P., Gregoire E., Jaworska A., Lloyd D., Oestreicher U., Romm H., Rothkamm K., Roy L., Sommer S., Terzoudi G., Thierens H., Trompier F., Vral A., Woda C.**
Uncertainty of fast biological radiation dose assessment for emergency response scenarios.
International Journal of Radiation Biology, 93, 1, 127-135 (2017).
4. **Apel P.Yu., Blonskaya I.V., Lizunov N.E., Olejniczak K., Orelvitch O.L., Sartowska B.A., Dmitriev S.N.**
Asymmetrical nanopores in track membranes: Fabrication, the effect of nanopore shape and electric charge of pore walls, promising applications.
Russian Journal of Electrochemistry, 53, 1, 58-69 (2017).
5. **Baranowska I., Buszewski B., Namieśnik J., Konieczka P., Magiera S., Polkowska-Motrenko H., Kościelniak P., Gadzała-Kopciuch R., Woźniakiewicz A., Samczyński Z., Kochańska K., Rutkowska M.**
Development of potential candidate reference materials for drugs in bottom sediment, cod and herring tissues.
Chemosphere, 169, 181-187 (2017).
6. **Barquinero J.F., Beinke C., Borràs M., Buraczewska I., Darroudi F., Gregoire E., Hristova R., Kulka U., Lindholm C., Moreno M., Moquet J., Oestreicher U., Prieto M.J., Pujol M., Ricoul M., Sabatier L., Sommer S., Sun M., Wójcik A., Barrios L.**
RENEB biodosimetry intercomparison analyzing translocations by FISH.
International Journal of Radiation Biology, 93, 1, 30-35 (2017).
7. **Brzozowska B., Ainsbury E., Baert A., Beaton-Green L., Barrios L., Barquinero J.F., Bassinet C., Beinke C., Benedek A., Beukes P., Bortolin E., Buraczewska I., Burbidge C., De Amicis A., De Angelis C., Della Monaca S., Depuydt J., De Sanctis S., Dobos K., Moreno Domene M., Domínguez I., Facco E., Fattibene P., Frenzel M., Monteiro Gil O., Gonon G., Gregoire E., Gruel G., Hadjidekova V., Hatzi V.I., Hristova R., Jaworska A., Kis E., Kowalska M., Kulka U., Lista F., Lumniczky K., Martínez-López W., Meschini R., Moertl S., Moquet J., Noditi M., Oestreicher U., Vázquez M.L.O., Palma V., Pantelias G., Montoro Pastor A., Patrono C., Piqueret-Stephan L., Quattrini M.C., Regalbuto E., Ricoul M., Roch-Lefevre S., Roy L., Sabatier L., Sarchiapone L., Sebastià N., Sommer S., Sun M., Suto Y., Terzoudi G., Trompier F., Vral A., Wilkins R., Zafiroopoulos D., Wieser A., Woda C., Wójcik A.**
RENEB accident simulation exercise.
International Journal of Radiation Biology, 93, 1, 75-80 (2017).

8. **Chajduk E., Polkowska-Motrenko H.**
Application of ICP-MS, INAA and RNAA to the determination of some “difficult” elements in infant formulas.
Journal of Radioanalytical and Nuclear Chemistry, 311, 1347-1353 (2017).
9. **Cieśla K., Abramowska A., Boguski J., Drewnik J.**
The effect of poly(vinyl alcohol) type and radiation treatment on the properties of starch-poly(vinyl alcohol) films.
Radiation Physics and Chemistry, 141, 142-148 (2017).
10. **Danko B., Dybczyński R.S., Samczyński Z., Gajda D., Herdzik-Koniecko I., Zakrzewska-Kołodziej G., Chajduk E., Kulisa K.**
Ion exchange investigation for recovery of uranium from acidic pregnant leach solutions.
Nukleonika, 62, 3, 213-221 (2017).
11. **Depuydt J., Baeyens A., Barnard S., Beinke C., Benedek A., Beukes P., Buraczewska I., Darroudi F., De Sanctis S., Domínguez I., Monteiro Gil O., Hadjidekova V., Kis E., Kulka U., Lista F., Lumniczky K., M'kacher R., Moquet J., Obreja D., Oestreicher U., Pajic J., Pastor N., Popova L., Regalbuto E., Ricoul M., Sabatier L., Slabbert J., Sommer S., Testa A., Thierens H., Wojcik A., Vral A.**
RENEB intercomparison exercises analyzing micronuclei (Cytokinesis-block micronucleous assay).
International Journal of Radiation Biology, 93, 1, 36-47 (2017).
12. **D'Huyvetter M., De Vos J., Xavier C., Pruszyński M., Sterckx Y.G.J., Massa S., Raes G., Caveliers V., Zalutsky M.R., Lahoutte T., Devoogdt N.**
¹³¹I-labeled anti-HER2 camelid sdAb as a theranostic tool in cancer treatment.
Clinical Cancer Research, 23, 21, 6616-6628 (2017).
13. **Dybczyński R.S., Samczyński Z., Bartosiewicz I., Kulisa K., Polkowska-Motrenko H., Pyszynska M., Zuba I.**
Two new separation schemes for the group isolation of rare earth elements (REE) from biological and other matrices and their determination by ICP-MS, NAA and chromatographic methods.
Nukleonika, 62, 3, 199-211 (2017).
14. **Dziawer Ł., Koźmiński P., Męczyńska-Wielgosz S., Pruszyński M., Łyczko M., Wąs B., Celichowski G., Grobelny J., Jastrzębski J., Bilewicz A.**
Gold nanoparticle bioconjugates labelled with ²¹¹At for targeted alpha therapy.
RSC Advances, 7, 41024-41032 (2017).
15. **Filipiak P., Bobrowski K., Hug G.L., Pogocki D., Schoneich C., Marciniak B.**
New insights into the reaction paths of 4-carboxybenzophenone triplet with oligopeptides containing N- and C-terminal methionine residues.
The Journal of Physical Chemistry B, 121, 5247-5258 (2017).
16. **Gniazdowska E., Koźmiński P., Wasek M., Bajda M., Sikora J., Mikiciuk-Olasik E., Szymański P.**
Synthesis, physicochemical and biological studies of technetium-99m labeled tacrine derivative as a diagnostic tool for evaluation of cholinesterase level.
Bioorganic & Medicinal Chemistry, 25, 912-920 (2017).
17. **Jaroszevska A., Biel W., Bojanowska-Czajka A., Wierzchnicki R.**
Influence of habitat conditions on chemical composition and content of isotopes in Sea Buckthorn (*Hippophae rhamnoides* L.) leaves.
Acta Scientiarum Polonorum Hortorum Cultus, 16, 1, 3-10 (2017).
18. **Karami K., Abedanzadeh S., Vahidnia O., Herves P., Lipkowski J., Łyczko K.**
Orthopalladated complexes of phosphorus ylides: Poly (N-vinyl-2-pyrrolidone)-stabilized palladium nanoparticles as reusable heterogeneous catalyst for Suzuki and Heck cross-coupling reactions.
Applied Organometallic Chemistry, 31, 10, e3768(13 p.) (2017).
19. **Kiegiel K., Abramowska A., Bieluszka P., Zakrzewska-Kołodziej G., Wołkiewicz S.**
Solvent extraction of uranium from leach solution obtained in processing of Polish low-grade ores.
Journal of Radioanalytical and Nuclear Chemistry, 311, 589-598 (2017).
20. **Kołacińska K., Chajduk E., Dudek J., Samczyński Z., Łokas E., Bojanowska-Czajka A., Trojanowicz M.**
Automation of sample processing for ICP-MS determination of ⁹⁰Sr radionuclide at ppq level for nuclear technology and environmental purposes.
Talanta, 169, 216-226 (2017).

21. **Kovacs A., Dobrowolski J.Cz., Ostrowski S., Rode J.E.**
Benchmarking density functionals in conjunction with Grimme's dispersion correction for noble gas dimers (Ne₂, Ar₂, Kr₂, Xe₂, Rn₂).
International Journal of Quantum Chemistry, 117, 9, e25358 (13 p.) (2017). doi: 10.1002.qua.25358.
22. **Kovacs A., Rode J.E.**
Modelling the matrix shift on the vibrational frequency of ThO by DFT-D3 calculations.
The Journal of Chemical Physics, 146, 124301 (2017).
23. **Kowalska M., Węgierek-Ciuk A., Brzóška K., Wojewódzka M., Męczyńska-Wielgosz S., Gromadzka-Ostrowska J., Mruk R., Øvrevik J., Kruszewski M., Lankoff A.**
Genotoxic potential of diesel exhaust particles from the combustion of first- and second-generation biodiesel fuels – the FuelHealth project.
Environmental Science and Pollution Research, 24, 24223-24234 (2017).
24. **Kulka U., Abend M., Ainsbury E., Badie C., Barquinero J.F., Barrios L., Beinke C., Bortolin E., Cucu A., De Amicis A., Domínguez I., Fattibene P., Frøvig A.M., Gregoire E., Guogyte K., Hadjidekova V., Jaworska A., Kriehuber R., Lindholm C., Lloyd D., Lumniczky K., Lyng E., Meschini R., Mörtl S., Della Monaca S., Monteiro Gil O., Montoro A., Moquet J., Moreno M., Oestreicher U., Palitti F., Pantelias G., Patrono C., Piqueret-Stephan L., Port M., Prieto M.J., Quintens R., Ricoul M., Romm H., Roy L., Sáfrány G., Sabatier L., Sebastià N., Sommer S., Terzoudi G., Testa A., Thierens H., Turai I., Trompier F., Valente M., Vaz P., Voisin P., Vral A., Woda C., Zafiroopoulos D., Wojcik A.**
RENEB – running the European network of biological dosimetry and physical retrospective dosimetry.
International Journal of Radiation Biology, 93, 1, 2-14 (2017).
25. **Lankoff A., Brzóška K., Czarnocka J., Kowalska M., Lisowska H., Mruk R., Øvrevik J., Węgierek-Ciuk A., Zuberek M., Kruszewski M.**
A comparison analysis of *in vitro* toxicity of diesel exhaust particles from combustion of 1st- and 2nd-generation biodiesel fuels in relation to their physicochemical properties – the FuelHealth project.
Environmental Science and Pollution Research, 24, 23, 19357-19374 (2017).
26. **Lazurik V.T., Lazurik V.M., Popov G., Zimek Z.**
Dosimetry method based on a two-parametric model of electrons beam for radiation processing.
Problems of Atomic Science and Technology, 6, 137-141 (2017).
27. **Lelegani A., Khalaj M., Sedaghat S., Łyczko K., Lipkowski J.**
Syntheses and structural characterization of Co(II) and Cd(II) coordination polymers with 1,4-bis(imidazolyl)butane ligand.
Journal of Molecular Structure, 1148, 479-485 (2017).
28. **Łyczko K.**
Tropolone as anionic and neutral ligand in lead(II) and bismuth(III) complexes: Synthesis, structure, characterization and computational studies.
Journal of Molecular Structure, 1127, 549-556 (2017).
29. **Łyczko K., Steczek Ł.**
Crystal structure of a hydroxo-bridged dimetric uranyl complex with a 2,2':6',2''-terpyridine ligand.
Journal of Structural Chemistry, 58, 1, 102-106 (2017).
30. **Łyczko M., Pruszyński M., Majkowska-Pilip A., Łyczko K., Wąs B., Męczyńska-Wielgosz S., Kruszewski M., Szkliniarz K., Jastrzębski J., Stolarz A., Bilewicz A.**
²¹¹At labeled substance P (5-11) as potential radiopharmaceutical for glioma treatment.
Nuclear Medicine and Biology, 53, 1-8 (2017).
31. **Magnusson P., Oczkowski M., Øvrevik J., Gajewska M., Wilczak J., Biedrzycki J., Dziendzikowska K., Kamola D., Królikowski T., Kruszewski M., Lankoff A., Mruk R., Brunborg G., Instanes C., Gromadzka-Ostrowska J., Myhre O.**
No adverse lung effects of 7- and 28-day inhalation exposure of rats to emission from petrodiesel fuel containing 20% rapeseed methyl esters (B20) with and without particulate filter – the FuelHealth project.
Inhalation Toxicology, 29, 5, 206-218 (2017).
32. **Manning G., Macaeva E., Majewski M., Kriehuber R., Brzóška K., Abend M., Doucha-Senf S., Oskamp D., Strunz S., Quintens R., Port M., Badie C.**
Comparable dose estimates of blinded whole blood samples are obtained independently of culture conditions and analytical approaches. Second RENEb gene expression study.
International Journal of Radiation Biology, 93, 1, 87-98 (2017).

- 33. Marchini M., Baroncini M., Bergamini G., Ceroni P., D'Angelantonio M., Franchi M., Negri F., Szreder T., Venturi M.**
Hierarchical growth of supramolecular structures driven by pimerization of tetrahedrally arranged bi-pyridinium units.
Chemistry – A European Journal, 23, 6380-6390 (2017).
- 34. Matysiak M., Kapka-Skrzypczak L., Jodłowska-Jędrych B., Kruszewski M.**
EMT promoting transcription factors as prognostic markers in human breast cancer.
Archives of Gynecology and Obstetrics, 295, 817-825 (2017).
- 35. Matysiak M., Kruszewski M., Kapka-Skrzypczak L.**
Nanopestycydy – jasna czy ciemna strona mocy? (Nanopesticides – light or dark side of the force?).
Medycyna Pracy, 68, 3, 423-432 (2017).
- 36. Misiak R., Walczak R., Wąs B., Bartyzel M., Mielinski J.W., Bilewicz A.**
⁴⁷Sc production development by cyclotron irradiation of ⁴⁸Ca.
Journal of Radioanalytical and Nuclear Chemistry, 313, 2, 429-434 (2017).
- 37. Monteiro Gil O., Vaz P., Romm H., De Angelis C., Antunes A.C., Barquinero J.F., Beinke C., Bortolin E., Burbidge C.I., Cucu A., Della Monaca S., Moreno Domene M., Fattibene P., Gregoire E., Hadjidekova V., Kulka U., Lindholm C., Meschini R., M'kacher R., Moquet J., Oestreicher U., Palitti F., Pantelias G., Montoro Pastor A., Popescu I.A., Quattrini M.C., Ricoul M., Rothkamm K., Sabatier L., Sebastià N., Sommer S., Terzoudi G., Testa A., Trompier F., Vral A.**
Capabilities of the RENE network for research and large scale radiological and nuclear emergency situations.
International Journal of Radiation Biology, 93, 1, 136-141 (2017).
- 38. Moquet J., Barnard S., Staynova A., Lindholm C., Monteiro Gil O., Martins V., Rößler U., Vral A., Vandevoorde C., Wojewódzka M., Rothkamm K.**
The second gamma-H2AX assay inter-comparison exercise carried out in the framework of the European biodosimetry network (RENEB).
International Journal of Radiation Biology, 93, 1, 58-64 (2017).
- 39. Nazaruk E., Majkowska-Pilip A., Bilewicz R.**
Lipid cubic-phase nanoparticles – cubosomes for efficient drug delivery to cancer cells.
ChemPlusChem, 82, 570-575 (2017).
- 40. Nichipor H., Sun Y., Chmielewski A.G.**
Kinetic modeling of NO heterogeneous radiation-induced oxidation on the TiO₂ surface in humid air under the electron beam irradiation.
Nukleonika, 62, 3, 235-240 (2017).
- 41. Nowicka-Scheibe J., Pawlukojć A., Sobczyk L., Jański J.**
On 2:1 melamine – squaric acid dihydrate complex: The structure and vibrational spectra.
Journal of Molecular Structure, 1127, 590-596 (2017).
- 42. Oestreicher U., Samaga D., Ainsbury E., Antunes A.C., Baeyens A., Barrios L., Beinke C., Beukes P., Blakely W.F., Cucu A., De Amicis A., Depuydt J., De Sanctis S., Di Giorgio M., Dobos K., Dominguez I., Pham Ngoc Duy, Espinoza M.E., Flegal F.N., Figel M., Garcia O., Monteiro O., Gregoire E., Guerrero-Carbajal C., Güçlü I., Hadjidekova V., Hande P., Kulka U., Lemon J., Lindholm C., Lista F., Lumniczky K., Martinez-Lopez W., Maznyk N., Meschini R., M'kacher R., Montoro A., Moquet J., Moreno M., Noditi M., Pajic J., Radl A., Ricoul M., Romm H., Roy L., Sabatier L., Sebastià N., Slabbert J., Sommer S., Stuck Oliveira M., Subramanian U., Suto Y., Que T., Testa A., Terzoudi G., Vral A., Wilkins R., Yanti L., Zafiropoulos D., Wojcik A.**
RENEB intercomparisons applying the conventional dicentric chromosome assay (DCA).
International Journal of Radiation Biology, 93, 1, 20-29 (2017).
- 43. Ostrowski S., Majkowska-Pilip A., Bilewicz A., Dobrowolski J.Cz.**
On Au_nAt clusters as potential astatine carriers.
RSC Advances, 7, 35854-35857 (2017).
- 44. Pawelec A., Dobrowolski A.**
Analysis of mixing conditions and multistage impact on NO_x removal efficiency in the electron beam flue gas treatment process.
Environmental Technology, 38, 1, 128-139 (2017).

