University of Warsaw

Heavy Ion Laboratory

Annual Report

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Annual Report of the
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The photo on the title page was taken in front of the HIL
building on 13 June 2013.

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Contents

Introduction

For the first time in the history of our Laboratory the Annual Report contains a large section devoted to radioisotopes for medical applications. This is due to the realisation of an on-going programme begun some years ago for the production of and research into short-lived isotopes with applications in the diagnosis and therapy of cancer. The most important event in 2012 was the opening of the Radiopharmaceuticals Production and Research Centre, a division of our Laboratory. The construction of the Centre was supported by grants from the Ministry of Science and Higher Education, the International Atomic Energy Agency, the Ministry of Health, European Structural Funds and the University of Warsaw. The Centre is equipped with a cyclotron delivering intense beams of protons and deuterons and is devoted to the routine, every-day production of the most classic isotopes for Positron Emission Tomography. The opening ceremony was followed by an international conference on Positron Emission Tomography in Research and Diagnostics (PETRAD2012) organised jointly by our Laboratory and Warsaw Medical University.

Due to very hard work by our technical staff the operation of the heavy-ion cyclotron was very stable during the whole year and the amount of beam-time hours delivered for experiments continued an upward trend.

One of our scientific "specialities" is the investigation of the electromagnetic properties of nuclei by means of Coulomb Excitation. In our laboratory we have all the necessary tools for such studies: the experimental facility and the computer program GOSIA, used world-wide to analyse experimental data of this type. An important role in the initiation of this scientific programme was played by Professor Douglas Cline from the University of Rochester. This year he was awarded the Smoluchowski Medal of the Polish Physical Society. The award ceremony will take place next year in Poznan, during the 42nd Meeting of the Polish Physical Society.

After the good news must come the bad. The main problem of such a large experimental laboratory is always related to the available funds. The majority of our budget is provided by the SPUB grant of the Ministry of Science and Higher Education of Poland. It is allocated on a yearly basis and the funds are usually available at the end of February/beginning of March. This year for the first time we had to wait until the end of May for our funding to be released, which caused us many very serious problems. Such a situation should never be repeated and our Scientific Council sent an appeal to the Ministry asking for changes in the rules applicable to the allocation of our grant, prolonging the period from one to a few years. There are rumours that the Ministry is working in this direction, giving us the hope that our financial situation will at last become more normal.

Prof. Krzysztof Rusek, Director of HIL

Part A

Laboratory overview

A.1 General information

K. Rusek, J. Choiński

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

The Heavy Ion Laboratory (HIL) is part of the University of Warsaw, the largest university in Poland. HIL was founded jointly by the Ministry of Education, the Polish Academy of Sciences and the Polish Atomic Energy Agency. It is the largest experimental nuclear physics laboratory in the country, equipped with a K=160 heavy-ion cyclotron, unique not only in Poland, but also in Central Europe.

The first beam was extracted in 1993 and since that time HIL has been an effective "user facility", serving up to the present time over 400 scientists from Poland and abroad and becoming a recognised element of the European Research Area. Beam time is allocated by the Director based on the recommendation of the international Programme Advisory Committee (see Sec. E.7). The only criteria are the scientific merit of the project and its technical feasibility. The research programme (see Part C) is mostly focused on nuclear and atomic physics, but materials science, biological and applications studies also play an important role and a significant amount of the beam time is allocated for these purposes.

Experimental teams may take advantage of permanent set-ups installed on the beam lines or use their own dedicated equipment. Available apparatus includes IGISOL — a Scandinavian type on-line separator, CUDAC — a PIN-diode array particle detection system, JANOSIK — a multi-detector system consisting of a large NaI(Tl) crystal with passive and active shields and 32-element multiplicity filter and ICARE, a charged particle detector system used for particle identification and energy measurements, moved to HIL from IReS Strasbourg. The most recent experimental tool, still being developed and improved, is the EAGLE array – a multi-detector γ-ray spectrometer, which can be easily coupled to ancillary detectors like an internal conversion electron spectrometer, a charged particle 4 π multiplicity filter (Si-ball), a scattering chamber equipped with 100 PIN-diode detectors, a 60-element BaF_2 gamma-ray multiplicity filter, a sectored HPGe polarimeter and a plunger.

Since this year HIL has become an accelerator centre, operating two cyclotrons. The second machine is a commercial proton-deuteron cyclotron which will be used for the production of and research with radiopharmaceuticals for Positron Emission Tomography (PET). Production of long-lived radiopharmaceuticals for other medical and life-science applications is also foreseen.

A.2 Cyclotron operation in 2012 and tasks carried out in order to improve the cyclotron infrastructure and efficiency

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Operation

A steady downward trend in the beam-time delivered by the Warsaw Cyclotron was observed in the years 2004–2010. This trend was the result of infrastructure ageing and the lack of sufficient funds for its restoration. Due to the great involvement of the Laboratory team and thanks to organisational efforts, this trend was broken in 2011. Further work on improving the technical infrastructure in 2012, although it has slightly reduced the beam delivered time to 2308 hours, will result in more stable operation in the coming years. Figure 1 shows the total number of beam hours delivered over the last eleven years.

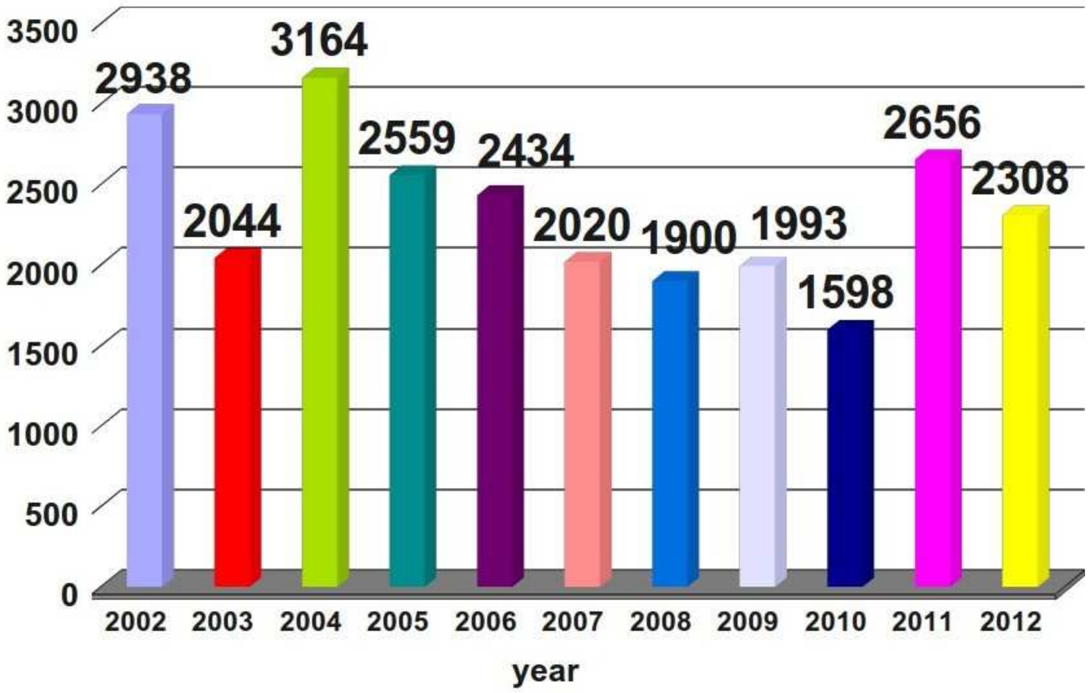

Figure 1: Total cyclotron beam time in the years 2002–2012.

The monthly distribution of beam time in 2012 is presented in Fig. 2. Lower experimental activity during July, August and September is correlated with the traditional summer vacation.

Main topics of the experiments are related to nuclear physics research, biological research, machine development and beam tests. Beam time was also allocated to national and international student workshops, as in the previous few years. The production of ^{211}At, initiated in 2010, was continued, in close collaboration with the Institute of Nuclear Chemistry and Technology and the Henryk Niewodniczański Institute of Nuclear

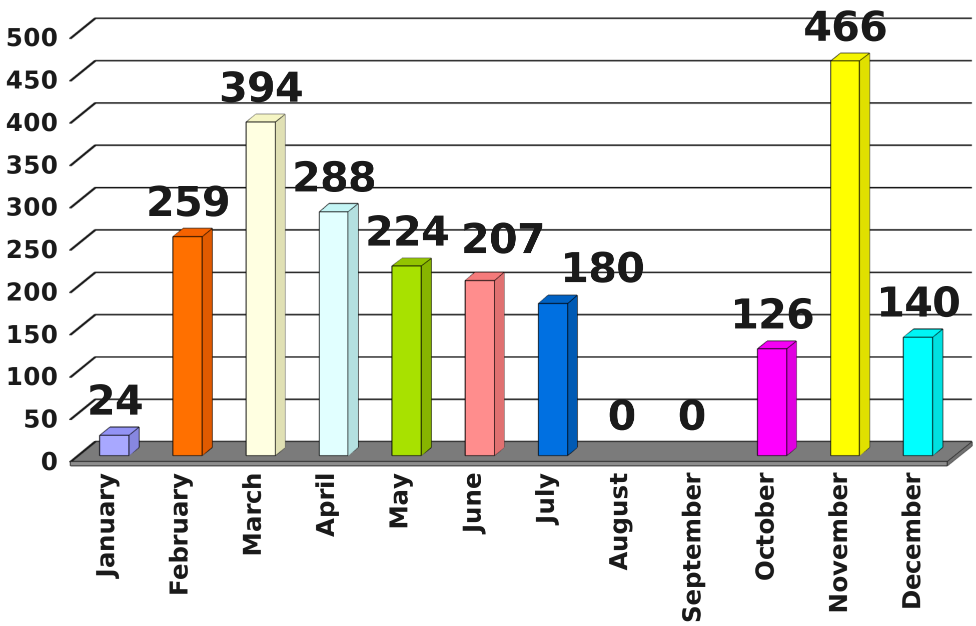

Figure 2: Beam time distribution (hours) in 2012 per month.

Physics of the Polish Academy of Sciences in Kraków. The diversity of the experiments performed during 2012 is illustrated in Fig. 3.

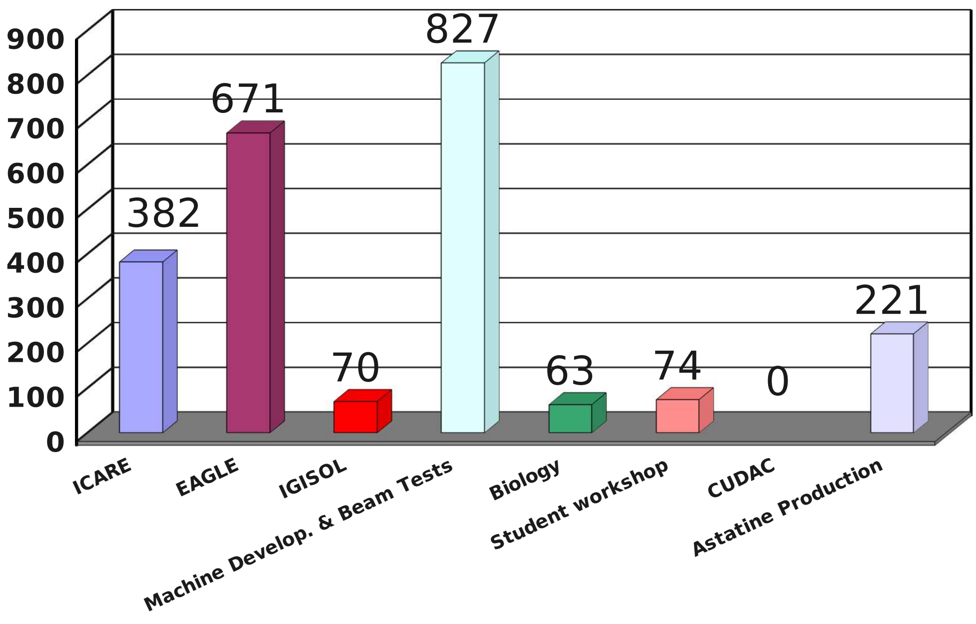

Figure 3: Distribution of beam-time (in hours) among different experiments.

In all the experiments, the involvement of young researchers, graduate and undergraduate students is traditionally large, which is illustrated in Fig. 4. Detailed descriptions of the experimental set-ups available at HIL can be found on the laboratory web page: www.slcj.uw.edu.

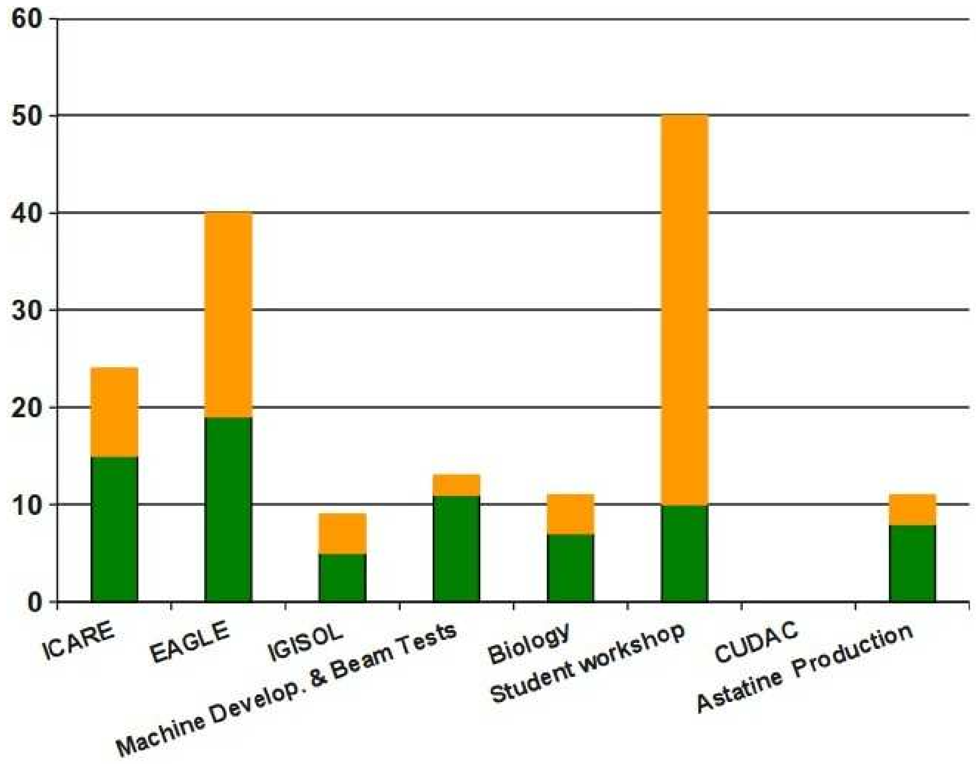

Figure 4: Number of users of Warsaw cyclotron beams in 2012.

A list of the experiments performed in 2012 is presented in Tables 1 and 2. The following acronyms are used in the table:

- HIL — Heavy Ion Laboratory
- Astana — Eurasia National University, Astana, Kazakhstan
- CEA — French Alternative Energies and Atomic Energy Commission, Saclay, France
- GANIL — GANIL, Caen, France
- GSI — Gesellschaft für Schwerionenforschung, Darmstadt, Germany
- HCCC — Holycross Cancer Center, Kielce, Poland
- Hulubei — Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucurest, Romania
- IB JKU — Institute of Biology, Jan Kochanowski University, Kielce, Poland
- IEP UW — Inst. of Experimnental Physics, Univ. of Warsaw
- INCT — Institute of Nuclear Chemistry and Technology, Warszawa, Poland
- INP — The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
- INPNNC Almaty — Institute of Nuclear Physics of National Nuclear Center, Almaty, Kazakhstan
- JYFL — Department of Physics, University of Jyväskylä, Finland
- KNU Almaty — Kazakh National University, Almaty, Kazakhstan
- NCNR Łódź — The National Centre for Nuclear Research, Łódź, Poland
- NCNR Świerk — The National Centre for Nuclear Research, Otwock, Świerk, Poland
- NCU Toruń — Nicolaus Copernicus University, Toruń
- NU Kharkiv — Kharkiv National University, Kharkiv, Ukraine
- Tanta — Faculty of Science, Tanta University, Tanta, Egypt
- UŁ — Fac. of Physics and Applied Computer Sci., U. of Lodz, Łódź, Poland
- US — University of Silesia, Katowice

Table 1: Experiments performed in 2012 — part 1

Dates	Ion and Energy	Experiment	Leading institution	Collaborating institutions
18, 19, 24.01	$^{20}Ne^{+4}$ $^{4}He^{+1}$	Test of new ion source and injection line	HIL	
07.02–08.02	$^{4}He^{+1}$ $^{4}He^{+1}$ $^{40}Ar^{+8}$	Test of new ion source and injection line	HIL	
14.02–23.02	$^{16}O^{+4}$ 90 MeV	EAGLE	UŁ	HIL, NCNR Świerk, IEP UW
29.02–09.03	$^{16}O^{+4}$ 90 MeV	Student workshop	HIL	
12.03–16.03	$^{4}He^{+1}$	^{211}At production	HIL	US, INCT, INP
19.03–30.03	$^{20}Ne^{+4}$ 72 MeV	ICARE	HIL	NCNR Świerk, NU Kharkiv, INP, GSI, IEP, JYFL
04.04	$^{20}Ne^{+4}$	Test of the cyclotron	HIL	
16.04–27.04	$^{16}O^{+3}$ 42 MeV	ICARE	INPNNC Almaty	HIL, NCNR Świerk, INP, Kurchatov, U. St. Petersburg, KNU Almaty, Tanta, Astana
07.05–11.05	$^{14}N^{+3}$ 85 MeV	IGISOL	IEP UW	HIL, NCNR Świerk, NCNR Łódź

Improvements and future projects

The possibility of changing the mirror inflector to one of spiral type was investigated in order to enlarge the scope of accelerated beams and to improve the inflector transmission coefficient. This work is also related to the major changes in the design of the central part of the cyclotron. This gives a chance to overcome the main obstacle from the point of view of the ion optics in the centre, that is to remove the constructional pillars. Mechanical measurements in the internal part of the cyclotron were made over the summer and a preliminary design for the spiral inflector and the new central part was finished at the end of 2012. The fabrication and installation of the new elements in the cyclotron is scheduled for the second half of 2013 in collaboration with specialists from JINR, Dubna. The first trial runs with this new configuration are planned for December 2013.

Table 2: Experiments performed in 2012 — part 2

Dates	Ion and Energy	Experiment	Leading institution	Collaborating institutions
22.05–23.05	$^{12}C^{+3}$	Biology	IEP UW, IB JKU	HIL, HCCC, NCNR Świerk, NCU Toruń, INCT
28.05–01.06	$^{4}He^{+1}$	^{211}At production	HIL	US, INCT, INP
11.06–15.06	$^{40}Ar^{+8}$ 182 MeV	EAGLE	UŁ	HIL, NCNR Świerk, IEP UW
25.06–29.06	$^{12}C^{+2}$ 50 MeV	Biology	IEP UW, IB JKU	HIL, HCCC, NCNR Świerk, NCU Toruń, INCT
02.07–06.07	$^{32}S^{+5}$ 83 MeV	Student workshop	HIL	
10.07–13.07	$^{19}F^{+4}$ 72 MeV	EAGLE	IEP UW	HIL, NCNR Świerk, UŁ, Hulubei
08.10–12.10	$^{16}O^{+3}$	Test of the cyclotron	HIL	
22.10–24.10	$^{20}Ne^{+3}$ 54 MeV	Student workshop	HIL	
25.10–26.10	$^{32}S^{+5}$	Test of the cyclotron	HIL	
05.11–23.11	$^{32}S^{+5}$ 95 MeV	EAGLE	CEA, KU Leuven	HIL, IEP UW, NCNR Świerk, UŁ, GANIL
26.11–27.11	$^{16}O^{+4}$	Test of the cyclotron	HIL	
04, 05, 08.12	$^{16}O^{+4}$	Test of the cyclotron	HIL	
10.12–14.12	$^{4}He^{+1}$	^{211}At production	HIL	US, INCT, INP

A measuring bar for magnetic measurements in the median plane of the cyclotron was designed but the fabrication of the system was postponed to 2014 due to lack of financial sources and shortages in manpower. These measurements are needed to improve the transmission factor during acceleration, especially for the new ECR ion source operating with at least 5 kV higher extraction voltage in comparison to the old one. Work to improve the transmission in the cyclotron vertical line using the electrostatic quadrupoles has also been carried out in 2012.

