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Załącznik nr 3 do Wniosku z dnia 27 czerwca 2017 r. o przeprowadzenie postępowania habilitacyjnego w dziedzinie nauk fizycznych w dyscyplinie fizyka.

Summary of professional achievements

1. First name and surname.

Przemysław Adrich

2. Diplomas and degrees held - with the name, place and year of obtaining them and the title of doctoral thesis.

Doctoral degree in physical sciences in physics, obtained at the Jagiellonian University in Cracow, 2005. Title of the doctoral dissertation: *Observation of Pygmy and Giant Dipole Resonances in* ^{132}*Sn and Neighboring Mass Isotopes.*

Master degree in physics, obtained at the Jagiellonian University in Cracow, 2000. Title of the master's thesis: *Spectroscopy of fragments of* ^{252}*Cf spontaneous fission.*

3. Information on employment in scientific institutions.

Since 2011 r.	National Centre for Nuclear Research (NCBJ), Otwock, Poland, senior research and technical specialist
2010 – 2011	Soltan Institute for Nuclear Studies, Otwock, Poland, senior research and technical specialist
2009 – 2010	Soltan Institute for Nuclear Studies, Otwock, Poland, physicist
2005 – 2008	National Superconducting Cyclotron Laboratory (NSCL), East Lansing, MI, USA, research associate
2001 – 2004	Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany, doctoral assistant
2000 – 2005	Jagiellonian University, Faculty of Physics, Astronomy and Applied Computer Science, Kraków, Poland, doctoral student

4. Indication of achievement based on Art. 16 sec. 2 of the Act of 14 March 2003 on academic degrees and academic title, and degrees and titles in the field of arts (Journal of Laws 2016, item 882, as amended, Journal of Laws 2016, item 1311.):

As a scientific achievement I present a monograph entitled
Formowanie wiązek elektronowych. Nowe koncepcje układów formowania i rozwój metod ich projektowania w oparciu o narzędzia współczesnej fizyki subatomowej
(title in English: *Electron beam forming. New concepts of beam forming systems and development of design methods based on tools of contemporary subatomic physics*), published by the National Centre for Nuclear Research, 2017, ISBN 978-83-941410-5-9. I am the sole author of this monograph.

Discussion of the scientific purpose of the aforementioned work and the results achieved, including discussion on their possible use.

In recent decades, electron accelerators operating in the energy range from few to several MeV have found numerous applications in industry, medicine, and scientific and technological research. It is estimated that there are currently over 20,000 such accelerators in use worldwide, of which about half are medical linear accelerators. Significant social and economic benefits of existing accelerator technologies are a driving force behind constant development of ever-increasing number of new applications, as well as of new designs and improvements of older designs.

For an accelerator to be useful for practical applications it must be equipped with a suitable beam forming system. The main task of such a system is to transform a narrow primary beam (often referred to as "pencil beam"), into a so-called broad beam (also referred to as "formed beam") that is suitable for practical use. The goal is to achieve a uniform distribution of radiation dose within the designated irradiation field, which is usually much larger than the transverse dimensions of the primary beam. This can be accomplished in two ways: either by periodic sweeping of the primary beam over the field area or by proper scattering of the primary beam. The first method is implemented in the so-called active systems, the second in passive systems, which are the topic of my monograph.

Active systems, due to their very high efficiency and the ability to operate with primary beams of very high power, are the backbone of many industrial radiative technologies. Passive systems, in turn, are used in medical applications[1] where we are dealing with beams of much lower power, but on the other hand one of the key requirements is the uniformity of dose distribution.

In the passive beam forming system, the primary beam is firstly scattered by means of a so-called scattering foils. Then, the scattered beam is collimated (spatially limited) to the area of designated irradiation field. The collimation system typically

[1] The use of active systems in medical electron accelerators was abandoned completely as a result of a series of tragic radiation accidents in the 1980s and 1990s caused by faults in these systems.

consists of an initial collimator (or a number of collimators) and an exchangeable collimator that finally determines the shape and size of the irradiation field. The latter is usually referred to as an "applicator".

Elements of the passive beam forming system must be individually designed accordingly to the specific requirements of a given application, energy of the beam (or beams in the case of multi-energy accelerators), size of the irradiation field, etc.

Known methods of designing and optimizing passive systems are based on a simple analytical model of beam scattering in the foils. This model omits many important physical processes such as the production of secondary radiation (Bremsstrahlung, delta electrons), energy loss in non-radiative processes, large angle scattering, etc. Moreover, this model does not account for secondary scattering off the elements of the collimation system, though it is known that this process significantly distorts the fluence (dose) distribution produced in absence of the collimation system. While over the years, the physics models have been gradually improved, the analytical model itself has not been extended towards more realistic geometry of the system (it seems, anyway, that the complexity of such an extended model would render it not suitable for practical use).