45. **Pawlukojć A., Hetmańczyk J., Nowicka-Scheibe J., Maurin J.K., Schilf W., Rozwadowski Z.**
Spectroscopic, thermal and structural studies of new L-leucine and D-leucine complexes with chloranilic acid.
Journal of Molecular Structure, 1133, 464-471 (2017).
46. **Pereira E., Antonio A.L., Rafalski A., Barreira J.C.M., Barros L., Oliveira M.B.P.P., Ferreira I.C.F.R.**
Electron-beam irradiation as an alternative to preserve nutritional chemical and antioxidant properties of dried plants during extended storage periods.
LWT-Food Science and Technology, 82, 386-395 (2017).
47. **Petranikova M., Herdzik-Koniecko I., Steenari B.-M., Ekberg C.**
Hydrometallurgical processes for recovery of valuable and critical metals from spent car NiMH batteries optimized in a pilot plant scale.
Hydrometallurgy, 171, 128-141 (2017).
48. **Piotrowska A., Męczyńska-Wielgosz S., Majkowska-Pilip A., Koźmiński P., Wójciuk G., Cędrowska E., Bruchertseifer F., Morgenstern A., Kruszewski M., Bilewicz A.**
Nanozeolite bioconjugated labeled with ²²³Ra for targeted alpha therapy.
Nuclear Medicine and Biology, 47, 10-18 (2017).
49. **Piotrowski P., Pawłowska J., Sadło J.G., Bilewicz R., Kaim A.**
TEMPO functionalized C₆₀ fullerene deposited on gold surface for catalytic oxidation of selected alcohols.
Journal of Nanoparticles Research, 19, 161(11 p). DOI: 10.1007/s11051-017-3857-z.
50. **Rode J.E., Dobrowolski J.Cz., Łyczko K., Wasiewicz A., Kaczorek D., Kawęcki R., Zając G., Barańska M.**
Chiral thiophene sulfonamide – a challenge for VOA calculations.
The Journal of Physical Chemistry A, 121, 6713-6726 (2017).
51. **Romm H., Ainsbury E., Barquinero J.F., Barrios L., Beinke C., Cucu A., Moreno Domene M., Filippi S., Monteiro Gil O., Gregoire E., Hadjidekova V., Hatzi V., Lindholm C., M'kacher R., Montoro A., Moquet J., Noditi M., Oestreicher U., Palitti F., Pantelias G., Prieto M.J., Popescu I., Rothkamm K., Sebastià N., Sommer S., Terzoudi G., Tesla A., Wojcik A.**
Web based scoring is useful for validation and harmonisation of scoring criteria within RENEb.
International Journal of Radiation Biology, 93, 1, 110-117 (2017).
52. **Skuland T.S., Refsnes M., Magnusson P., Oczkowski M., Gromadzka-Ostrowska J., Kruszewski M., Mruk R., Myhre O., Lankoff A., Øvrevik J.**
Proinflammatory effects of diesel exhaust particles from moderate blend concentrations of 1st and 2nd generation biodiesel in BEAS-2B bronchial epithelial cells – The FuelHealth project.
Environmental Toxicology and Pharmacology, 52, 138-142 (2017).
53. **Smoliński T., Wawszczak D., Deptuła A., Łada W., Olczak T., Rogowski M., Pyszynska M., Chmielewski A.G.**
Solvent extraction of Cu, Mo, V, and U from leach solutions of copper ore and flotation tailings.
Journal of Radioanalytical and Nuclear Chemistry, 314, 1, 69-75 (2017).
54. **Stepkowski T.M., Męczyńska-Wielgosz S., Kruszewski M.**
mitoLUHMES: an engineered neuronal cell line for the analysis of the motility of mitochondria.
Cellular and Molecular Neurobiology, 37, 1055-1066 (2017).
55. **Szołucha M.M., Chmielewski A.G.**
A comparison of uranium recovery from low-grade ore by bioleaching and acid leaching.
Physicochemical Problems of Mineral Processing, 53, 1, 136-149 (2017).
56. **Terzoudi G., Pantelias G., Darroudi F., Barszczewska K., Buraczewska I., Depuydt J., Georgieva D., Hadjidekova V., Hatzi V.I., Karachristou I., Karakosta M., Meschini R., M'kacher R., Montoro A., Palitti F., Pantelias G., Pepe G., Ricoul M., Sabatier L., Sebastià N., Sommer S., Vral A., Zafiroopoulos D., Wojcik A.**
Dose assessment intercomparisons within the RENEb network using G₀-lymphocyte prematurely condensed chromosomes (PCC assay).
International Journal of Radiation Biology, 93, 1, 48-57 (2017).
57. **Trojanowicz M., Bojanowska-Czajka A., Capodaglio A.G.**
Can radiation chemistry supply a highly efficient AO(R)P process for organics removal from drinking and waste water? A review.
Environmental Science and Pollution Research, 24, 20187-20208 (2017).

58. **Trompier F., Baumann M., Barrios L., Gregoire E., Abend M., Ainsbury E., Barnard S., Barquinero J.F., Bautista J.A., Brzozowska B., Perez-Calatayud J., De Angelis C., Domínguez I., Hadjidekova V., Kulka E., Mateos J.C., Meschini R., Monteiro Gil O., Moquet J., Oestreicher U., Montoro Pastor A., Quintens R., Sebastià N., Sommer S., Stoyanov O., Thierens H., Terzoudi G., Villaescusa J.I., Vral A., Wojcik A., Zafirooulos D., Roy L.**
Investigation of the influence of calibration practices on cytogenetic laboratory performance for dose estimation.
International Journal of Radiation Biology, 93, 1, 118-126 (2017).
59. **Wojcieszak M., Pyzik A., Poszytek K., Krawczyk P.S., Sobczak A., Lipiński L., Roubinek O., Palige J., Skłodowska A., Drewniak L.**
Adaptation of methanogenic inocula to anaerobic digestion of maize silage.
Frontiers in Microbiology, 8, article 1881 (2017).
60. **Zwolińska E., Gogulancea V., Sun Y., Lavric V., Chmielewski A.**
A kinetic sensitivity analysis for the SO₂ and NO_x removal using the electron beam technology.
Radiation Physics and Chemistry, 138, 29-36 (2017).

Scientific journals (without IF) evaluated by the Ministry of Science and Higher Education (List B)

61. **Markowska-Radomska A., Dłuska E., Zakrzewska-Kołtuniewicz G., Miśkiewicz A.**
Odzysk metali ziem rzadkich z roztworów po ługowaniu magnezów trwałych w procesie zintegrowanym z wykorzystaniem emulsyjnych membran ciekłych (Recovery of rare earth metals from solutions after leaching of permanent magnets in integrated process using liquid emulsion membranes).
Inżynieria i Aparatura Chemiczna, 56, 4, 128-129 (2017).

Other journals

62. **Apel P.Yu., Blonskaya I.V., Lizunov N.E., Olejniczak K., Orelovitch O.L., Sartowska B.A., Dmitriev S.N.**
Asimetritchnye nanopory v trekovykh membranach: Polutchenie, efekty formy i elektritcheskogo zaryada na stenkach por, perspektivnye primeneniya.
Elektrokhimiya, 53, 1, 66-79 (2017).
63. **Głuszewski W.**
Chemia radiacyjna jako źródło unikatowych technologii syntezy i modyfikacji polimerów (Radiation chemistry as a source of unique technologies of synthesis and modification of polymers).
Postępy Techniki Jądrowej, 60, 4, 21-25 (2017).
64. **Głuszewski W.**
Czy napromieniowane polimery mogą być radioaktywne? (Whether irradiated polymers may be radioactive?).
Tworzywa Sztuczne w Przemysle, 3, 72-776 (2017).
65. **Głuszewski W.**
Identyfikacja i konserwacja dzieł sztuki a ochrona radiologiczna (Radiological protection in identification and conservation of art objects).
Bezpieczeństwo Jądrowe i Ochrona Radiologiczna, 2, 34-39 (2017).
66. **Głuszewski W.**
Polskie Towarzystwo Nukleoniczne wczoraj i dziś (Polish Nuclear Society yesterday and today).
Bezpieczeństwo Jądrowe i Ochrona Radiologiczna, 3, 33-36 (2017).
67. **Głuszewski W.**
Różne aspekty ochrony radiologicznej (Various aspects of radiological protection).
Bezpieczeństwo Jądrowe i Ochrona Radiologiczna, 3, 37-39 (2017).
68. **Głuszewski W.**
Rzecz o Marii Curie-Skłodowskiej, jej odkryciach i najczęściej popełnianych błędach (The thing about Maria Curie-Skłodowska, her discoveries and the most common mistakes made).
Wszystko co Najważniejsze (2017). <https://wszystkoconajwazniejsze.pl/wojciech-gluszewski-rzecz-o-marii-curie-sklodowskiej/>.
69. **Głuszewski W., Kubacki R., Rajkiewicz M.**
Modyfikowane radiacyjnie kompozyty polimerowe w ochronie przed promieniowaniem mikrofalowym (Radiation modified polymer composites in protection from microwave radiation).
Postępy Techniki Jądrowej, 60, 1, 20-23 (2017).

- 70. Głuszewski W., Kubacki R., Rajkiewicz M.**
Modyfikowane radiacyjnie materiały w ochronie przed promieniowaniem mikrofalowym (Radiation modified materials in protection from microwave radiation).
Bezpieczeństwo Jądrowe i Ochrona Radiologiczna, 1, 21-25 (2017).
- 71. Głuszewski W., Kubacki R., Rajkiewicz M.**
Polimerowe kompozyty barierowe dla promieniowań mikrofalowych (Polymeric barrier composites for microwave radiation).
Tworzywa Sztuczne w Przemysle, 2, 36-37 (2017).
- 72. Głuszewski W., Tran Q.K., Cortella L.**
Radioliza naturalnych i syntetycznych polimerów a ochrona dziedzictwa kulturowego (Radiolysis of natural and synthetic polymers and the protection of cultural heritage).
Tworzywa Sztuczne w Przemysle, 6, 44-45 (2017).
- 73. Latek S.**
ICARST 2017.
Postępy Techniki Jądrowej, 60, 2, 9-11 (2017).
- 74. Latek S.**
Promieniujemy na całą gospodarkę – polski przemysł dla elektrowni jądrowej (Radiate for all the economy – Polish industry for nuclear plant).
Postępy Techniki Jądrowej, 60, 1, 2-5 (2017).
- 75. Lazurik V.M., Lazurik V.T., Popov G.F., Zimek Z.**
Estimation of accuracy at determination of electron energy based on two parametric model of electron beam.
Visnyk of Kherson National Technical University, 3, 123-127 (2017).
- 76. Sartowska B., Barlak M., Waliś L., Starosta W.**
Re-melting technique with high intense pulsed plasma beams applied for surface modification of steel. Own investigations.
Materials Science Forum, 879, 1668-1673 (2017). DOI: 10.4028/www.scientific.net/MSF.879.1668.
- 77. Smoliński T., Rogowski M., Pyszynska M., Chmielewski A.G.**
Odzysk metali optymalizowany metodami radioizotopowymi (Metal recovery optimized by radioisotope methods).
Gospodarka Odpadami, 2, 24-27 (2017).
- 78. Sommer S.**
50 lat działalności Polskiego Towarzystwa Badań Radiacyjnych im. Marii Skłodowskiej-Curie: 1967-2017 (50 years of activity of the Polish Radiation Research Society memorial to Maria Skłodowska-Curie: 1967-2017).
Postępy Techniki Jądrowej, 60, 3, 12-17 (2017).
- 79. Zakrzewska-Kołtuniewicz G.**
Water management in nuclear power plant using advanced low-temperature systems.
European Water, 58, 345-350 (2017).
- 80. Zimek Z.**
Akceleratory elektronów stosowane w technice radiacyjnej (niezawodność, aspekty ekonomiczne) (Accelerators of electrons applied in radiation processing (reliability, economic aspects)).
Postępy Techniki Jądrowej, 60, 1, 12-19 (2017).

BOOKS

- 1. XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji, Warszawa, 19-20.10.2017.**
Instytut Chemii i Techniki Jądrowej, Warszawa 2017, [83] p.
- 2. Bodzek M., Bryjak M., Koter S., Kujawski W., Mozia S., Tomaszewska M., Turek M., Wolińska-Grabczyk A., Zakrzewska-Kołtuniewicz G.**
Angielsko-polski i polsko-angielski słownik terminologii membranowej z wyjaśnieniami / English-Polish and Polish-English explanatory dictionary of membrane terminology.
Eds. A. Wolińska-Grabczyk, M. Tomaszewska, W. Kujawski. Polskie Towarzystwo Membranowe, Toruń 2017. 106 p.

3. **Applications of ionizing radiation in materials processing. Vol. 1.**
Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, 244 p.
4. **Applications of ionizing radiation in materials processing. Vol. 2.**
Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, 272 p.
5. **Cieszykowska I., Fornalski K., Gajda D., Gajda P., Janczyszyn J., Latek S., Mikołajczak R., Rabiński M., Rzymkowski K., Sobieszczak-Marciniak M., Strzelecki R., Szreder T., Wołkowicz S.**
Polska atomistyka / Polish nuclear science.
Wydawnictwo Instytutu Zrównoważonej Energetyki, Kraków 2017, 330 p.
6. **Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”. Streszczenia wykładów. Warszawa, Poland, 8-9.06.2017.**
Instytut Chemii i Techniki Jądrowej, Warszawa 2017, 64 p.

CHAPTERS IN BOOKS

1. **Bandzierz K., Bieliński D.M., Przybytniak G., Jaszczak M., Marzec A.**
Comparison between peroxide and radiation crosslinking of nitrile rubber. Chapter 33.
In: Deformation and fracture behaviour of polymer materials. Eds. W. Grellmann, B. Langer. Springer Series in Materials Science, vol. 247, pp. 475-483. Springer International Publishing 2017.
2. **Bobrowski K.**
Radiation chemistry of liquid systems. Chapter 4.
In: Applications of ionizing radiation in materials processing. Vol. 1. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 81-116.
3. **Chiari M., Chmielewski A., Roegner F.-H.**
Accelerators and industry. Chapter 4.
In: Applications of particle accelerators in Europe. Ed. Nina Hall. CERN 2017, pp. 42-69.
4. **Chmielewska D.**
Radiation methods and uses in nanotechnology. Chapter 17.
In: Applications of ionizing radiation in materials processing. Vol. 2. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 395-414.
5. **Chmielewski A.G.**
Future developments in radiation processing. Chapter 22.
In: Applications of ionizing radiation in materials processing. Vol. 2. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 501-516.
6. **Cieśla K.**
Radiation modification of polysaccharides and their composites/nanocomposites. Chapter 14.
In: Applications of ionizing radiation in materials processing. Vol. 2. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 327-354.
7. **Głuszewski W.**
Czy promieniotwórczość może być zaraźliwa? Napromieniowany czy promieniotwórczy? (Do radioactivity can be contagious? Irradiated or radioactive?).
In: Czasopisma towarzystw naukowych w Polsce. Pod red. Andrzeja Kansego. Polska Akademia Nauk, Warszawa 2017, pp. 256-262.
8. **Głuszewski W.**
Disinfection of cultural heritage objects using electron beam accelerators.
In: Uses of ionizing radiation for tangible cultural heritage conservation. IAEA Radiation Technology Series no. 6. (STI/PUB/1747). International Atomic Energy Agency, Vienna 2017, pp. 173-177.
9. **Guzik G.P., Shukla A.K.**
ESR detection of irradiated food materials.
In: Electron spin resonance in food science. Ed. A.K. Shukla. Academic Press, Boston 2017, pp. 45-62.
10. **Hulst M., Kunicki-Goldfinger J.J.**
The golden age of Amsterdam glass. A chemical and typological approach to recognize Amsterdam 17th century glass production.

In: Annales du 20^e Congrès de l'Association Internationale pour l'Histoire du Verre Fribourg/Romont 7-11 septembre 2015. Eds. S. Wolf, A. de Pury-Gysel. Verlag Marie Leidorf GmbH, Romont 2017, pp. 547-553.

11. Kisała J., Hęclik K., Masłowska A., Celuch M., Pogocki D.

Natural environments for nanoparticles synthesis of core-shell and bimetallic systems.

In: Studies in natural products chemistry. Vol. 52. Bioactive natural products. Ed. Atta-ur-Rahman. Elsevier, Amsterdam 2017, pp. 1-67.

12. Kornacka E.M.

Radiation-induced oxidation of polymers. Chapter 8.

In: Applications of ionizing radiation in materials processing. Vol. 1. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 183-192.

13. Latek S.

„Postępy Techniki Jądrowej” (PTJ) – kroniką współczesnej nukleoniki.

In: Czasopisma towarzystw naukowych w Polsce. Pod red. Andrzeja Kansego. Polska Akademia Nauk, Warszawa 2017, pp. 247-255.

14. Perkowski J., Głuszewski W.

Preservation of large collections of artefacts.

In: Uses of ionizing radiation for tangible cultural heritage conservation. IAEA Radiation Technology Series no. 6. (STI/PUB/1747). International Atomic Energy Agency, Vienna 2017, pp. 159-162.

15. Przybytniak G.

Crosslinking of polymers in radiation processing. Chapter 11.

In: Applications of ionizing radiation in materials processing. Vol. 2. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 249-267.

16. Rafalski A., Rzepna M., Gryczka U., Bułka S.

Radiation sterilization. Chapter 12.

In: Applications of ionizing radiation in materials processing. Vol. 2. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 269-289.

17. Smoliński T.

Radiometric methods applied in hydrometallurgical processes development and optimization.

In: Radiometric methods for exploration and process optimization in mining and mineral industries. Report of the 2nd RCM of the CRP F22065, April 18-21, 2017. IAEA, Vienna 2017, pp. 48-63.

18. Starosta W.

Radiation use in producing track-etched membranes. Chapter 18.

In: Applications of ionizing radiation in materials processing. Vol. 2. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 415-445.

19. Trojanowicz M., Kołacińska K.

Rozwój koncepcji analizy przepływowej. Rozdział 1 (Development of the flow analysis concept. Chapter 1).

In: Analiza przepływowa. Od teorii do praktyki. Opracowanie pod redakcją K. Pyrzyńskiej. Wydawnictwo Malamut, Warszawa 2017, pp. 10-30.

20. Walo M.

Radiation-induced grafting. Chapter 9.

In: Applications of ionizing radiation in materials processing. Vol. 1. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 193-210.

21. Zimek Z.

Application of radiation technologies for the modification of electronic devices. Chapter 21.

In: Applications of ionizing radiation in materials processing. Vol. 2. Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, pp. 485-499.

THE INCT PUBLICATIONS

1. INCT Annual Report 2016.

Institute of Nuclear Chemistry and Technology, Warszawa 2017, 172 p.

2. Applications of ionizing radiation in materials processing. Volume 1.

Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, 244 p.

3. Applications of ionizing radiation in materials processing. Volume 2.

Eds. Y. Sun and A.G. Chmielewski. Institute of Nuclear Chemistry and Technology, Warszawa 2017, 272 p.

4. Bułka S., Zimek Z.

Obniżenie energii wiązki elektronów w akceleratorze IŁU-6 (Reduction of electron beam energy in the IŁU-6 accelerator).

Instytut Chemii i Techniki Jądrowej, Warszawa 2017. Raporty IChTJ. Seria B nr 1/2017, 18 p.

5. Narbutt J., Herdzik-Koniecko I., Rejnis-Strzelak M.

Wykorzystanie efektów synergicznych lipofilowych modyfikatorów fazy organicznej z ekstrahentem TODGA do skuteczniejszego oddzielania ameryku(III) od lantanowców lekkich w procesie reekstrakcji ligandami hydrofilowymi. Nowa koncepcja rozwiązania problemu (The use of synergistic effects of lipophilic modifiers of TODGA-containing organic phase for improving separation of Am(III) from the early lanthanides in the process of stripping the metals with hydrophilic ligands. A novel concept for solving the problem).

Instytut Chemii i Techniki Jądrowej, Warszawa 2017. Raporty IChTJ. Seria B nr 2/2017, 14 p.

CONFERENCE PROCEEDINGS

1. Baumont G., Perko T., Zakrzewska G., Kralj M., Diaconu D., Zeleznik N.

Review of the content analysis of physics school books coming from different European countries on radioactivity and nuclear energy.

Proceedings of the 25. International Conference on Nuclear Engineering ICON14, July 2-6, 2017, Shanghai, China. Vol. 8: Computational fluid dynamics (CFD) and coupled codes; nuclear education, public acceptance and related issues. ASME 2017, [11] p. (ICONE25-66020).

2. Chmielewski A.G.

Stacje sterylizacji radiacyjnej wyposażone w izotopowe źródła promieniowania gamma (Gamma radiation sterilization plants).

XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [8] p.

3. Cieśla K.

Zastosowanie promieniowania jonizującego w opakowalnictwie. Nowoczesne materiały opakowaniowe specjalnego przeznaczenia i higienizacja opakowanych produktów (Application of ionising radiation in packaging industry. Modern packaging materials with special allocation and decontamination of the packed products).

Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 35-38.

4. Głuszewski W.

Oddziaływanie promieniowania jonizującego na materię (The impact of ionizing radiation on matter).

Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 13-18.

5. Głuszewski W.

Oddziaływanie promieniowania jonizującego na materię (The impact of ionizing radiation on matter).

XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [6] p.

6. Głuszewski W.

Zastosowanie technik radiacyjnych do wulkanizacji opon i modyfikacji elastomerów. Radiacyjne sieciowanie poliolefin w produkcji pianek (Application of radiation techniques for tire vulcanization and elastomer modification. Radiation crosslinking of polyolefins in the production of foams).

Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 31-34.

7. Kiegiel K., Gajda D., Zakrzewska-Kołtuniewicz G.

Secondary raw materials as a potential source of uranium.

Proceedings of NUCLEAR 2017. The 10. Annual International Conference on Sustainable Development through Nuclear Research and Education, Pitesti, Romania, 24-26.05.2017, pp. 161-166.

8. Kubacki R., Smólski B., Głuszewski W., Przesmycki R., Rudyk K.

Absorber for microwave investigation in the open space.

XI Conference on Reconnaissance and Electronic Warfare Systems 2016, Ołtarzew, Poland, 21-23.11.2016. Proceedings of SPIE – The International Society for Optical Engineering, vol. 10418, article no. 104180G (2017).

9. Migdał W., Gryczka U.

Mikrobiologiczna dekontaminacja radiacyjna ziół i przypraw – przepisy Unii Europejskiej (Microbiological radiation decontamination of herbs and spices – European Union regulations).

XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [4] p.

10. Przybytniak G.

Modyfikacja materiałów polimerowych pod wpływem promieniowania jonizującego (Radiation-induced modification of polymeric materials).

XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [4] p.

11. Przybytniak G.

Otrzymywanie rur i taśm termokurczliwych (Production of heat-shrinkable tapes and tubes).

Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 27-30.

12. Przybytniak G.

Zastosowania akceleratora elektronów w przetwórstwie polimerów (Application of electron accelerators in polymer processing).

Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 18-22.

13. Przybytniak G., Nowicki A.

Poprawa właściwości materiałów izolacyjnych w kablach i przewodach elektrycznych (Improving the properties of insulating materials in electrical cables and wires).

Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 23-26.

14. Rafalski A.

Kontrola dozymetryczna radiacyjnej sterylizacji wyrobów medycznych (Dosimetry control of the radiation sterilization of medical devices).

XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [5] p.

15. Sartowska B., Barlak M., Waliś L., Senatorski J.

Surface layer of austenitic stainless steel formed by alloying with REE using high intense pulsed plasma beams (HIPPB).

Solidification processing 2017: Proceedings of the 6. Decennial International Conference on Solidification Processing, Beamont Estate, Old Windsor, UK, 25-28.07.2017. Ed. Z. Fan. SS Media, Hertfordshire 2017, pp. 663-666.

16. Sartowska B., Starosta W., Waliś L., Miłkowska M., Barlak M., Kołodziejczak P., Smolik J., Rydzewski M., Tomassi P.

Accident tolerant materials – ideas and research directions.

23. International QUENCH Workshop, Karlsruhe, Germany, 17-19.10.2017. Ed. M. Steinbrück, [1] p. + 18 p. DOI: 10.5445/IR/1000076201.

17. Zakrzewska-Kołtuniewicz G.

Water management in nuclear power plant using advanced low-temperature systems.

Panta Rhei. Proceedings of the 10th World Congress of EWRA on Water Resources and Environment, 5-9 July 2017, Athens, Greece. Eds. G. Tsakiris, V.A. Tsihrintzis, H. Vangelis, D. Tigkas. European Water Resources Association, Athens 2017, pp. 1391-1396.

18. Zimek Z.

Akceleratory elektronów dla potrzeb sterylizacji radiacyjnej (Electron accelerators for radiation sterilization).

XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [4] p.

19. Zimek Z.

Akceleratory elektronów w technologiach radiacyjnych (Electron accelerators for radiation processing).

Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 7-12.

20. Zimek Z.

Aktualne możliwości stosowania obróbki radiacyjnej w Polsce i perspektywy rozwoju techniki i technologii radiacyjnych (Current opportunity of radiation processing implementation in Poland and progress perspective of radiation techniques and technologies).

Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 52-58.

21. Zimek Z.

Aspekty ekonomiczne wykorzystania technik radiacyjnych (Economic aspects of radiation processing implementation).

Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 59-64.

CONFERENCE ABSTRACTS

1. Barlak M., Kołodziejczak P., Starosta W.

The studies on silicon incorporation into zirconium alloy surface layers using TIG technology for high temperature corrosion resistance improvement of zirconium claddings.

NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.

2. Baumont G., Perko T., Zakrzewska G., Kralj M., Diaconu D., Zeleznik N.

Review of the content analysis of physics school books coming from different European countries on radioactivity and nuclear energy.

25. International Conference on Nuclear Engineering ICONE14, Shanghai, China, 2-6.07.2017, [1] p.

3. Bilewicz A., Dziawer Ł., Koźmiński P.

Bioconjugates of gold nanoparticles with trastuzumab labelled with ^{211}At for internal alpha therapy.

22. International Symposium on Radiopharmaceutical Sciences (ISRS 2017), Dresden, Germany, 14-19.05.2017. Journal of Labelled Compounds and Radiopharmaceuticals, 60, Suppl. 1, S66 (2017).

4. Brzóška K.

Biologiczne działanie i ryzyko promieniowania jonizującego (Biological effects and risk of ionizing radiation).

XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [3] p.

5. Brzóška K., Sikorska K., Grądzka I.

Impact of nanoparticles on transcriptional response of HepG2 cells to tumor necrosis factor.

42. FEBS Congress: From Molecules to Cells and Back, Jerusalem, Israel, 10-14.09.2017. The FEBS Journal, 284, Suppl. 1, 353-354 (2017).

6. Brzóška K., Sikorska K., Grądzka I.

Insight into the interactions between silver nanoparticles and tumor necrosis factor signaling.

ICONAN 2017 International Conference on Nanomedicine and Nanotechnology, Barcelona, Spain, 25-27.09.2017, p. 174.

7. Bułka S.

Analiza i ryzyko procesu sterylizacji radiacyjnej (Risk analysis for radiation sterilization process).

XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [2] p.

8. Bułka S., Gryczka U., Zimek Z., Migdał W.

ILU-6 type electron accelerator modification for low energy electron beam surface microbiological decontamination.

NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.

9. Cędrowska E., Pruszyński M., Bilewicz A., Morgenstern A., Bruchertseifer F.

Koniugaty magnetycznych nanocząstek z przeciwciałami monoklonalnymi jako nośniki dla ^{225}Ac w celowanej terapii radionuklidowej i hipertermii (Conjugates of magnetic nanoparticles with monoclonal antibodies as carriers for ^{225}Ac in targeted radionuclide therapy and hyperthermia).

ChemSession'17. XIV Warszawskie Seminarium Doktorantów Chemików, Warszawa, Poland, 9.06.2017. Streszczenia, p. 56.

- 10. Cędrowska E., Pruszyński M., Bilewicz A., Morgenstern A., Bruchertseifer F.**
Multimodal nanoparticles labelled with ^{225}Ac for targeted radionuclide therapy and hyperthermia.
22. International Symposium on Radiopharmaceutical Sciences (ISRS 2017), Dresden, Germany, 14-19.05.2017. Journal of Labelled Compounds and Radiopharmaceuticals, 60, Suppl. 1, S278 (2017).
- 11. Chajduk E., Pyszynska M., Kalbarczyk P., Polkowska-Motrenko H.**
Study of chemical speciation of trace elements in infant formulas by neutron activation analysis and other techniques.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 12. Chajduk E., Pyszynska M., Kalbarczyk P., Polkowska-Motrenko H., Stobiński L., Miśta E.**
Possibility of usage of modified Graphene oxide with MnO_2 in neutron activation analysis NAA and inductively coupled plasma mass spectrometry ICP-MS.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 13. Chmielewska D., Henczka M.**
Zastosowanie nanokompozytowego sorbentu SiEA-KNiFe w procesie oczyszczania wody z izotopów radioaktywnych (Application of nanocomposite SiEA-KNiFe sorbent in the proces of water purification from radioactive isotopes).
Seminarium „Praktyczne aspekty inżynierii chemicznej”, Poznań, Poland, 23.06.2017. Materiały konferencyjne, pp. 43-44.
- 14. Chmielewska D., Siwek M., Henczka M., Sartowska B., Starosta W., Wawszczak D., Dudek J.**
SiEA-KNiFe sorbent – from the synthesis through radionuclides sorption to the vitrification with sol-gel method.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, p. 87.
- 15. Chmielewska D., Wójcik M., Migdał W., Sadło J., Kopeć K.**
Application of different methods for evaluation of paper properties after decontamination with electron beam irradiation.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, p. 86.
- 16. Chmielewska-Śmietanko D., Gryczka U., Migdał W., Kopeć K.**
Application of electron beam for preservation biodeteriorated cultural heritage paper-based objects.
ICARST 2017. International Conference on Applications of Radiation Science and Technology, Vienna, Austria, 24-28.04.2017, p. 309.
- 17. Chmielewski A.G.**
Flue gas treatment using electron beam technology – status and challenges.
International Joint Conference on Environmental and Light Industry Technologies, Budapest, Hungary, 23-24.11.2017, p. 19.
- 18. Chmielewski A.G.**
Ionizing radiation: Innovative and effective tool for science and industry.
ICARST 2017. International Conference on Applications of Radiation Science and Technology, Vienna, Austria, 24-28.04.2017, p. 80.
- 19. Chmielewski A.G.**
New trends in radiation processing.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 20. Chmielewski A.G.**
Radioisotopes in industrial and environmental studies.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 21. Chmielewski A.G., Palige J., Roubinek O., Usidus J., Kryłowicz A., Witman-Zajac S.**
Mobilne zintegrowany system oczyszczania ścieków, produkcja biogazu oraz jego wzbogacania w metan (Integrated system of sewage treatment, biogas production and its enrichment with methane).
ChemSession'17. XIV Warszawskie Seminarium Doktorantów Chemików, Warszawa, Poland, 9.06.2017. Streszczenia, p. 184.

22. **Chmielewski A.G., Palige J., Roubinek O., Witman-Zajac S., Usidus J., Kryłowicz A.**
Integrated system of sewage treatment biogas production and methane enrichment of biogas unit.
6. Central European Congress of Life Sciences – Eurobiotech, Kraków, Poland, 11-14.09.2017, p. 186.
23. **Chmielewski A.G., Sun Y., Pawelec A., Zwolińska E., Witman-Zajac S.**
Overview of reduction of SO₂ and NO_x using wet scrubber and hybrid system.
10. Symposium on Vacuum Based Science and Technology, Koszalin–Kołobrzeg, Poland, 28-30.11.2017, p. 67.
24. **Cieśla K., Abramowska A., Drewnik J., Buczkowski M., Głuszewski W., Grabowska M., Nowicki A.**
The effect of composition and ionising radiation on the properties of the films formed in the starch-PVA-nanocellulose system.
Cellulosic material. Properties and industrial potential. Final Meeting in COST Action FP1205, Stockholm, Sweden, 9.03.2017, pp. 41-42.
25. **Cieśla K., Abramowska A., Drewnik J., Głuszewski W., Grabowska M.**
The effect of ionising radiation on the starch-PVA-nanocellulose films foreseen for packaging application. Active food packaging.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
26. **Cieśla K., Pandey G., Rahier H., Stiens J.**
The effect of gamma irradiation on interaction of nanocellulose with water studied by differential scanning calorimetry and mm-wave spectroscopy.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [2] p.
27. **Czajka M., Kruszewski M., Kapka-Skrzypczak L.**
Chlorpyrifos impact on preadipocytes proliferation and differentiation.
42. FEBS Congress From Molecules to Cells and Back, Jerusalem, Israel, 10-14.09.2017. The FEBS Journal, 284, Suppl. 1, 389-390 (2017).
28. **De la Fuente J.R., Cañete A., Diaz-Hernández D., Bobrowski K., Skotnicki K.**
Transiente species in the photoreduction of styrylquinoxalinone derivatives by *N*-phenylglycine studied by flash photolysis and pulse radiolysis.
14. Latin American Conference on Physical Organic Chemistry, Concón, Chile, 7-11.05.2017, p. 69.
29. **Drewnik J., Grabowska M., Cieśla K.**
Preparation and ionising radiation effect on the active starch-PVA-nanocellulose films.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
30. **Dybczyński R.**
New method for the selective determination of yttrium in the mixture of rare earth elements by ion interaction chromatography on the background of foregoing chromatographic methods for Y.
XI Polska Konferencja Chromatograficzna, Sopot/Gdańsk, Poland, 10-13.09.2017. Abstract book, p. 39.
31. **Dybczyński R., Kulisa K.**
Nowy układ do rozdzielania anionów nieorganicznych za pomocą chromatografii oddziaływania jonów (New system for the separation of inorganic anions by ion interaction chromatography).
5. Konferencja Naukowa: Monitoring i analiza wody. Chromatograficzne metody oznaczania substancji o charakterze jonowym, Toruń, Poland, 2-4.04.2017, p. 48.
32. **Dybczyński R., Kulisa K.**
Wpływ temperatury i rodzaju fazy stacjonarnej na rozdzielanie anionów nieorganicznych za pomocą chromatografii oddziaływania jonów (Effect of temperature and the kind of stationary phase on the separation of inorganic anions by ion interaction chromatography).
5. Konferencja Naukowa: Monitoring i analiza wody. Chromatograficzne metody oznaczania substancji o charakterze jonowym, Toruń, Poland, 2-4.04.2017, p. 13.
33. **Dybczyński R.S.**
Słowo wstępne – przypomnienie prawdziwego znaczenia niektórych pojęć i definicji (Foreword – reminder true meaning of some terms and definitions).
Ogólnopolska Konferencja Naukowa: Jakość w chemii analitycznej 8, Mory k. Warszawy, Poland, 22-24.11.2017, p. 6.
34. **Edgecock R., Chmielewski A., Roegner F.H., Faus-Golfe A., Oliver C., Dethier P.**
The ARIES Industrial and Societal Applications Network.

- NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
35. **Fernandes A., Antonio A.L., Rafalski A., Barreira J.C.M., Oliveira M.B.P.P., Martins A., Ferreira I.C.F.R.**
Conservation of wild mushrooms through electron beam irradiation.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
36. **Gajda D., Abramowska A., Miśkiewicz A., Kiegiel K., Filipowicz B., Zakrzewska-Kołodziej G.**
Pre-treatment of radioactive waste using destructive processes of organic compounds followed by concentration of radionuclides.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
37. **Głuszewski W.**
Maria Skłodowska-Curie prekursora metody radiacyjnej sterylizacji (Maria Skłodowska-Curie – the precursor of radiation sterilization).
XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [2] p.
38. **Głuszewski W., Stasiak A., Raszewska-Kaczor A., Kaczor D.**
Effect of polyethylene crosslinking for properties of foams.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
39. **Głuszewski W., Tran Q.K., Cortella L., Abbasova D.**
Maria Skłodowska-Curie prekursora radiacyjnych metod konserwacji obiektów o znaczeniu historycznym (Maria Skłodowska-Curie – the precursor of ionizing radiation for tangible cultural heritage conservation).
XVII Konferencja Analiza Chemiczna w Ochronie Zabytków, Warszawa, Poland, 7-8.12.2017, p. 31.
40. **Grądzka I., Sikorska K., Brzóska K.**
Interference of silver nanoparticles with tumor necrosis factor action in epithelial lens.
Proceedings of the 2. World Congress on Recent Advances in Nanotechnology (RAN'17), Barcelona, Spain, 4-6.04.2017, [2] p.
41. **Gryczka U., Migdał W., Bułka S., Chmielewska-Śmietanko D.**
Application of low energy electron beam in microbiological decontamination process.
ICARST 2017. International Conference on Applications of Radiation Science and Technology, Vienna, Austria, 24-28.04.2017, p. 323.
42. **Gryczka U., Migdał W., Bułka S., Chmielewska-Śmietanko D., Ptaszek M., Jarecka-Boncela A.**
Application of low energy electron beam in elimination of plant pathogens from ornamental bulbs.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
43. **Gumiela M., Bilewicz A., Dudek J.**
Wydzielanie technetu-99m z naświetlonej protonami tarczy molibdenowej (Separation of technetium-99m from proton irradiated molybdenum target).
ChemSession'17. XIV Warszawskie Seminarium Doktorantów Chemików, Warszawa, Poland, 9.06.2017. Streszczenia, p.85.
44. **Guzik G.P.**
Wykrywanie żywności napromieniowanej (Detection of food irradiation).
XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [3] p.
45. **Kalbarczyk P., Miśta E.A., Chajduk E., Dudek J., Duczek W., Turos A., Wyczółkowski D., Widawski M.**
Origins of silver and production of jewelery (Słuszków) and coins in early medieval Poland.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
46. **Kapka-Skrzypczak L., Męczyńska-Wielgosz S., Matysiak-Kucharek M., Wojewódzka M., Kruszewski M.**
Toxicity of binary mixtures of metal(oxide) nanoparticles and quantum dots in two human cell lines HepG2 and A549.
12. International Comet Assay Workshop, Pamplona, Spain, 29-31.08.2017. Conference guide, p. 67.