Some experiments require good control of the beam duty factor. A series of experiments was thus carried out to design a chopper system in the injection line. A model system was fabricated and preliminarily checked. The system will be finally developed in 2013.

Due to the ageing of the cyclotron, in 2012 technical forces were focused on improving the technical infrastructure. One of the most important improvements of the cyclotron functionality will be achieved with replacement of the RF amplifiers, some of the power supplies and crucial parts of the vacuum system. A series of tenders were solicited in 2012 to choose a supplier for the RF amplifier. Unfortunately no satisfactory offers were received. A new tender is scheduled for 2013.

HIL has joined the European EMILIE project which aims at the improvement of charge breeder efficiency. The purpose of participating in this project is to increase knowledge and practices concerning ion sources of the ECR type.

A.3 EAGLE — the central European Array for Gamma Levels Evaluation

J. Mierzejewski[1], J. Srebrny[1], M. Kowalczyk[1,2], M. Kisieliński[1,3] T. Abraham[1], M. Komorowska[2,1], Ch. Droste[2], E. Grodner[2], T. Marchlewski[1,2], J. Andrzejewski[4], J. Perkowski[4], J. Samorajczyk[4], Ł. Janiak[4], K. Hadyńska-Klęk[1], P. Napiorkowski[1], K. Wrzosek-Lipska[1,5], M. Zielińska[6] J. Iwanicki[1]

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5) Instituut voor Kern- en Stralingfysica, K.U. Leuven, Leuven, Belgium
6) IRFU/SPhN, CEA Saclay, Gif-sur-Yvette, France

The EAGLE array (central European Array for Gamma Levels Evaluations [1], Fig. 1) has been designed as a multi-configuration detector set-up for in-beam nuclear spectroscopy studies at the Heavy Ion Laboratory of the University of Warsaw. The EAGLE collaboration combines over 60 scientists from 20 institutes all around Europe. The array can accommodate a maximum of 30 Compton suppressed Ge detectors coupled to various ancillary devices, such as a conversion-electron spectrometer, the Köln-Bucharest plunger, a compact scattering chamber equipped with 110 PIN diodes placed at backward angles, the 4π inner ball consisting of 60 BaF_2 crystals and a 30 element 4π silicon detector array. Until June 2011 EAGLE was equipped with 12 ACS HPGe detectors and had a total photo-peak efficiency of 0.5% at 1.3 MeV. This initial configuration was replaced by a configuration with 15 Eurogam Phase1 ACS HPGe detectors loaned by GAMMAPOOL, with a photo peak efficiency equal to 1.8%. In addition, 5 GASP-type ACS HPGe detectors were used in spring 2012 by courtesy of the JUROGAM II collaboration, increasing the photo peak efficiency to 2.4%.

The scientific case of the EAGLE project focuses on the phenomenon of spontaneous symmetry breaking in atomic nuclei. Experiments performed during the EAGLE campaigns (October 2011–June 2013) revolved around three main research axes:

Experimental study of chiral symmetry breaking

Following the research that led to the discovery of the spontaneous chiral symmetry breaking phenomenon in ^{128}Cs [2] and ^{126}Cs [3], DSAM lifetime measurements of the excited states of the chiral partner bands in ^{124}Cs were performed. Preliminary results [4] indicate the first observation of the critical frequency in nuclear chiral rotation [5].

Tests of K-quantum number conservation: studies of K-isomers by combined gamma and internal conversion electron spectroscopy

The collaboration continued research on the role of triaxiality in the breaking of K selection rules that was demonstrated to be important in the decay of the $I^{\pi} = K^{pi} = 8^{-}$ isomeric state in ^{132}Ce (N = 74) [6]. In 2012, the decay of K-isomers in ^{134}Nd (N = 74) and ^{184}Pt (N = 106) was studied.

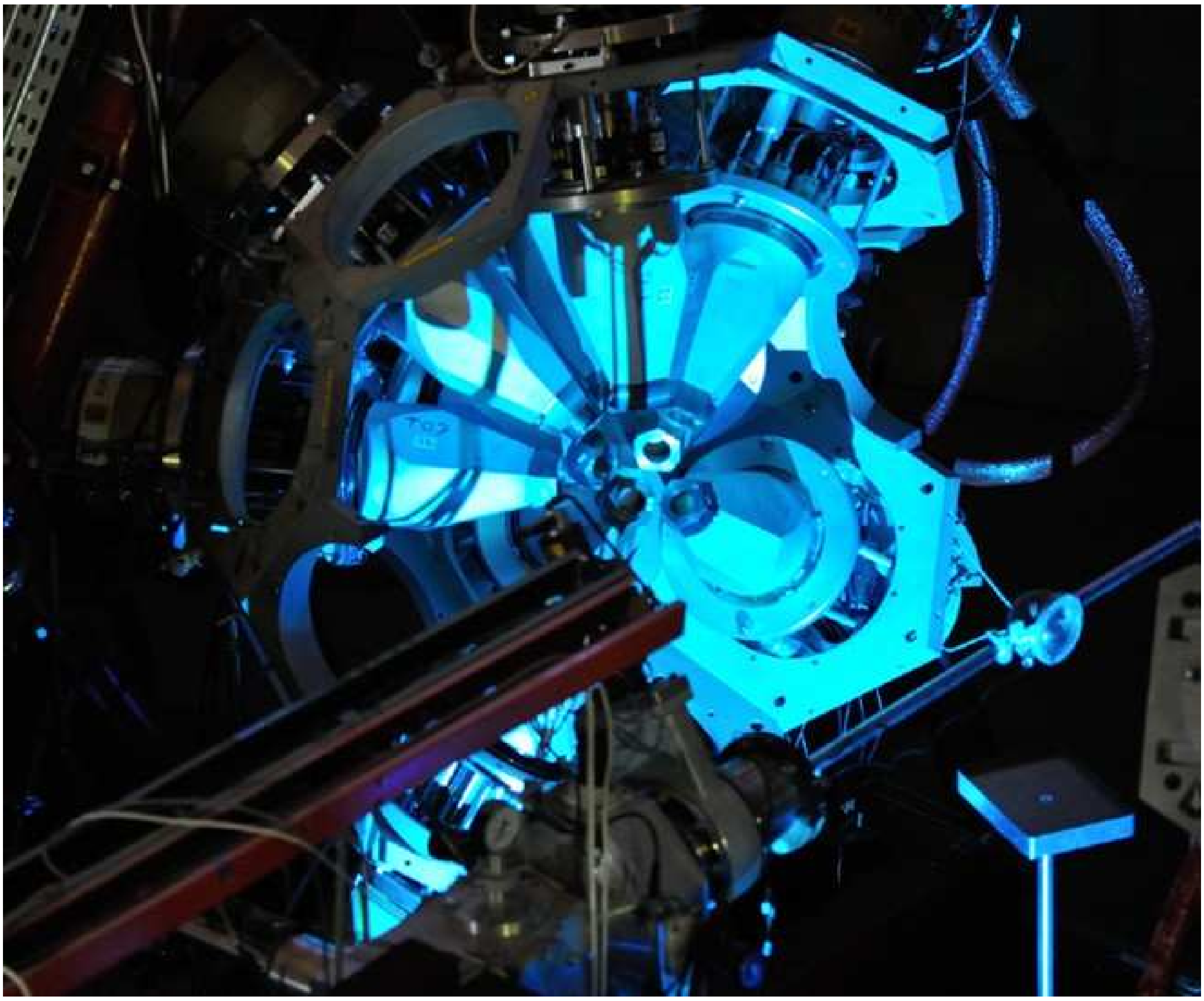

Figure 1: EAGLE γ-ray spectroscopy array at HIL.

Shape coexistence and shape evolution studied by measurements of transition probabilities

To complement the Coulomb excitation measurement of ^{42}Ca carried out in the first run of AGATA at LNL, an experiment was performed aiming at refinement of the low spin level scheme of this nucleus. The excited states in ^{42}Ca were populated in the ^{12}C(^{32}S,2p)^{42}Ca reaction. The results are crucial for the analysis of the COULEX data [7]. Moreover, EAGLE was coupled to the Köln-Bucharest plunger device in order to measure the lifetimes of low-lying states in ^{140}Sm and ^{125}Cs. The ^{140}Sm experiment complements the COULEX measurements performed at the REX-ISOLDE facility. Two COULEX runs with ^{32}S beams were performed: ^{107}Ag and ^{70}Zn.

The above mentioned experiments form the basis of 6 on-going PhD theses and several MSc and BSc projects. A workshop devoted to EAGLE experiments was organised at HIL in January 2012 — see the programme at `http://www.slcj.uw.edu.pl/en/experiments/eagle/PAC-EAGLE-pgmJan2012v2.pdf`. Besides the rich scientific programme, the EAGLE array is also used for teaching and training purposes, especially in the students workshops organised at HIL [8, 9].

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A.4 Maintenance of 20 HPGe GAMMAPOOL detectors during the experimental campaign at HIL in 2012

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Twenty High Purity Germanium detectors (HPGe) as well as 15 BGO anti-Compton shields arrived at the Heavy Ion Laboratory in July 2011. The detectors were transferred to HIL for use in experiments with the European Array for Gamma Levels Evaluations (EAGLE) [1, 2] in the period July 2011 till June 2013, within the framework of the GAMMAPOOL collaboration.

The equipment was tested after arrival and 16 HPGe detectors and all 15 BGO shields met the requirements for use in EAGLE [1]. In 2012 the detectors were employed in 6 experiments, with a total in-beam time of 45 days. The HPGe detectors while in use in-beam suffer so-called neutron damage. The neutrons produced in nuclear reactions hit the germanium crystal in the detector and cause disturbances in its crystal network. This effect impairs the performance of the detectors by increasing the noise, worsening the energy resolution. The affected detector may be cured by a process of annealing. The whole annealing cycle lasts one week and in HIL it is possible to anneal two detectors at a time, using two regeneration set-ups (see Fig. 1), located in the detector laboratory [2]. In 2012 the annealing process was performed 28 times to ensure the detectors used in experiments provided results of the highest possible quality.

Figure 1: HPGe detector regeneration set-ups at HIL.

In autumn 2012, one member of the staff responsible for the quality of the germanium detectors took part in a one week training course at CEA Saclay (France). The workshop was focused on repairing and testing germanium segmented detectors and their cryostats, and methods of supplying the detectors with liquid nitrogen. The training was provided as a part of the STT-LPP ERASMUS programme.

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[2] J. Mierzejewski *et al.*, HIL Annual Report 2010, page 24

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A.5 High voltage supplies for the HIL injection line

M. Sobolewski, J. Miszczak, Z. Kruszyński

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A set of eight high voltage power supplies was required to power up the electrostatic lenses in the cyclotron injection line [1]. The electrical requirements for the supplies were modest (up to 1 kV of voltage, and up to 1 mA of current), but additional constraints like switchable polarity, changeable configuration (steering-quadrupole), local/remote control for both the power supply and the high voltage switch, made the whole design more complicated. Since the power supplies work basically in pairs, it was decided to build in-house four dual power supplies to simplify the HV switches and the control circuitry, instead of buying single output power supplies and designing and building an elaborate switching matrix, as well as the associated control and protection circuitry. The supplies have local digital read-out, output over-current protection, voltage stability, and other parameters similar to comparable commercial units, and have performed flawlessly since their installation in mid 2012.

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A.6 RF team activity report

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In 2012, the RF generator team handled about 15 planned experiments, several tests and international student workshops. During this period, in spite of the RF team efforts, a number of generator system failures occurred. These were mainly due to the natural wear of the components.

At the beginning of the year we had to deal with the loss of the insulating properties of the Teflon insulators in the coupling loop of resonators A and B. The reason was the deposition of a metallic layer on the insulators due to the long lasting operation of the cyclotron.

In the middle of the year we overhauled the high-voltage power supplies in generator A and B. We also replaced a broken capacitor in the driver amplifier "Henry" in generator A. There was also a water leak in the cooling system of generator A. Operators were warned in time by an alarm installed last year. We replaced the cooling water hoses of the power stage.

Before the summer break we repaired corroded ground connection of the variable vacuum capacitor of the anode resonant system of the power stage. We fixed the worn out cardan joint of the mechanical system for tuning this capacitor. Before the holidays there was a failure of the resonator coupling loop A. We replaced the sealing elements from the side of the feeder and from the side of the impedance matching capacitor. At the end of the year there was a failure of the variable vacuum capacitor of the anode power stage A. The capacitor has been replaced. It was decided to supplement the reserve of these capacitors.

A.7 Activity report of the electrical support group

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Activities of the electrical support group in 2012 were mainly focused on maintaining the existing electrical infrastructure. The group also dealt with the repair of failed power supplies. A set of power supplies which power optical devices in the beam lines are ending their technical lives therefore it was decided to gradually replace them with new models. This project requires major changes in the energy infrastructure as well as the control methods and software. The implementation of the new system started in April 2012. Consecutive steps are planned over the next years depending on available funds. In particular the following major repairs and out of routine tasks were carried out in 2012:

- Repair and adjustment of power supplies UZ1, UZ2, and the power supplies of the quadrupoles.
- Supervising work on assembling the new power switching station RGW, to power the high frequency generators and the PET Laboratory.

The following routine measurements and maintenance procedures were performed:

- Measurement and maintenance of power supplies, electromagnets and the wiring of the laboratory equipment.
- Measurement and maintenance of the electrical power system and the electrical installation, including lighting inside and outside of the HIL building.

In addition, five members of the electrical support group performed regular cyclotron operator duties according to the schedule of experiments. They also participated in the science popularisation and teaching activities at HIL: guided tours of the facility, Polish Workshop of Acceleration of Heavy Ions, International Workshop on Acceleration and Applications of Heavy Ions, and Festival of Science.

A.8 Educational and science popularisation activities at HIL

A. Trzcińska[1], *K. Hadyńska-Klęk*[1,2], *M. Zielińska*[3], *G. Jaworski*[1,4], *K. Kilian*[1], *P.J. Napiorkowski*[1], *M. Palacz*[1], *K. Rusek*[1], *J. Srebrny*[1], *O. Steczkiewicz*[1]

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For many years the Laboratory has been strongly involved in education and science popularisation. Guided tours at HIL have become a regular activity. These "live" lessons on the cyclotron and nuclear physics continue to enjoy popularity in high schools, including ones from outside Warsaw. During the guided tour visitors can see the control room and the cyclotron, and get acquainted with the facilities installed in the Laboratory, as well as the experiments performed here. Short lectures providing a basic introduction to nuclear physics and the principles of cyclotron operation are also offered, especially to high school students. Tours are free of charge.

In 2012, 25 groups (almost 700 people) visited our Laboratory. High-school classes were the largest category of visitors, but we also welcomed students from faculties of the University of Warsaw: Physics and Biology, as well as from the Maria Curie-Skłodowska University in Lublin, and the Warsaw University of Technology. Participants in the Summer School of Physics organised by the Faculty of Physics, University of Warsaw, and groups of physics teachers were also among our visitors.

In September HIL participated in the annual Festival of Science for the 16th time. Besides the standard series of so-called Festival Lessons on physics for secondary school classes, we prepared a series of lectures and shows on subjects related to nuclear physics and its applications in technology and medicine. These meetings took place on 21 September and were accompanied by guided tours of the cyclotron. In the framework of the Festival of Science, we also organised the final presentation of the EUREKA contest for the most talented secondary school pupils, who prepared special projects in physics or chemistry.

On May 19, 2012, more than 500 guests of different ages and backgrounds visited HIL on the occasion of the "European Night of Museums". In this event, not only museums remain open late into the evening, but also other institutions which are not normally accessible (e.g. ministries, embassies, scientific institutes, etc.) open their doors to the general public. Traditionally, guided tours of the facility attracted most attention, but our guests could also enjoy a performance of the improvisational theatre LUBIETO, listen to a special concert given by young musicians supported by the Polish Children's Fund or participate in a measurement of natural radioactivity.

The Eighth Polish Workshop on the Acceleration and Applications of Heavy Ions was organised at HIL in October 2012 (see Sec. A.9 of this Report), and for the third time we also hosted an international version of the workshop (Sec. A.10). For the first time we organised a one week "Summer School on the Acceleration and Applications of Heavy Ions" for nuclear physics students (Sec. A.10). HIL staff members are also engaged in supervising MSc and PhD theses — see Sec. E.1.

A.9 Polish Workshop on the Acceleration and Applications of Heavy Ions

P.J. Napiorkowski[1], A. Trzcińska[1], T. Abraham[1], P. Gmaj[1], K. Hadyńska-Klęk[1,2], M. Komorowska[1,2], M. Kowalczyk[1,2], K. Kilian[1], T. Marchlewski[1,2] J. Mierzejewski[1], M. Palacz[1], A. Pękal[1,3], E. Piasecki[1], J. Srebrny[1], O. Steczkiewicz[1], A. Stolarz[1], I. Strojek[4]

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The Polish Workshop on the Acceleration and Applications of Heavy Ions has been organised at HIL every year since 2005. It is intended for students of first cycles studies interested in nuclear physics, and offers them a unique opportunity to gain experience in methods of data acquisition and analysis, in operating the cyclotron including beam diagnostics measurements, and in charged particle and gamma-ray detection techniques.

In 2012 the Workshop was organised as a general university course for the first time. The new status attracted to the Workshop 5 students from the University of Warsaw. They attended lectures and practical training together with 15 students who came from other Polish universities: 6 from the University of Silesia, 4 from the Jagiellonian University in Kraków, 2 from the Adam Mickiewicz University in Poznań, 2 from Szczecin University and 1 student from the Maria Curie Skłodowska University in Lublin. The Workshop was concluded by student presentations — each group prepared a 20 minute talk on their measurements and results.

In 2012, the programme of lectures was as follows:

- Presentation of HIL (K. Rusek);
- Radioprotection at HIL (R. Tańczyk);
- Introduction to heavy ion acceleration and elements of ion optics (O. Steczkiewicz);
- Radiopharmaceuticals for Positron Emission Tomography (K. Kilian).
- Detection of gamma radiation, charged particles and neutrons (M. Palacz);
- In-beam gamma spectroscopy (P. Napiorkowski);
- Targets for nuclear physics (A. Stolarz),
- Radioactive decays as a source of nuclear structure information (Z. Janas),
- Nuclear reactors and power plants (P. Olbratowski),

Students took part in the following experimental tasks:

- Beam focusing in heavy ion acceleration;
- Beam energy measurements based on Rutherford scattering;
- Identification of excited bands in gamma-gamma coincidences;

- Thin target production and thickness control;
- Measurement of ^{137}Cs activity in environmental samples;
- Radiopharmaceuticals - productions and quality control .

The inclusion in the programme of a task related to radiopharmaceuticals became possible thanks to the newly opened facility at HIL — The Radiopharmaceuticals Production and Research Centre. The students got acquainted with various chemistry techniques used in medical applications of nuclear physics.

A.10 International student training programmes at HIL

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Nuclear physics students have often quite limited possibilities to become acquainted with modern scientific apparatus. Low quality and out-of-date equipment as well as the basic, uninspiring character of laboratory exercises are among the main complaints in student questionnaires concerning laboratories at physics faculties in Poland.

To meet the needs of Polish nuclear physics students, the Heavy Ion Laboratory organised the first Workshop on the Acceleration and Applications of Heavy Ions in 2005, which, after the success of the first edition, has been repeated every year since [1]. In general, the workshops were very well received by participants, who appreciated especially the possibility of performing nuclear physics measurements using real scientific equipment, used every day for research, and the experience of work in an accelerator laboratory. The evaluation showed, however, that the participants judge the time allocated for the workshop (6 working days) as being too short to fully benefit from it. Larger working groups (4 persons and more) were also disfavoured.

These remarks were taken into account when organising the International Workshops on the Acceleration and Applications of Heavy Ions [2] based on this concept. A consortium of four universities: University of Warsaw, University of Huelva (Spain), Sofia University "Saint Kliment Ohridski" (Bulgaria) and Akdeniz University in Antalya (Turkey) obtained significant financial support from the ERASMUS LLP Programme for three editions of this event. In order to be eligible for this type of funding (under the so-called Erasmus Intensive Programme initiative), several conditions concerning the duration and intensity of the course as well as the number of foreign participants had to be fulfilled. Only students affiliated to partner institutions forming the consortium can benefit from the ERASMUS financial support that we received. The workshop is integrated in the teaching programmes at the partner institutions: students from Warsaw, Huelva and Antalya receive ECTS credits upon successful completion of the course, and in Huelva it has become a mandatory course for the second cycle of studies in the field of nuclear engineering.