The limitations inherent to the analytical model, despite many improvements introduced over the years, make the design methods that are based on this model essentially unfit for designing beam forming systems that would be capable of meeting current day demands – which are particularly elevated in the case of modern medical applications. A reflection of this fact may be found in numerous imperfections of existing devices, as documented in the subject literature.

On the other hand, the most modern and advanced applications, such as e.g. intraoperative electron beam radiation therapy[2], present a number of new challenges, not only related to design methods, but also to some of the well-established concepts, principles, and solutions.

In the aforementioned monograph I presented results of my research aimed at solving the problems outlined above. Some of the results are:

- a new, universal method for designing the system of scattering foils. The new method, by taking into account complete physics as well as realistic geometry, removes all the disadvantages of the methods of previous generations. The new method also offers a number of new, previously inaccessible, ways of deep optimization of passive systems (e.g. the new method allowed me to demonstrate that, under certain conditions, a properly optimized passive system can be equally efficient as an active system while being much simpler and more economical),
- development of a number of new concepts and solutions of passive beam forming systems for medical and research applications. In particular, a new, optimal solution of the beam collimation system for the first Polish mobile electron accelerator for intraoperative radiation therapy, a universal algorithm for optimization of beam forming system (in particular the so-called "aperture

[2] Intraoperative radiotherapy is one of the most modern methods of treating cancer. It involves the combination of oncological surgery with radiotherapy performed in the operating room. In recent years, this technique has increasingly gone beyond the field of scientific research and clinical trials towards routine use.

plate applicators") in electron beam teleradiotherapy, as well as, a systems for high dose rate research irradiations under cryogenic conditions.

Secondary, nonetheless important, motivation for writing the abovementioned monograph was to fill a burdensome gap in the existing subject literature related to the lack of a complete text on passive beam forming systems (works that deal with issues of interest in respect to passive systems are both fragmentary and scattered in various sources over the period of at least the last 40 years).

My works and results presented in the abovementioned monograph are closely related to the programs carried in recent years in the National Centre for Nuclear Research that were aimed at development of innovative linear electron accelerators for medical and industrial applications. Much of the presented results were obtained within two large long-term research and development projects:

- Project No. POIG.01.01-14-012/08-00, entitled "Development of Dedicated Systems Based on Accelerators and Detectors of Ionizing Radiation for Medical Therapy and in Detection of Hazardous Materials and Toxic Wastes" (abbreviated as "Accelerators & Detectors" or "AiD") implemented in the years 2008 – 2013 in the framework of the national Operational Programme "Innovative economy" supported by the European Union Structural Funds,
- Project No PBS2/B9/26/2014, entitled "Comprehensive System for Intraoperative Electron Beam Radiation Therapy" (acronym "Intra-Dose"), implemented in the years 2014 – 2016 within the Applied Research Program in path B, co-funded by the National Center for Research and Development.

Below, I will present my works and the results achieved in more detail, alongside presentation of the contents and outline of the monograph. Some of the results have already been published in the form of articles in scientific journals and papers at international scientific conferences, as indicated in the appropriate places below.

The main part of the monograph is preceded by an introductory chapter. To place my work in a broader context and to outline the potential for future applications of the results presented, I first explain the current role and significance, as well as the anticipated increased use of electron accelerators in industry, medicine, and in scientific and technological research. Then, at first in a simplified way, I discuss the existing solutions of beam forming systems and their applications, paying the most attention to the passive systems that are the main subject of this work. I am outlining the existing problems and my solutions, which are then discussed in details in subsequent chapters of the monograph. I also discuss the secondary, albeit not least important, purpose of this work which is to create a kind of textbook for physicists designing passive electron beam forming systems (yet equally accessible and useful to other members of interdisciplinary teams that develop modern electron accelerators).

The first chapter of the monograph is devoted to the presentation of the physics of electron beam interaction with matter. A good understanding of physics fundamentals is a prerequisite for a thorough understanding of the beam forming system operation, and especially for undertaking work aiming at development of new solutions or new design methods. The material in this first chapter is presented in the most accessible way, also to non-physicists, but at the same time in sufficient detail to allow referring to it throughout all subsequent chapters. The chapter begins with a dictionary of terms and symbols used. Then, the discussion of physics commences with a simple, qualitative illustration of the propagation of electron beams of different energies in different materials. The focus here is on a qualitative description of the most important processes, which are subsequently discussed in more quantitative terms. It is indispensable to introduce certain quantities fundamental in description of propagation of the beam in material media, such as stopping power, scattering power, range, radiation yield, etc. The emphasis is always placed on explaining the physical meaning of formulas, quantities and their relations. Discussions are illustrated with examples referring to the actual beam forming systems covered in following chapters.