47. **Kiegiel K., Gajda D., Zakrzewska-Kołodziej G.**
Industrial wastes as a potential source of uranium.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
48. **Kiegiel K., Gajda D., Zakrzewska-Kołodziej G.**
Secondary raw materials as a potential source of uranium.
10. Annual International Conference on Sustainable Development through Nuclear Research and Education, Pitesti, Romania, 24-26.05.2017. Book of abstracts, p. 26.
49. **Kiegiel K., Miśkiewicz A., Iwińska K.**
Social aspects of the implementation of the Polish Nuclear Power Programme.
RICOMET 2017: Social and ethical aspects of decision-making in radiological risk situation, Vienna, Austria, 27-29.06.2017. Book of abstracts, p. 77.
50. **Kisała J., Szreder T., Bojanowska-Czajka A., Pogocki D., Bartosiewicz I., Kulisa K., Bobrowski K., Trojanowicz M.**
Rozkład kwasów perfluoroalkilowych pod wpływem promieniowania jonizującego (Degradation of perfluoroalkyl acids using ionizing radiation).
60. Zjazd Naukowy Polskiego Towarzystwa Chemicznego, Wrocław, Poland, 17-21.08.2017, p. 964.
51. **Kołacińska K., Chajduk E., Dudek J., Samczyński Z., Łokas E., Bojanowska-Czajka A., Trojanowicz M.**
Automation of sample processing for ICP-MS determination of ^{90}Sr radionuclide at ppq level for nuclear technology and environmental purposes.
62. Radioassay & Radiochemical Measurements Conference (RRMC), Honolulu, Hawaii, 6-10.02.2017, p. 102.
52. **Kołacińska K., Samczyński Z., Dudek J., Bojanowska-Czajka A., Trojanowicz M.**
A comparison of sorbents in optimization of a flow procedure for determination of ^{99}Tc in SIA-LOV system with ICP-MS detection.
62. Radioassay & Radiochemical Measurements Conference (RRMC), Honolulu, Hawaii, 6-10.02.2017, p. 135.
53. **Kołacińska K., Seliman A.F., Bliznyuk V.N., DeVol T.A.**
Characteristics of a new synthesized sorbent for plutonium determination in an automated flow system.
62. Radioassay & Radiochemical Measurements Conference (RRMC), Honolulu, Hawaii, 6-10.02.2017, p. 96.
54. **Kornacka E.M.**
Rola opakowań w sterylizacji radiacyjnej (The role of packaging in radiation sterilization).
XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [3] p.
55. **Kornacka E.M.**
Szczepienie radiacyjne polimerów: nieograniczone możliwości zastosowań w przemyśle i medycynie (Radiation vaccination of polymers: unlimited applications in industry and medicine).
Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 41-42.
56. **Kornacka E.M.**
Zastosowanie technik radiacyjnych w medycynie – hydrożele, implanty (Application of radiation techniques in medicine – hydrogels, implants).
Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 39-40.
57. **Korzeniowska-Sobczuk A.**
Pomiar dawek technologicznych/zapewnienie spójności pomiarowej (Measurement of technological doses / ensuring measurement traceability).
XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [2] p.
58. **Koźmiński P., Janiszewska Ł., Pruszyński M., Wąs B., Jastrzębski J., Choiński J., Stolarz A., Sitarz M., Szkliniarz K., Grobelny J., Celichowski G., Bilewicz A.**
Gold nanoparticle – conjugates as a carrier for ^{211}At in alpha particle therapy.
10. International Symposium on Targeted Alpha Therapy, Kanazawa, Japan, 30.05.-1.06.2017, p. 50.
59. **Kruszewski M., Sikorska K., Bartłomiejczyk T., Lewandowska-Siwkiewicz H., Sochanowicz B., Męczyńska S., Lankoff A., Wojewódzka M.**

- Nanoradiotherapy: Window to the world or dead end?
XXI Gliwice Scientific Meeting 2017, Gliwice, Poland, 17-18.11.2017, p. 47.
60. **Łyczko K., Łyczko M., Męczyńska-Wielgosz S., Kruszewski M., Mieczkowski J.**
Tricarbonylrhenium(I) complexes with the N-methylpyridine-2-carbothioamide ligand – experimental and calculation studies.
4. European Crystallography School, Warsaw, Poland, 2-7.07.2017. Book of abstracts, p. 59.
61. **Łyczko M., Łyczko K., Bilewicz A.**
Arsenic(III) compounds with 1,2-benzenedithiol and toluene-3,4-dithiol – synthesis, structure and spectroscopic characterization.
4. European Crystallography School, Warsaw, Poland, 2-7.07.2017. Book of abstracts, p. 60.
62. **Łyczko M., Walczak R., Dziawer Ł., Gumiela M., Gniazdowska E., Koźmiński P., Majkowska A., Pruszyński M., Krajewski S., Bilewicz A.**
Application of accelerator produced isotopes in nuclear medicine – INCT research activity.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
63. **Majkowska-Pilip A., Rius M., Bruchertseifer F., Apostolidis C., Weis M., Bonelli M., Laurenza M.**
²²⁵Ac-DOTA-substance P as a potential radiopharmaceutical for targeted alpha therapy of glioblastoma multiform.
10. International Symposium on Targeted Alpha Therapy, Kanazawa, Japan, 30.05.-1.06.2017, p. 74.
64. **Matysiak-Kucharek M., Kruszewski M., Kapka-Skrzypczak L.**
The biological activity of the silver nanoparticles to MDA-MB-436 cells.
42. FEBS Congress From Molecules to Cells and Back, Jerusalem, Israel, 10-14.09.2017. The FEBS Journal, 284, Suppl. 1, 388 (2017).
65. **Męczyńska-Wielgosz S., Kędziora A., Wojewódzka M., Kapka-Skrzypczak L., Kruszewski M.**
Comparative toxicity of silver and titanium dioxide nanoparticles, their binary mixture and silver-doped titanium dioxide nanoparticles to mammalian cells.
12. International Comet Assay Workshop, Pamplona, Spain, 29-31.08.2017. Conference guide, p. 22.
66. **Miłkowska M., Sartowska B., Starosta W.**
Sol-gel synthesis of silicon-based coatings on zirconium alloys for high temperature corrosion resistance improving.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
67. **Miśkiewicz A., Zakrzewska-Kołtuniewicz G., Antoszewski M., Plich M., Iwińska K.**
Implementation of the Polish Nuclear Power Programme – a study of socioeconomic effects.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
68. **Miśkiewicz A., Zakrzewska-Kołtuniewicz G., Pasieczna-Patkowska S., Sartowska B.**
A study of selected aspects of the membranę fouling phenomena.
International Scientific Conference – Chemical Technology and Engineering, Lviv, Ukraine, 26-30.06.2017. Book of abstracts, p. 256.
69. **Miśkiewicz A., Zakrzewska-Kołtuniewicz G., Sartowska B., Pasieczna-Patkowska S.**
Application of the radiometric method for membrane processes investigation.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
70. **Nowicki A.**
Metody badań tworzyw sztucznych poddawanych modyfikacji radiacyjnej, zmiany właściwości mechanicznych i termicznych (Methods for testing plastics modified by radiation, changes in mechanical and thermal properties).
Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 46-48.
71. **Nowicki A., Mirkowski K.**
Utwardzanie kompozytów polimerowych za pomocą promieniowania jonizującego, tworzywa samonaprawialne (Curing of polymer composites using ionizing radiation, self-healing materials).
Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, pp. 49-51.

- 72. Orelovich O., Sartowska B., Presz A.**
New kinds and properties of track membranes produced with heavy ion beam irradiation.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 73. Oszczak-Nowińska A., Fuks L.**
Substancje pochodzenia naturalnego jako sorbenty w procesie zateżenia ciekłych odpadów promieniotwórczych (Natural polysaccharides as sorbents for concentration of liquid radioactive wastes).
60. Zjazd Naukowy Polskiego Towarzystwa Chemicznego, Wrocław, Poland, 17-21.08.2017, p. 991.
- 74. Polkowska-Motrenko H., Samczyński Z., Dybczyński R.S., Chajduk E., Pyszynska M., Zuba I., Danko B., Kalbarczyk P.**
Wnioski z porównań międzylaboratoryjnych w celu certyfikacji materiałów odniesienia dla nieorganicznej analizy śladowej: tkanka śledzia MODAS-3 Herring Tissue (M-3HerTis), tkanka kormorana MODAS-4 Cormorant Tissue (M-4 CormTis), tkanka dorsza MODAS-5 Cod Tissue (M-5 CodTis) (Conclusions from interlaboratory comparisons to certify reference materials for inorganic trace analysis: MODAS-3 Herring Tissue (M-3HerTis), MODAS-4 Cormorant Tissue (M-4 CormTis), MODAS-5 Cod Tissue (M-5 CodTis)).
Ogólnopolska konferencja naukowa: Jakość w chemii analitycznej 8, Mory k. Warszawy, Poland, 22-24.11.2017, p. 20.
- 75. Pruszyński M.**
Scandium radionuclides in nuclear medicine application.
2. Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, Kraków, Poland, 4-9.06.2017, [2] p. <http://koza.if.uj.edu.pl/jagiellonian-symposium-2017/program>.
- 76. Pruszyński M., Cędrowska E., Bilewicz A., Bruchertseifer F., Morgenstern A.**
Radiochemical separation of ^{224}Ra from ^{232}U or ^{228}Th sources for $^{224}\text{Ra}/^{212}\text{Pb}/^{212}\text{Bi}$ generator.
10. International Symposium on Targeted Alpha Therapy, Kanazawa, Japan, 30.05.-1.06.2017, p. 89.
- 77. Pruszyński M., D'Huyvetter M., Cędrowska E., Lahoutte T., Bruchertseifer F., Morgenstern A.**
Preclinical evaluation of anti-HER2 2Rs15d nanobody labeled with ^{225}Ac .
10. International Symposium on Targeted Alpha Therapy, Kanazawa, Japan, 30.05.-1.06.2017, p. 34.
- 78. Przybytniak G., Kornacka E., Dąbrowska M., Zimek Z.**
Radiation induced radicals in collagen and its major residues as seen by EPR spectroscopy.
30. Miller Conference on Radiation Chemistry, Castellammare del Golfo, Sicily, Italy, 7-11.10.2017. Book of abstracts, p. 63.
- 79. Przybytniak G., Rzepna M., Sadło J.**
Effect of ionizing radiation on the properties of PBAT.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 80. Rafalski A.**
Sterylicacja radiacyjna na tle innych metod wyjąławiania (Radiation sterilization against other sterilization methods).
XIV Szkoła Sterylicacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [2] p.
- 81. Rafalski A.**
Sterylicacja radiacyjna wyrobów medycznych wykonanych z tworzyw sztucznych (Radiation sterilization of medical plastic devices).
Symposium „Techniki radiacyjne w przetwórstwie tworzyw sztucznych”, Warszawa, Poland, 8-9.06.2017, p. 43-45.
- 82. Rafalski A.**
Wiadomości niezbędne dla klientów Stacji Sterylicacji Radiacyjnej (Information necessary for customers of the Radiation Sterilization Station).
XIV Szkoła Sterylicacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [2] p.
- 83. Rode J.E., Łyczko K., Jawiczuk M., Kawęcki R., Stańczyk W., Jaglińska A., Dobrowolski J.Cz.**
The pattern of $n(\text{C}=\text{O})$ VCD bands of isoindolinones in solid phase.
XIV International Conference on Molecular Spectroscopy: From Molecules to Functional Materials, Kraków-Białka Tatrzańska, Poland, 3-7.09.2017, p. 324.

- 84. Rogowski M., Smoliński T.**
Radiotracer methods for ore and flotation tailing leaching.
ICARST 2017. International Conference on Applications of Radiation Science and Technology, Vienna, Austria, 24-28.04.2017, p. 246.
- 85. Rogowski M., Smoliński T., Pyszynska M., Chmielewski A.G.**
Application of radiotracers for copper leaching from flotation tailing.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 86. Rzepna M.**
Wyznaczanie dawki sterylizacyjnej (Determination of the sterilizing dose).
XIV Szkoła Sterylizacji i Mikrobiologicznej Dekontaminacji Radiacyjnej, Warszawa, Poland, 19-20.10.2017, [3] p.
- 87. Rzepna M., Przybytniak G.**
Skutki działania promieniowania jonizującego na biodegradowalny kopoliester PBAT (The influence of ionizing radiation on biodegradable PBAT copolyester).
ChemSession'17. XIV Warszawskie Seminarium Doktorantów Chemików, Warszawa, Poland, 9.06.2017. Streszczenia, p. 157.
- 88. Sartowska B., Starosta W.**
Accident tolerant materials ideas and perspectives.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 89. Seliman A.F., Kołacińska K., Husson S.M., DeVol T.A.**
Actinides complexation with diglycolamide compounds: the effect of alkyl substituents and polymerizable form.
62. Radioassay & Radiochemical Measurements Conference (RRMC), Honolulu, Hawaii, 6-10.02.2017, p. 97.
- 90. Sikorska K., Grądzka I., Wasyk I.**
The effect of silver nanoparticles on the scavenger receptor Scara-1 on microglia.
Proceedings of the 2. World Congress on Recent Advances in Nanotechnology (RAN'17), Barcelona, Spain, 4-6.04.2017, [1] p.
- 91. Skotnicki K., Taras-Goslinska K., Bobrowski K.**
Three-electron bonded sulfur-centered radicals from aromatic heterocycles containing nitrogen.
30. Miller Conference on Radiation Chemistry, Castellammare del Golfo, Sicily, Italy, 7-11.10.2017. Book of abstracts, p. 67.
- 92. Smoliński T., Rogowski M., Pyszynska M., Chmielewski A.G.**
Application of ^{64}Cu radiotracer for investigation of leaching copper ore.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 93. Smoliński T., Rogowski M., Pyszynska M., Chmielewski A.G.**
Ługowanie miedzi z odpadów poflotacyjnych z wykorzystaniem izotopu ^{64}Cu jako radioznacznika (Copper leaching process from flotation tailing with using ^{64}Cu as a radiotracer).
ChemSession'17. XIV Warszawskie Seminarium Doktorantów Chemików, Warszawa, Poland, 9.06.2017. Streszczenia, p. 164.
- 94. Smoliński T., Wojtowicz P., Chmielewski A.G.**
Synthesis method of multimodal radiotracers for industrial processes and environmental research.
ICARST 2017. International Conference on Applications of Radiation Science and Technology, Vienna, Austria, 24-28.04.2017, p. 441.
- 95. Starosta W., Barlak M., Kochmańska A., Kołodziejczak P., Miłkowska M., Rydzewski M., Sartowska B., Smolik J., Tomassi P., Waliś L.**
The studies on zirconium alloys surface layer properties modifications for the enhancement of their high temperature oxidation resistance.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 96. Sudlitz M., Zimek Z., Chmielewski A.G., Głuszewski W.**
Irradiation of wastewater from solvay process.

- NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 97. Sun Y., Chmielewski A.G.**
Radiation technology application in environmental protection.
ICARST 2017. International Conference on Applications of Radiation Science and Technology, Vienna, Austria, 24-28.04.2017, p. 109.
- 98. Trojanowicz M., Bojanowska-Czajka A., Kciuk G., Kulisa K., Bartosiewicz I.**
Radiolytic degradation of selected perfluorinated surfactants by gamma and electron beam irradiation for environmental protection.
27. Annual International Conference on Soil, Water, Energy, and Air, San Diego, USA, 20-23.03.2017. Abstract book, p. 96.
- 99. Trojanowicz M., Kołacińska K., Chajduk E., Dudek J.**
Multicomponent radionuclide determinations in flow systems for monitoring of nuclear operation and safety.
21. International Conference on Flow Injection Analysis and Related Techniques, Saint Petersburg, Russia, 3-8.09.2017. Book of abstracts, p. 21.
- 100. Walczak R., Bilewicz A., Misiak R., Pruszyński M., Choiński J., Sitarz M., Stolarz A., Jastrzębski J.**
Cyclotron production of theranostic pair radionuclides ^{43}Sc - ^{47}Sc on calcium targets.
22. International Symposium on Radiopharmaceutical Sciences (ISRS 2017), Dresden, Germany, 14-19.05.2017. Journal of Labelled Compounds and Radiopharmaceuticals, 60, Suppl. 1, S24 (2017).
- 101. Walczak R., Pruszyński M., Misiak R., Bilewicz A.**
Radionuklidy skandiu dla radiofarmaceutyków teranostycznych (Scandium radionuclides for theranostic radiopharmaceuticals).
ChemSession'17. XIV Warszawskie Seminarium Doktorantów Chemików, Warszawa, Poland, 9.06.2017. Streszczenia, p. 178.
- 102. Wasilewska M., Majkowska-Pilip A., Bilewicz A., Lankoff A.**
Nanozeolit NaA jako nośnik izotopu ^{223}Ra w celowanej terapii nowotworowej (Nanozeolite NaA labeled with radioisotope ^{223}Ra for targeted alpha therapy).
60. Zjazd Naukowy Polskiego Towarzystwa Chemicznego, Wrocław, Poland, 17-21.08.2017, [1] p.
- 103. Wasilewska M., Majkowska-Pilip A., Bilewicz A., Lankoff A.**
Nanozeolite LTA labeled with ^{223}Ra for targeted alpha therapy.
ISSON17. International Summer Schools on Nanosciences & Nanotechnologies, Organic Electronics & Nanomedicine, Thessaloniki, Greece, 1-8.07.2017, p. 32.
- 104. Wasilewska M., Majkowska-Pilip A., Bilewicz A., Lankoff A.**
Optymalizacja metody otrzymywania NaA nanozeolitu oraz jego charakterystyka (Synthesis of NaA nanozeolite and characterization).
ChemSession'17. XIV Warszawskie Seminarium Doktorantów Chemików, Warszawa, Poland, 9.06.2017. Streszczenia, p. 179.
- 105. Wójcik M., Chmielewska D., Migdał W.**
Electron beam for preservation of water-damaged paper.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, p. 85.
- 106. Wójcik M., Chmielewska D., Migdał W.**
Wpływ promieniowania jonizującego na właściwości optyczne papieru (Influence of ionizing radiation on the paper optical properties).
ChemSession'17. XIV Warszawskie Seminarium Doktorantów Chemików, Warszawa, Poland, 9.06.2017. Streszczenia, p. 188.
- 107. Wójcik M., Chmielewska D., Migdał W., Sadło J.**
Wpływ promieniowania jonizującego na właściwości różnych typów papieru po dekontaminacji mikrobiologicznej (Effect of ionizing radiation on the properties of the different kinds of paper after microbiological decontamination).
XVII Analiza Chemiczna w Ochronie Zabytków, Warszawa, Poland, 7-8.12.2017, p. 50.
- 108. Zakrzewska-Kołtuniewicz G.**
Water management in nuclear power plant using advanced low-temperature systems.
Panta Rhei. 10th World Congress of EWRA on Water Resources and Environment, 5-9 July 2017, Athens, Greece. Eds. G. Tsakiris, V.A. Tsihrintzis, H. Vangelis, D. Tigkas. European Water Resources Association, Athens 2017, p. 232.

- 109. Zimek Z.**
Economic evaluation of radiation processing with high intensity X-rays.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.
- 110. Zimek Z., Roman K., Długoń S.**
Electron accelerator for R&D study and radiation processing.
ICARST 2017. International Conference on Applications of Radiation Science and Technology, Vienna, Austria, 24-28.04.2017, p. 359.
- 111. Zuba I., Polkowska-Motrenko H.**
Podstawowa procedura pomiarowa odniesienia RNAA (metoda definitywna) oznaczania chromu w materiałach biologicznych (The primary reference RNAA procedure (definitive method) for the determination of chromium in biological materials).
Ogólnopolska Konferencja Naukowa: Jakość w chemii analitycznej 8, Mory k. Warszawy, Poland, 22-24.11.2017, p. 10.
- 112. Zwolińska E., Chmielewski A.G., Licki J., Sun Y., Zimek Z., Bułka S.**
Usuwanie tlenków siarki i azotu za pomocą metody hybrydowej wykorzystującej wiązkę elektronów (The removal of NO_x and SO₂ from exhaust gases using a hybrid electron beam method).
ChemSession'17. XIV Warszawskie Seminarium Doktorantów Chemików, Warszawa, Poland, 9.06.2017. Streszczenia, p. 198.
- 113. Zwolińska E., Sun Y., Chmielewski A.G., Licki J., Pawelec A., Bułka S., Zimek Z.**
The removal of NO_x and SO₂ from exhaust gases using a hybrid electron beam method.
NUTECH-2017. International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017, [1] p.

