Review

for competition for a professor in professional direction **4.2. Chemical Sciences (Processes and Apparatus in Chemical and Biochemical Technology)** for the needs of the Laboratory "Transfer Processes in Multiphase Media" at the Institute of Engineering Chemistry - BAS

Announced: state newspaper no. 66/16.08.22

Candidate: Assoc. Dr. Maxim Ivanov Boyanov

Reviewer: Prof. Viktor Genchev Ivanov, Faculty of Physics of SU "St. Kliment Ohridski"

1. Brief biographical data and description of the applicant's scientific interests

Maxim Boyanov was born in 1973 in the city of Sofia. He began his secondary education in 1986 at 114. English Language High School in Sofia. In 1989, he went to the USA, where in 1990 he graduated from Marie Curie High School in the city of Chicago.

In the period 1990-1991, Maxim Boyanov was a physics student at the Illinois Institute of Technology (Chicago, USA). In 1991, he continued his higher education at the Faculty of Physics of the SU, where in 1995 he graduated with an excellent grade of 5.84 in the semester exams and a grade of 6.00 in the defense of a thesis entitled "Two new solutions to the inverse ellipsometric problem".

Since 1997, Maxim Boyanov has been a doctoral student at the University of Notre Dame, USA. In 2003, he obtained a doctorate degree (Ph.D.) after defending a dissertation on "XAFS Studies of Metal-Ligand Interactions at Organic Surfaces and in Solution". By a decision of the Upper Accreditation Council (VAK) from 2007, the scientific degree obtained in the USA was equated to the degree "Doctor" in the scientific specialty 01.03.25 "Structure, mechanical and thermal properties of condensed matter".

From a general point of view, the scientific interests of the candidate fall into a modern interdisciplinary field - biogeochemistry, the subject of which is the study of the influence of natural geochemical and biological factors on the cycle of chemical elements in nature. Most of his works are dedicated to the study of reduction-oxidation processes and the adsorption of heavy metals on biological and mineral surfaces by means of synchronous X-ray spectroscopy - EXAFS (extended x-ray absorption fine structure), XANES (x-ray absorption near-edge structure), XRF (x-ray fluorescence). In this field, he gained extensive experience during two long-term postdoctoral specializations in the USA - in the period 2003-2006 at the Argonne National Laboratory (ANL), Illinois, and in 2006-2007 at the University of Notre Dame Dame. From 2008 to 2014 Maxim Boyanov continued his work on the same topic at the Argonne National Laboratory as a full-time research physicist.

The candidate started his current job at the Laboratory for Transfer Processes in Multiphase Environments at IIH-BAS, in 2014, where a year later he obtained his habilitation, acquiring the academic title "Associate Professor".

In addition to active research activities, the candidate has also acquired significant teaching experience In particular, for two years he led seminar and laboratory exercises at the University of Notre Dame and one year of internship as chief assistant at the Department of Condensed Matter Physics at the Faculty of Physics of SU "St. Klimen Ohridski".

2. General characteristics of the candidate's scientific research and applied scientific activity

The candidate has documented leadership of seven scientific projects with international participation, of which six ended in the period 2007–2022 and one ongoing project with a term of 2022–2025. Five of the projects are inter-institutional – one between Argonne National Laboratory (ANL) and Sofia University, and four between ANL and the Institute of Engineering Chemistry - BAS. In these projects, Maxim Boyanov is the principal investigator from the Bulgarian side. In the remaining two projects, the candidate was a co-principal investigator with affiliation from ANL. All seven projects are funded by the US Department of Energy, with the total amount of funds raised being approximately 9M USD. A total of USD 258,000 was received from these funds as overhead funds for IIH.

The management of such large-scale projects shows that the candidate is one of the initiators and leading researchers in the scientific works presented for the competition. It also outlines the candidate as an excellent scientific manager. Proof of this is the fact that Maxim Boyanov was the organizer and chairman of three thematic sections of international conferences, as well as an invited speaker at 27 conferences in the period after his habilitation as an associate professor.

Recognition of the candidate's scientific expertise is his work as an editor in the prestigious academic journal PLoS ONE, as well as his participation in 49 reviews for international scientific journals.

Maxim Boyanov has been the joint supervisor of two doctoral students at ANL, as well as the supervisor of one postdoctoral student at ANL.

3. Evaluation of the presented materials

Maxim Boyanov has presented a list of a total of 50 scientific publications in scientific journals, of which 30 fall into the highest Q1 quartile according to Web of Science. The high Hirsch index of the candidate - 34, exceeds severalfold the minimum required for holding the academic position "Professor" in Bulgarian academic institutions. Maxim Boyanov also co-authored a chapter entitled "Redox processes affecting the speciation of technetium, uranium, neptunium, and plutonium in aquatic and terrestrial

environments" from the book "Aquatic Redox Chemistry", 2011 ACS edition. This publication summarizes to a significant extent the candidate's earlier research.