In 2012, the programme of lectures included subjects such as target preparation, presentation of various experimental techniques as well as applications of nuclear methods in other fields, for example medicine and nuclear energy. B. Fornal, P. Olko, K. Mazurek (Institute for Nuclear Physics, Kraków), N. Alamanos, C. Simenel, M. Zielińska (CEA Saclay, France), K.W. Kemper (Florida State University, Tallahassee, USA), I. Martel (University of Huelva, Spain), I. Boztosun (Akdeniz University, Antalya, Turkey), S. Kistryn (Jagiellonian University, Kraków), K. Czerski (University of Szczecin) and L. Próchniak (Maria Curie-Sklodowska University in Lublin), were among the lecturers along with several researchers from HIL (K. Rusek, A. Stolarz, M. Palacz, L. Pieńkowski, K. Kilian) and the Institute of Experimental Physics, University of Warsaw (Z. Janas, T. Matulewicz).

Twenty students (Fig. 1) from four countries took part in the following experimental tasks:

A. Gamma-ray spectroscopy (supervisors: M. Palacz, T. Abraham);
B. Rutherford scattering (supervisors: J. Iwanicki, J. Srebrny, I. Strojek);
C. Nuclear reactions — experimental (supervisors: I. Martel, K. Kemper, I. Strojek);
D. Nuclear reactions — theory (supervisors: K. Rusek, I. Boztosun, N. Keeley)
E. TOF measurements with scintillators (supervisor: V. Kozhuharov) and particle detector tests (supervisor: A. Kordyasz);
F. Fast timing (supervisors: K. Hadyńska-Klęk, P.J. Napiorkowski)
G. Measurements of activity in biological samples (supervisor: A. Trzcińska) + preparation of targets for nuclear physics (supervisors: A. Stolarz, A. Trzcińska)

Figure 1: Participants and teachers of the II International Workshop on the Acceleration and Applications of Heavy Ions, HIL, 26 February – 10 March 2012

Student presentations in the form of 20 minute talks on the measurements and results of each team, concluding the workshop, were assessed by an external international jury consisting of four specialists in the domain of nuclear physics.

The funding from the LLP Erasmus Programme cannot be extended beyond three years and thus an effort has been made to preserve this initiative beyond the period of support. The first edition of the Summer School on the Acceleration and Applications of Heavy Ions [3] took place at July 1-7, 2012, and attracted 11 students from Armenia, Belgium, Croatia, Italy, Poland, Russia and Spain (Fig. 2). The lectures and student exercises prepared for the two-week workshop were used after necessary adaptation to the shorter duration of the school. The task supervisors were mostly from outside HIL (N. Patronis – University of Ioannina, Greece, K. Wrzosek-Lipska – KU Leuven, Belgium, M. Zielińska – CEA Saclay, France, A. Stolarz, A. Trzcińska – HIL).

To the best of our knowledge, apart from the Workshops on the Acceleration and Applications of Heavy Ions organised at HIL, there is no other training of this kind offered by European accelerator centres. Existing training programmes and summer schools do not provide accelerator beam time and sophisticated equipment for teaching purposes

Figure 2: Participants and teachers of the Summer School on the Acceleration and Applications of Heavy Ions, HIL, 1–7 July 2012

only: the common practice is to incorporate students into research groups and assign them routine and sometimes unskilled tasks. In this aspect, our project is unique and innovative: it offers real hands-on experience with modern equipment and an opportunity to work in an international group on an open problem. In addition to specific knowledge on methods of data acquisition and analysis, in operating the cyclotron (including beam diagnostics measurements) and in charged particle and gamma-ray detection techniques, participation in the workshop enables the students to develop their teamwork and communication skills as well as their ability to deal with open questions and to think critically. The project encourages both student and teacher mobility and strengthens the existing collaboration between participating institutions.

Bibliography

[1] P.J. Napiorkowski *et al*, this Report, page 23

[2] Workshop website: `http://www.slcj.uw.edu.pl/workshop`

[3] Summer School website: `http://www.slcj.uw.edu.pl/summerschool`

Part B

Radioisotopes for medical applications at HIL

B.1 The Opening Ceremony of the Radiopharmaceuticals Production and Research Centre at the Heavy Ion Laboratory of the University of Warsaw, May 15, 2012, followed by an International Conference PETRAD2012[a]

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Two important events happened at the Heavy Ion Laboratory of the University of Warsaw in May this year. First, on May 15 the new Radiopharmaceuticals Production and Research Centre (RPRC) was inaugurated by the Rector Elect, Prof. Marcin Pałys. The construction of this Centre, located on the premises of the Laboratory, was supported by grants from the Ministry of Sciences, International Atomic Energy Agency, Ministry of Health and European Structural Funds. General Electric Medical System Company was the main contractor for the adaptation of the building and the provision of the PETtrace proton/deuteron cyclotron together with the FDG production line.

Figure 1: Opening ceremony guests.

The cyclotron of the RPRC is the second accelerator operated by the Laboratory, where the first machine, accelerating heavy ions, was launched in 1993 for fundamental research in nuclear physics and its applications. The existence of an excellent accelerator construction and operation team together with a nearby Nuclear Medicine Department at the Warsaw Medical University Clinical Hospital was the main rationale for the development of the Laboratory into the domain of medical radioisotope and radiopharmaceuticals production.

Besides the 100 micro-Amperes proton machine, the new Centre consists of two adjacent laboratories equipped with hot cells, radiopharmaceutical synthesisers and dispensers. The first laboratory is devoted to the routine, every-day production of the most classic

[a]Text originally published in Nuclear Medicine Review 2012, 15, 2:85–86

Figure 2: Opening ceremony guests.

PET radiopharmaceutical: fluoro-deoxy-glucose (FDG) with the intention to be the supplier of at least the Warsaw PET cameras. The second Laboratory is intended to perform research on new innovative radiopharmaceuticals and to produce radiopharmaceuticals based on ^{11}C for pre-clinical research at the neighbouring Nuclear Medicine Department. The production of ^{15}O is also considered for perfusion research at this Department. To this end, however, a capillary underground connection between the two Laboratories will need to be constructed. The well equipped Quality Control Laboratory completes the RPRC facility.

During the opening ceremony, attended by more than a hundred of participants from Warsaw, elsewhere in Poland and from abroad, group visits were organised, allowing our guests to become acquainted not only with the new Centre but also with the whole Laboratory with its large, heavy ion accelerator and experimental stations.

On the evening of the following day a Get Together party for the participants of the Positron Emission Tomography in Research and Diagnostics (PETRAD2012) International Conference was organised in the Laboratory Building. The Conference was opened on May 17 and lasted till mid-day of May 19. 140 Conference participants came from 29 different countries, both within Europe and further afield. They heard 14 invited talks presented by world class specialists in Positron Emission Tomography and a number of contributed communications. They could also attend the Poster Session and select three best posters for oral presentation. (see Nuclear Medicine Review Vol. 15, Supplement A for the Conference Abstracts). The Conference Proceedings will be published as a Supplement to NMR.

B.2 The Radiopharmaceuticals Production and Research Centre at the Heavy Ion Laboratory of the University of Warsaw[b]

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Introduction

At the beginning of this century, after more than six years successful operation of the U-200P heavy ion cyclotron and after the installation of the home-made ECR ion source, the Heavy Ion Laboratory (HIL) management decided that a new direction in the development of the Laboratory was necessary in order to maintain its vitality and place at the forefront of the Polish research infrastructure.

After profound internal discussions followed by the approval of the Laboratory Scientific Council the decision was taken that from a number of options considered the most appropriate would be the installation on the premises of HIL of a new, commercial cyclotron for the production of medical radioisotopes, with special emphasis on those used for Positron Emission Tomography (PET).

At that time PET techniques had not yet been introduced in Poland. The motivation of the decision taken was mainly based on two arguments. First, the Laboratory team had long experience and expertise unique in Poland in cyclotron operation, so the installation of a second machine of this type at HIL should not give major running problems. Another argument was the vicinity of the Nuclear Medicine Department of the (at that time) Warsaw Academy of Medicine where the installation of a PET scanner was seriously considered.

Two major events occurred at the beginning of 2003. In February the first PET Centre in Poland was inaugurated at the Oncology Centre of the Prof. Lukaszczyk Memorial Hospital in Bydgoszcz with a 10 MeV proton cyclotron and PET/CT scanner. This pioneering initiative financed by Hospital funds had an enormous impact on the promotion of this branch of nuclear medicine in Poland. Similar funding was not imaginable in the case of the HIL project. Instead, a Warsaw Consortium for PET Collaboration was organised by HIL together with the Nuclear Medicine Department with the objective of obtaining the necessary funding to create a production centre for PET radiopharmaceuticals in Warsaw. Soon twenty Warsaw scientific and diagnostic centres had adhered to the Consortium.

In the second half of the same year a proposal was submitted to the International Atomic Energy Agency (IAEA) for support of the project within the Technical Cooperation Program aiming at the installation at HIL of a commercial cyclotron for the production of PET radioisotopes. This proposal was strongly supported by the Minister of Sciences and the Minister of Health, with declarations to contribute substantially to the cost of this project. A crucial step was the final decision by the Minister of Sciences, taken at the end of 2004, to allocate to this project a grant of 10 Mzł for the adaptation of the building and purchase of equipment, shortly followed by a second grant allocated by the IAEA of the order of 1 MUS$ for the purchase of the cyclotron. In the following years

[b]Text originally published in Nuclear Medicine Review 2012, 15, Suppl. C: C5–C8

consecutive grants from the Ministry of Health and European Structural Funds allowed almost all the necessary funds to be collected and eventually completed, during the final construction phase, by the University of Warsaw. The participation of the IAEA in the project was not limited to the purchase of equipment; its whole realisation was aided by the Agency's expertise in the planning of the site design, tender preparation and launching, and by its contribution to the training of the Laboratory team during a number of years before completion of the project.

Project implementation

After many months of preparation, in February 2006 the Agency launched a turn-key tender for the complete execution of the Radiopharmaceuticals Production and Research Centre (RPRC present name) at the premises of the Heavy Ion Laboratory. The tender included the adaptation of the building, the cyclotron and the equipment for the FDG (fluoro-deoxy-glucose) production line. At the end of the same year the General Electric Medical Systems Company was declared as the successful bidder. The above mentioned successive grants allowed a more extended (in comparison with the tender terms) completion of the Centre project, described in more detail below.

The very fact that all the funds collected for the construction of the Centre were not available at the moment of the tender launch substantially delayed the completion of the project. A number of unexpected events also contributed to the accumulated delays. Fortunately, during the first half of this year all building adaptation and equipment installation work was completed and on May 15, 2012 the Centre was officially inaugurated by the Rector Elect of the University of Warsaw [1].

Description of the centre

Project rationale

From the very beginning it was assumed that, based on the produced short lived radioisotopes, both commercial and research activities would be conducted at the RPRC. To this end chemical equipment allowing the production, distribution and quality control of various radiopharmaceuticals would have to be installed. The area for the everyday production of the most popular commercial PET radiopharmaceutical, fluoro-deoxy-glucose (FDG), would be separated from the research one. It would also be useful for separate quality control areas to be arranged for commercial and research activities. As described below, the available space for the installation of the Centre and the available funds allowed the implementation of these objectives.

The site project also allows the construction of an external beam line for solid target irradiations producing longer lived species during the cyclotron spare time between the commercial FDG production cycles. The installation of underground capillary connections to the neighbouring (around 500 m) Nuclear Medicine Department PET/CT scanner for ^{15}O transportation for perfusion diagnostics will also be possible when the appropriate funds are available. Similarly, the animal micro-PET scanner, situated in the neighbouring Chemistry/Biology Faculties CENT III building, will also be connected with the ^{15}O production facility.

The Centre on the HIL Premises

In the HIL building about 500 sqm underground area was available and could be adapted to host the Centre. Figure 1 shows the ground floor of this building, where the large $K = 160$ heavy ion cyclotron, its experimental stations and the position of the RPRC are indicated.

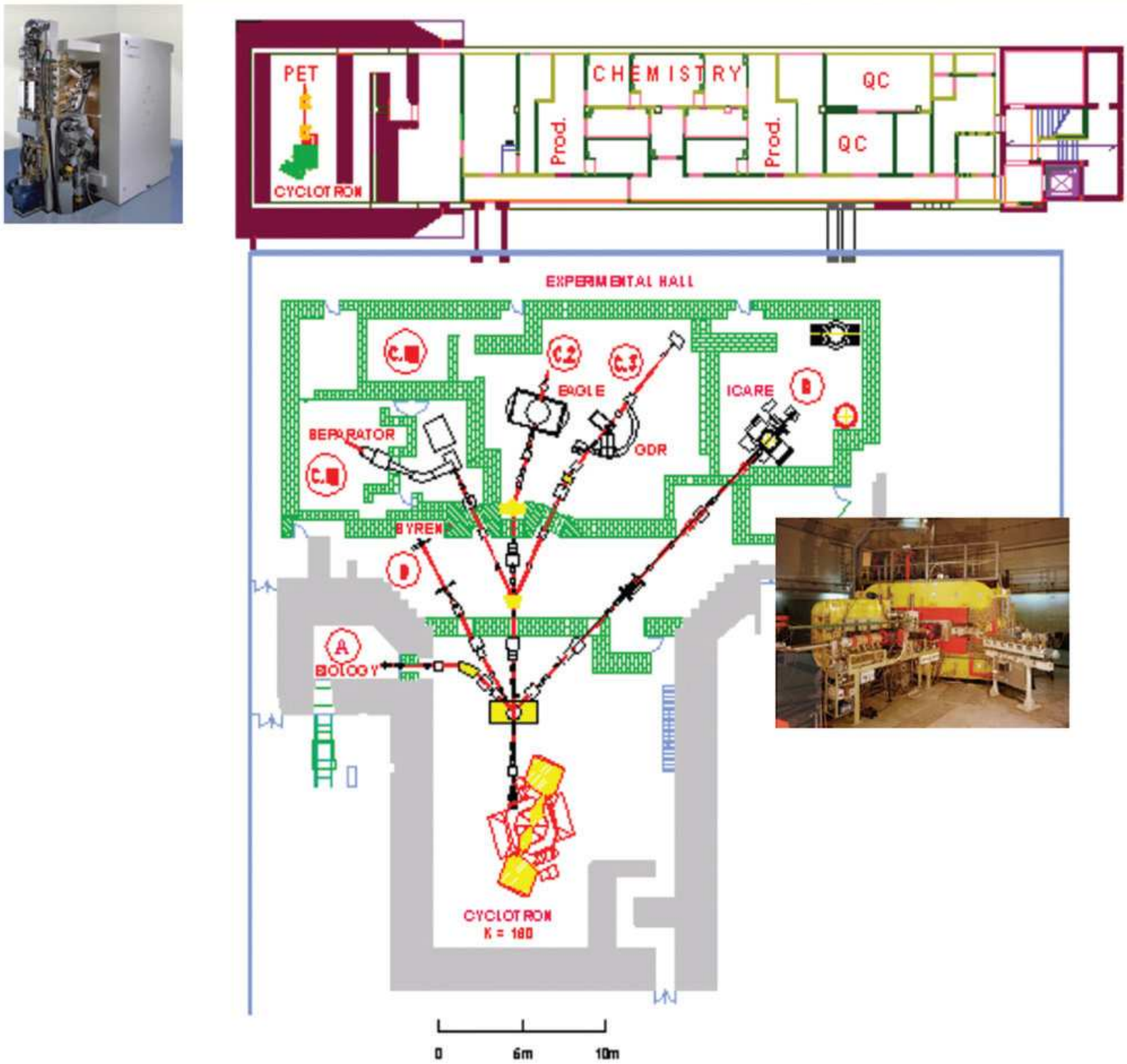

Figure 1: Layout of the ground floor of the HIL building. Lower part of the layout shows the heavy ion cyclotron, its beam lines and the nuclear physics experimental stations. Upper part shows the Radiopharmaceuticals Production and Research Centre, placed 6 m underground (adapted from Ref. [2]).

Centre layout and equipment

The layout of the Centre is displayed in Figures 2, 3, 4. The GE PETtrace cyclotron (Fig. 5) is able to deliver up to 100 microamperes proton current of 16.5 MeV energy and up to 60 microamperes, 8.4 MeV energy deuterons. As indicated above, the chemistry area is composed of two parts: the so called area L1 for the everyday synthesis and dispensing of the most current radiopharmaceutical FDG, intended for the commercial activity of the Centre, and area L2 for the research activity. In area L1 two hot cells (single and double, Fig. 6) host the FDG automatic synthesis and dispensing units. In area L2 two single and two double hot cells are available equipped with a universal ^{18}F synthesis unit (for FDG but also other ^{18}F-based radiopharmaceuticals) and a complete ^{11}C-based radiopharmaceuticals line with appropriate synthesis and dispensing units. A ^{15}O based water synthesis unit is also available there.

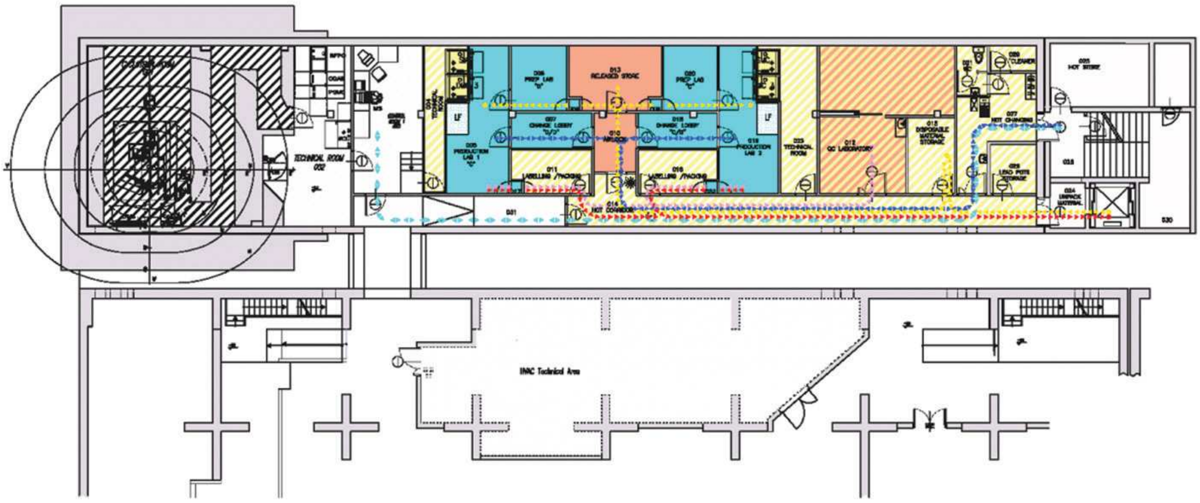

Figure 2: Layout of the RPRC. The proton/deuteron cyclotron and its control room is placed on the left part of the figure. Two independent production rooms are placed in the middle of the figure (the first one for the routine FDG production and the second one for other, also innovative, radiopharmaceuticals). The Quality Control room is placed in the right part of the figure (adapted from Refs. [2, 4]).

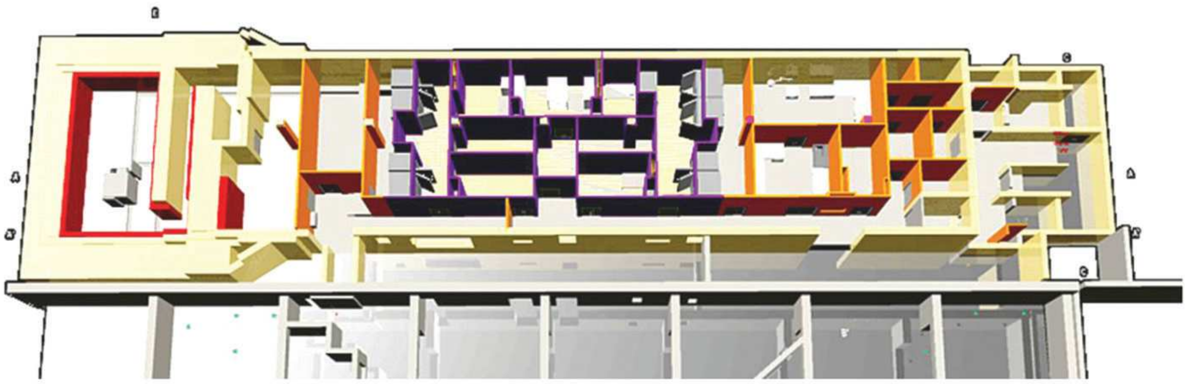

Figure 3: A 3D view of the RPRC represented in Figure 2 (courtesy of the M + W group, building adaptation designer and executor).