In Chapter 2, I discuss in depth the principle of operation of the passive beam forming system as well as the existing methods for designing such systems, including numerous references to the literature of the subject. On this ground I introduce, at first formally, a new, proprietary method for designing scattering foils. This method, by accounting in a consistent way for all relevant physical processes, removes all drawbacks and limitations of previously known methods as well as it provides a deep insight into the behavior of the complete system in function of all of its important parameters. This, in turn, allows for a conscious and complete optimization of the system. It also allows addressing certain important specific issues that were so far virtually unsolvable. Furthermore, what so far was also practically beyond reach, the new method makes it possible to unequivocally document that the solution developed is indeed the best one of all otherwise possible solutions. The new method is also universal, i.e., it can be applied regardless of the degree of complexity of the system under consideration. In addition, the scope of its applicability is not limited to electron beams. The new method can be easily adapted, for example, to the domain of proton beam therapy of eye tumors (what attracted attention of scientists from the Henryk Niewodniczański Institute of Nuclear Physics PAN in Cracow - Poland's only center treating eye tumors with proton beams. See item III H 2a of the statement of achievements, Appendix 4).

The new method requires calculation, in discrete space, of certain functions that model the operation of a real system. This is possible only with the use of advanced research tools of contemporary subatomic physics, such as the Geant4 library for Monte Carlo simulation of radiation transport in matter, originally built for high energy physics experiments. In this regard, however, a question may be raised whether the complexity and duration of the necessary computations would not render the new method impractical?

To address this question and to illustrate the potential of the new method, in Chapter 3, I describe the application of my new method to designing a real beam forming system for the LILLYPUT 3 accelerator built at NCBJ and installed in the Non-Destructive Testing Laboratory (NDT) of the Wrocław Technology Park. This system is going to be part of an experimental setup for high dose rate electron beam irradiations under cryogenic conditions. As I have shown, the new method is not only practical, but it also greatly reduces the overall design time, while warranting the best possible result. I have also demonstrated that, noteworthy, under certain conditions, the new design method allows optimizing the passive system to such an extent that it can become at least as efficient as a, much more complex, active system. In addition, in Chapter 3, I discuss in detail multiple practical aspects of the application of the new method, including experimental software tools that I have developed and that allow to apply the method to any arbitrarily complex system.

The material presented in Chapters 2 and 3 is largely based on a series of my publications in English-language scientific journals (items II A 1, II A 2, II A 4 of the statement of achievements, Appendix 4). I am the sole author of the two most important papers in this set and the first author of the third one. I also presented this work at international conferences (items II H 1, II H 3 of the statement of achievements, Appendix 4). The development of the new method and the aforementioned series of publications granted me the Diploma of the National Centre for Nuclear Research for the Scientific Achievements in 2016, awarded by the Director of the Institute.

Chapter 4 is devoted to the problem of initial collimation of a beam scattered in the scattering foils. Usually, this is not a particularly difficult problem. In standard applications, a collimator made of heavy metal alloy performs very well. Here, however, I am dealing with a case that requires rethinking the issue from the ground up and developing a completely new concept. The case mentioned is a collimation system for the prototype of the first Polish mobile accelerator for intraoperative radiation therapy, built at the NCBJ within the framework of the "Intra-Dose" project. This accelerator is designed to work under conditions of an operation room where it will be used to administer single radiation dose, of the order of 10 Gy, directly into a surgically exposed lodge after resected tumor. The device has to meet a whole lot of new challenges. One such challenge is the construction of a collimation system that should be very light and compact (so that the device does not lose on mobility) but at the same time it should very effectively reduce the level of leakage X-ray radiation (in order to protect the patient, staff, and other persons who may be present in adjacent areas). It seems that these requirements are self-contradictory. But, as I demonstrated, by moving away from the well-established schemes of collimation system construction, these two contradictory requirements could be reconciled. This, however, requires an in-depth study of the issue, including localization and elimination of the most important sources of leakage radiation.