SUPPLEMENT LIST OF THE PUBLICATIONS IN 2016

- 1. Cędrowska E., Łyczko M., Piotrowska A., Bilewicz A., Stolarz A., Trzcńska A., Szkliniarz K., Wąs B.**
Silver impregnated nanoparticles of titanium dioxide as carriers for ²¹¹At.
Radiochimica Acta, 104, 4, 267-275 (2016).
- 2. Kunicki-Goldfinger J., Freestone I.C., McDonald I., Hobot J.A., Gilderdale-Scott H., Ayers T.**
Technology, production and chronology of red window glass in the Medieval period – rediscovery of a lost technology, Journal of Archaeological Science, 41, 2014, pp. 89-105.
In: Medieval archaeology. Ed. R. Gilchrist, G.L. Watson. (Critical concepts in archaeology). Vol. 3: Medieval life. Chapter 55. Routledge, New York 2016.
- 3. Rode J.**
Raman optical activity (ROA).
In: Vibrational spectroscopy. From theory to practice. Ed. K. Malek. PWN, Warszawa 2016, pp. 57-67.
- 4. Zhao L., Dudek J., Polkowska-Motrenko H., Chmielewski A.G.**
A magnetic nanosorbent for cesium removal in aqueous solutions.
Radiochimica Acta, 104, 6, 423-433 (2016).

NUKLEONIKA THE INTERNATIONAL JOURNAL OF NUCLEAR RESEARCH

EDITORIAL BOARD

Andrzej G. Chmielewski (Editor-in-Chief, Poland), **Krzysztof Andrzejewski** (Poland), **Henryk Anglart** (Sweden), **Jacqueline Belloni** (France), **Grażyna Bystrzejewska-Piotrowska** (Poland), **Hilmar Förstel** (Germany), **Andrzej Gałkowski** (Poland), **Evgeni A. Krasavin** (Russia), **Marek Lankosz** (Poland), **Stanisław Latek** (Poland), **Dan Meisel** (USA), **Jacek Michalik** (Poland), †**Robert H. Schuler** (USA), **Christian Streffer** (Germany), **Irena Szumiel** (Poland), **Alexander Van Hook** (USA), **Bożena Bursa** (secretary)

CONTENTS OF NO. 1/2017

1. COREDIV modelling of JET ILW discharges with different impurity seeding: nitrogen, neon, argon and krypton
I. Ivanova-Stanik, R. Zagórski and JET contributors
2. Thermal stability of the krypton Hall effect thruster
A. Szelecka, J. Kurzyna, I. Bourdain
3. A new concept of fusion neutron monitoring for PF-1000 device
S. Jednorog, E. Laszyna, B. Bienkowska, A. Ziolkowski, M. Paduch, K. Szewczak, K. Mikszuta, K. Malinowski, M. Bajdel, P. Potrykas
4. Thermal-hydraulic analysis of LTS cables for the DEMO TF coil using simplified models
M. Lewandowska, A. Dembkowska
5. Measurements of doses from photon beam irradiation and scattered neutrons in an anthropomorphic phantom model of prostate cancer: a comparison between 3DCRT, IMRT and tomotherapy
A. Kowalik, W. Jackowiak, J. Malicki, M. Skórska, M. Adamczyk, E. Konstanty, T. Piotrowski, K. Polaczek-Grelik
6. Investigation of ^{99}Mo potential production via UO_2SO_4 liquid target irradiation in a 5 MW nuclear research reactor
Z. Gholamzadeh, S.M. Mirvakili, A. Davari, M. Alizadeh, A. Joz-Vaziri
7. Precise determination of HPGe detector efficiency for gamma spectrometry measurements of environmental samples with variable geometry and density
M. Barrera, M. Casas-Ruiz, J.J. Alonso, J. Vidal
8. Degradation and detoxification of 2-chlorophenol aqueous solutions using ionizing gamma radiation
A.A. Basfar, M. Muneer, O.A. Alsager

CONTENTS OF No. 2/2017

Proceedings of the 11th All-Polish Seminar on Mössbauer Spectroscopy OSSM 2016, Radom-Turno, Poland, 19-22 June 2016

1. In memoriam – Prof. Andrzej Hryniewicz
2. Synthesis and characterization of iron oxide magnetic nanoparticles
Z. Surowiec, M. Budzyński, K. Durak, G. Czernel
3. Mössbauer and magnetic studies of FeCoNiCuNbSiB nanocrystalline alloys
A. Grabias, V. Basykh, J. Ferenc, G. Cieślak, T. Kulik, M. Kopcewicz
4. Microstructure and magnetic properties of amorphous $\text{Fe}_{51}\text{Co}_{12}\text{Si}_{16}\text{B}_8\text{Mo}_5\text{P}_8$ alloy
M. Hasiak, M. Migliorini, N. Amini, M. Bujdoš

5. Features of the structural and magnetic properties of $\text{Pb}(\text{Ti}_x\text{Zr}_{1-x}\text{O}_3)\text{-NiFe}_{1.98}\text{Co}_{0.02}\text{O}_4$ in the polarized state
V. Baev, M. Budzyński, V. Laletin, V. Mitsiuk, N. Poddubnaya, Z. Surowiec, K. Yanushkevich
6. Structural properties of Mn-substituted hercynite
I. Jastrzębska, W. Bodnar, K. Witte, E. Burkel, P. Stoch, J. Szczerba
7. ^{57}Fe Mössbauer spectroscopy investigations of iron phase composition in fluidized beds from the ELCHO power plant in Chorzów, Poland
M. Kądziołka-Gaweł, D. Smolka-Danielowska
8. Thermodynamic properties of dilute Co-Fe solid solutions studied by ^{57}Fe Mössbauer spectroscopy
R. Konieczny, R. Idczak
9. Compositional dependence of hyperfine interactions and magnetoelectric coupling in $(\text{BiFeO}_3)_x\text{-}(\text{BaTiO}_3)_{1-x}$ solid solutions
K. Kowal, P. Guzdek, M. Kowalczyk, E. Jartych
10. Spin reorientation process in $\text{Tm}_{2-x}\text{Ho}_x\text{Fe}_{14}\text{B}$ – analysis of conical arrangement based on Mössbauer spectra
P.M. Kurzydło, A.T. Pędziwiatr, B.F. Bogacz, J. Przewoźnik, D. Oleszak
11. Mössbauer and heat capacity studies of ErZnSn_2
K. Łątka, J. Przewoźnik, J. Żukrowski, Yu. Verbovytsky, A.P. Gonçalves
12. Hyperfine interactions and some thermomagnetic properties of amorphous $\text{FeZr}(\text{Cr})\text{NbBCu}$ alloys
A. Łukiewska, J. Olszewski
13. Preliminary results of ^{57}Fe Mössbauer spectroscopy of metamict samarskite after one-hour high temperature annealing in argon
D. Malczewski, A. Grabias
14. Identification of iron-bearing minerals in basalts and pillow lavas of the Kaczawa Mountains using ^{57}Fe Mössbauer spectroscopy
D. Malczewski, M. Jeleń, J. Żaba, A. Błachowski, K. Ruebenbauer, M. Dziurawicz
15. Effect of BaTiO_3 concentration on structural and magnetic properties of mechanically activated $\text{BiFeO}_3\text{-BaTiO}_3$ system
B. Malesa, T. Pikula, D. Oleszak, E. Jartych
16. A comparative study of hyperfine interactions in Aurivillius compounds prepared by mechanical activation and solid-state sintering
M. Mazurek, E. Jartych
17. An example of the application of Mössbauer spectroscopy for determination of concentration of iron in lyophilized brain tissue
P. Rzepecka, P. Duda, J. Giebułtowicz, M. Sochacka, A. Friedman, J. Gałązka-Friedman
18. Synthesis and characterization of AgFeO_2 delafossite with non-stoichiometric silver concentration
K. Siedliska, T. Pikula, D. Chocyk, E. Jartych
19. Metallurgical quality evaluation of the wind turbine main shaft 42CrMo4 steel: microscopic and Mössbauer studies
Z. Siemiątkowski, M. Gzik-Szumiata, T. Szumiata, M. Rucki, R. Martynowski
20. Crystal structure and Mössbauer effect in multiferroic $0.5\text{BiFeO}_3\text{-}0.5\text{Pb}(\text{Fe}_{0.5}\text{Ta}_{0.5})\text{O}_3$ solid solution
A. Stoch, J. Maurin, P. Stoch, J. Kulawik, D. Szwagierczak
21. Investigation of magnetite Fe_3O_4 nanoparticles for magnetic hyperthermia
Z. Surowiec, A. Miaskowski, M. Budzyński
22. Iron-containing phases in metallurgical and coke dusts as well as in bog iron ore
T. Szumiata, M. Rachwał, T. Magiera, K. Brzózka, M. Gzik-Szumiata, M. Gawroński, B. Górka, J. Kyzioł-Komosińska

CONTENTS OF No. 3/2017

1. Two new separation schemes for the group isolation of rare earth elements (REE) from biological and other matrices and their determination by ICP-MS, NAA and chromatographic methods
R.S. Dybczyński, Z. Samczyński, I. Bartosiewicz, K. Kulisa, H. Polkowska-Motrenko, M. Pyszynska, I. Zuba

2. Ion exchange investigation for recovery of uranium from acidic pregnant leach solutions
B. Danko, R.S. Dybczyński, Z. Samczyński, D. Gajda, I. Herdzik-Koniecko, G. Zakrzewska-Końtuniewicz, E. Chajduk, K. Kulisa
3. Characterization of some modern scintillators recommended for use on large fusion facilities in γ -ray spectroscopy and tomographic measurements of γ -emission profiles
P. Sibczynski, A. Broslawski, A. Gojska, V. Kiptily, S. Korolczuk, R. Kwiatkowski, S. Mianowski, M. Moszyński, J. Rządkiwicz, L. Swiderski, A. Szydłowski, Z. Zychor
4. Deconvolution of alpha spectra from air filters applied for measurements of the short-lived radon progeny concentration
K. Skubacz
5. Kinetic modelling of NO heterogeneous radiation-catalytic oxidation on the TiO₂ surface in humid air under the electron beam irradiation
H. Nichipor, Y. Sun, A.G. Chmielewski

CONTENTS OF No. 4/2017

Proceedings of the International Conference on Applications of Radiation Science and Technology (ICARST-2017), 24-28 April 2017, Vienna, Austria

1. Preface
N. Ramamoorthy
2. Application of gamma radiation and physicochemical treatment to improve the bioactive properties of chitosan extracted from shrimp shell
J. Aktar, Z. Hasan, T. Afroz, Harun-or-Rashid, K. Pramanik
3. Radiation processing for cultural heritage preservation – Romanian experience
I.V. Moise, M. Ene, C.D. Negut, M. Cutrubinis, M.M. Manea
4. Radiation activities and application of ionizing radiation on cultural heritage at ENEA Calliope gamma facility (Casaccia R.C., Rome, Italy)
S. Baccaro, A. Cemmi
5. Chemical reduction of nitrate by zerovalent iron nanoparticles adsorbed radiation-grafted copolymer matrix
S.Y. Ratnayake, A.K. Ratnayake, D. Schild, E. Maczka, E. Jartych, J. Luetzenkirchen, M. Kosmulski, R. Weerasooriya
6. Flow dynamics study of catalyst powder in catalytic cracking unit for troubleshooting
V. Yelgaonkar, G. Agrahari, D. Vikrant, R. Prasanna, B.K. Pathak
7. Performance evaluation of a rectifier column using gamma column scanning
D.D. Aquino, J.P. Mallillin, R.F. Sulit, F.C. Hila, I.A.A. Nuñez, A.D.M. Bulos
8. Radiotracer investigation of a pulp and paper mill effluent treatment plant
M. Sakar, V.K. Sangal, H. Bhunia, P.K. Bajpai, H.J. Pant, V.K. Sharma, A. Kumar, A.K. Naithani
9. Technetium-99m: From nuclear medicine applications to fine sediment transport studies
J.V. Bandeira, I.H. Salim
10. Development of the irradiation facility SIBO INRA/Tangier, Morocco by upgrading cobalt-60 in a temporary pool and enhancing safety and control features
M. Mohammed, C. Mouad, G. Amina
11. Erratum to “Preliminary results of ⁵⁷Fe Mössbauer spectroscopy of metamict samarskite after one-hour high temperature annealing in argon” [Nukleonika 2017;62(2):141-144]
D. Malczewski, A. Grabias

Information

INSTITUTE OF NUCLEAR CHEMISTRY AND TECHNOLOGY
NUKLEONIKA

Dorodna 16, 03-195 Warszawa, Poland

phone: +48 22 504 11 32, fax: +48 22 811 15 32, e-mail: nukleon@ichtj.waw.pl

Full texts are available on-line at <http://www.nukleonika.pl>

POSTĘPY TECHNIKI JĄDROWEJ

EDITORIAL BOARD

Stanisław Latek (Editor-in-Chief), **Wojciech Głuszewski**, **Maria Kowalska**, **Łukasz Sawicki**, **Marek Rabiński**, **Edward Rurarz**, **Elżbieta Zalewska**

CONTENTS OF No. 1/2017

1. Promieniujemy na całą gospodarkę – polski przemysł dla elektrowni jądrowej (Radiate for all the economy – Polish industry for nuclear plant)
S. Latek
2. Inne wrażenia po konferencji „Polski przemysł dla elektrowni jądrowej” (Other impressions after the Conference “Polish industry for nuclear power plant”)
A. Mikulski
3. Low energy electron beams for industrial and environmental applications / Niskoenergetyczne wiązki elektronów do zastosowań w przemyśle i ochronie środowiska
V. Skarda
4. Akceleratory elektronów stosowane w technice radiacyjnej (niezawodność, aspekty ekonomiczne) (Accelerators of electrons applied in radiation processing (reliability, economic aspects))
Z. Zimek
5. Modyfikowane radiacyjnie kompozyty polimerowe w ochronie przed promieniowaniem mikrofalowym (Radiation modified polymer composites in protection from microwave radiation)
W. Głuszewski, R. Kubacki, M. Rajkiewicz
6. Praca reaktora badawczego MARIA w 2016 roku (Research reactor MARIA operation in 2016)
A. Gołąb, E. Borek-Kruszewska
7. MUTSU
K. Rzymkowski
8. Uwarunkowania polityki energetycznej Unii Europejskiej i odniesienie do Polski – wykład prof. Jerzego Buzka (European Union energy policy and its relevance for Poland – lecture by Prof. Jerzy Buzek)
D.W. Kulczyński

CONTENTS OF No. 2/2017

1. Maria Skłodowska-Curie i powstanie Instytutu Radowego w Warszawie (Maria Skłodowska-Curie and the establishment of the Radium Institute in Warsaw)
M. Sobieszczak-Marciniak
2. 85. Rocznica otwarcia Instytutu Radowego (85th Anniversary of the opening of the Radium Institute in Warsaw)
M. Sobieszczak-Marciniak
3. ICARST 2017
S. Latek
4. Philosophical and social aspects of the cold fusion controversy/Filozoficzne i społeczne aspekty nieporozumień na temat zimnej fuzji
L. Kowalski
5. “Site evaluation for nuclear installations”, IAEA Safety Standards, Safety Requirements, No. NS-R-3 (Rev. 1), Vienna, 2016
T. Musiałowicz
6. Wybrane aspekty procesów inżynierii chemicznej od wydobycia rud uranowych do wzbogacania uranu (Selected aspects of chemical engineering processes from the mining of uranium to the uranium enrichment)
M.M. Szolucha

7. Bezpośrednia radiografia cyfrowa (Digital direct radiography)
G. Jezierski

CONTENTS OF No. 3/2017

1. O konieczności zmiany paradygmatu ochrony radiologicznej – komentarz SARI – Stowarzyszenia Uczonych dla Rzetelnej Informacji o Promieniowaniu (On the need to replace the present paradigm of radiation protection – comments by SARI – Scientists for Accurate Radiation Information)
L. Dobrzyński, M.K. Janiak, A. Strupczewski, M. Waligórski
2. 50 lat działalności Polskiego Towarzystwa Badań Radiacyjnych im. Marii Skłodowskiej-Curie: 1967-2017 (50 Years of activity of the Polish Radiation Research Society memorial to Maria Skłodowska-Curie: 1967-2017)
S. Sommer
3. Elektrownia jądrowa w Polsce – odsłona sierpień 2017 (Nuclear power plant in Poland – status in August 2017)
A. Mikulski
4. Akcelerator IntraLine-IOERT do radioterapii śródoperacyjnej (The IOERT IntraLine accelerator for intraoperative radiotherapy)
J. Prac, A. Syntfeld-Każuch
5. 150-lecie urodzin Marii Skłodowskiej-Curie, dwukrotnej laureatki Nagrody Nobla (w 1903 r. i w 1911 r.) (150 Years from nativity of Madame Maria Skłodowska-Curie, twice winner of the Nobel Prize (in 1903 and 1911))
E. Rurarz, M. Sobieszczak-Marciniak

CONTENTS OF No. 4/2017

1. Irena Joliot-Curie, genialna córka genialnej matki – w 120 rocznicę urodzin (Irene Joliot-Curie, brilliant daughter of brilliant mother – on the 120th anniversary of the birth)
M. Sobieszczak-Marciniak
2. W poszukiwaniu seryjnie produkowanego reaktora XXI wieku (In the search for mass produced reactor of the twenty first century)
D.W. Kulczyński
3. Basen wypalonego paliwa (Spent fuel pool)
K. Rzymkowski
4. Chemia radiacyjna jako źródło unikatowych technologii syntezy i modyfikacji polimerów (Radiation chemistry as a source of unique technologies of synthesis and modification of polymers)
W. Głuszewski

Information

INSTITUTE OF NUCLEAR CHEMISTRY AND TECHNOLOGY
POSTĘPY TECHNIKI JĄDROWEJ
Dorodna 16, 03-195 Warszawa, Poland
phone: +48 22 504 12 48, fax: +48 22 811 15 32, e-mail: PTJ-redakcja@ichtj.waw.pl
www.ptj.waw.pl