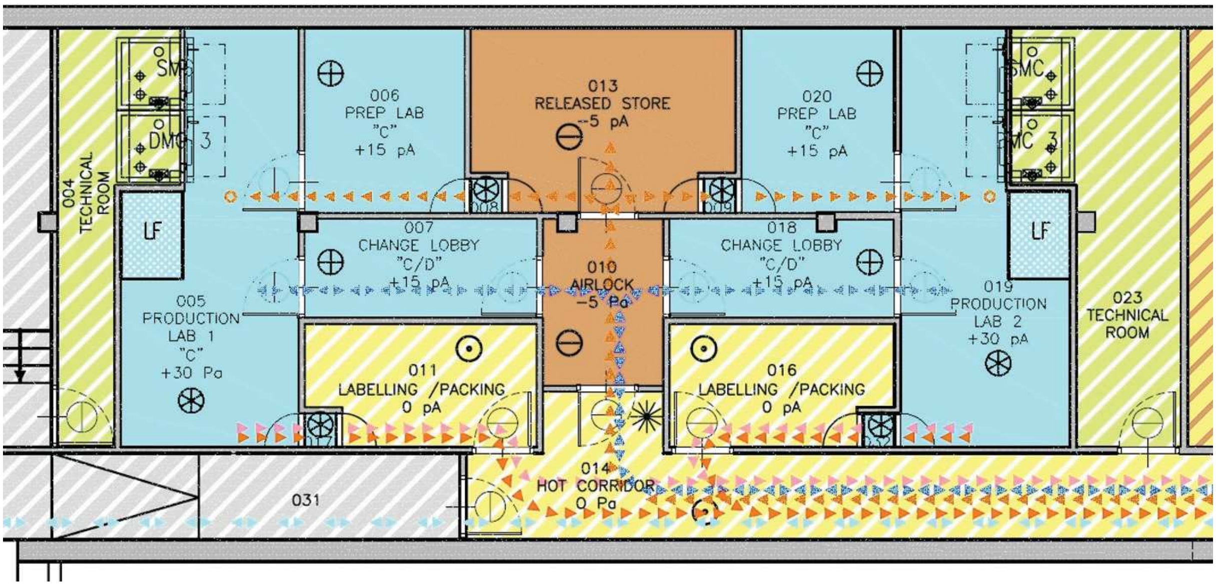

Figure 4: Enlarged view of the production rooms (adapted from Ref. [3]).

Figure 5: The PETtrace p/d cyclotron.

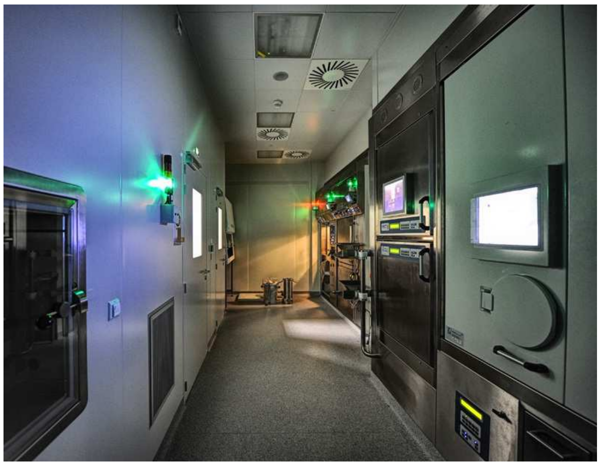

Figure 6: Hot cells in the research laboratory (photo Grzegorz Krzyżewski).

Expected centre activity

Besides the regular everyday production of the commercialised FDG radiopharmaceutical, syntheses of other known species are planned for preclinical research in collaboration with institutions belonging to the Warsaw Consortium for PET Collaboration or members of the Ochota Campus network. At the very beginning, depending on the expressed needs, the production of ^{18}F-FLT, ^{18}F-Choline or ^{18}F-Dopa may begin almost immediately. Two fully equipped ^{11}C radiopharmaceuticals synthesis lines can be used for e.g. ^{11}C-Choline, ^{11}C-Acetate or ^{11}C-Methionine production.

Another research area will be innovative radiopharmaceuticals for PET and combined imaging methods (PET-NMR). The research work and the application activity is focused mainly on new drugs applied in oncology, cardiology and neurology, significant fields of modern medicine.

The initial aim is to develop production technologies for substrates like ^{11}C-halogenes, ^{11}C-alcohols and $^{11}CO_2$, for studies of functioning and functional changes in the nervous system, to answer questions on the origin and course of Alzheimer's disease, Parkinson s disease or various forms of schizophrenia. The next task is to create the infrastructure for the production and application of ^{15}O marked water in advanced cardiologic and neurological diagnostics. The research programme strongly supports the activities conducted by neighbouring institutions: the Medical University of Warsaw, which is interested in applying the above radiopharmaceuticals in clinical practice and the Institute of Experimental Biology, focused on ^{15}O application in research on neurobiological processes and fundamental research on the mechanisms of mental illnesses. An important example of cyclotron beam use for non-PET radiopharmaceuticals will be research into an alternative (via accelerators) way of producing the most popular isotope in nuclear medicine, ^{99m}Tc, presently obtained from the nuclear reactor produced ^{99}Mo generator.

Summary and conclusions

Supported by grants from the Ministry of Sciences, International Atomic Energy Agency, Ministry of Health, European Structural Funds and the University of Warsaw resources the Radiopharmaceuticals Production and Research Centre was created on the premises of the University of Warsaw Heavy Ion Laboratory. The main objective of the Centre will be the production of and research into Positron Emission Tomography radiopharmaceuticals. However, after the installation of the external beam line the available high intensity proton or deuteron beam will also be used for the production of other longer lived radioisotopes for life-sciences applications.

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B.3 Accelerator production of ^{99m}Tc

J. Choiński[1], A. Jakubowski[1], J. Jastrzębski[1], I. Mazur[1], A. Stolarz[1], A. Trzcińska[1], J. Chudyka[2], K. Szkliniarz[2], W. Zipper[2]

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The ^{99m}Tc isotope is the most popular radioisotope in nuclear medicine. More than 90% of currently available radiopharmaceuticals for SPECT technology are produced with this isotope. This radioisotope is obtained from the ^{99}Mo generator, produced via the fission route in nuclear reactors, specially designed to have a very intense neutron flux in their core with a limited power output to enhance the production process. Such high flux research reactors were constructed by governmental research groups and heavily funded by grants more than 40 years ago. The actual worldwide problem is the availability of these specific reactors, since they are almost all very old and prompt to multiple failures or repairs. The recent unexpected shutdown of the Chalk River and Petten reactors caused a worldwide crisis in the supply of ^{99m}Tc .

This was the reason which prompted a search for an alternative way to produce this isotope, using particle accelerators. There are several potential reactions that can be used for production of ^{99m}Tc in this way. In Ref. [1] direct cyclotron production of ^{99m}Tc by the (p,2n) reaction on a ^{100}Mo target is recommended as a short term solution. The most advanced studies have so far been performed and published by a Canadian team [2]. Recently, the International Atomic Energy Agency (IAEA) launched a Coordinated Research Project (CRP) for research into the accelerator production of this isotope. Calculations indicate that via the reaction ^{100}Mo(p,2n)^{99m}Tc, having a maximum cross section at 15–16 MeV, up to 6 Ci of ^{99m}Tc can be produced during one 6 hour-long cycle of proton irradiation. Irradiations made 2–3 times per day on a common medical cyclotron with 150 A proton current would be sufficient to supply a large metropolitan area. The ^{100}Mo material needed for the reaction is sold by a commercial isotope supplier at purity greater than 99.5%.

In Warsaw a consortium of three institutions was established to carry out a research programme on accelerator production of the ^{99m}Tc radioisotope: POLATOM at the National Centre for Nuclear Research, the Heavy Ion Laboratory (HIL) at the University of Warsaw and the Institute of Nuclear Chemistry and Technology. This consortium is a member of the IAEA Coordinated Research Project with a one year Research Contract (with possible prolongation) and was recently awarded a research grant by the Polish funding agency NCBiR (National Centre of Research and Development).

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B.4 Porphyrine complexes with Ga and Cu as potential PET radiopharmaceutical candidates

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The project aim was to develop methods of synthesis, quality control and physicochemical characteristics of copper and gallium complexes with porphyrins, as potential candidates for diagnostic and therapeutic radiopharmaceuticals in nuclear medicine.

The PET technique is applied in the study of functioning and functional changes in the human body, enabling, among others, precise oncology diagnostics. It is also an appreciated diagnostic method in cardiology, allowing the condition of the cardiovascular system to be evaluated in a non-invasive way.

Porphyrin and its derivatives exhibit affinity for tumor cells. Hence, porphyrins labelled with a suitable therapeutic or diagnostic radionuclide could be envisaged as potential agents for tumor therapy and diagnostics.

The main goal of this project was to obtain porphyrin complexes with copper or gallium with a reasonable synthesis path, acceptable kinetics and purity.

^{64}Cu and ^{68}Ga are described in the literature as potentially effective diagnostic radioisotopes, used in positron emission tomography (PET). The quality of imaging is in some applications comparable to the quality of imaging with ^{18}F, which is one of the most frequently used isotopes in PET.

In recent years ^{68}Ga has gained importance in molecular imaging by positron emission tomography. Due to the advantages of the easy availability of ^{68}Ga from the generator ^{68}Ge/^{68}Ga, good radiation properties ($T_{1/2}$ = 68 min, 90% β^+-decay) and rich Ga^3+ coordination chemistry. These factors may cause a considerable increase in interest in ^{68}Ga-labelled compounds in biology and medicine.

The wide half-life range of other isotopes of copper allows imaging of processes with different dynamics, while the identical chemistry of the labelling process is maintained. In addition copper-64, because of its decay scheme, is also used as a therapeutic agent.

The reaction of porphyrins with Cu(II) and Ga(III), was studied spectrophotometrically and the kinetics of the process was optimised (Fig. 1). On the basis of the SAT mechanism and determined kinetics of these reactions, fast methods for the synthesis of Cu(II) and Ga(III) complexes were developed (Fig. 2). Using “cold” compounds, all required characteristics of the complexes were determined and a full synthesis and purification path was defined. After validation of synthesis procedure and separation methods, labelling reactions with ^{64}Cu and ^{68}Ga will be performed.

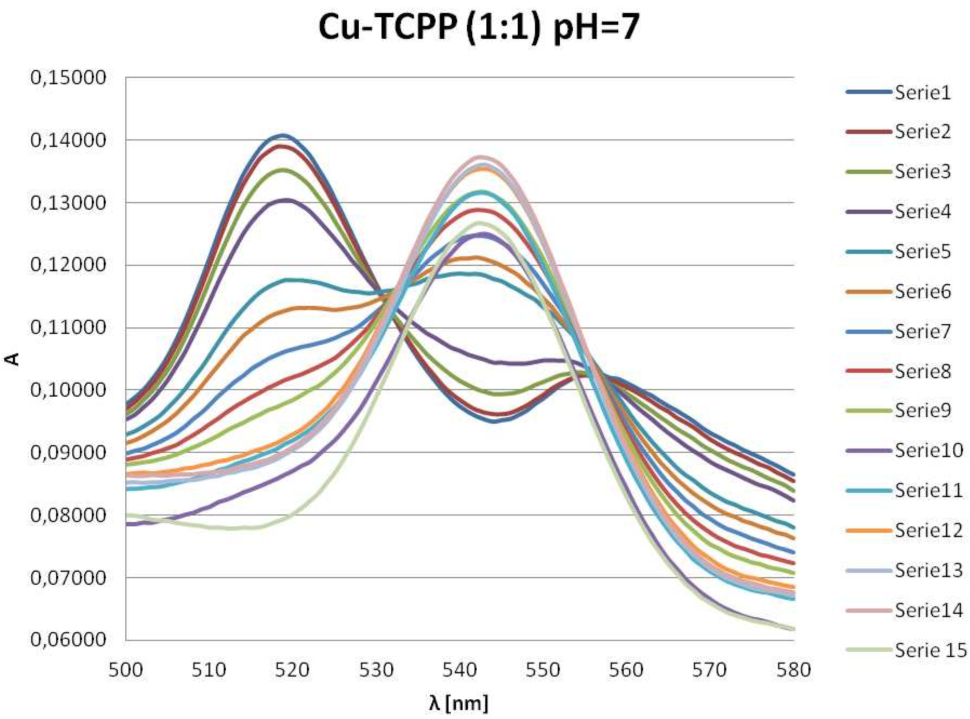

Figure 1: Kinetic spectra of Cu-Tetracaroboxyphenyloporphyrin formation.

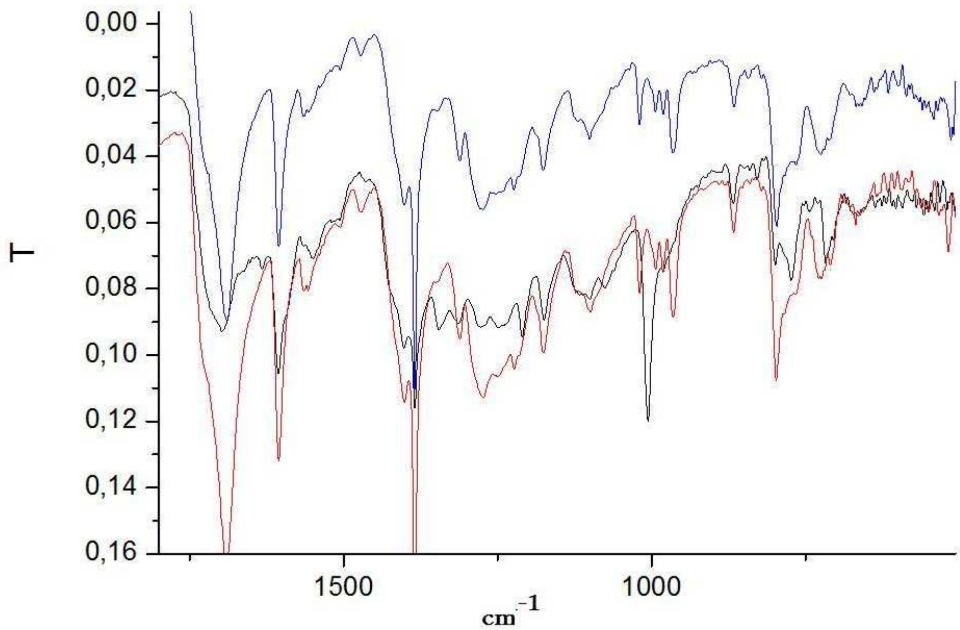

Figure 2: FT-IR spectra of tetracarboxyphenyloporphyrin (blue, red) and Ga-Tetracaroboxyphenyloporphyrin complex.

B.5 Quality control of radiopharmaceuticals

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The compound used routinely for Positron Emission Tomography is a derivative of glucose, labelled with a radioactive isotope fluorine-18 (^{18}FDG-Fluorodeoxyglucose). For the synthesis of ^{18}F-fluorodeoxyglucose automatic synthesisers are used, allowing a synthesis time of less than 30 minutes with a yield of over 60% EOB.

One of the most important aspects of working with ^{18}FDG is the short time (about 30 minutes) that can be spent on quality control and release procedures, thus the speed, simplicity and reliability of developed analytical methods are critical factors. For radiopharmaceuticals the general requirements are listed in the European Pharmacopoeia and these parameters have to be checked before application for human use.

The aim of this study was to synthesise ^{18}F-FDG in some consecutive runs and check the quality of the manufactured radiopharmaceuticals. Source of the isotope was the GE PETTrace 8 medical cyclotron with a 16.5 MeV, 80 microampere beam, with a high-yield niobium target, delivering up to 300 GBq after 2 h of irradiation. For synthesis a dedicated GE MXFDG unit was used. Radiopharmaceutical was sterilised by filtration and dispensed in automatic system DDS-Vials. To ensure the quality of FDG the following control methods were developed and validated with certified reference standards (CRS):

- Nuclidic purity,
- Residual organic solvents content,
- Radiochemical purity,
- Isotonicity and pH,
- Kryptofix content.

Nuclidic purity

Nuclidic purity was determined using gamma spectroscopy with both NaI and Ge detectors. The first was used for fast spectra recording of main components and half-life determination (108 min). In all the samples main line at 511 ± 6 keV was determined with the sum peak at 1.022 MeV. Long term studies with the Ge detector showed trace (sub-ppb) content of metallic impurities, identified as ^{57}Co, ^{58}Co, ^{56}Co, ^{52}Mn, ^{54}Mn and ^{51}Cr.

Residual organic solvents

Organic solvents were determined with headspace gas chromatography (HS-GC). In all samples acetonitrile and ethanol were determined quantitatively, with traces of methanol observed in some samples. For the determination an originally developed method was used, where separation of organic solvents was completed in 1 minute (Fig. 1) with total time of analysis below 4 minutes, whereas pharmacopoeial method or procedures described in the literature need about 20 minutes for complete separation only.

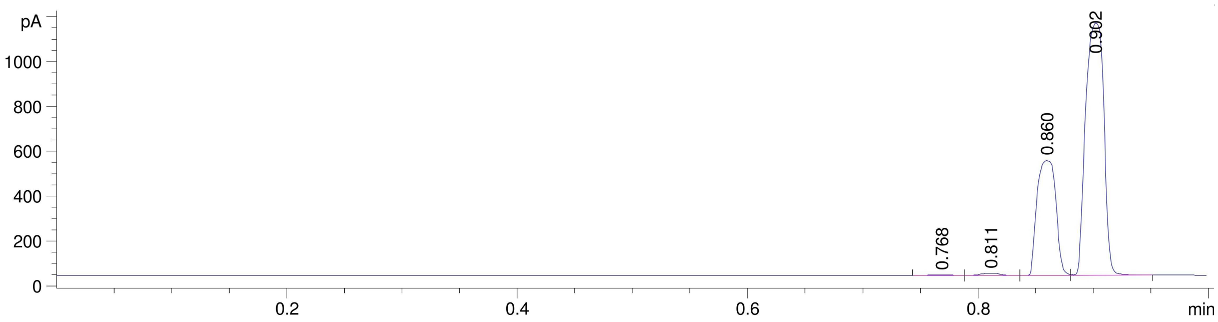

Figure 1: Gas-chromatographic separation of residual solvents. Signals, in order of appearance: methanol, ethanol, acetornitrile.

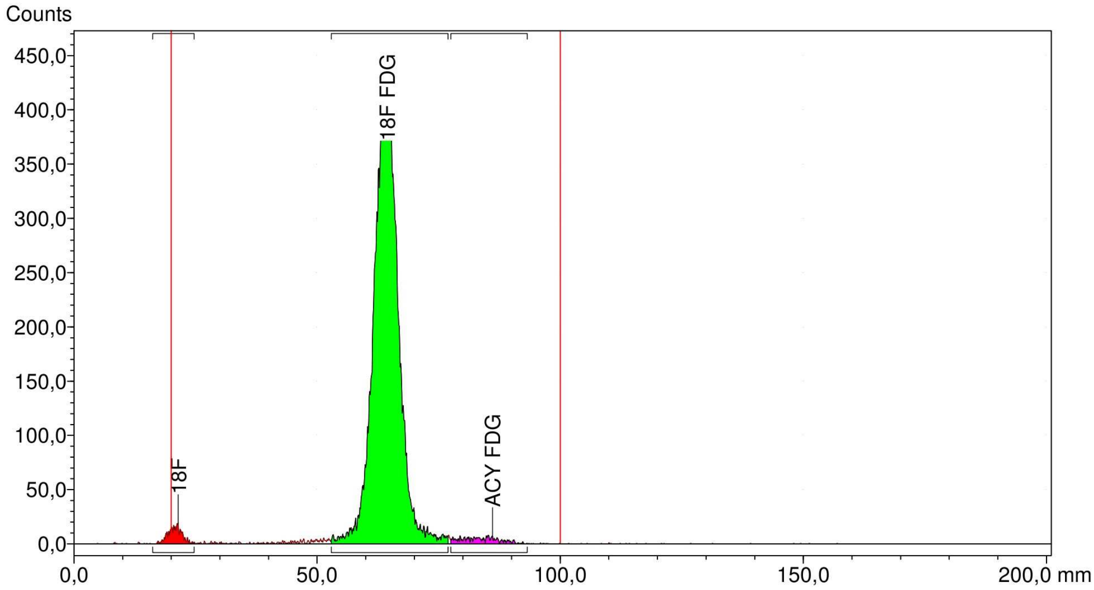

Figure 2: Gas-chromatographic separation of residual solvents. Signals, in order of appearance: methanol, ethanol, acetornitrile.