The solution that I have developed is entirely based on lightweight aluminum alloys and was implemented in the prototype of the accelerator constructed within the "Intra-Dose" project. The results of the preliminary measurements indicate that, while very good parameters of the therapeutic beams are maintained, the level of leakage radiation meets all the requirements of the relevant standard for medical electron accelerators. Furthermore, doses due to leakage X-ray radiation as measured at different locations around the accelerator are either lower or similar to the results reported in the literature for the Mobetron accelerator. It is worth noting that, among commercially available electron accelerators dedicated to intraoperative radiation therapy, the Mobetron accelerator has the lowest X-ray leakage radiation, what, however, was achieved by means of massive collimators that significantly reduce the mobility of the device. Unlike as in the Mobetron, the small mass of the beam collimation system of the new prototype accelerator built in the NCBJ (less than 6 kg) made it possible to employ a mechanical construction of excellent mobility and unusually large working space of the therapeutic head - key features of an intraoperative radiation therapy device.

The innovative design of the NCBJ's accelerator and the abovementioned preliminary results of dosimetric measurements of both the therapeutic electron beams and the leakage radiation have attracted interest from potential future users, led by the Greater Poland Cancer Center in Poznan – NCBJ's partner in the "Intra-Dose" project and the country's leader in intraoperative electron radiation therapy. Thus, there are good perspectives for the already started commercialization efforts and for establishing production of this kind of accelerators in the Institute in Świerk.

The material presented in Chapter 4 is partly based on the results of research carried out within the "AiD" project and previously published in the form of articles in scientific journals (items IIA 3, II B 1, II B 2, II B 4, II C 1 of the statement of achievements, Appendix 4) and papers at numerous scientific conferences (items II H 2, II H 4, II H 5, II H 6 of the statement of achievements, Appendix 4). However, the main part of the chapter consists of a presentation of the new original concept that I have developed within the "Intra-Dose" project and that is here published for the first time.

In Chapter 5, an algorithm developed by myself for optimization of aperture plate applicators for electron beam teleradiotherapy is presented. This subject is also directly related to the project conducted in NCBJ and aimed at developing a modern medical accelerator for advanced radiotherapeutic procedures involving both, electron and megavoltage X-ray beams of several different energies (in what follows this accelerator is referred to as "highly specialized accelerator").

This work was done within the framework of the "AiD" project, but has not been previously published (except for a short note in the Institute' Annual Report for 2010 and a series of internal seminars delivered by myself). Unlike in the case of intraoperative radiation therapy, here we are dealing with a rather typical initial beam collimation system, however, the exchangeable applicators of the therapeutic beam require much more attention.

Interestingly, despite the fact that the general concept of the aperture plate applicator is known and used in numerous variants for a relatively long time, the majority of actual constructions has various drawbacks that are well documented in the literature. These drawbacks are often associated with excessive levels of leakage radiation and/or substantial applicator weight, which is not ergonomic. The lack of reports on in-depth studies on the principles of optimization of this kind of applicators is somewhat astonishing. I decided to fill this gap while working on the beam forming system for the highly specialized accelerator that is being developed at NCBJ. As a result of this venture I created a complete, universal optimization algorithm that is presented in Chapter 5.

As discussed in this chapter, optimization of the aperture plate applicator (as well as the entire electron beam forming system) is not trivial. There exist in the subject literature reports on certain specific issues, however, a general optimization algorithm has not been previously known. Such a state of affairs results in the, already mentioned, drawbacks of available devices.

In Chapter 5, I presented my algorithm along with an example of application of this algorithm in designing a set of applicators for the demonstrator of the highly specialized accelerator that is being developed at NCBJ. Then, based on the results of detailed Monte Carlo simulations, I showed that the beam forming system optimized accordingly to the new algorithm allows to achieve parameters of the therapeutic beams that match, and in some cases even exceed, the parameters of the therapeutic beams of the most modern accelerator currently available on the market, i.e. the Varian' TrueBeam accelerator (noteworthy Varian is the world's largest manufacturer of medical accelerators). Whereas the weights of comparable applicators are similar in both cases (and much smaller than the weight of applicators produced by the world's second largest medical accelerator manufacturer, Elekta). What is important, my algorithm is universal, i.e. it can be successfully applied to optimize the aperture plate applicator regardless of the construction of the remaining components of the therapeutic head.

It is noteworthy that the work on an algorithm for optimization of aperture plate applicators was independently undertaken at Louisiana State University (LSU) in Baton Rouge, USA - a center known of numerous accomplishments in improving electron beam radiotherapy techniques and devices.