THE INCT PATENTS AND PATENT APPLICATIONS IN 2017

PATENTS

1. Sposób selektywnego wydzielenia uranu i protaktynu z materiału zawierającego tor (A selective extraction of uranium and protactinium from material containing thorium)
P. Kalbarczyk, H. Polkowska-Motrenko, E. Chajduk
Polish Patent 226415
2. Sposób i układ transportu i mieszania zawiesiny biomasy w hydrolizerze i w fermentorze (Method and system of transferring and mixing of a biomass slurry in a hydrolyser and fermenter)
A.G. Chmielewski, A. Kryłowicz, J. Usidus, K. Chrzanowski
Polish Patent
3. Kompozytowy wymiennicz jonowy, zwłaszcza do sorpcji radioizotopów Sr-85, Co-60, Zn-65 i sposób jego wytwarzania (Composite ion exchanger for adsorption of Sr-85, Co-60, Zn-65 and method for its preparation)
B. Filipowicz, B. Bartoś, M. Łyczko, K. Łyczko, A. Bilewicz
Polish Patent
4. A process for the preparation of uranium dioxide with spherical and irregular grains
A.G. Chmielewski, A. Deptuła, M. Brykała, W. Łada, D. Wawszczak, T. Olczak
European Patent EP2316794
5. Method of dissolution of thorium oxide
K. Łyczko, M. Łyczko, I. Herdzik, B. Zielińska
European Patent EP2397443
6. A process for the preparation of uranium dioxide with spherical and irregular grains
A.G. Chmielewski, A. Deptuła, M. Brykała, W. Łada, D. Wawszczak, T. Olczak
Ukrainian Patent UK104857

PATENT APPLICATIONS

1. Sposób sorpcji wieloskładnikowych metali ziem rzadkich (The sorption method of multicomponent rare earth metals from aqueous solutions)
O. Roubinek
Polish Patent Application P-421860
2. Sposób redukcji wysokich stężeń tlenków azotu w gazach odlotowych z wysokoprężnych silników Diesla (A method of reducing high concentrations of nitrogen oxides in the exhaust gases from diesel engines)
A.G. Chmielewski, J. Licki, Y. Sun, E. Zwolińska, Z. Zimek, A. Błocka
Polish Patent Application P-420468
3. Sposób ługowania metali z pomiedziowych odpadów poflotacyjnych z pirometalurgicznej metody produkcji miedzi (Leaching of metals from post-flotation copper waste from the pyrometallurgical process of copper production)
T. Smoliński, M. Rogowski, M. Pyszynska, A.G. Chmielewski
Polish Patent Application
4. Sposób redukcji wysokich stężeń tlenków azotu w gazach odlotowych z wysokoprężnych silników Diesla (A method of reducing high concentrations of nitrogen oxides in the exhaust gases from diesel engines)
A.G. Chmielewski, J. Licki, Y. Sun, E. Zwolińska, Z. Zimek, A. Błocka
European Patent Application

CONFERENCES ORGANIZED AND CO-ORGANIZED BY THE INCT IN 2017

1. SEMINAR ERASMUS+ KA1, 22-26 MAY 2017, WARSZAWA, POLAND

Organized by the Institute of Nuclear Chemistry and Technology

Organizer: Yongxia Sun, Ph.D., D.Sc., professor in INCT

2. DISSEMINATION OF THE TEXTBOOK "APPLICATIONS OF IONIZING RADIATION IN MATERIALS PROCESSING" IN THE FRAME OF THE PROJECT ENTITLED "JOINT INNOVATIVE TRAINING AND TEACHING/LEARNING PROGRAM IN ENHANCING DEVELOPMENT AND TRANSFER KNOWLEDGE OF APPLICATION OF IONIZING RADIATION IN MATERIALS PROCESSING" OF ERASMUS+ KA2 PROGRAMME, 25 MAY 2017, WARSZAWA, POLAND

Organized by the Institute of Nuclear Chemistry and Technology; Centre for Innovation and Technology Transfer Management, Warsaw University of Technology

Organizing Committee: Yongxia Sun, Ph.D., D.Sc., professor in INCT, Grażyna Przybytniak, Ph.D., D.Sc., professor in INCT

3. SYMPOZJUM „TECHNIKI RADIACYJNE W PRZETWÓRSTWIE TWORZYW SZTUCZNYCH” (SYMPOSIUM “RADIATION TECHNIQUES IN PLASTICS PROCESSING”), 8-9 JUNE 2017, WARSZAWA, POLAND

Organized by the Institute of Nuclear Chemistry and Technology

Organizing Committee: Ewa M. Kornacka, Ph.D., Wojciech Głuszewski, Ph.D., Andrzej Nowicki, Ph.D., Magdalena Rzepna, M.Sc.

4. SUMMER SCHOOL “ADVANCED APPLICATION OF ELECTRON BEAM ACCELERATORS” IN THE FRAME OF THE PROJECT ENTITLED “ACCELERATOR RESEARCH AND INNOVATION FOR EUROPEAN SCIENCE AND SOCIETY” (ARIES), 19-23 JUNE 2017, WARSZAWA, POLAND

Organized by the Institute of Nuclear Chemistry and Technology, International Atomic Energy Agency

Organizing Committee: Sunil Sabharwal, Ph.D., Prof. Andrzej G. Chmielewski, Ph.D., D.Sc., Zbigniew Zimek, Ph.D.

5. DISSEMINATION OF THE TEXTBOOK “APPLICATIONS OF IONIZING RADIATION IN MATERIALS PROCESSING” IN THE FRAME OF THE PROJECT ENTITLED “JOINT INNOVATIVE TRAINING AND TEACHING/LEARNING PROGRAM IN ENHANCING DEVELOPMENT AND TRANSFER KNOWLEDGE OF APPLICATION OF IONIZING RADIATION IN MATERIALS PROCESSING” OF ERASMUS+ KA2 PROGRAMME, 23 JUNE 2017, WARSZAWA, POLAND

Organized by the Institute of Nuclear Chemistry and Technology, International Atomic Energy Agency

Organizing Committee: Yongxia Sun, Ph.D., D.Sc., professor in INCT, Sunil Sabharwal, Ph.D.

6. SEMINARIUM „PROGRAM JĄDROWY W POLSCE – ANALIZA SPOŁECZNO-EKONOMICZNA” W RAMACH PROJEKTU “BADANIE SPOŁECZNYCH I SPOŁECZNO-EKONOMICZNYCH EFEKTÓW WDRAŻANIA POLSKIEGO PROGRAMU ENERGETYKI JĄDROWEJ PRZY UŻYCIU NOWEJ METODOLOGII” (SEMINAR “NUCLEAR POWER PROGRAMME IN POLAND – SOCIO-ECONOMIC ANALYSIS” IN THE FRAME OF THE IAEA COORDI-

NATED PROJECT “STUDYING THE SOCIAL AND SOCIO-ECONOMIC EFFECTS OF THE IMPLEMENTATION OF THE POLISH NUCLEAR POWER PROGRAMME USING NEW METHODOLOGY”), 25 AUGUST 2017, WARSZAWA, POLAND

Organized by the Institute of Nuclear Chemistry and Technology

Organizing Committee: Agnieszka Miśkiewicz, Ph.D., Prof. Grażyna Zakrzewska-Kołtuniewicz, Ph.D., Dorota Gajda, M.Sc.

7. NUTECH-2017 INTERNATIONAL CONFERENCE ON DEVELOPMENTS AND APPLICATIONS OF NUCLEAR TECHNOLOGIES, 10-13 SEPTEMBER 2017, KRAKÓW, POLAND

Organized by the Faculty of Energy and Fuels, AGH University of Science and Technology; Faculty of Physics and Applied Computer Science, AGH University of Science and Technology; Foundation for AGH University of Science and Technology; Institute of Nuclear Chemistry and Technology; Ministry of Energy; Ministry of Science and Higher Education; National Atomic Energy Agency; Polish Nuclear Society; International Atomic Energy Agency

Organizing Committee: Prof. Marek Lankosz, Ph.D., D.Sc., Prof. Andrzej G. Chmielewski, Ph.D., D.Sc., Prof. Kazimierz Różański, Ph.D., D.Sc., Jakub Nowak, Ph.D., Leszek Furman, Ph.D., Lucyna Samek, Ph.D., Marek Ciechanowski, Ph.D., Joanna Dudała, Ph.D., Paweł Wrobel, Ph.D., Jerzy Cetnar, Ph.D., D.Sc., professor in AGH, Mikołaj Oettingen, Ph.D., Paweł Gajda, Ph.D., Przemysław Stanisław, Ph.D., Prof. Grażyna Zakrzewska-Kołtuniewicz, Ph.D., D.Sc., Wojciech Migdał, Ph.D., D.Sc., professor in INCT

8. XIV SZKOŁA STERYLIZACJI I MIKROBIOLOGICZNEJ DEKONTAMINACJI RADIACYJNEJ (XIV TRAINING COURSE ON RADIATION STERILIZATION AND HYGIENIZATION), 19-20 OCTOBER 2017, WARSZAWA, POLAND

Organized by the Institute of Nuclear Chemistry and Technology

Organizing Committee: Zbigniew Zimek, Ph.D., Andrzej Rafalski, Ph.D., Wojciech Głuszewski, Ph.D., Magdalena Rzepna, M.Sc.

9. KONFERENCJA NAUKOWA „WYBRANE ZAGADNIENIA ANALIZY ŚLADOWEJ” Z OKAZJI JUBILEUSZU 60-LECIA PRACY W IBJ-ICHTJ PROF. DR. HAB. RAJMUNDA S. DYBCZYŃSKIEGO (SCIENTIFIC CONFERENCE “SELECTED PROBLEMS OF TRACE ANALYSIS” ON THE OCCASION OF THE 60th ANNIVERSARY OF WORK OF PROF. RAJMUND S. DYBCZYŃSKI AT THE INR-INCT), 5 DECEMBER 2017, WARSZAWA, POLAND

Organized by the Institute of Nuclear Chemistry and Technology

Organizing Committee: Halina Polkowska-Motrenko, Ph.D., D.Sc., professor in INCT, Anna Bojanowska-Czajka, Ph.D., Jakub Dudek, Ph.D.

Ph.D./D.Sc. THESES IN 2017

Ph.D. THESES

1. Iwona Bartosiewicz, M.Sc. (INCT Ph.D. student)
Biogeochemiczne zachowania uranu i pierwiastków towarzyszących na terenach poeksploatacyjnych rud uranu w bloku karkonosko-izerskim (Biogeochemical behaviour of uranium and associated elements in areas of uranium post-mining wastes in the Karkonosze-Izera block)
supervisor: Halina Polkowska-Motrenko, Ph.D., D.Sc., professor in INCT
Institute of Nuclear Chemistry and Technology, 31.03.2017
2. Grzegorz Guzik, M.Sc. (Institute of Nuclear Chemistry and Technology, Warszawa, Poland)
Badania trwałych efektów radiacyjnych w cukrach prostych pod kątem identyfikacji napromieniowanej żywności (Stable radiation effects in simple sugars related to detection of irradiated food)
supervisor: Prof. Jacek Michalik, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology, 31.03.2017
3. Liang Zhao, M.Sc. (INCT Ph.D. student)
Magnetic sorbent for the removal of cesium from aqueous solutions
supervisor: Prof. Andrzej G. Chmielewski, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology, 31.03.2017
4. Łukasz Steczek, M.Sc. (Co-tutelle, INCT Ph.D. student)
Complexation of actinides Am(III), Th(IV), Pu(IV) and U(VI) with poly-N-dentate ligands SO₃-Ph-BTP and SO₃-Ph-BTBP
supervisors: Philippe Moisy, Ph.D., Prof. Jerzy Ostyk-Narbutt, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology, 5.07.2017
5. Katarzyna Łuczynska, M.Sc. (Institute of Nuclear Chemistry and Technology, Warszawa, Poland)
Synthesis and complementary structural spectroscopy study of selected organic complexes of donor-acceptor type
supervisor: Prof. Jan Cz. Dobrowolski, Ph.D., D.Sc.
Institute of Nuclear Chemistry and Technology, 15.12.2017
6. Ewa Anna Zwolińska, M.Sc. (Institute of Nuclear Chemistry and Technology)
The removal of NO_x and SO₂ from exhaust gases using a hybrid electron beam method
supervisor: Yongxia Sun, Ph.D., D.Sc., professor in INCT
Institute of Nuclear Chemistry and Technology, 15.12.2017

D.Sc. THESES

1. Marek Danilczuk, Ph.D. (Institute of Nuclear Chemistry and Technology, Warszawa, Poland)
Badania spektroskopowe membran jonowymiennych stosowanych w ogniwach paliwowych (Spectroscopic studies of ion exchange membranes for fuel cells applications)
Institute of Nuclear Chemistry and Technology, 15.12.2017

EDUCATION

Ph.D. PROGRAMME IN CHEMISTRY

The Institute of Nuclear Chemistry and Technology (INCT) holds a four-year Ph.D. degree programme for graduates of chemical, physical and biological departments of universities, for graduates of medical universities and to engineers in chemical technology and material science.

The main areas of the studies are:

- chemical aspects of nuclear energy,
- radiation chemistry and biochemistry,
- chemistry of radioelements,
- isotopic effects,
- radiopharmaceutical chemistry,
- analytical methods,
- chemistry of radicals,
- application of nuclear methods in chemical and environmental research, material science and protection of historical heritage.

The candidates can apply for a doctoral scholarship. The INCT offers accommodation in 10 rooms in the guesthouse for Ph.D. students not living in Warsaw.

During the four-year Ph.D. programme, the students participate in lectures given by senior staff from the INCT, University of Warsaw and the Polish Academy of Sciences. In the third year, the Ph.D. students are obliged to prepare a seminar related to the various aspects of nuclear energy. Each year the Ph.D. students are obliged to deliver a lecture on topic of his/her dissertation at a seminar. The final requirements for the Ph.D. programme graduates, consistent with the regulation of the Ministry of Science and Higher Education, are:

- submission of a formal dissertation, summarizing original research contributions suitable for publication;
- final examination and public defence of the dissertation thesis.

In 2017, the following lecture series and lectures were organized:

- Selected problems in nanomaterials chemistry – Prof. Adam Proń, Ph.D., D.Sc. (Warsaw University of Technology, Faculty of Chemistry, Poland);
- Drug chemistry – Piotr Jakub Lipiński, Ph.D. (Mossakowski Medical Research Centre, Polish Academy of Sciences, Warszawa, Poland);
- Radioactive waste – Prof. Grażyna Zakrzewska-Kołodziej, Ph.D., D.Sc. (Institute of Nuclear Chemistry and Technology, Warszawa, Poland);
- (1) Spent fuel: reprocessing *vs.* direct disposal; characterization, inventory verification and disposal. The reasoning for the CHANCE project WP4; (2) Calorimetric characterization of rad-waste and the reasoning for the CHANCE project, WP3 – Prof. Holger Tietze-Jaensch (Forschungszentrum Jülich, Germany).

The qualification interview for the Ph.D. programme takes place in the mid of September. Detailed information can be obtained from:

- head: Prof. Aleksander Bilewicz, Ph.D., D.Sc.
(phone: +48 22 504 13 57, e-mail: A.Bilewicz@ichtj.waw.pl);
- secretary: Ewa Gniazdowska, Ph.D., D.Sc., professor in INCT
(phone: +48 22 504 11 78, e-mail: E.Gniazdowska@ichtj.waw.pl).

TRAINING OF STUDENTS

Institution	Country	Number of participants	Period
Gdańsk University of Technology, Faculty of Applied Physics and Mathematics	Poland	1	5 months
International Atomic Energy Agency	Myanmar	1	1 week

Institution	Country	Number of participants	Period
International Atomic Energy Agency	Myanmar	1	2 months
University of Gdańsk, Faculty of Chemistry	Poland	1	1 month
Military University of Technology	Poland	1	1 month
		1	1.5 months
University of Warsaw, Faculty of Chemistry	Poland	1	2 weeks
		1	2.5 weeks
		3	3 weeks
		2	1 month
		2	1.5 months
University of Warsaw, Faculty of Physics	Poland	1	2 months
		1	6 months
Warsaw University of Life Sciences – SGGW	Poland	2	1 month
Warsaw University of Technology, Faculty of Chemical and Process Engineering	Poland	1	1 month
		1	1 year
Warsaw University of Technology, Faculty of Chemistry	Poland	2	3.5 weeks
		1	3 weeks
		2	1 month
		1	1 year
Warsaw University of Technology, Faculty of Physics	Poland	24	one-day course

MASTER'S, BACHELOR'S AND ENGINEER'S THESES

1. Emilia Balcer

Master's thesis: Synteza i badanie właściwości fizykochemicznych ^{68}Ga -NODA-GA-Tocilizumab jako potencjalnego radiofarmaceutyku do diagnostyki reumatoidalnego zapalenia stawów (Synthesis and physicochemical properties of the ^{68}Ga -NODA-GA-Tocilizumab, a potential radiopharmaceutical for the diagnosis of rheumatoid arthritis)

supervisors: Przemysław Koźmiński, Ph.D., Michał Grdeń, Ph.D., D.Sc.

University of Warsaw, Faculty of Chemistry

2. Marta Jolanta Kania

Engineer's thesis: Badanie wpływu parametrów procesowych na efektywność adsorpcji radionuklidów ^{134}Cs i ^{60}Co z roztworów wodnych przez sorbent SiEA-KNiFe (Investigation of influence of operating parameters on effectiveness of adsorption process of radionuclides ^{134}Cs and ^{60}Co in water solutions using SiEA-KNiFe)

supervisors: Marek Henczka, Ph.D., D.Sc., WUT professor

supervisor in INCT: Dagmara Chmielewska-Śmietanko, M.Sc.

Warsaw University of Technology, Faculty of Chemical and Process Engineering

3. Aneta Piasecka

Master's thesis: Trikarbonylkowe kompleksy technetu(I) i renu(I) z ligandami bidentnymi (Tricarbonyl technetium(I) and rhenium(I) complexes with bidentate ligands)

supervisors: Maciej Mazur, Ph.D., D.Sc., Monika Łyczko, Ph.D.

University of Warsaw, Faculty of Chemistry

4. Magdalena Rodak

Master's thesis: Nanociało HER2 znakowane ^{177}Lu jako potencjalny radiofarmaceutyk terapeutyczny (^{177}Lu labelled HER2 nanobody as a potential therapeutic radiopharmaceutical)

supervisors: Maciej Jan Kamiński, Ph.D., D.Sc., Marek Pruszyński, Ph.D.

University of Warsaw, Faculty of Physics

5. Ilona Ściśniak

Master's thesis: Analiza ekspresji genów związanych z odpowiedzią na uszkodzenia DNA jako potencjalny biomarker wrażliwości komórek na promieniowanie (Analysis of gene expression related to DNA damage response as a potential biomarker of intrinsic radiosensitivity)

supervisors: Beata Brzozowska, Ph.D., Kamil Brzóska, Ph.D.

University of Warsaw, Faculty of Physics

6. Piotr Żmijewski

Engineer's thesis: Badanie kinetyki procesu adsorpcji radionuklidów ^{134}Cs i ^{60}Co z roztworów wodnych przez sorbent SiEA-KNiFe (Investigation of kinetics of adsorption process of radionuclides ^{134}Cs and ^{60}Co from aqueous solution onto SiEA-KNiFe sorbent)

supervisor: Marek Henczka, Ph.D., D.Sc., WUT professor

supervisor in INCT: Dagmara Chmielewska-Śmietanko, M.Sc.