Radiochemical purity

Radiochemical purity was determined with the standard method (thin layer chromatography, acetonitrile:water 95:5) and all impurities were determined and identified with CRSs (Fig 2).

All samples met the acceptance criteria and fulfilled the requirements of the European Pharmacopoeia (Table 1).

Determined values in n=6 consecutive runs		
Parameter	Acceptance criteria	Value
pH	4.5 – –8.5	6.24 – –6.75
Osmolality	280 – –310 mOsm	293 ± 14 mOsm
Residual solvents - ethanol	< 3000 mg/kg	29 ± 1 mg/kg
Residual solvents - acetonitrile	< 4.10 mg/V	0.77 ± 0.03 mg/V
Kryptofix content	< 2.2 mg/V	Pass
Radiochemical purity	> 95 %	98.6 ± 0.6 %

Table 1: Determined QC parameters in ^{18}F-FDG

B.6 ^{211}At production at the Warsaw Cyclotron

J. Choiński[1], A. Jakubowski[1], J. Jastrzębski[1], W. Kalisiewicz[1], B. Paprzycki[1], A. Pietrzak[1], R. Tańczyk[1], A. Stolarz[1], D. Szczepaniak[1], A. Trzcińska[1], J. Chudyka[2], A. Kuc[2], K. Szkliniarz[2], W. Zipper[2], A. Bilewicz[3], E. Leszczuk[3], M. Łyczko[3], A. Piotrowska[3], B. Wąs[4]

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In the last few years special attention has been concentrated on alpha-particle emitters as therapeutic radioisotopes. Alpha particles, thanks to their large linear energy transfer (LET $\alpha \sim 100$ keV/μm) are very well suited to double-strand breaking of malignant cells. Their range in tissue is 40–100 μm which corresponds to the dimension of a few cells. They are very effective in the destruction of small tumours of a few cells in dimension with much lower interaction with surrounding healthy cells, provided a vector molecule that can effectively seek out the tumour cells is identified and the link between this molecule and the alpha-particle emitter is chemically established.

The ^{211}At isotope is one of the most promising alpha emitters that could be applied in radionuclide targeted therapy. However, until now its links to the vector molecule are still in the research phase, although some preclinical studies have already been published.

^{211}At is produced at the Warsaw heavy ion cyclotron via the ^{209}Bi(α,2n)^{211}At reaction [1]. The irradiated samples are transported to the Institute of Nuclear Chemistry and Technology where a new method for binding ^{211}At to substance P, a peptide with high affinity to receptors of glioma cancer cells, is being investigated. For binding ^{211}At to substance P we plan to use the N-succinimidyl 3-[*I]iodobenzoate method and the "metal bridge" approach developed in our laboratory. The radiobioconjugates obtained will be examined for their stability and cell binding affinity. As a research result, we expect to obtain a radiopharmaceutical for glioma cancer treatment after tumour resection.

Another way of searching for ^{211}At carriers consists in the investigation of silver coated TiO_2 nanoparticles. The chemical investigation of this method is also being conducted by our team [2].

The ^{211}At is produced during one working week irradiation runs when the cyclotron parameters are set for the most efficient internal irradiation conditions. The samples for the chemistry investigations are produced during night periods whereas the day beam time is used for the efficiency calibrations and other research related to the He^+ irradiation conditions. In 2012 three one week runs were performed with the irradiated samples transported to the Żerań Laboratory every morning. There the astatine was distilled at 650°C with a nitrogen flow of 120 ml/min. and condensed in PEEK-(polyether ether ketone)-capillary trap. The capillary trap immersed in an ethanol-liquid nitrogen cooling bath was kept at -50°C. For 100 μm Bi targets and perpendicular beam impact on the target, about 200 MBq (EOB) of ^{211}At was produced with 500 nA He^+ beam during one night irradiation. About 50% of this activity was extracted from the irradiated targets for chemical research.

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B.7 Nanodosimetry of At-211

A. Bantsar[1], S. Pszona[1], W. Czarnacki[1], A. Bilewicz[2] Z. Szefliński[3],

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The cyclotron-produced α-emitter At-211 is particularly propitious for application to targeted radionuclide therapy of cancer, especially for treatment of micrometastatic disease and cancer that is resistant to other forms of radiation (e.g. melanoma). Therefore, it is important to describe the physical pattern of the interaction of At-211 at the DNA level, shortly, to provide physical descriptors based on a nanodosimetry approach. The nanodosimetric descriptors are derived from a frequency distribution of ion clusters which can be determined experimentally. A first experimental attempt to describe the nanodosimetric descriptors of At-211 was carried out using the device called "Jet Counter" [1] at the National Centre for Nuclear Research. The radioactive source of At-211 was provided by a group of researchers from HIL and INCT [2].

An At-211 source was obtained by evaporation of At from ethanol solution on an Al rod support with 5 mm diameter. The emitted alpha particle spectrum of this source was measured on a Si spectrometer and is shown in Figure 1. Two mono-energetic lines are seen, namely 5.87 MeV due to the decay of At-211 and 7.45 MeV due to the decay of Po-211 (daughter of At-211).

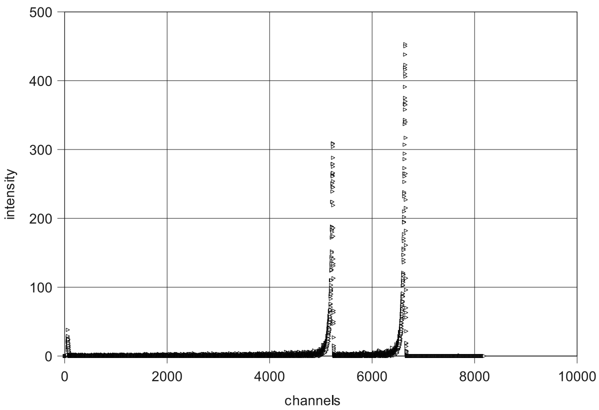

Figure 1: Measured spectra of alpha particles emitted by a sample with At-211
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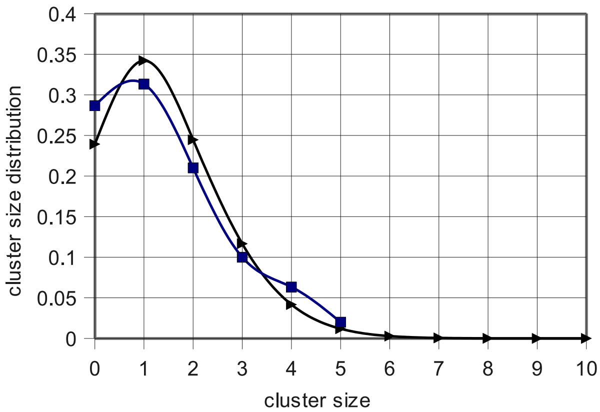

Figure 2: Frequency distribution of ionisation cluster size generated by alpha particles from At-211. Squares — experimental points, triangles — Poisson distribution for the mean cluster size.

The cluster size spectrum generated by this source in a nitrogen cavity with dimension of 3 nm (on a unit density scale) was measured and preliminary results are seen in Figure 2, together with the Poisson distribution calculated for the mean cluster size (experimental).

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Part C

Experiments at HIL

C.1 Study of the K-isomer in ^{134}Nd using electron conversion spectroscopy

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The goal of our measurements was to study K selection rule violation for electromagnetic transitions in nuclei with mass number $A \sim 130$ and neutron number $N = 74$ by determination of absolute transition probabilities from the decay of the $I^\pi = K^\pi = 8^-$ isomeric state observed in even-even nuclides [1, 2]. Their modes of decay are different, but decay branches of E1 transitions with a degree of K forbiddenness $n = 7$, leading directly to the 8^+ member of the ground state band with $K = 0$, have been found in several nuclei such as ^{130}Ba, ^{134}Nd, ^{136}Sm, and ^{138}Gd. This branch severely violates the K selection rule. The main goal of the measurement was to determine the multipolarities of the gamma transitions de-exciting the $I^\pi = K^\pi = 8^-$ isomeric state in ^{134}Nd and confirm the existing decay path of this isomer by de-excitation to the γ band ($8^- \rightarrow 5^+$) (see Fig. 1).

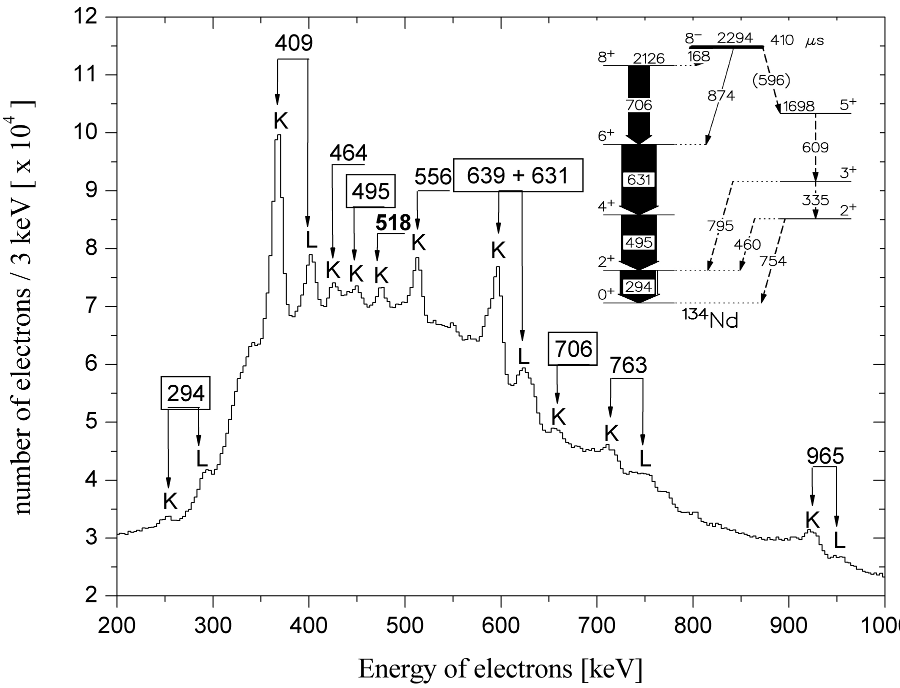

Figure 1: Total electron spectrum from the reaction: $^{16}O + ^{122}Te \rightarrow ^{128}Te^*$. The following lines may be recognised: decay of the isomeric state $I^\pi = K^\pi = 8^-$ in ^{134}Nd (text in rectangles), decay of ^{134}Pr and decay of ^{135}Ce (bold text).

This state was populated in the ^{122}Te(^{16}O,4n)^{134}Nd reaction . A ^{16}O beam with an energy of 90 MeV and intensity of 40 enA from the cyclotron of the Heavy Ion Laboratory was used. The experiment was performed in e-γ and γ-γ coincidence modes using the electron spectrometer [3] coupled to the EAGLE gamma-ray array [4]. The spectroscopy of internal conversion electrons in coincidence with γ rays allows multipolarities and absolute values of the transition probabilities to be determined.

The "beam-off" total electron spectrum collected during 100 hours of measurement is presented in Fig. 1. The experimentally obtained value of the conversion coefficients for the K line for the ($8^- \rightarrow 6^+$) 874 keV transition is $\alpha_K = 0.007(9)$. The summed electron spectrum in coincidence with the 294, 495 and 631 keV γ-ray transitions is shown in Fig. 2. Comparison of this value with theoretically predicted conversion coefficients (α_K(E3) $= 0.00551$, $alpha_K$(M2) $= 0.0103$ [5]) suggests that this is an E3/M2 mixed transition. The postulated decay path of this isomer to the γ band ($8^- \rightarrow 5^+$) is not seen.

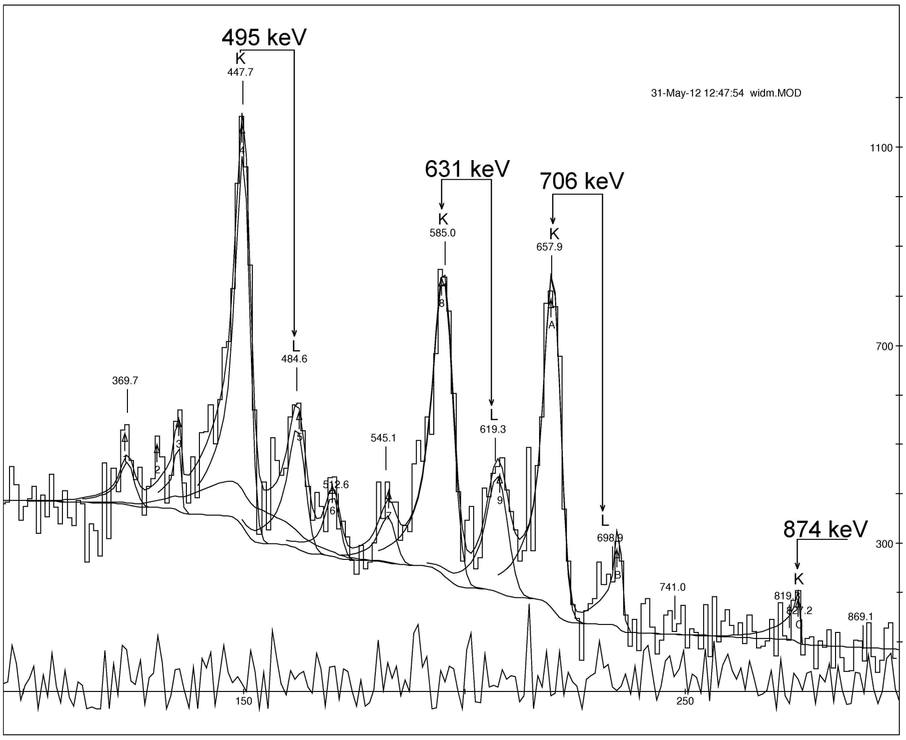

Figure 2: The summed "beam-off" electron spectrum in coincidence with the 294, 495 and 631 keV γ-ray transitions.

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C.2 Quadrupole moments of excited states in ^{107}Ag

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The Coulomb excitation of ^{107}Ag was measured in November 2012 using an 84 MeV ^{32}S beam delivered by the Warsaw Cyclotron. The main goal of the experiment was to extract quadrupole moments of the $3/2^-$ and $5/2^-$ states, as well as relative signs of the E2 and M1 matrix elements which couple higher-lying excited states. The determination of the signs and the magnitudes of matrix elements, especially quadrupole moments, is crucial to understanding the character of the low-lying states of ^{107}Ag and will provide a stringent test for different theoretical approaches based mainly on various "particle plus core" coupling models, e.g. [1–3]. The second motivation for this study comes from the fact that missing information on the quadrupole moment of the $3/2^-$ and $5/2^-$ states in ^{107}Ag seriously complicates the analysis of recent Coulomb excitation studies of exotic nuclei, where this isotope has been used as a target. In such experiments, the absolute excitation cross-section of the projectile is determined by normalising to the target excitation, which depends both on known B(E2) values and quadrupole moments. Therefore a precise normalisation is not possible, when the latter values are unknown. This may lead to ambiguity in the final results obtained for the exotic nuclei.

The gamma rays de-populating Coulomb excited states of ^{107}Ag were detected by the EAGLE array [4] consisting of 15 HPGe detectors of 70% efficiency equipped with anti-Compton BGO shields. A compact Coulex chamber (the so-called Munich Chamber), inside which 48 small PIN-diodes were placed, each of 0.5×0.5 cm^2 active area, was used to detect the back-scattered beam particles. The PIN-diodes were placed at backward angles, with respect to the beam direction to enhance the probability of multi-step excitation. The particle detection system covered the angular range from 121° to 157° in the laboratory frame. The measurements were carried out in particle-gamma coincidence mode. The beam intensity varied between 0.1 – 0.5 pnA.

Fig. 1 presents low-energy part of the level scheme for ^{107}Ag together with γ-ray transitions observed in the experiment.

A sample γ-ray spectrum of ^{107}Ag detected in prompt coincidence with scattered ^{32}S particles is shown in Fig 2. This spectrum was collected during the first 40 hours (out of 216 hours) of data taking and is summed over all HPGe and particle detectors. In the experiment a thick ^{107}Ag target was used in order to avoid the Doppler broadening of

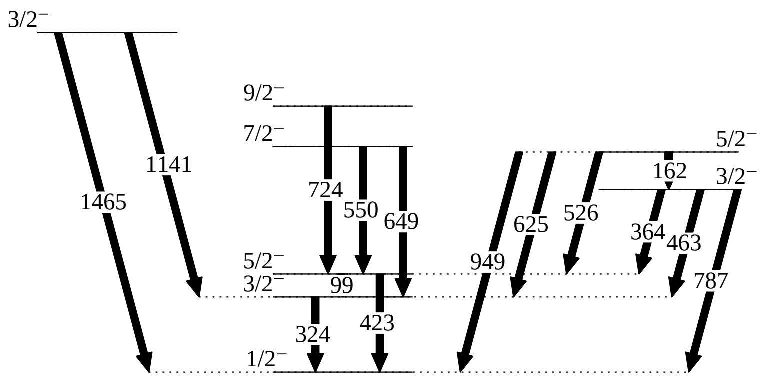

Figure 1: Low-energy part of the level scheme of ^{107}Ag populated in the Coulomb excitation experiment performed at HIL in November 2012.

the γ-lines originating from states whose lifetimes are in the range of a few picoseconds. Gamma ray transitions depopulating the $3/2^-_2$ state are clearly Doppler broadened since they were emitted in flight ($\tau_{3/2^-_2} = 0.37$ ps).

The data collected are encouraging. The $9/2^-_1$ and $7/2^-_1$ states, populated exclusively in the double step Coulomb excitation process, are clearly observed via de-excitation γ-ray transitions: 724 keV, 550 keV and 649 keV. These γ lines are of particular interest to us, as the analysis of their intensities, based on the different projectile scattering angle, will increase the experimental sensitivity to the quadrupole moment of the $3/2^-_1$ and $5/2^-_1$ states.

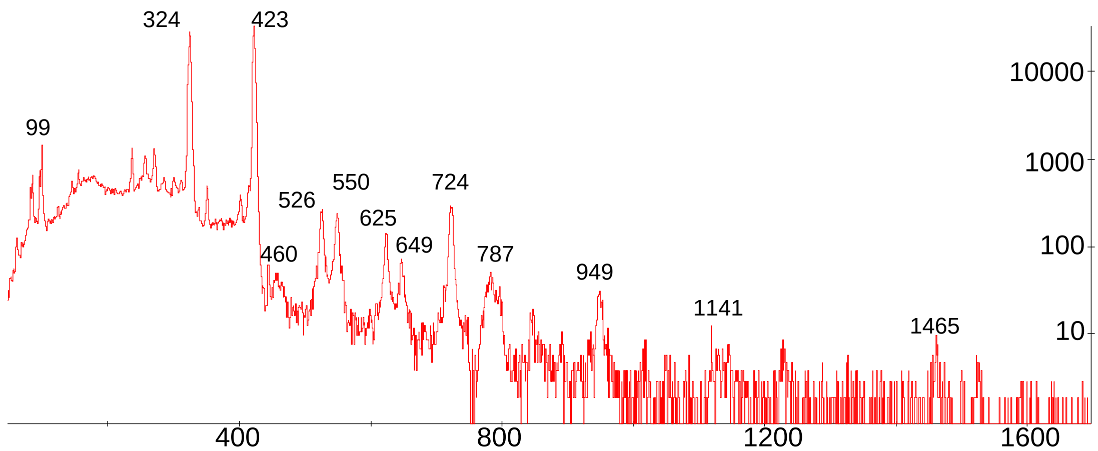

Figure 2: Gamma ray spectrum of ^{107}Ag Coulomb excited by a ^{32}S beam, summed over all HPGe and particle detectors. The γ-rays are in prompt coincidence with the scattered projectiles.