The algorithm created by myself and the algorithm developed in LSU (and presented in a recent doctoral dissertation by G. Pitcher) have many common features. Nevertheless, the algorithm presented here is more complete in that it takes into account and solves the problem of parallel optimization of the scattering foils, which is lacking in the Pitcher's algorithm. Pitcher, in turn, more closely examined (though not implemented in the realized model) the possibilities of some additional small improvements in the applicator design, which here were only signaled. It seems therefore that there is still some room for mutually inspired improvements in both algorithms, although in case of my algorithm, one should not expect those improvements to be significant.

The last, 6th chapter contains a succinct summary of the most important results presented in the monograph.

5. Discussion of other achievements

The most significant of my other research achievements are related to experimental nuclear physics, in particular studies of so-called exotic nuclei. Exotic nuclei are unstable isotopes characterized by a ratio of neutron (N) to proton (Z) numbers that are very distant from the values typical to stable nuclei (hence "exotic" in the name). Exotic nuclei do not exist under normal conditions on Earth. Studies of nuclear structure and reactions involving exotic nuclei allow gaining knowledge of these properties of nuclear forces and nuclear matter that are not manifested in stable isotopes. In addition, exotic nuclei play an important role in many astrophysical processes (nucleosynthesis in supernovae), thus data on their properties is crucial to understanding these processes.

Artificial production and studies of the properties of exotic nuclei require very complex equipment, available only in very few research centers around the world, as well as, large, usually international, research teams. For this reasons, research works that I will discuss below have been largely accomplished during my long-term visits in two foreign laboratories: the Gesellschaft für Schwerionenforschung (GSI) in Darmstadt, Germany and the National Superconducting Cyclotron Laboratory (NSCL) in East Lansing, USA (both centers belong to the group of world class leading laboratories in the field of nuclear physics). These works I had completed in the period before employment at the National Centre for Nuclear Research. Although my research at GSI and NSCL was not directly related to the topic of my habilitation dissertation, it provided me with an excellent background to undertake my own unsupervised research of electron beam forming systems.

Period of doctoral studies

I was awarded with the degree of doctor of physical sciences in physics by the Council of the Faculty of Physics, Astronomy and Applied Computer Science of the Jagiellonian University, by the resolution of 29 September 2005, on the basis of a doctoral thesis entitled "Observation of Pygmy and Giant Dipole Resonances in ^{132}Sn and neighboring mass isotopes". The promoter in the doctoral thesis was prof. dr hab. Władyslaw Waluś. The reviewers in the doctoral thesis were prof. dr hab. Adam Maj and prof. dr hab. Tomasz Matulewicz.

Subject of my doctoral thesis was experimental study of collective dipole excitations in exotic atomic nuclei from the region of mass number $A \approx 130$ and atomic number $Z \approx 50$, including the doubly magic nucleus ^{132}Sn.

These nuclei are characterized by much higher neutron numbers than exhibited by the heaviest stable isotopes of these elements. For example, the doubly magic ^{132}Sn nucleus has 8 neutrons more than the heaviest stable tin isotope ^{124}Sn. The excess of neutrons, while causing instability of these nuclei, also determines their extraordinary properties. According to modern theoretical models, excess neutrons are expected to occupy mainly the outer regions of the atomic nucleus, forming a layer of nuclear matter almost completely devoid of protons. This region is usually referred to as the "neutron skin". In these peripheral areas of the nucleus, the central nuclear potential gradually decreases, leading to a decrease in the density, as well as to a decrease in the binding energy of the nucleons that are residing there. Under these circumstances residual interactions between valence neutrons become the most significant. As a result, the neutron skin becomes weakly bound to the core of the nucleus. This in turn should allow for the existence of a new type of collective excitation (unobserved in stable nuclei), i.e. oscillation of the neutron skin with respect to the core of the nucleus. Such excitations are referred to as Pygmy Dipole Resonance (PDR). This term refers to well-known Giant Dipole Resonance (GDR), which is one of the universal types of collective nuclear excitation. The GDR resonance is a coherent, dipole mode oscillation of all protons against all neutrons in the atomic nucleus. Theoretically predicted mean excitation energies and excitation probabilities of the PDR resonances are much lower than that of the GDR resonances (hence the term "Pygmy" in the name of the former ones).

The main aim of my doctoral dissertation was to experimentally verify the existence of PDR in the ^{132}Sn nucleus and isotopes with similar N/Z ratio, as well as to determine essential characteristics of those resonances (such as mean excitation energy, resonance width, cross section, etc.). This work was an important part of a larger scientific program of the FRS-LAND collaboration leaded by the Gesellschaft für

Schwerionenforschung (GSI) in Darmstadt, Germany. I accomplished majority of my doctoral research (including the experiment, data analysis and interpretation of the results) during a 3 year visit at this institute in the years 2001—2004.