For participation in the current competition, the candidate has selected 25 articles in scientific journals from the period 2011 - 2021, as well as the above-mentioned book chapter. The publications of the competition do not repeat those used for the acquisition of the ONS "Doctor" and for the academic position "Associate Professor". Of the publications presented, 17 fall into the Q1 quartile, with 6 of them from the last 3 years. This fact unequivocally shows that the candidate maintains a high pace in his research work, following the highest global standards.

A pleasant impression is made by the clearly designed certificate of compliance of the candidate's science indicators with the minimum national requirements and the additional requirements of IIH-BAS for occupying the academic position "Professor" in the professional direction 4.2. After checking the submitted documents, I confirm the correctness of the data given in the reference, from which it is clear that the candidate fully meets the requirements of the Law for the Development of the Scientific Capacity of Republic of Bulgaria of the and its regulations, as well as the quantitative criteria according to the IIH Regulations. According to some of the criteria - number of publications with IF, citations, H-index, amount of funds attracted through projects, the candidate exceeds many times the threshold values laid down in the regulations.

4. Basic scientific and scientific-applied contributions

Maxim Boyanov's scientific research shows a thematic sequence from his earliest works to the present day. More than half of the papers submitted for peer review are a continuation of the themes laid out in his doctoral dissertation and in his candidacy for associate professorship. They are dedicated to the study of reduction-oxidation processes in uranium compounds under the influence of biological and mineral factors in the environment. This topic is becoming more and more relevant in connection with the disruption of the natural balance of heavy metals in nature due to man-made pollution - from the mining industry, the production of nuclear fuel and the storage of spent fuel in the energy industry, the intensive production of nuclear weapons in the second half of the 20th century. etc. It is known that the highly oxidized form of U(VI) uranium is easily soluble in water, which determines its high mobility in soils and groundwater. On the other hand, in the oxidation state U(IV) uranium forms compounds insoluble or slightly soluble in a pH-neutral environment, which can be more easily separated. This fact raises two fundamental questions:

1) What environmental factors lead to the natural reduction of U(VI) to U(IV), i.e. serve as a natural self-cleaning mechanism in nature?

2) Can artificial clean-up technologies be developed based on these mechanisms for the industries emitting the most pollution from uranium and other heavy metals?

In works [25–22,20,18–16] the bioreduction processes of U(VI) by bacterial cultures were studied in detail, and new and significant results were obtained:

• The presence of phosphates in biological systems has been found to result in the formation of molecular phosphate complexes of reduced U(IV).

• Complexation of U(IV) with the carboxyl groups on bacterial surfaces has been demonstrated.

• Uranium reduction in bacterial films cultured near a former U.S. uranium enrichment plant was studied. The formation of "hot" adsorption centers (hot spots) for U(VI) in biofilms. It is shown that uranium in biofilms is reduced to U(IV), even in an oxygenated environment.

• A reaction column was constructed, with the help of which the immobilization and re-mobilization processes of uranium in soil sediments in interaction with groundwater were studied.

• Of particular practical interest is the technology developed in work [16] for cleaning uranium-contaminated soils by stimulated bioreduction during injection of emulsified vegetable oil into underground boreholes. In this way, extraction from solution of a solid phase containing reduced U(IV), as well as other pollutants such as nitrates and phosphates, was established.

In the articles [21,19,15,13,8,2] mainly processes of reduction and immobilization of uranium on mineral surfaces were studied. The results obtained in these works have significant practical value in the development of new technologies for the extraction of uranium contamination:

• In paper 21, U(VI) reduction processes on porous minerals are simulated in laboratory conditions. For this purpose, samples of porous aluminum oxide were synthesized in a wide range of pore sizes. It was found that the most favorable conditions for the reduction of UVI to UIV are observed with macroporous alumina.

• It was shown that in natural conditions molecular phases of U(IV) can be obtained not only by biogenic mechanisms, but also from interaction with minerals such as magnetite and aluminum oxide, with the so-called green rust, etc. [15,13,8].

• In a recent work [2], the combined interaction of uranium in a bacterial medium with EDTA complexes in combination with iron-containing clays was investigated. U(IV)–EDTA–Fe molecular complexes have been identified, which proves that the EDTA molecule is the binding mediator between uranium and the mineral surface.

Undoubtedly, such large-scale studies are the strength of large collectives, in which it is often difficult to distinguish the role of an individual author. In this case, however, Maxim Boyanov's contribution is clearly distinguishable and refers to the formulation of new scientific hypotheses and development of models for presumed reduction-oxidation reactions, modeling of the reaction products - molecular complexes of uranium, and experimental confirmation or rejection of the hypotheses by means of synchrotron XANES and EXAFS spectroscopy. These two types of X-ray spectroscopy are extremely powerful methods for characterizing the local chemical environment of a given type of atom, and their

choice as the primary research tool is fully justified, since the oxidation state of uranium is a function of the ligands bound to it.