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C.3 Collectivity of the 4^+ state in ^{70}Zn studied via Coulomb excitation

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Shell evolution in the vicinity of the spherical nucleus ^{68}Ni has recently attracted many theoretical and experimental investigations. By now it has been clearly established that the presumed subshell closure at N=40 is not very pronounced. While the intruder character of the $1g_{9/2}$ and $2d_{5/2}$ neutron orbital induces collectivity by pair excitations from the fp shell into the $g_{9/2}$ orbital, the parity change hinders quadrupole excitations and therefore mimics the properties of a doubly magic nucleus in ^{68}Ni, i.e., a high 2_1^+ energy and a low B(E2; $2_1^+ \rightarrow 0_1^+$) value. Adding valence nucleons to the N=40 open shell leads to a rapid increase of collectivity, with an interplay of both collective and single-particle degrees of freedom. Such rapid changes indicate underlying complex effects and make this region ideal for testing theoretical calculations. While measurements of B(E2; $2_1^+ \rightarrow 0_1^+$) values are useful to investigate the evolution of collectivity along isotopic chains, even more insight into the collective behaviour can be gained by measuring lifetimes of higher-lying states. Almost all stable and neutron-rich Zn isotopes present an anomalously low B(E2; $4_1^+ \rightarrow 2_1^+$)/ B(E2; $2_1^+ \rightarrow 0_1^+$) ratio of 1 or less, which is normally observed only around closed shells. A strong increase of collectivity of the 4_1^+ state was observed for ^{70}Zn [1] and could not be explained in the framework of nuclear structure models. A recent lifetime measurement [2] yielded a considerably longer lifetime for this state, yet its accuracy was not sufficient to draw any firm conclusions.

Given the complex scheme of low-lying states in ^{70}Zn including many nearly degenerate transitions, Coulomb excitation seemed a more appropriate method to study this nucleus. A dedicated Coulomb excitation measurement was performed at the Heavy Ion Laboratory, University of Warsaw, to measure the B(E2; $4_1^+ \rightarrow 2_1^+$) in ^{70}Zn. The gamma rays from Coulomb excited states in ^{70}Zn were detected by the EAGLE array [3] of 15 ACS Ge detectors of 70% efficiency, working in coincidence with 48 PIN-diode detectors of scattered beam particles. The particle detectors were placed in the backward hemisphere to enhance the probability of multi-step Coulomb excitation.

The ^{32}S beam was chosen for this measurement as a compromise between kinematical constraints (requirement of detection of back-scattered beam particles at energies above the typical noise level for this setup made it impossible to use beams of Ar or heavier ions) and relative population of the 4^+ state with respect to 3_1^-. As the $4_1^+ \rightarrow 2_1^+$ and $3_1^- \rightarrow 2_3^+$ lines form a doublet at 902 keV, the contribution of the latter to the observed intensity was minimised by using a relatively heavy beam. The beam energy was degraded from

82 MeV to 68 MeV by an Al foil placed at the entrance of the scattering chamber (see Fig. 1).

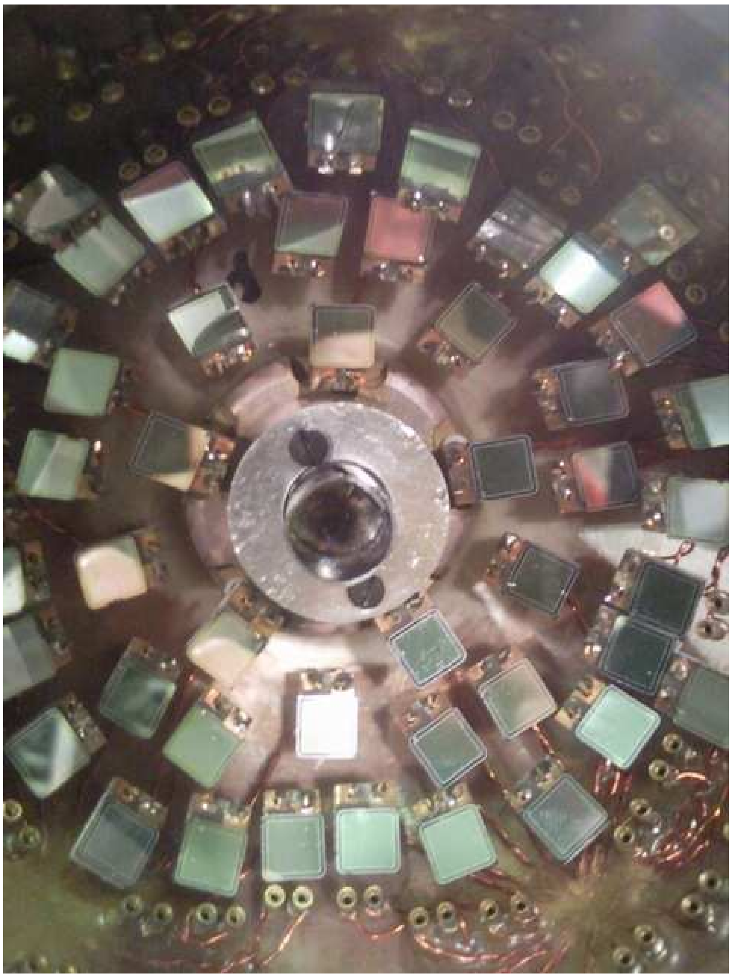

Figure 1: Backward hemisphere of the scattering chamber, with the degrader and PIN-diode detectors visible.

Another potential experimental problem was related to the relatively short lifetimes (below 2 ps) of several excited states in ^{70}Zn. For a thick target measurement, the stopping time of recoils would be comparable to the lifetimes of the excited states, and an important part of the detected gamma-rays would be emitted from recoils slowing down in the target material, which would strongly complicate the data analysis. This effect was minimised by using a thin ^{70}Zn target of 0.6 mg/cm^2, prepared at the GANIL target laboratory. Assuming the lifetime of the 4^+ state equal to 1.9 ps [1], the observed tail of the gamma line was estimated to be below 5% for all scattering angles used (120–150 degrees) and even less if a longer lifetime [2] is assumed. The data are currently under analysis.

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C.4 Alpha cluster transfer in ^{16}O+^{12}C scattering at 41.3 MeV

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Experimental data for the differential cross sections [1] for ^{16}O+^{12}C elastic scattering near the Coulomb barrier showed a significant rise in the backward hemisphere, which can be explained by the alpha-cluster transfer mechanism. In this contribution we report on a recent measurement performed at a higher energy, well above the barrier, in order to further study this effect.

Differential cross sections for elastic scattering of oxygen ions from ^{12}C nuclei were measured using a 41.3 MeV beam from the U-200P cyclotron at the Heavy Ion Laboratory of the University of Warsaw, at a wide range of scattering angles. The charged particle detection system ICARE was employed for particle identification ($\Delta E - E$ method) and for measurement of their energy spectra. The data are plotted in Figure 1. In the forward hemisphere the measured angular distribution shows weak oscillations, whereas at backward angles there is a well-pronounced oscillatory structure showing a significant enhancement of the differential cross section with angle. Such behaviour of the angular distributions of elastic scattering of heavy ions is poorly described in terms of the optical model.

Thus, we calculated the elastic scattering of ^{12}C taking into account the α-cluster exchange mechanism using the Coupled Reaction Channels (CRC) method and the program FRESCO [2]. Calculations were performed with an optical potential describing well the angular distribution at forward angles (red curve in the figure). The parameters of the potential are listed in Table 1. A Woods-Saxon potential with radius $R_0 = 0.81(A_{core} + A_{cluster})^{1/3}$ fm and diffuseness $a = 0.65$ fm was used for the calculation of the bound state wave-function of ^{16}O=^{12}C+α. The potential depth was adjusted to reproduce the binding energy of the alpha cluster in ^{16}O. The CRC calculations with α-transfer included explain the enhancement of the differential cross section at backward angles (green curve in the figure).

Table 1: Optical potential parameters.

E (MeV)	V_0 (MeV)	R_r (fm)	a_r (fm)	W_0 (MeV)	R_i (fm)	a_i (fm)	SF
41.3	87.383	1.21	0.56	25.0	1.31	0.273	1.8

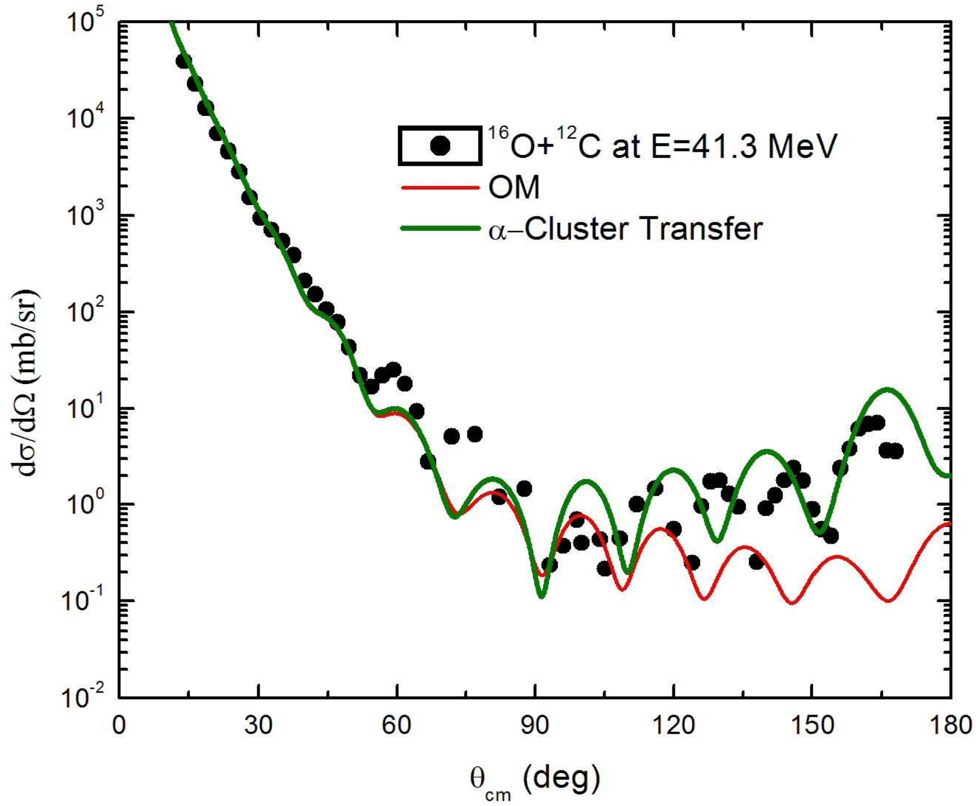

Figure 1: The angular distribution for ^{16}O elastically scattered from ^{12}C at an energy of 41.3 MeV. The solid circles represent experimental data; the solid red line represents the theoretical prediction for pure elastic scattering, and the solid green line represents the theoretical prediction the elastic scattering taking into account of the α-cluster exchange mechanism by means of the CRC method.

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C.5 Weak couplings in the back-scattering of ^{20}Ne on ^{118}Sn — excitation energy measurement

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The study of barrier distributions is an on-going project of the Barrier Group that has continued for some years now. We determine the barrier height distribution in back-scattering experiments using the method described in detail in Ref. [1]. The barrier height distribution is deduced as: $D_{qe}(E) = -\frac{d}{dE}\frac{\sigma_{qe}}{\sigma_{Ruth}}$ where $\frac{\sigma_{qe}}{\sigma_{Ruth}}$ is the quasi-elastic scattering excitation function normalised to the Rutherford scattering cross section.

In our experiments we have focused on the ^{20}Ne projectile, since this nucleus has extremely large deformation parameters: $\beta_2 = 0.46$, $\beta_3 = 0.39$, $\beta_4 = 0.27$ [2–4].

It was shown for Zr and Ni targets [5,6] that excitation of weakly coupled but numerous non-collective states of the target during the back-scattering of ^{20}Ne can give rise to a significant smoothing of the barrier height distribution, D_{qe}. Interpretation of this phenomenon within the framework of the Coupled Channels method is difficult since the form factor of non-collective excitations is not known.

In the search for information necessary to elucidate further this phenomenon a new experiment was proposed and performed at HIL. The evolution of the Q spectrum (distribution of system excitation energy) with scattering angle for the system: ^{20}Ne + ^{118}Sn was measured.

A ^{20}Ne beam was delivered by the Warsaw Cyclotron and the measurements were performed using the multi-detector system ICARE. The ToF (Time of Flight) technique was used to identify the masses of back-scattered ions. The "start" signal was given by a MCP (Microchannel Plate) detector. The "stop" signal was triggered by any of four 20×20 mm Si detectors placed on a movable arm. The base length of the ToF system was 33 cm.

Data analysis is in progress.

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C.6 Determination of the spectroscopic factor in ^{21}Ne from the ^{208}Pb(^{20}Ne,^{21}Ne)^{207}Pb cross section

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In an experiment performed at HIL, the ICARE system and the TOF method were used to detect and identify back-scattered ions emerging from scattering of 102 MeV ^{20}Ne ions on a ^{208}Pb target. The time measurement was started by the signal of a microchannel plate (MCP) detector, and stopped by an array of four 20 mm× 20 mm semiconductor detectors, placed at an angle of 142.5° with respect to the beam axis.

The experiment indicated an important role of the transfer reactions in the collision of ^{20}Ne on a ^{208}Pb target. The two-dimensional spectrum collected during the experiment (Fig. 1) shows a large number of ^{21}Ne nuclei produced in the scattering. Apart from the neon isotopes (^{22,21,20}Ne), ^{19}F, ^{16,17,18}O and ^{14,15}N are also present [1].

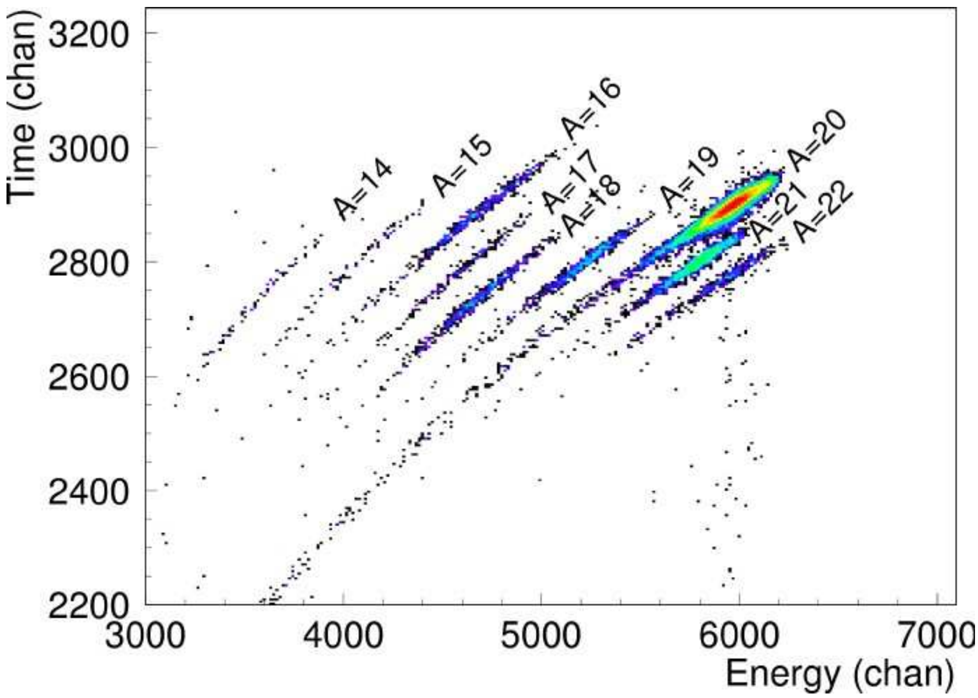

Figure 1: Typical two-dimensional E-TOF spectrum of the reaction products collected during one of the experimental runs.

The spectroscopic factors of the colliding nuclei are needed to perform calculations of the transfer reaction cross section. Knowledge of one of them and the experimental value of the cross section makes it possible to determine the second one. A calculation of the one neutron transfer (pick-up) reaction, ^{208}Pb(^{20}Ne,^{21}Ne)^{207}Pb was performed. The distorted wave Born approximation (DWBA) with the post interaction and an optical potential of the form

$$V(r) = (N_r + iN_i)V_{DF}$$

was used. V_{DF} is a double-folded potential, calculated using the DFPOT code [2] and N_r, N_i are normalisation parameters. The spectroscopic factors for $^{208}\mathrm{Pb} =^{207} \mathrm{Pb} + 1\mathrm{n}$ were taken from [3]. The three strongest transfer channels leading to three low-lying states in ^{207}Pb and the first excited state in ^{21}Ne were included. By fitting the calculated curve to the experimental data, the spectroscopic factor for the $1d_{5/2}$ state in $^{21}\mathrm{Ne} =^{20} \mathrm{Ne} + \mathrm{n}$ was determined:

$$SF = 0.79$$

Fig. 2 shows the effect of the calculations including the individual channels, their sum and the experimental data.

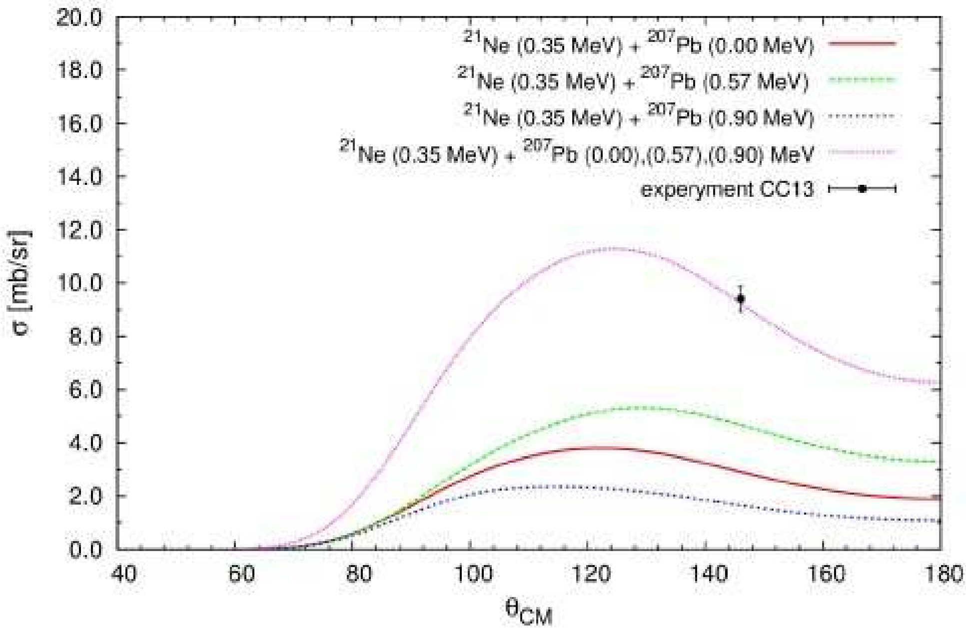

Figure 2: The cross section for the ^{208}Pb(^{20}Ne,^{21}Ne)^{207}Pb transfer. The red, green and blue curves correspond to calculations including the individual channels. The violet curve represent their sum.

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C.7 The ^{6}Li(^{18}O,^{17}O)^{7}Li reaction mechanism and the ^{7}Li+^{17}O potential

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Angular distributions of the ^{6}Li(^{18}O,^{17}O)^{7}Li reaction were measured at an ^{18}O beam energy of 114 MeV for the ground and excited states of the exit nuclei. The data were analysed within the coupled-reaction-channels method (CRC) [1].

The ^{6}Li+^{18}O elastic and inelastic scattering channels as well as the simplest one- and two-step reactions were included in the coupled-reaction-channels scheme. In the CRC calculations a ^{6}Li+^{18}O potential with parameters deduced from the elastic scattering data measured (simultaneously) with the reaction, was used for the entrance channel.

The spectroscopic amplitudes of nucleons and clusters were calculated within the translational-invariant shell model (TIMO). The ^{7}Li+^{17}O potential parameters were deduced by fitting the ^{6}Li(^{18}O,^{17}O)^{7}Li reaction data. It was found that n-transfer dominates in this reaction (Fig. 1).