The foundation of the technique employed in the experiment is the process of electromagnetic excitation of the projectile nuclei impinging, at relativistic velocity, on a high atomic number target (e.g. lead, uranium). At relativistic energies, this process is mainly sensitive to dipole electric transitions E1, with a slight admixture of quadrupole E2 transitions. Total cross sections are substantial, of the order of hundreds milibarns. The dipole strength distribution, $S_1(E^*)$, can be deduced from the measured differential cross section ($d\sigma/dE^*$) by means of the semiclassical virtual photon method. This experimentally obtained strength distribution can then be used to verify predictions of various contemporary theoretical models. The excitation energy, E^*, of the projectile is obtained, by means of the so-called invariant mass method, based on the identification and kinematically complete measurement of four-momenta of the projectile as well as of all the decay products of the excited state of the projectile, i.e., neutron(s), γ rays and heavy residue nucleus remaining after neutron emission.

The beam of studied exotic nuclei was produced by means of electromagnetically induced fission of primary ^{238}U beam. The primary uranium beam was first accelerated to 550 MeV/nucleon in the SIS synchrotron and then directed onto beryllium production target. The resulting secondary beam was purified from undesired isotopes by the fragment separator FRS and then transmitted to the experimental station.

A very complex experimental setup was used for the measurements. Projectile nuclei were identified by measurement of the atomic number Z (by means of energy loss measured in a semiconductor PIN diode detector) and by measurement of its mass determined from the measured momentum (from the trajectory in the magnetic field of the particle separator) and velocity (from the time-of-flight over 80 m distance between the fragment separator and the experimental station). The charge of the heavy fragment recoiling from the reaction of the projectile nucleus in the target was measured in the same way as the nuclear charge of the projectile. The mass of the fragment was determined by tracking its trajectory in the magnetic field. For this purpose the ALADIN dipole magnet was setup behind the reaction target. The position of the fragments was measured in front of the magnet by means of position sensitive semiconductor detectors, and behind the magnet, by means of a multiwire chamber and position sensitive detectors made of scintillator fibers. Time of flight of heavy fragment was measured with a scintillator detector. Four-momentum of emitted neutron(s) was measured with position sensitive neutron detector LAND, located approximately 11 m downstream from the target. The emitted γ radiation was measured in the 4π geometry with the Crystal Ball detector consisting of 162 NaI crystals.

As a result of my analysis of collected experimental data, I was able to reconstruct the dipole strength distributions in ^{130}Sn and ^{132}Sn nuclei over the excitation energy range from the neutron emission thresholds up to 25 MeV. These distributions, which were here measured for the first time, are different than in case of stable isotopes. In particular, a significant fraction of total dipole strength is concentrated below the Giant Dipole Resonance. This result is a clear confirmation of the existence of PDR type mode of excitation in these nuclei, although it does not prejudge its nature (in particular, whether this excitation correspond to collective oscillation of the neutron skin or to other mechanisms postulated in some theoretical works).

In parallel with the doctoral dissertation, the most important results, including the measured dipole strength distributions in ^{130}Sn and ^{132}Sn nuclei, were published in the prestigious English language scientific journal Physical Review Letters (item II A 13 of the statement of achievements, Appendix 4). This work, of which I am the first author, has been cited more than 270 times. I also presented these results at international scientific conferences (items II H 11 – II H 14 of the statement of achievements, Appendix 4).

The analysis and interpretation of the dipole strength distributions in odd-mass nuclei measured in the same experiment was published in subsequent papers, which I also co-authored, published in English-language scientific journals with high impact factors (items II A 6, II A 10 of the statement of achievements, Appendix 4) and as conference proceedings (items II B 5 – 7 of the statement of achievements, Appendix 4). These works also received similarly high number of citations.

While working at GSI Darmstadt I have also actively participated in many other experimental studies of exotic nuclei. These works resulted in numerous articles in scientific journals of which I am a co-author (items II A 14 – 15, II A 19, II A 26 – 27, II A 29 – 30, II A 37, II A 41 – 46, II B 8 – 11, II B 13, II B 15 – 22 of the statement of achievements, Appendix 4), although my contribution to these experiments was often significantly lower than in the case of the above described studies of collective excitations in ^{130}Sn and ^{132}Sn nuclei.

Period after obtaining a PhD degree

Immediately after getting the PhD degree, I successfully applied for a postdoc position at the National Superconducting Cyclotron Laboratory (NSCL) in East Lansing, Michigan, USA. I was employed there in the time period 10.2005 – 6.2008.