Warsaw University of Technology, Faculty of Chemical and Process Engineering

RESEARCH PROJECTS AND CONTRACTS

RESEARCH PROJECTS GRANTED BY THE NATIONAL SCIENCE CENTRE IN 2017

- 1. Chiral cores/monomers of drugs and conducting polymers: from calculations to experimental characteristics.**
supervisor: Prof. Jan Cz. Dobrowolski, Ph.D., D.Sc.
- 2. Nanobodies labelled with alpha emitters as potential radiopharmaceuticals in targeted radioimmunotherapy.**
supervisor: Marek Pruszyński, Ph.D.
- 3. Nanoparticles of gold, gold-gold sulphide and titanium dioxide modified with tellurium as carriers for At-211 for targeted alpha therapy.**
supervisor: Prof. Aleksander Bilewicz, Ph.D., D.Sc.
- 4. Studies on the phenomena occurring in the membrane boundary layer during the filtration of aqueous solutions and suspensions proceeding in membrane apparatuses with different configurations.**
supervisor: Agnieszka Miśkiewicz, Ph.D.
- 5. The influence of nanoparticles on beta-amyloid removal by microglia cells.**
supervisor: Katarzyna Sikorska, M.Sc.
- 6. Impact of nanoparticles on cellular signalling activated by tumour necrosis factor.**
supervisor: Kamil Brzóska, Ph.D.
- 7. Analytical, kinetic and toxicological study of degradation selected perfluorinated compounds using ionizing radiation.**
supervisor: Prof. Marek Trojanowicz, Ph.D., D.Sc.
- 8. New analytical procedures based on neutron activation analysis for the determination of chosen Se, As and Fe chemical formulae in infant alimentation.**
supervisor: Halina Polkowska-Motrenko, Ph.D., D.Sc., professor in INCT
- 9. Radiation-induced radical processes involving amino acids and quinoxalin-2-one derivatives relevant to their pharmacological applications.**
supervisor: Konrad Skotnicki, M.Sc.
- 10. Bioconjugates of multimodal nanoparticles for targeted alpha and hyperthermia therapy. Synthesis, retention studies of recoiling daughters radionuclides and preliminary cell.**
supervisor: Edyta Cędrowska, M.Sc.
- 11. In vitro and in vivo preclinical studies of NaA nanozeolite functionalized with antibodies anti-PSMA and labelled with radium radioisotope for targeted prostate cancer therapy.**
supervisor: Prof. Anna Lankoff, Ph.D., D.Sc.
- 12. In vitro studies of NaA nanozeolite functionalized with integrins inhibitor – cilengitide and labelled with radium radioisotope for targeted breast cancer therapy.**
supervisor: Sylwia Męczyńska-Wielgosz, Ph.D.
- 13. Studies on cefepime labelling with Ga-68.**
supervisor: Przemysław Koźmiński, Ph.D.
- 14. Nanostructured lipidic liquid-cystalline carriers for chemotherapeutics and corpuscular radiation emitters in targeted cancer therapy.**
supervisor: Agnieszka Majkowska-Pilip, Ph.D.
- 15. Radiopharmaceuticals based on neurokinin-1 receptor antagonists for the diagnosis and therapy of brain tumour-glioblastoma multiforme.**
supervisor: Ewa Gniazdowska, Ph.D., D.Sc., professor in INCT

16. **6xS for chiral semiconducting naphthalene diimides: synthesis, simulations, structure, spectroscopy, spectroelectrochemistry, sensors.**
supervisor: Prof. Jan Cz. Dobrowolski, Ph.D., D.Sc.

**PROJECTS GRANTED
BY THE NATIONAL CENTRE FOR RESEARCH AND DEVELOPMENT
IN 2017**

1. **Plasma technology to remove NO_x from off-gases.**
(common undertaking of the National Science Centre, and the National Centre for Research and Development "TANGO2")
supervisor: Prof. Andrzej G. Chmielewski, Ph.D., D.Sc.
2. **The integrated system of sewage treatment, biogas production and its enrichment in the methane.**
supervisor: Jacek Palige, Ph.D.
3. **Syntheses of radiopharmaceuticals based on scandium radionuclides for positron emission tomography (Petscand).**
supervisor: Prof. Aleksander Bilewicz, Ph.D., D.Sc.
4. **The development of innovative advanced therapy with use of a biological dressing of the human race in the treatment of *epidermolysis bullosa* and other chronic wounds (STRATEGMED).**
supervisor: Zbigniew Zimek, Ph.D.

IAEA RESEARCH CONTRACTS IN 2017

1. **Based on starch-PVA system and cellulose reinforced active packaging materials for food prepared using of radiation modification (PackRad).**
No. 17493
principal investigator: Krystyna Cieśla, Ph.D., D.Sc., professor in INCT.
2. **The study of the influence of the environmental factors on the isotopic compositions of dairy products.**
No. 18056
principal investigator: Ryszard Wierchnicki, Ph.D.
3. **Application of advanced membrane systems in nuclear desalination.**
No. 18539
principal investigator: Prof. Grażyna Zakrzewska-Kołtuniewicz, Ph.D., D.Sc.
4. **Studying the social and socio-economic effects of the implementation of the Polish nuclear programme using new methodology.**
No. 18541
principal investigator: Agnieszka Miśkiewicz, Ph.D.
5. **Application of low energy electron beam for microbiological control of food and agricultural products.**
No. 19000
principal investigator: Urszula Gryczka, M.Sc.
6. **Radiometric methods applied in hydrometallurgical processes development and optimization.**
No. 18945
principal investigator: Prof. Andrzej G. Chmielewski, Ph.D., D.Sc.
7. **Silicide/silicate coatings on zirconium alloys for improving the high temperature corrosion resistance.**
No. 19026
principal investigator: Bożena Sartowska, Ph.D.
8. **Recovery of uranium and accompanying metals from various types of industrial wastes.**
No. 18542
principal investigator: Katarzyna Kiegiel, Ph.D.

9. **Electron beam for preservation of biodeteriorated cultural heritage paper-based objects.**
No. 18493
supervisor: Dagmara Chmielewska-Śmietanko, M.Sc.
10. **Synthesis of 50 g synthesized nanotracer material by sol-gel process including a detailed report with the methodology and characterization of the material.**
No. 201506067-VG
supervisor: Tomasz Smoliński, M.Sc.
11. **New cyclotron method for ^{47}Sc production and conjugation of ^{47}Sc to monoclonal antibodies.**
No. 20488
supervisor: Prof. Aleksander Bilewicz, Ph.D., D.Sc.
12. **Cyclic $^{99\text{m}}\text{Tc}$ isolation from the gamma irradiated ^{100}Mo target.**
No. 22521
supervisor: Przemysław Koźmiński, Ph.D.

PROJECTS WITHIN THE FRAME OF EUROPEAN UNION PROGRAMME HORIZON 2020

1. **Accelerator research and innovation for European science and society (ARIES).**
GA 730871
principal investigator: Prof. Andrzej G. Chmielewski, Ph.D., D.Sc.
2. **Characterization of conditioned nuclear waste for its safe disposal in Europe (CHANCE).**
GA 755371
principal investigator: Prof. Grażyna Zakrzewska-Kołtuniewicz, Ph.D., D.Sc.
3. **GEN IV integrated oxide fuels recycling strategies (GENIORS).**
GA 755171
principal investigator: Prof. Jerzy Narbutt, Ph.D., D.Sc.
4. **European tools and methodologies for an efficient ageing management of nuclear power plant cables (TeamCABLES).**
GA 755187
principal investigator: Grażyna Przybytniak, Ph.D., D.Sc., professor in INCT

OTHER INTERNATIONAL RESEARCH PROGRAMMES IN 2017

1. **Nanostructured porous materials with tailored properties** (with Joint Institute for Nuclear Research, Dubna, Russia).
Contract No. 04-4-1131-2017/2021
supervisor: Bożena Sartowska, Ph.D.
2. **Studies on oxidation resistance in water and on radiation resistance of zirconium silicide coatings on zirconium alloys** (with Joint Institute for Nuclear Research, Dubna, Russia).
Contract No. 04-5-1131-2017/2021
supervisor: Wojciech Starosta, Ph.D.
3. **New nanocomposite sorbent for different radionuclides removal** (with Joint Institute for Nuclear Research, Dubna, Russia).
Contract No. 04-4-1131-2017/2021
supervisor: Dagmara Chmielewska-Śmietanko, M.Sc.
4. **Measurement of the depth profiling of the cesium atom on the surface of the adsorbent for its recovery from the spent nuclear waste by time-of-flight elastic recoil detection analysis (TOF-ERDA).**
No. 20152054 (Central European Research Infrastructure Consortium project)
supervisor: Danuta Wawszczak, Ph.D.

ERASMUS+ PROGRAMME

- 1. Joint innovative training and teaching/learning program in enhancing development and transfer knowledge of application of ionizing radiation in materials processing.**
No. 2014-1-PL01-KA203-003611
- 2. Mobility for learners and staff higher education student and staff mobility.**
Key action 103
- 3. Inter-institutional agreement 2015-2017 between institutions from programme and partner countries (China).**
Key action 107
- 4. Inter-institutional agreement 2017-2019 between institutions from programme and partner countries (USA).**
Key action 107

ANALYSES FOR THE MINISTRY OF ENERGY

- 1. Analysis “Treatment of nuclear waste and burnt nuclear fuel in Poland – present situation and perspectives”.**
Contract No. 156/II/P/15004/4390/17/DEJ-244/062/2017 (together with ZUOP Radioactive Waste Management Plant)
- 2. Analysis of non-nuclear applications of ionizing radiation and recommendations for domestic industrial companies.**
Contract No. 149/II/15004/4390/17/DEJ

LIST OF VISITORS TO THE INCT IN 2017

1. **D'Angelantonio Mila**, Institute of Polymers, Composites and Biomaterials (IPCB), National Research Council (CNR), Bologna, Italy, *18-22.04.2017*
2. **Dzeba Iwa**, Ruđer Bošković Institute, Zagreb, Croatia, *26.03-01.04.2017*
3. **Gryzlov Anatoly**, TORIJ, Russia, *13-22.03.2017*
4. **Günel Aytaç**, Anadolu University, Turkey, *24.07-29.09.2017*
5. **Kyaw Myat**, International Atomic Energy Agency, Myanmar, *31.05-1.08.2017*
6. **Nadarayah Manivannan**, Brunel University London, the United Kingdom, *14-15.03.2017*
7. **Orelovitch Oleg**, Joint Institute for Nuclear Research, Dubna, Russia, *4-10.09.2017, 13-16.09.2017*
8. **Pesnekhonov Vladimir**, Przedsiębiorstwo Naukowo-Produkcyjne TORIJ, Russia, *13-22.03.2017*
9. **Pillai Surech D.**, Texas A&M University/Texas A&M AgriLife Research, Texas, USA, *26-30.06.2017*
10. **Tietze-Jaensch Holger**, Forschungszentrum, Jülich, Germany, *13-14.12.2017*
11. **Wamadera Balachandran**, Brunel University London, the United Kingdom, *14-15.03.2017*
12. **Zaw Min Min**, International Atomic Energy Agency, Myanmar, *17-25.06.2017*

THE INCT SEMINARS IN 2017

- 1. Marek Danilczuk, Ph.D. (Institute of Nuclear Chemistry and Technology, Warszawa, Poland; Bowling Green State University, Ohio, USA)**
Badania spektroskopowe membran jonowymiennych stosowanych w ogniwach paliwowych (Spectroscopic studies of ion exchange membranes for fuel cells applications)
- 2. Łucja Dziawer, M.Sc. (Institute of Nuclear Chemistry and Technology, Warszawa, Poland)**
Biokoniugaty nanocząstek złota jako nośniki ^{211}At w celowanej terapii promieniowaniem alfa (Bioconjugates of gold nanoparticles as ^{211}At carriers for targeted alpha therapy)
- 3. Ireneusz Janik, Ph.D. (Notre Dame Radiation Laboratory, University of Notre Dame, USA)**
Termochemia wiązań połowicznych i jej związek z mechanizmem przekształceń wolnorodnikowych (Thermochemistry of odd-electron bonds in relation to free radical transformation)
- 4. Prof. Anna Lankoff, Ph.D., D.Sc. (Institute of Nuclear Chemistry and Technology, Warszawa, Poland)**
Biopaliwa I i II generacji – korzyści i zagrożenia (First and second generation biofuels – advantages and disadvantages)
- 5. Prof. Janusz Lipkowski, Ph.D., D.Sc. (Cardinal Stefan Wyszyński University in Warsaw, Poland)**
Chemia supramolekularna – w pół wieku od prapoczątków (Supramolecular chemistry – half a century from the origin)
- 6. Nadarajah Manivannan, Ph.D. (Brunel University London, London, the United Kingdom)**
Non-thermal plasma technologies for the marine diesel engine exhaust emission control
- 7. Andrzej Pawlukojć, Ph.D., D.Sc., professor in INCT (Institute of Nuclear Chemistry and Technology, Warszawa, Poland; Joint Institute for Nuclear Research, Dubna, Russia)**
Zastosowanie neutronowej spektroskopii oscylacyjnej do badania oddziaływań w ciele stałym (Application of the neutron oscillation spectroscopy in the studies of interaction in solid state)
- 8. Prof. Suresh D. Pillai (College of Agriculture & Life Sciences, Texas A&M University/Texas A&M AgriLife Research, Texas, USA)**
The status of electron beam irradiation technology in N. America and the role the National Center for Electron Beam Research plays in commercializing the technology
- 9. Prof. Suresh D. Pillai (College of Agriculture & Life Sciences, Texas A&M University/Texas A&M AgriLife Research, Texas, USA)**
The research and outreach program at the National Center for Electron Beam Research as it relates to environmental quality
- 10. Prof. Suresh D. Pillai (College of Agriculture & Life Sciences, Texas A&M University/Texas A&M AgriLife Research, Texas, USA)**
The research and outreach program at the National Center for Electron Beam Research as it relates to foods
- 11. Prof. Suresh D. Pillai (College of Agriculture & Life Sciences, Texas A&M University/Texas A&M AgriLife Research, Texas, USA)**
The research and outreach program at the National Center for Electron Beam Research as it relates to vaccines, advanced materials including packaging materials
- 12. Rafał Walczak, M.Sc. (Institute of Nuclear Chemistry and Technology, Warszawa, Poland)**
Radionuklidy skandiu dla radiofarmaceutyków teranostycznych (Scandium radionuclides for teranostic radiopharmaceuticals)
- 13. Iga Zuba, M.Sc. (Institute of Nuclear Chemistry and Technology, Warszawa, Poland)**
Podstawowa procedura oznaczania chromu metodą radiochemicznej neutronowej analizy aktywacyjnej (RNAA) i jej zastosowanie w procesie certyfikacji materiałów odniesienia dla nieorganicznej analizy śladowej (Primary procedure for the determination of chromium by radiochemical neutron activation analysis (RNAA) and its application in certification of reference materials for inorganic trace analysis)

LECTURES AND SEMINARS DELIVERED OUT OF THE INCT IN 2017

LECTURES

- 1. Bobrowski K.**
Chemia radiacyjna cieczy (Radiation chemistry of liquids).
Dissemination of the textbook "Applications of ionizing radiation in materials processing" in the frame of the project entitled "Joint innovative training and teaching/learning program in enhancing development and transfer knowledge of application of ionizing radiation in materials processing" of Erasmus+ KA2 programme, Warszawa, Poland, 25.05.2017.
- 2. Brykała M.**
Synteza ziaren ditlenku uranu dotowanych wybranymi pierwiastkami przy zastosowaniu kompleksowej metody zol-zel (CSGP) (Synthesis of spherical grains of uranium dioxide doped with different elements by complex sol-gel process (CSGP)).
Konferencja naukowa „Polska nukleonika w drugiej dekadzie XXI wieku”, Warszawa, Poland, 27.05.2017.
- 3. Brykała M., Wawszczak D., Olczak T.**
Sol-gel for radiochemistry and nuclear medicine.
1st Joint CNRS/PAN Workshop: Nuclear Medicine & Radiochemistry, Gif-sur-Yvette, France, 11-12.12.2017.
- 4. Chmielewski A.G.**
IChTJ – atom dla społeczeństwa (The INCT – atom for society).
Konferencja „Promieniujemy na całą gospodarkę – polski przemysł dla elektrowni jądrowej”, Warszawa, Poland, 30.01.2017.
- 5. Chmielewski A.G.**
Hybrid biogas – an electron beam system for electricity and bio-fertilizer production.
EuCARD-2 (Enhanced European Coordination for Accelerator Research and Development) Annual Meeting, Glasgow, UK, 28-30.03.2017.
- 6. Chmielewski A.G.**
Science and education in the nuclear project in Poland.
Seminar "Nuclear energy: educational policy", Warszawa, Poland, 16.05.2017.
- 7. Chmielewski A.G.**
Environmental applications of electron accelerators – gaseous pollutants.
Summer School "Application of accelerators for radiation processing", Warszawa, Poland, 19-23.06.2017.
- 8. Chmielewski A.G.**
Rola chemii radiacyjnej i radiochemii w rozwoju bezpiecznej energetyki jądrowej (The role of radiation chemistry and radiochemistry in the development of safe nuclear power).
Jubileuszowa Sesja Naukowa Polskiego Towarzystwa Badań Radiacyjnych im. Marii Skłodowskiej-Curie „Promieniowanie w nauce, technologii, medycynie i środowisku naturalnym”, Warszawa, Poland, 29.06.2017.
- 9. Chmielewski A.G.**
Fostering industrial development through radiation technology.
International Conference on the IAEA Technical Cooperation Programme: Sixty years and beyond – contributing to development, Vienna, Austria, 30.05.-01.06.2017.
- 10. Chmielewski A.G.**
INCT at ARIES WP3.
ARIES WP3 Kick-off Meeting, Kraków, Poland, 13-14.09.2017.
- 11. Chmielewski A.G.**
New applications of low energy electron beams.
ARIES WP3 Kick-off Meeting, Kraków, Poland, 13-14.09.2017.