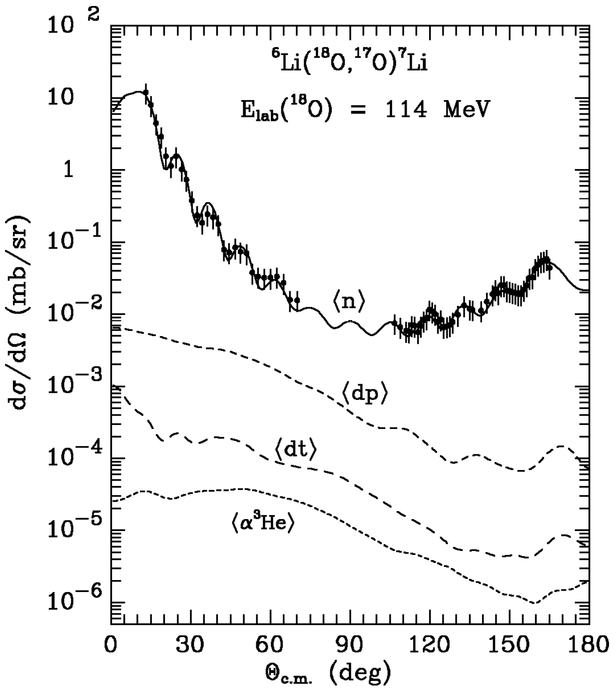

Figure 1: Differential cross-section of the ^{6}Li(^{18}O,^{17}O)^{7}Li reaction at $E_{lab}(^{18}O)$ = 114 MeV. Curves show CRC calculations for transfers of n, d+p, d+t and α+^{3}He, as marked on the plot.

Isotopic differences of the ^{7}Li+^{17}O, ^{7}Li+^{18}O and ^{7}Li+^{16}O potentials were studied, see

Fig. 2.

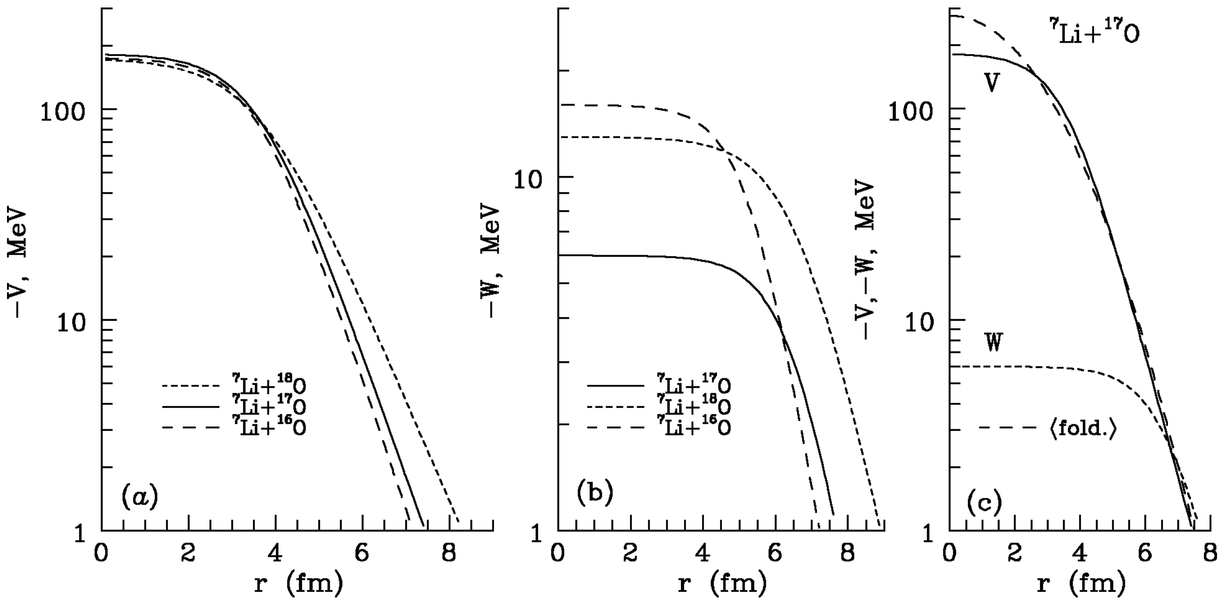

Figure 2: Comparison of the ^{7}Li + ^{16,17,18}O potentials (a, b) as well as the ^{7}Li + ^{17}O potential calculated with the double-folding method (c).

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C.8 Elastic and inelastic scattering of ^{11}B ions by ^{14}C at 45 MeV

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New experimental data for differential cross-sections of ^{14}C(^{11}B,^{11}B)^{14}C inelastic scattering at the energy E_{lab}(^{11}B)=45 MeV were measured for transitions of the ^{11}B nucleus to the excited states at 2.12–8.56 MeV [1].

The experimental data were analysed within the optical model (OM) and coupled-reaction channels (CRC) method. Elastic and inelastic scattering, reorientation of ^{11}B spin and the simplest transfers of nucleons and clusters were included in the coupling scheme. Woods-Saxon optical model parameters for the ^{14}C+^{11}B interaction and deformation parameters of ^{11}B were deduced. Contributions of one- and two-step transfer reactions to the elastic and inelastic channels of ^{14}C+^{11}B scattering were obtained (Fig. 1).

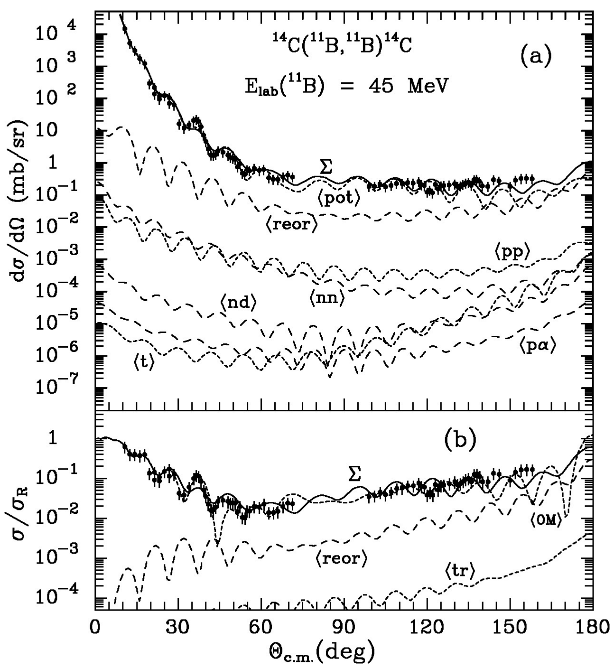

Figure 1: Differential cross-sections of the ^{14}C+^{11}B elastic scattering at E_{lab}(^{11}B)=45 MeV. Curves show the CRC-calculations for potential scattering (pot), ^{11}B reorientation (reor) and transfer of nucleons and clusters x+y (x, xy, tr).

It was found that the low-energy excited states of ^{11}B have a collective nature (Fig. 2). In Fig 3, the ^{14}C+^{11}B optical potential is compared with the corresponding double-folding potential.

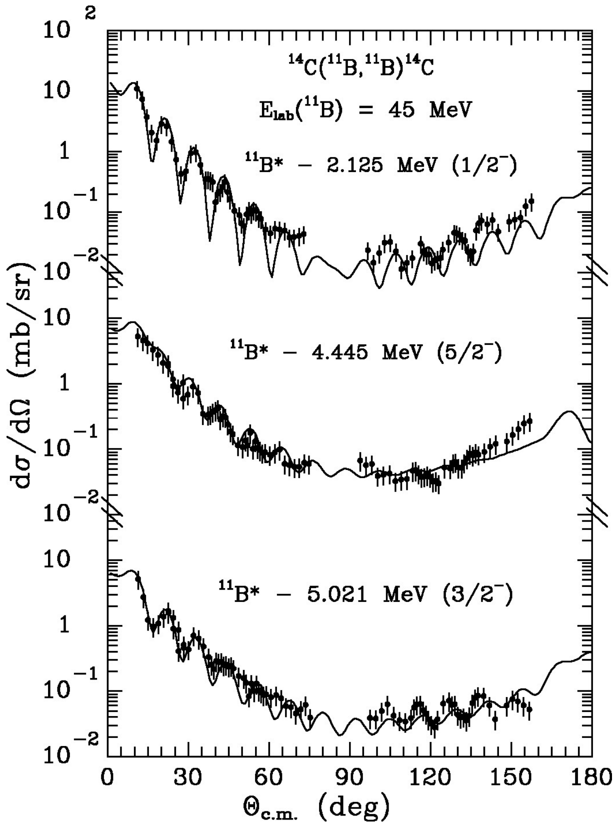

Figure 2: Differential cross-sections of the ^{14}C+^{11}B inelastic scattering atE_{lab}(^{11}B)=45 MeV. Curves show the CRC-calculations for transition to the ^{11}B exited states of collective nature.

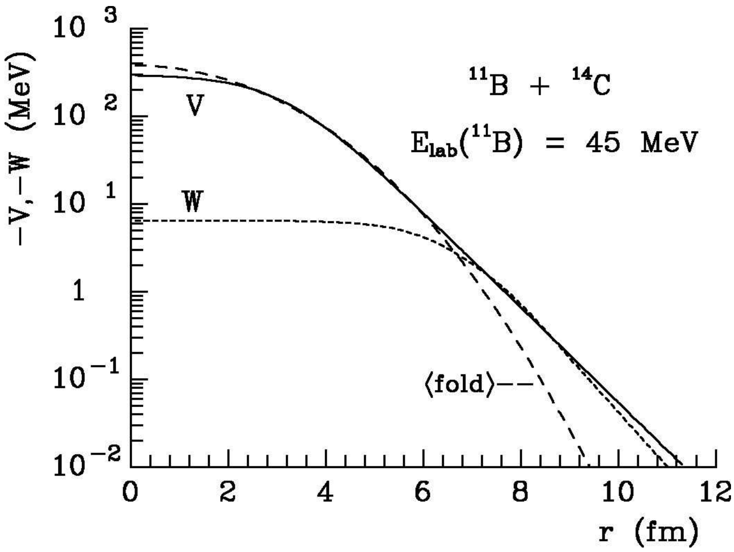

Figure 3: Comparison of the ^{14}C+^{11}B optical potential with the double-folded potential.

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C.9 Single diamonds and diamond polycristal layers obtained by the MWCVD process

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Using the MWCVD reactor [1,2] with optical stabilisation of target temperature [3] we have obtained diamonds grown on high resistivity ($1500\ \Omega\cdot$cm $< \rho < 5000\ \Omega\cdot$cm), n-type, 7 mm diameter, 300 μm thick silicon wafers. The diamonds were created at a temperature of about 650 °C, pressure 70 Th and a concentration of butane/H_2 of about 2%. During 8 days process performed on polished silicon surface separate single diamond crystals of diameter about 0.2 mm were grown (Figure 1). For diamond detector purposes the diamond polycrystal layers were created by performing the MWCVD process on a lapped silicon surface (Figure 2).

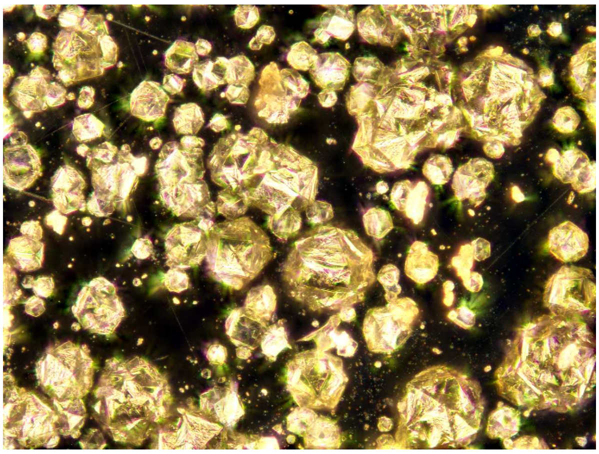

Figure 1: Diamond single crystals grown on a polished silicon surface.

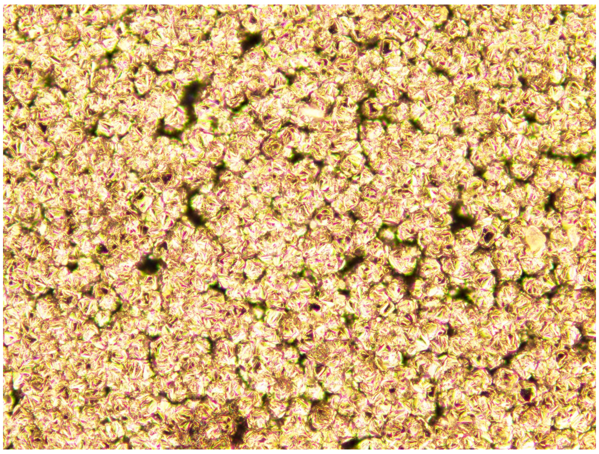

Figure 2: Diamond polycrystal layer grown on a lapped silicon surface.

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C.10 New technology for thin silicon ion implanted epitaxial detectors

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The technology of thin silicon epitaxial ion implanted detectors is illustrated by Fig. 1. We started with a silicon epitaxial structure n^+- n, of resistivity and thickness of the epitaxial layer of about 900 Ω·cm and 21 μm, respectively, grown on a thick (400 μm), low resistivity (0.01 Ω·cm) substrate (upper part of the figure). The substrate of the n^+- n structure was removed by anodic dissolution [1] (middle part of the figure). The external part of the substrate close to the wafer edge supports mechanically the thin silicon epitaxial membrane. The top of the etched silicon n^+- n epitaxial structure was collimated by an Al mask (see the lower part of the figure) in order to select the region of the epitaxial layer for 50 keV B^+ ion implantation with the dose $5 \cdot 10^{14}$ ions/cm^2. After implantation was finished, Al metalisation through the Al mask was performed. The 50 keV B^+ ions implanted in the silicon epitaxial layer produce p^+- n junctions and the evaporated Al creates an electric contact to the p^+ implanted layer face of the detector. The back detector contact was made by Al evaporation to the back side of the wafer. To activate the detector p^+- n junction, the wafer was baked for a long time. In this way a detector with an active area 20×20 mm^2 was used to build E-ΔE telescope with a 500 μm thick silicon E detector. Preliminary tests of this telescope were conducted at LNS cyclotron in Catania (Italy) using the products of the heavy ion reaction ^{84}Kr (E=35 MeV/A) + ^{112}Sn.The E-ΔE scatter plot of measured results is presented in Fig. 2 and the charge distribution of the measured ions is shown in Fig. 3 . Additional tests of the thin detector (measurement of thickness distribution using 11.2 MeV α particles from ^{252}Cf, C-V measurements and current-voltage characteristics) are in preparation.

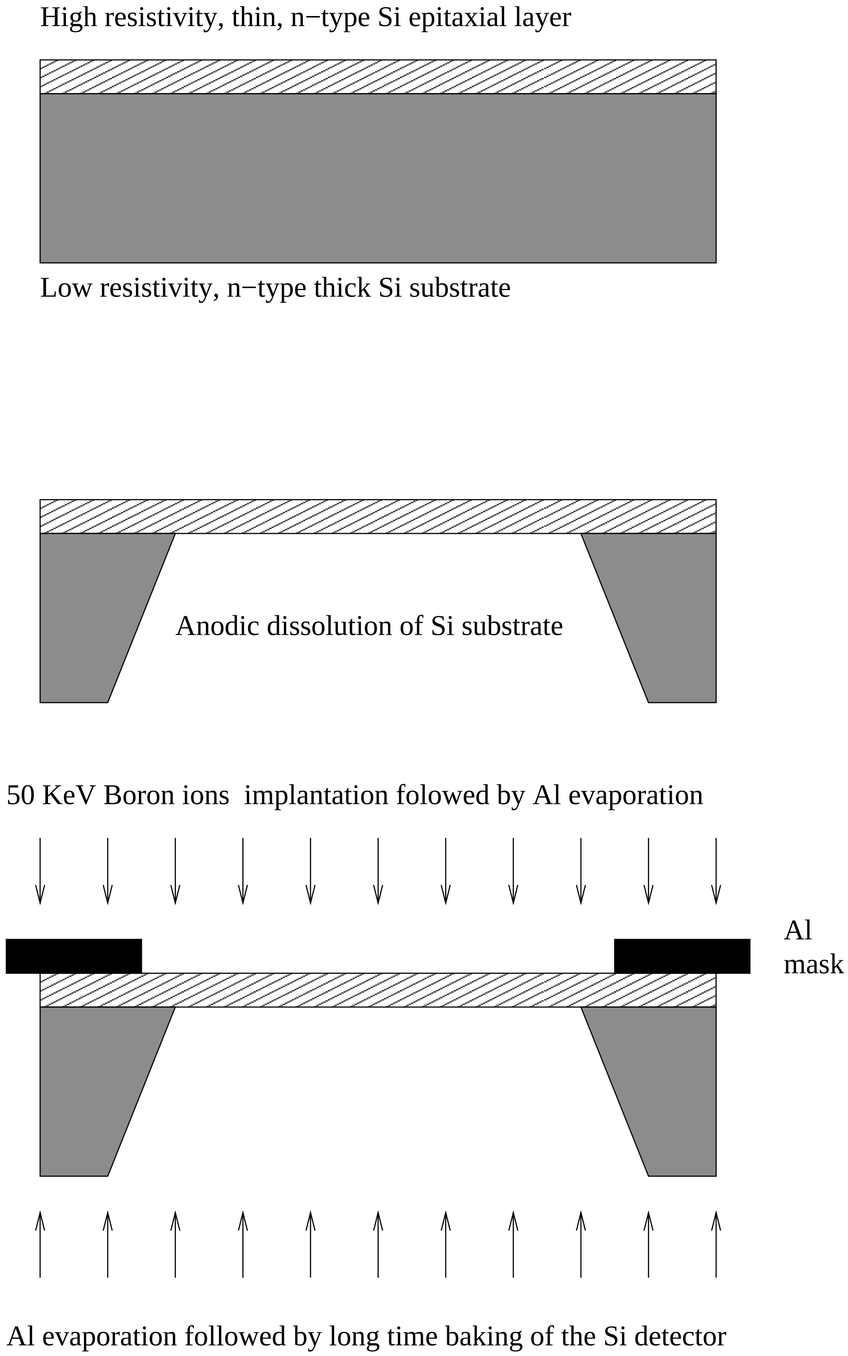

Figure 1: Technology of thin silicon detectors. We use n^+- n silicon structure (upper part of figure). The low-resistivity n^+ substrate was removed by anodic dissolution (central part of figure) then 50 keV B^+ ion implantation followed by Al metalisation was performed through Al mask on the n-type epitaxial 21 μm silicon membrane. After Al metalisation of back side the wafer was baked during long time.

The essence of the new technology is the application of the low temperature baking process for post-implantation thermal treatment instead of the high temperature annealing process used elsewhere.The new technology gives the possibility of applying the baking process after evaporation of metal contacts on both sides of the detector. An

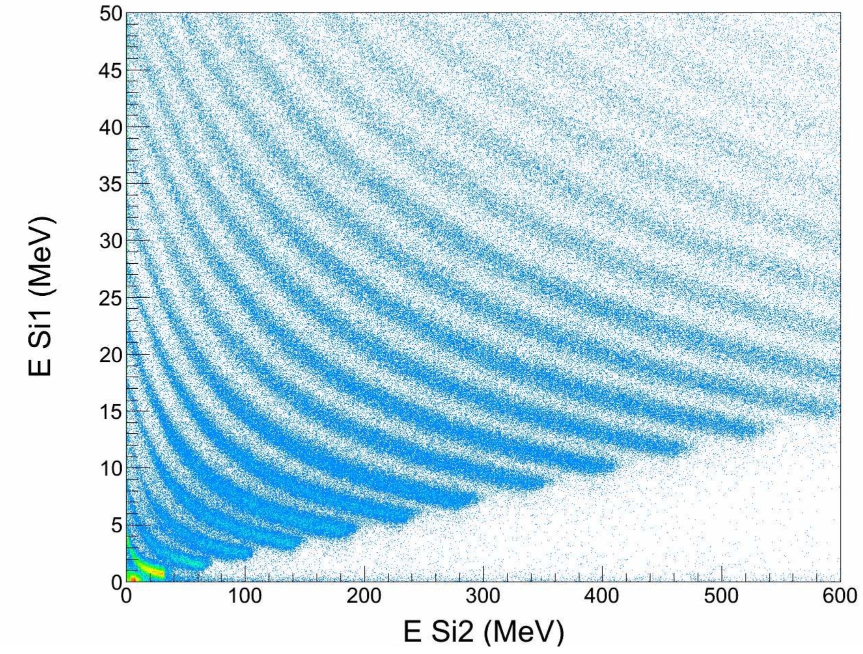

Figure 2: E−ΔE scatter plot obtained using the E−ΔE telescope consisting of 21 μm ΔE detectors with an active area of 20 * 20 mm^2 and a 500 μm E detector.