At that time, the Laboratory hosted large and constantly expanded research infrastructure. The Laboratory was equipped with, among others, a set of coupled superconducting cyclotrons, superconducting fragment separator A1900, magnetic spectrometer S800, array of position sensitive germanium (HPGe) γ radiation detectors - SeGA. This is one of the world's best facilities for experiments with exotic nuclear beams.

While working at NSCL, I continued fundamental research in nuclear physics. I was simultaneously member of two research groups led by prof. T. Glasmacher and prof. K. Starosta, respectively. The research interests of the first group included γ spectroscopy of exotic nuclei as well as studies of nuclear reactions. The second group was engaged, among other subjects, in development of the Recoil Distance Method (RDM) towards application of this method for measurements of picosecond lifetimes of excited states in exotic nuclei.

Being an active member of two busy research groups, I am co-author of numerous papers published in peer-reviewed scientific journals indexed by the ISI (items II A 5,

II A 7 – 9, II A 11 – 12, II A 16 – 18, II A 20 – 25, II A 28, II A 31 – 36, II A 38 – 40, II B 12, II B 14 of the statement of achievements, Appendix 4). Below I will focus on discussing only some selected works, i.e. those in which my contribution was dominant or more significant than in the others.

An important achievement of my postdoc at NSCL was an experimental investigation of the nuclear structure of exotic, neutron-rich iron and chromium nuclei, with the neutron number N≈40 (item II A 9 of the statement of achievements, Appendix 4). My contribution in this work was very large. I was responsible for conducting the experiment, entire data analysis and, to a large extent, interpretation of the results. I am also the first author of the above mentioned article. The results of this work I presented also as oral contributions at international scientific conferences (items II H 7 – 9 of the statement of achievements, Appendix 4).

In this work, γ-rays associated with de-excitation of excited states of ^{68}Fe nucleus were measured for the first time and the energy of the first excited state (2_1^+) of this isotope was proposed. These results were since then confirmed in subsequent experiments.

The second most important result that I published in the same paper were cross sections for the knockout of two protons from the ^{68}Ni, ^{70}Ni and ^{66}Fe nuclei impinging on the ^{9}Be target, at about 70 MeV/nucleon energy. In these reactions, respectively, ^{66}Fe, ^{68}Fe, and ^{64}Cr nuclei were produced and identified using the S800 magnetic spectrometer. In the latter case, the measured cross-section turned out to be considerably smaller than expected on the basis of calculations with the valence space limited to *pf* subshell. This result was interpreted as the signature of the emergence of a so-called island of inversion. An island of inversion is a region within the chart of isotopes in which the order of certain orbitals changes (inverts) with respect to the order of the same orbitals in stable isotopes. The first such island was discovered shortly before, also at NSCL, near the ^{31}Na isotope. The existence of islands of inversion is a manifestation of the poorly known, tensor component of the nuclear force. Investigations of nuclear structure variation within islands of inversion provide valuable data to better understand, inter alia, these components of the nuclear force.

Results published in the aforementioned work (item II A 9 of the statement of achievements, Appendix 4), are one of the first empirical indications of the existence of an island of inversion in the vicinity of ^{64}Cr isotope. This attracted considerable interest reflected in more than 60 citations of this work. In the following years these results were confirmed and refined by observations of many subsequent experiments.

While participating in the work of prof. K. Starosta's group, I made a noteworthy contribution to the development of tools for designing the experiments as well as methods of interpretation of data from the RDM measurements on beams of exotic nuclei. The RDM method allows direct measurement of lifetimes of excited states that decay by emission of γ radiation. Lifetimes of these states are in turn directly related to the probabilities of electromagnetic transitions, which carry important information about structure of studied nuclei as well as about details of nuclear interactions.

The utilization of the RDM method in the case of secondary beams of artificially produced exotic nuclei is non-trivial. Both, the proper arrangement of the experiment and proper interpretation of the measured data require very detailed simulation of the complete experimental setup. As a member of prof. Starosta's group I participated in the construction of a tool dedicated to facilitate RDM measurements at NSCL. This tool is based on Geant4 library for Monte Carlo modeling of radiation transport in matter and on Root library for statistical analysis. I contributed particularly to the development of a method for the interpretation of the measured data. The method relies on comparison, by means of appropriate statistical tests, of the simulated and measured γ radiation energy spectra. The simulator as well as the developed method for data analysis was described in the paper of which I am the first author (item II A 8 of the statement of achievements, Appendix 4). This work is used until today to design new experiments and to analyze data from RDM lifetime measurements at NSCL. So far, this work has been cited more than 20 times.