The most complete idea of the nature of Maxim Boyanov's work can be obtained from the presented SI (supporting information) appendices to the articles, where the methodology of the conducted XANES and EXAFS studies is described in detail. The results of these two types of spectroscopy usually cannot be interpreted directly. Finding the correct atomic environment is the result of additional quantum chemical modeling of the suggested structures, numerical fitting of the experimentally obtained radial distribution function to the theoretically calculated interatomic distances, as well as comparison with reference compounds with a previously known type of uranium atomic environment. This comes to show that the use of these two methods is not so much a matter of routine handling of a certain apparatus as of deep knowledge of chemical processes and professional mastery of modern numerical and quantum chemical methods.

Other interesting topics are represented in the more recent publications submitted by the candidate. One of them is related to the biochemical processes in absorption of nanoparticles by plants. The migration and impact of nanoparticles on living matter is of extreme interest for modern ecology in the context of the ubiquitous penetration of nanotechnology in industry and in everyday life. Paper No. 19 investigated the accumulation of CuO and ZnO nanoparticles in wheat. By means of XANES spectroscopy, the partial dissolution of copper and its association with sulfate groups in plant tissues has been established. In the case of ZnO, the almost complete dissolution of the nanoparticles and the functionalization of zinc to phosphate groups. Of particular interest to me, as a specialist in Raman spectroscopy, is paper #6, in which a methodology was developed for visualizing plasmonic RNA markers in plants using three complementary methods - surface-enhanced Raman spectroscopy (SERS), two-photon fluorescence, and X-ray fluorescence (XRF). For this purpose, two types of star-like nanoparticles (so-called nanostars) were infiltrated into the leaves of Arabidopsis thaliana - uniform gold and heterogeneous with a gold core and a silver shell. Precious metals are known for their narrow plasma resonance, which near the pointed parts - in this case the "rays" of the nanostars, leads to an amplification of the local electric field by several orders of magnitude. In this way, all forms of optical response - absorption, luminescence and Raman scattering - undergo multiple amplification in the vicinity of the nanoparticle. This allows spatial localization of certain biomolecules according to their characteristic spectral response. The methodology developed in this article, in my opinion, has great potential for application in the near future in biomedical diagnostics, ecology, etc.

In conclusion, the works presented for review prove an undoubtedly significant contribution of the candidate to the research described, which can be characterized as “developing a new theory or hypothesis; enrichment of existing knowledge and theories; application of scientific achievements in practice". In my opinion, the candidate's self-assessment summary correctly and fully reflects his scientific contributions.

6. Reflection of the candidate's scientific publications in Bulgarian and foreign literature

The candidate submitted a list of 765 citations to the works submitted for participation in the competition. I have not identified self-citations by the author or his co-authors. The citations are fairly evenly distributed among the papers, but paper #19 stands out, with 278 citations to date, and can be defined as the candidate's "golden paper".

7. Critical notes and recommendations

I have no fundamental objections to the candidate and to the submitted documents. All references required by law are prepared precisely and are easy to read. Only minor technical errors are noted (for example repeated number 5 in the contract reference), which are however unavoidable when preparing such voluminous documentation.

If successful in winning the current competition, I would recommend the candidate to form his own scientific group, to which he would attract young scientists who graduated from chemistry or physics majors in Bulgarian universities.

8. Personal impressions of the reviewer about the candidate

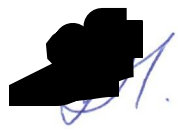
I have known Maxim Boyanov recently in connection with his invitation to participate in the jury for the current competition, and until now I have had no personal impressions of his work. My assessment is based solely on the materials submitted for the competition.

CONCLUSION

Maxim Boyanov has an impressive portfolio of scientific publications that have received wide international recognition. He works in a modern and rapidly developing interdisciplinary field, and his research is of interest from both an academic and an applied perspective. His scientific profile corresponds to the theme of the competition, as well as to the scientific direction of the "Transfer Processes in Multiphase Environments" laboratory at IIH. An important advantage is the candidate's experience in attracting funding for his scientific projects and his ability to organize large working groups. The teaching experience of the candidate is also important, which would allow him to select and train doctoral students in the future, as well as to form his own scientific group.

Based on the above, I give a strongly positive assessment of the candidacy of Associate Professor Dr. Maxim Boyanov in the current competition and recommend to the respected Scientific Council of the Institute of Engineering Chemistry to select the candidate for the academic position "Professor" in the professional field 4.2 Chemical Sciences.

Date: 01/12/2022

Reviewer: 

/prof. Viktor Ivanov/