- 12. Chmielewski A.G.**

Where we are and we go – Polish case.
RER1017 Regional Meeting on Feasibility of Radiation Processing Technologies for Decision Makers, Zagreb, Croatia, 23-25.10.2017.
- 13. Chmielewski A.G.**

Current status and recent information of activities at INCT Collaborating Centre.
IAEA Consultants Meeting on the Evolving Role of the IAEA Collaborating Centers in the Advancement of Radiation Processing Applications, Vienna, Austria, 27-30.11.2017.
- 14. Chmielewski A.G.**

Electron beam treatment of marine diesel exhaust gases.
ARIES Meets Industry – accelerator application to the ship exhaust gases treatment, Geneva, Switzerland, 1.12.2017.
- 15. Dziawer Ł., Bilewicz A., Majkowska-Pilip A.**

Gold nanoparticle-trastuzumab conjugate as a carrier for ^{211}At in alpha immunotherapy.
13th Cyclotron – European Network of Cyclotron Research Centers – Workshop, Lisbon, Portugal, 23-24.11.2017.
- 16. Głuszewski W.**

Maria Skłodowska-Curie prekursorką radiacyjnych metod konserwacji obiektów o znaczeniu historycznym (Maria Skłodowska-Curie – the precursor of radiation conservation of cultural heritage objects).
5. Targi Konserwacji i Restauracji Zabytków oraz Ochrony, Wyposażenia Archiwów, Muzeów i Bibliotek DZIEDZICTWO, Warszawa, Poland, 7-9.11.2017.
- 17. Głuszewski W.**

Skutki oddziaływania promieniowania jonizującego na suplementy diety (Effects of ionizing radiation on dietary supplements).
XII Międzynarodowe Forum Suplementów Diety, Warszawa, Poland, 17.11.2017.
- 18. Kiegiel K., Gajda D., Zakrzewska-Kołodziej G.**

Secondary raw materials as a potential source of uranium and accompanying metals.
2nd Research Coordination Meeting of T11006 on Uranium/Thorium Fuelled High Temperature Gas Cooled Reactor Applications for Energy Neutral and Sustainable Comprehensive Extraction and Mineral Product Development Processes, Vienna, Austria, 3-6.07.2017.
- 19. Kiegiel K., Zakrzewska-Kołodziej G., Brykała M., Chmielewski A.G.**

Research on an advanced fuel cycle on-going at INCT and perspective of fuel management in Poland.
Technical Meeting on Advanced Fuel Cycles to Improve the Sustainability of Nuclear Power through the Minimization of High Level Waste, Vienna, Austria, 17-19.10.2017.
- 20. Polkowska-Motrenko H.**

Neutronowa analiza aktywacyjna – unikalne narzędzie chemii analitycznej (Neutron activation analysis – a unique tool of analytical chemistry).
Konferencja Naukowa „Wybrane zagadnienia analizy śladowej” z okazji jubileuszu 60-lecia pracy w IBJ-ICH TJ prof. dr. hab. Rajmunda S. Dybczyńskiego, Warszawa, Poland, 5.12.2017.
- 21. Pruszyński M., Walczak R.**

Krótki wykład z medycyny nuklearnej (Short lecture on nuclear medicine).
II Akademickie Forum Energii Jądrowej, Kraków, Poland, 17-19.05.2017.
- 22. Przybytniak G.**

Od nauki do technologii – sieciowanie radiacyjne polimerów (From science to technology – radiation crosslinking of polymers).
Dissemination of the textbook “Applications of ionizing radiation in materials processing” in the frame of the project entitled “Joint innovative training and teaching/learning program in enhancing development and transfer knowledge of application of ionizing radiation in materials processing” of Erasmus+ KA2 programme, Warszawa, Poland, 25.05.2017.
- 23. Samczyński Z.**

Porównania międzylaboratoryjne jako narzędzie w procesie certyfikacji nowych materiałów odniesienia (Interlaboratory comparisons as a tool in the process of certification of new reference materials).
Panel konferencyjny „Problemy laboratoriów”, Warszawa, Poland, 30.03.2017.
- 24. Sommer S.**

Wpływ energetyki jądrowej na zdrowie człowieka (Nuclear energy industry effects on human health).
Ogólnopolska konferencja naukowa “Wyzwania energetyki jądrowej”, Kraków, Poland, 20-21.03.2017.

- 25. Sommer S.**
Laboratorium Dozymetrii Biologicznej (Laboratory for Biological Dosimetry).
Konferencja „Cywilne instytuty badawcze wspierają bezpieczeństwo Polski”, Warszawa, Poland, 27.03.2017.
- 26. Starosta W.**
Radiacyjne przetwórstwo materiałów – nanotechnologie (Radiation processing of materials – nanotechnologies).
Dissemination of the textbook “Applications of ionizing radiation in materials processing” in the frame of the project entitled “Joint innovative training and teaching/learning program in enhancing development and transfer knowledge of application of ionizing radiation in materials processing” of Erasmus+ KA2 programme, Warszawa, Poland, 25.05.2017.
- 27. Sun Y.**
Textbook brief introduction.
Dissemination of the textbook “Applications of ionizing radiation in materials processing” in the frame of the project entitled “Joint innovative training and teaching/learning program in enhancing development and transfer knowledge of application of ionizing radiation in materials processing” of Erasmus+ KA2 programme, Warszawa, Poland, 25.05.2017.
- 28. Zakrzewska-Kołodziej G.**
INCT: capabilities and contribution to the CHANCE project.
CHANCE Kick-Off Meeting, SCK-CEN, Brussels, Belgium, 12-13.06.2017.
- 29. Zakrzewska-Kołodziej G.**
Membrany w technologiach jądrowych (Membranes in nuclear technologies).
XIV Szkoła Membranowa: Od badań podstawowych do wdrożenia, Wilga, Poland, 22-25.10.2017.
- 30. Zakrzewska-Kołodziej G., Wołkiewicz S.**
Uranium resources in Poland – update.
54th Uranium Group Meeting NEA, Paris, France, 15-17.11.2017.
- 31. Zimek Z.**
Zastosowanie akceleratorów elektronów w przetwórstwie materiałów (Application of electron accelerators in materials processing).
Dissemination of the textbook “Applications of ionizing radiation in materials processing” in the frame of the project entitled “Joint innovative training and teaching/learning program in enhancing development and transfer knowledge of application of ionizing radiation in materials processing” of Erasmus+ KA2 programme, Warszawa, Poland, 25.05.2017.
- 32. Zimek Z.**
Current applications of electron beam accelerators up to 10 MeV.
ARIES WP3 Kick-off Meeting, Kraków, Poland, 13-14.09.2017.
- 33. Zimek Z.**
Radiacyjne techniki dla przemysłu chemicznego i przetwórczego (Radiation techniques for the chemical and processing industries).
Konferencja „Chemiczne instytuty badawcze dla rozwoju polskiej gospodarki”, Nadarzyn, Poland, 14.11.2017.
- 34. Zuba I., Polkowska-Motrenko H.**
Oznaczanie złota w matrycach biologicznych metodą neutronowej analizy aktywacyjnej (NAA) (Determination of gold in biological matrices by neutron activation analysis (NAA)).
XV Ogólnopolskie Seminarium Doktorantów „Na pograniczu chemii i biologii”, Karpacz, Poland, 21-24.05.2017.

SEMINARS

- 1. Brykała Marcin**
Reaktory energetyczne (Energy reactors).
Warsaw University of Technology, Faculty of Chemical and Process Engineering, Warszawa, Poland, 21.04.2017.
- 2. Brzóska Kamil**
Promieniowrażliwość wewnątrzkomórkowa i jej potencjalne markery (Intrinsic radiosensitivity and its potential markers).
University of Warsaw, Faculty of Physics, Warszawa, Poland, 18.10.2017.

3. Chmielewski Andrzej G.

Promieniowanie jonizujące w medycynie, przemyśle i ochronie środowiska – dar naszej Wielkiej Rodzki dla ludzkości (Ionizing radiation in medicine, industry and environmental protection – gift of Maria Skłodowska-Curie for humanity).

Silesian University of Technology, Faculty of Chemistry, Gliwice, Poland, 10.05.2017.

4. Chmielewski Andrzej G.

R&D in the field of radioactive waste and spent fuel.

Ministry of Energy, Warszawa, Poland, 5.10.2017.

5. Gajda Dorota

Analiza możliwości pozyskiwania uranu dla energetyki jądrowej z zasobów krajowych (Analysis of the possibility of uranium supply from domestic resources).

University of Szczecin, Szczecin, Poland, 11.01.2017.

6. Kołacińska Kamila

Analiza kosztów i korzyści wdrożenia energetyki jądrowej w Polsce (Cost and benefit analysis of nuclear power energy in Poland).

SGH Warsaw School of Economics, Collegium of Business Administration, Warszawa, Poland, 3.11.2017.

7. Lankoff Anna

Nanocząstki jako nośniki radioizotopów w diagnostyce i terapii (Nanoparticles as radioisotope carriers for diagnosis and therapy).

Siedlce University of Natural Sciences and Humanities, Faculty of Sciences, Siedlce, Poland, 20.10.2017.

8. Pruszyński Marek

Nowe metody znakowania przeciwciał monoklonalnych radionuklidami jodu (New methods of monoclonal antibodies labelling with iodine radionuclides).

National Centre for Nuclear Research, Otwock-Świerk, Poland, 29.09.2017.

9. Pruszyński Marek

Nanociała – nowe wektory jako nośniki dla radionuklidów diagnostycznych i terapeutycznych (Nanobodies – new vectors for diagnostic and therapeutic radionuclides).

National Centre for Nuclear Research, Otwock-Świerk, Poland, 18.10.2017.

AWARDS IN 2017

1. Synthesis method of radiotracer and a radiotracer
Gold medal with mention at the International Warsaw Invention Show IWIS 2017, Warszawa, Poland, 9-11.10.2017
Tomasz Smoliński, Partyk Wojtowicz, Andrzej G. Chmielewski
2. A method of reducing high concentrations of nitrogen oxides present in the exhaust gases from diesel engines
Gold medal at the International Warsaw Invention Show IWIS 2017, Warszawa, Poland, 9-11.10.2017
Andrzej G. Chmielewski, Janusz Licki, Yongxia Sun, Ewa Zwolińska, Zbigniew Zimek, Aleksandra Błocka
3. Method and system for the transport and mixing of biomass in hydrolyzer and in the fermenter
Gold medal at the International Warsaw Invention Show IWIS 2017, Warszawa, Poland, 9-11.10.2017
Adam Kryłowicz, Janusz Usidus, Andrzej G. Chmielewski, Kazimierz Chrzanowski
4. A method for hygienization
Gold medal at the International Warsaw Invention Show IWIS 2017, Warszawa, Poland, 9-11.10.2017
Andrzej G. Chmielewski, Jacek Palige, Otton Roubinek, Zbigniew Zimek, Urszula Gyczka, Janusz Usidus, Krzysztof Pietrzak, Rob Edgecock
5. Method for obtaining diagnostic amounts of ^{43}Sc radionuclide
Gold medal at the International Warsaw Invention Show IWIS 2017, Warszawa, Poland, 9-11.10.2017
Aleksander Bilewicz, Rafał Walczak, Agnieszka Majkowska-Pilip
6. A process for the preparation of diagnostic amounts of $^{99\text{m}}\text{Tc}$ radionuclide
Gold medal at the International Warsaw Invention Show IWIS 2017, Warszawa, Poland, 9-11.10.2017
Aleksander Bilewicz, Magdalena Gumiela
7. Wysokowydajna polska technologia uzyskiwania biometanu z wytwarzaniem nawozu organicznego (High efficient Polish technology of obtaining biomethane with organic fertilizer production)
Gold Laurel of Innovation in the 7th edition of Stanisław Staszic competition for the best innovative products organized by the Polish Federation of Engineering Associations, Warszawa, Poland, 14.11.2017
Institute of Nuclear Chemistry and Technology
8. A method of reducing high concentrations of nitrogen oxides in the exhaust gases from diesel engines
Bronze medal at the International Trade Fair "Ideas – Inventions – New Products" iENA 2017, Nuremberg, Germany, 2-5.11.2017
Andrzej G. Chmielewski, Janusz Licki, Yongxia Sun, Ewa Zwolińska, Zbigniew Zimek, Aleksandra Błocka
9. Andrzej Waksmundzki medal awarded by the Committee of Analytical Chemistry, Polish Academy of Sciences for the achievements in chromatography
Marek Trojanowicz
10. Bioconjugates of gold nanoparticles with trastuzumab labelled with ^{211}At for internal alpha therapy
Young Scientist Award for oral presentation at the Wiley Award Session of the 22nd International Symposium on Radiopharmaceutical Sciences, Dresden, Germany, 14-19.05.2017
Lucja Dziawer
11. Pre-treatment of radioactive waste using destructive processes of organic compounds followed by concentration of radionuclides
iia scientific award in recognition for contributing to the advancement of the science of ionizing radiation at the NUTECH-2017 International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017
Dorota Gajda

12. Irradiation of wastewater from Solvay process
Scientific award in recognition for contributing to the advancement of the science of ionizing radiation at the NUTECH-2017 International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017
Marcin Sudlitz
13. The removal of NO_x and SO₂ from exhaust gases using a hybrid electron beam method
The first prize in the category of best oral presentation at the NUTECH-2017 International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017
Ewa Zwolińska
14. Electron beam for preservation of water-damaged paper
The second prize for the best poster presentation at the NUTECH-2017 International Conference on Developments and Applications of Nuclear Technologies, Kraków, Poland, 10-13.09.2017
Marta Wójcik
15. Uzasadnienie ekonomiczne wdrożenia Programu Polskiej Energetyki Jądrowej (Economical aspects of nuclear power programme in Poland)
Second degree award of the Polish Nuclear Society for the best master's thesis in 2016 concerning nuclear sciences
Kamila Kołacińska
16. Generowanie rodników utleniających i ich reaktywność w wytypowanej grupie cieczy jonowych (Generation of oxidizing radicals and their reactivity in ionic liquids)
Distinction of the Polish Nuclear Society for the best doctoral thesis in 2016-2017 concerning nuclear sciences
Małgorzata Nyga (INCT Ph.D. student)
17. First degree team award of Director of the Institute of Nuclear Chemistry and Technology in 2017 for publications concerning the application of flow measurements and modern nanotechnology to improve methods of chemical analysis
Marek Trojanowicz, Kamila Kołacińska
18. Second degree team award of Director of the Institute of Nuclear Chemistry and Technology in 2017 for a series of original scientific publications concerning the fuel cycle and the search for alternative sources of fissile materials
Grażyna Zakrzewska-Kołtuniewicz, Katarzyna Kiegiel, Agnieszka Miśkiewicz, Dorota Gajda, Ewelina Chajduk
19. Second degree team award of Director of the Institute of Nuclear Chemistry and Technology in 2017 for publications on the current problems of air pollution, presenting the practical solutions for reduction of sulphur and nitrogen oxides emissions in the air
Andrzej G. Chmielewski, Yongxia Sun, Ewa Zwolińska
20. Third degree team award of Director of the Institute of Nuclear Chemistry and Technology in 2017 for two publications on cable aging processes in nuclear power plants
Grażyna Przybytniak, Jacek Boguski
21. First degree team award of Director of the Institute of Nuclear Chemistry and Technology in 2017 for the application achievements in 2015-2016 – Technetium-99m labelled antibiotics for healing bacterial infections
Ewa Gniazdowska, Przemysław Koźmiński
22. Second degree team award of Director of the Institute of Nuclear Chemistry and Technology in 2017 for the application achievements in 2015-2016 – Analytical procedures for radionuclides and heavy metals in inorganic fertilizers
Halina Polkowska-Motrenko, Ewelina Chajduk, Jakub Dudek, Zbigniew Samczyński, Paweł Kalbarczyk, Iga Zuba
23. Distinction of the first degree of Director of the Institute of Nuclear Chemistry and Technology in 2017 for the achieved progress in the preparation of Ph.D. thesis and professional activity
Paweł Halik
24. Distinction of the second degree of Director of the Institute of Nuclear Chemistry and Technology in 2017 for the achieved progress in the preparation of Ph.D. thesis and professional activity,
Weronika Gawęda

25. Distinction of the second degree of Director of the Institute of Nuclear Chemistry and Technology in 2017 for the achieved progress in the preparation of Ph.D. thesis and professional activity, including published articles
Kamila Kołacińska
26. Distinction of the second degree of Director of the Institute of Nuclear Chemistry and Technology in 2017 for the achieved progress in the preparation of Ph.D. thesis and professional activity
Rafał Walczak
27. Award of Director of the Institute of Nuclear Chemistry and Technology in 2017 for the activity in events promoting science, among others, Science Festival, Night of Museums
Marcela Grabowska
28. Award of Director of the Institute of Nuclear Chemistry and Technology in 2017 for the activity in events promoting science, among others, Science Festival, Night of Museums
Marcin Sudlitz
29. Award of Director of the Institute of Nuclear Chemistry and Technology in 2017 for the activity in events promoting science, among others, Science Festival, Night of Museums
Ewa Zwolińska
30. Distinction of Director of the Institute of Nuclear Chemistry and Technology for outstanding achievements in the field of scientific publications
Marek Trojanowicz

INDEX OF THE AUTHORS

A

Adamska Renata 76, 77

B

Bakowska Ela 69
 Bojanowska-Czajka Anna 48
 Brykała Marcin 27
 Bułka Sylwester 20
 Buraczewska Iwona 44

C

Chajduk Ewelina 54
 Chmielewski Andrzej G. 73

D

Dąbrowska Małgorzata 17
 Dobrowolski Andrzej 73
 Dudek Jakub 52
 Dybczyński Rajmund S. 54
 Dzierżanowski Piotr 69

F

Fornal Emilia 48
 Fuks Leon 31, 52

G

Gajda Dorota 30, 37
 Głuszewski Wojciech 19
 Gniazdowska Ewa 25
 Grądzka Iwona 44
 Guzik Grzegorz Piotr 83

H

Halik Paweł Krzysztof 25
 Herdzik-Koniecko Irena 31, 52

K

Kalbarczyk Paweł 52
 Kiegiel Katarzyna 30, 37
 Koźmiński Przemysław 25
 Kruszewski Marcin 44
 Kubacki Roman 19
 Kuenzli Stephen 69
 Kulisa Krzysztof 52
 Kunicki-Goldfinger Jerzy J. 69

L

Lankoff Anna 42
 Lewandowska Hanna 42, 44

Ł

Łyczko Krzysztof 42

M

Majkowska-Pilip Agnieszka 25
 Męczyńska-Wielgosz Sylwia 44
 Miłkowska Magdalena 83
 Miśkiewicz Agnieszka 37

O

Olczak Tadeusz 27
 Orliński Wawrzyniec 67

P

Pańczyk Ewa 67
 Pawelec Andrzej 73
 Polkowska-Motrenko Halina 52, 54
 Przybytniak Grażyna 17

R

Rajkiewicz Maria 19
 Rogowski Marcin 27
 Roubinek Otton 73
 Rydzewski Michał 61

S

Sadło Jarosław 17, 42
 Samczyński Zbigniew 54, 76
 Sartowska Bożena 17, 61, 64
 Semina Viera K. 61
 Singer Jared W. 69
 Smolik Jerzy 61
 Smoliński Tomasz 31
 Sochanowicz Barbara 44
 Sommer Sylwester 44
 Starosta Wojciech 61, 64
 Stępkowski Tomasz 42
 Sun Yongxia 73
 Szreder Tomasz 48

T

Trojanowicz Marek 48

W

Waliś Lech 61, 64, 67
 Wawszczak Danuta 31
 Weker Władysław 67
 Wierchnicki Ryszard 76, 77
 Wojewódzka Maria 44

Z

Zakrzewska-Kołodziej Grażyna 30, 37

Zimek Zbigniew 20

Zuba Iga 54

Zwolińska Ewa 73