In addition to the above, during my postdoc at NSCL, I had a rare opportunity to take an active part in the construction of a new, large-scale, γ radiation detector system for experiments with relativistic beams of exotic nuclei - CAESAR. The motivation of the project was the need to supplement the research infrastructure of the Laboratory with a highly efficient detector. While the HPGe germanium detectors of the existing SeGA array have very high energy resolution (about 3% in case of measurements with exotic beams), the total detection efficiency is only a few percent (depending on the SeGA configuration). Such low efficiency was one of the bottlenecks that made it impossible to study the most exotic nuclei (that are often also the most interesting) that are particularly difficult to produce and hence available only as very low intensity beams.

The CAESAR detector was conceived as an array of scintillation detectors. After considering various alternatives, the detectors were finally made of popular CsI(Na) scintillator. Due to much smaller costs of production of such detectors, relative to HPGe, it was possible to build an array with a close to 4π geometry (that is, to achieve very high detection efficiency).

While participating in the CAESAR detector construction project, I was responsible for investigating the impact of the detector geometry on the scintillation light collection efficiency in the scintillator - light guide - photomultiplier system. There was a concern that some of the detector geometries contemplated in the project would exhibit too much heterogeneity in light transport efficiency depending on where the light was produced, leading to a reduction in energy resolution. I did research on this issue using Monte Carlo simulation technique.

The constructed CEASAR detector consists of 192 CsI(Na) crystals of rectangular shape. The array was completed and commissioned in 2009 (shortly after I finished my postdoc at NSCL). The total detection efficiency of the array is 35%, and the energy resolution is better than 10% (at 1 MeV). Since its inception, the detector has played an important role in many of the experiments performed at NSCL, allowing for, among other accomplishments, more detailed investigations of the structure of exotic nuclei in the region of the above mentioned island of inversion near ^{64}Cr. The paper describing the detector construction and its performance under real conditions (which I co-authored; item II A 5 of the statement of achievements, Appendix 4) was so far cited nearly 30 times.

The experience gained during my work at NSCL, especially with regard to the application of Monte Carlo simulation of radiation transport in matter, turned out to be very beneficial for my current work at the National Centre for Nuclear Research. This experience was an invaluable help in addressing the challenges associated with development of electron beam forming systems, as described in the monograph discussed in item 4 above.

Period after commencing work at the Institute in Świerk

At the beginning of 2009, I began working as a physicist and then as a senior research and technical specialist at the Andrzej Soltan Institute for Nuclear Studies in Otwock-Świerk (since 2011 under the name of the National Centre for Nuclear Research, NCBJ), which I continue to date. My most important achievements of this period are detailed in the work presented in item 4 above. Nevertheless, at the sidelines of my core activity related to development of electron beam forming systems, I was also able to carry out several other works, including research for the domestic industry.

Worth mentioning is the work done for, and in cooperation with, the company KGHM Ecoren S.A. (a subsidiary company of the leading Polish copper producer). In the work by P. Gambal, P. Adrich et al., entitled "Slag from the electric furnace of the Głogów copper smelter (Huta Miedzi Głogów) as a material for construction of shielding against ionizing radiation" (item II B 3 of the statement of achievements, Appendix 4), absorption coefficients of various types of ionizing radiation, including X-ray from the megavoltage accelerator source, were measured for the samples of slag from the smelting of copper. This work has demonstrated considerable potential for the utilization of this waste material, e.g. as a substitute for heavy concretes in the construction of shielding against ionizing radiation.

In the area of education, I developed and conducted several specialized practical laboratory classes for university students (item III B 1 of the statement of achievements, Appendix 4), I was the supervisor of several internships and apprenticeships (items III C 1 - 2 of the statement of achievements, Appendix 4), co-promoter of three engineering thesis (which were de facto carried entirely under my supervision; item III C 3 of the statement of achievements, Appendix 4). I was also, two times, lecturer at training courses organized by the NCBJ's Division of Nuclear Equipment for technicians and medical physicists from national oncological centers that use accelerators in radiotherapy (item III B 2 of the statement of achievements, Appendix 4). I also had a privilege and a pleasure of presenting the NCBJ's experience in production of accelerators during an international meeting of experts held at CERN to explore possibilities to improve access to radiotherapy in developing countries (item II H 2 of the statement of achievements, Appendix 4). Since recently, in response to the growing problem of unethical "predatory open access" publishers, I try to popularize knowledge about this serious threat to science and society (item III B 3 of the statement of achievements, Appendix 4).

Przemysław Adrich