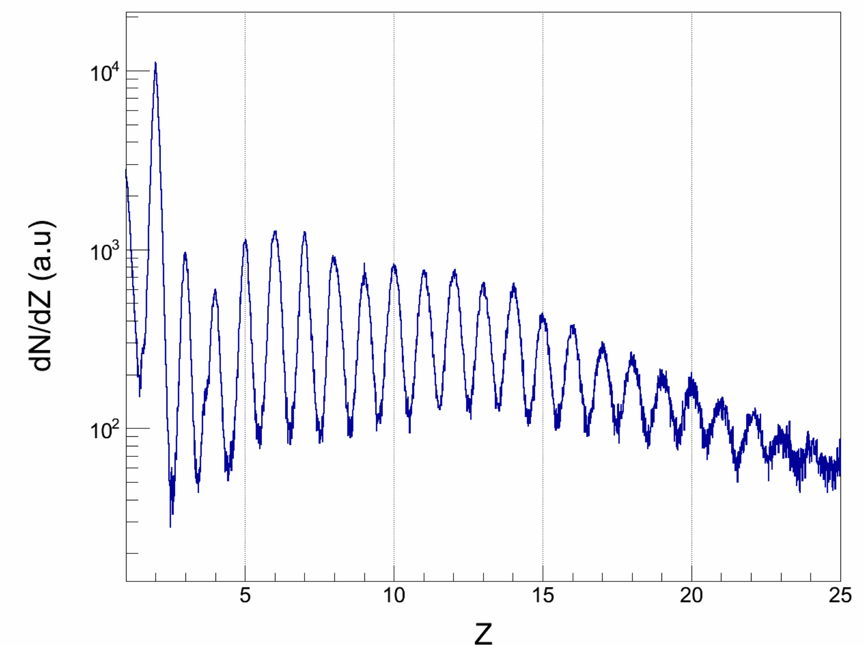

Figure 3: Charge distribution distribution of ions detected by the $E - \Delta$E telescope.

additional achievement of the technology is the possibility to use a common Al mask for ion implantation and Al evaporation on the detector face side.

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Part D

Experiments using external facilities

D.1 Preliminary results from the ^{42}Ca Coulomb excitation experiment

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In order to resolve the existing ambiguities concerning the magnitude of the deformation of the side rotational band in ^{42}Ca, a Coulomb excitation measurement has been performed to measure the B(E2) values [1]. The experiment took place in 2010 at the Laboratori Nazionali di Legnaro. The γ-ray spectrometer AGATA Demonstrator [2] coupled to the charged particle detection set-up DANTE [3] was used for the first time during the experiment.

Doppler correction was performed based on the information of particle scattering angle provided by MCP detectors. In addition to the γ lines coming from known low energy states in ^{42}Ca, γ rays depopulating the Coulomb excited states of lead target nuclei are visible. These lines were significantly broadened since the Doppler correction was performed for the ^{42}Ca scattered projectile.

Transitions deexciting the highly deformed side band were observed, as well as γ rays from the decay of low-lying states in the yrast band. It was possible to detect Coulomb excited levels up to 4^+ in both the ground state and the highly deformed band (Figure 1).

The least squares fitting code GOSIA [4] was used to determine E2 reduced matrix elements in ^{42}Ca from the Coulomb excitation experiment performed in LNL.

Based on the obtained set of E2 matrix elements and using the Quadrupole Sum Rules method [5] the overall deformation parameters of 0^+_1, 2^+_1, 4^+_1 (ground state band) and 0^+_2, 2^+_2 (side band) in ^{42}Ca were extracted for the first time [6]. The calculated $\sqrt{\langle\beta^2\rangle}$ quadrupole deformation parameter values are shown in Figure 2.

The relatively large $\sqrt{\langle\beta^2\rangle}$ values determined for the 2^+_2 and 0^+_2 states at 2424 keV and 1837 keV, respectively, strongly support a highly deformed character of the side rotational band. Our results also indicate a non-spherical shape of the ground state.

Preliminary results of the COULEX analysis provided information on the electromagnetic properties of the states in the side deformed band in ^{42}Ca by determination of the B(E2) values. Recent results were presented at the Zakopane Conference on Nuclear Physics, 2012 and at the Second European Nuclear Physics Conference (EuNPC 2012) held in Bucharest, Romania.

Improved Pulse Shape Analysis and tracking algorithms allow to the final data reconstruction to be performed. An analysis aimed at reducing the uncertainties of recent results is in progress.

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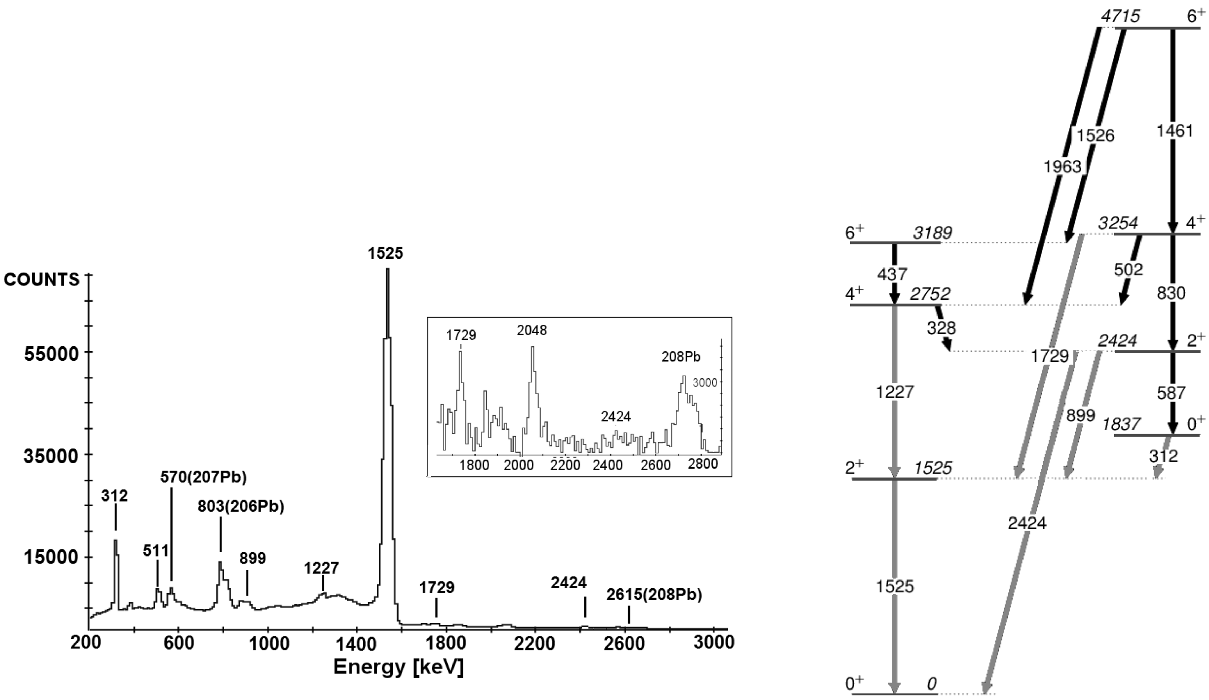

Figure 1: Left panel: a Doppler-corrected γ-ray spectrum observed in the ^{42}Ca + ^{208}Pb Coulomb excitation experiment. Right panel: The scheme of excited states in ^{42}Ca. Transitions observed in the current Coulomb excitation experiment are marked in grey.

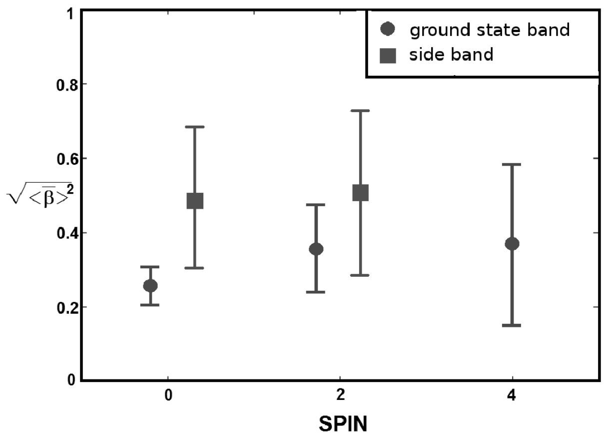

Figure 2: Preliminary values of the overall quadrupole deformation parameters $\sqrt{\langle\beta^2\rangle}$ calculated for 0^+, 2^+ states in both ground state and side bands, as well as that of the 4_1^+ state in ^{42}Ca.

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D.2 Electric dipole polarisability of ^{11}Li

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We have analysed ^{11}Li + ^{208}Pb elastic scattering data at a beam energy of 29.8 MeV, recently measured at the TRIUMF facility [1], using the Continuum Discretized Coupled Channels (CDCC) method assuming a di-neutron model of the projectile. The ^{11}Li nucleus is known to be weakly bound, with a threshold against ^{9}Li + 2n breakup of only 370 keV.

The dynamic polarisation potential representing the effects of real and virtual processes taking place during the scattering was derived from the calculation. Both its parts, real and imaginary, were found to have very long tails. The attractive tail of the real part could be attributed to the Coulomb couplings with the dipole states in the ^{9}Li + 2n continuum. Thus, it should be well described by a classical dipole correction to the potential energy,

$$\Delta V = -\frac{1}{2}\alpha\frac{Z^2e^2}{R^4} \tag{1}$$

where Z is the charge number of the target nucleus, R is the distance between the projectile and the target and the constant α is the electric dipole polarisability of ^{11}Li.

The solid curve plotted in Fig. 1 represents the real part of the dynamic polarisation potential derived from the CDCC calculations. At separations larger than 40 fm it could be well reproduced by the potential calculated using Eq. 1, with α = 5.7 fm^3 (dashed curve) predicted by theory [2].

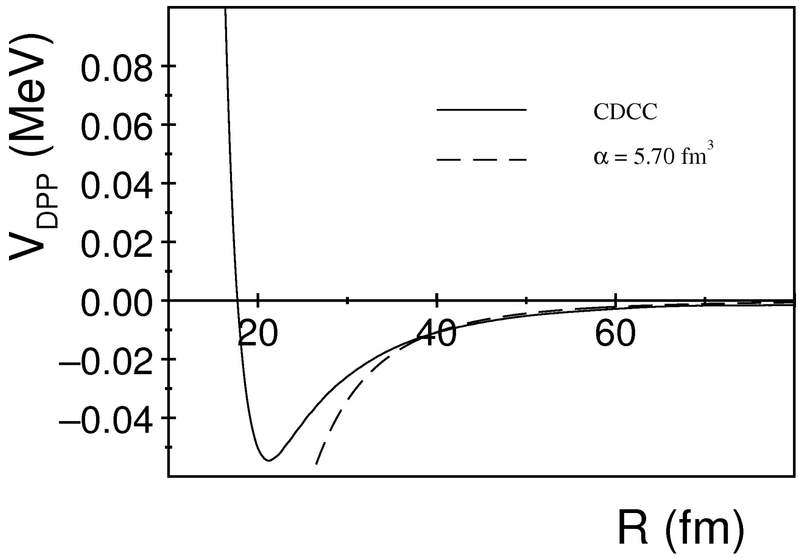

Figure 1: Real part of the dynamic polarisation potential for ^{11}Li+^{208}Pb derived from the CDCC calculation (solid curve) compared to that calculated using Eq. 1.

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D.3 Odd parity excitations of the N=Z=50 core

M. Palacz[1] *for the Neutron Wall — EUROBALL collaboration*

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

Nuclei situated in the nuclidic chart close to the heaviest self-conjugate doubly-magic nucleus ^{100}Sn give opportunities to evaluate phenomena which cannot be observed in other regions, like enhanced interactions of protons and neutrons situated in identical shell model orbits. In spite of much experimental and theoretical effort, a number of issues in the region remains unresolved — see Ref. [1] for a recent review.

One of the key points and questions in the region is the role of the excitations of the N=Z=50 core. Such excitations have been extensively studied in several close Z<50 neighbours of ^{100}Sn: ^{101}In [3], ^{102}In [4, 5], ^{98}Cd [6, 7], ^{99}Cd [3], ^{96}Ag [2] and ^{97}Ag [8]. The core excited states in these nuclei are in general successfully interpreted in the Shell Model space consisting of only even parity orbitals, with proton (and neutron) valence holes located in the $g_{9/2}$ orbital and particle-hole excitations across the N=Z=50 gap to the $g_{7/2}$, $d_{5/2}$, $d_{3/2}$, $s_{1/2}$ orbitals. Odd-parity orbitals have so far seemed unnecessary for the description of such core excitations, as negative parity core-excited states were not experimentally observed in any of the above mentioned nuclei.

Analysis of data collected in an experiment performed at the Institute de Recherches Subatomiques in Strasbourg, France, lead to establishing new extended level schemes of the ^{97}Ag and ^{96}Pd nuclei, which correspond to systems consisting of the N=Z=50 core and three or four proton-holes, respectively — see Fig. 1. The EUROBALL γ-ray detector array together with the Neutron Wall and EULICDES were employed in the experiment. Some of the newly observed excited states have been assigned odd-parity, namely the isomeric state at 8384 keV in ^{96}Pd, as well as states at 6306 and 6418 keV in ^{97}Ag. These states were interpreted as odd-parity N=Z=50 core excitations. Shell Model calculations indicated that the corresponding wave functions are dominated by components with one $g_{9/2}$ neutron excitation across the $N = 50$ gap to the $d_{5/2}$ and $g_{7/2}$ orbitals, coupled to odd-parity valence configurations. It was also noted that a precise quantitative description of the odd-parity states requires a more complete model than the one available at present, with larger model space, improved interactions, which are consistent for odd- and even-parity orbitals, and multiple particle-hole excitations allowed. See Refs. [9, 10] for details of the experiment, data evaluation, description of the Shell Model calculations and an extensive discussion.

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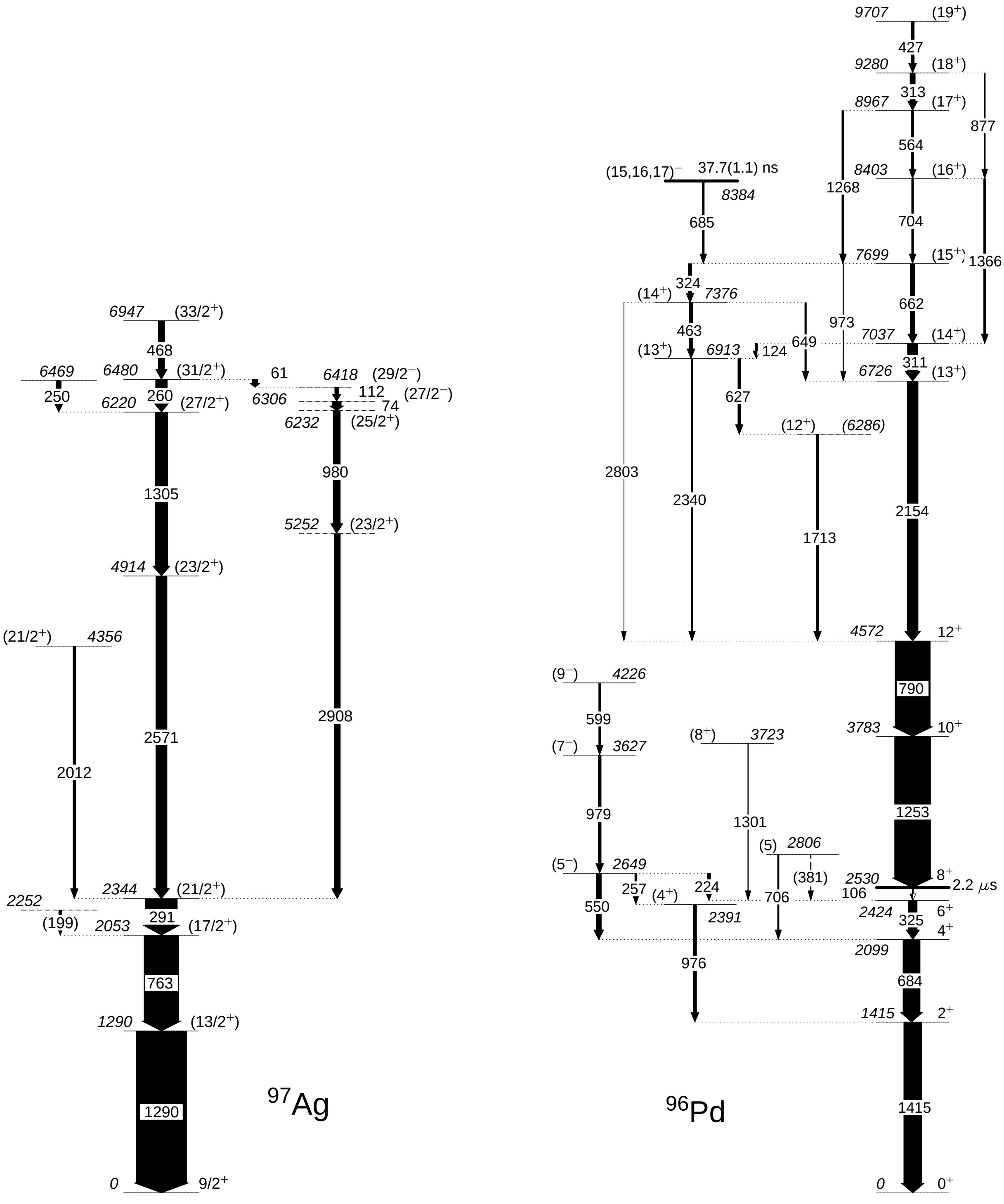

Figure 1: Level schemes of ^{97}Ag (left) and ^{96}Pd (right).

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D.4 Status of the NEDA project

G. Jaworski[1,2,3], M. Palacz[2], J. Agramunt Ros[4], G. de Angelis[3], G. de France[5], A. Di Nitto[6,7], J. Egea[8,5], M.N. Erduran[9], S. Ertürk[10], E. Farnea[11], A. Gadea[5], V. González[8], A. Gottardo[3], T. Hüyük[4], M. Jastrząb[12], J. Kownacki[2], J. Nyberg[13], E. Sanchis[7], P.-A. Söderström[14,13], R. Tarnowski[2], A. Triossi[3], J.J. Valiente Dobon[3], R. Wadsworth[15]

1) Faculty of Physics, Warsaw University of Technology, Warszawa, Poland
2) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
3) INFN, Laboratori Nationali di Legnaro, Legnaro, Italy
4) Instituto de Física Corpuscular, Valencia, Spain
5) GANIL, Caen, France
6) Johannes Gutenberg-Universität Mainz, Mainz, Germany
7) INFN Sezione di Napoli, Napoli, Italy
8) Department of Electronic Engineering, University of Valencia, Burjassot (Valencia), Spain
9) Fac. of Engineering and Natural Sciences, Istanbul Sabahattin Zaim Univ. Istanbul, Turkey
10) Nigde Universitesi, Fen-Edebiyat Falkültesi, Fizik Bölümü, Nigde, Turkey
11) Padova University, Padua, Italy
12) The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
13) Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
14) RIKEN Nishina Center, Wako-shi, Japan
15) Department of Physics, University of York, York, UK

The NEutron Detector Array (NEDA) (see earlier HIL Annual reports [1, 2] and Ref. [3]) will be a new aggregate of neutron detectors, designed to operate at stable and radioactive beam facilities, in conjunction with the most advanced γ-ray detection arrays like AGATA [4], EXOGAM2 [5], GALILEO [6] or PARIS [7]. Compared to existing neutron detection systems (the Neutron Wall [8, 9] and the Neutron Shell [10]) NEDA will have higher efficiency, especially for the detection of multiple neutrons, when special measures are required to distinguish events in which real 2, 3 or 4 neutrons were registered from events in which a single neutron interacted in more than one detector. A prerequisite to achieve this goal is an excellent discrimination between neutrons and γ rays detected in the array. The processing of signals from the NEDA detectors will be realised in a fully digital manner, using a version of the NUMEXO2 digitiser [11], which will assure compatibility with the data acquisition system of the γ-ray detectors.

NEDA will be a perfect tool to study exotic neutron-deficient and neutron-rich nuclei. It will demonstrate its full capabilities when a complete array is built, covering 2 Π of the solid angle around the target. It is, however, foreseen to construct NEDA in steps. At first, NEDA will complement detectors of the Neutron Wall array — see Fig. 1. It is planned to use such a setup at GANIL in 2015, in connection with AGATA and the DIAMANT charged particle detector [12].

In 2012 activities of the NEDA collaboration concentrated on: an evaluation of the properties of the photomultipliers available in the market and foreseen for NEDA, development of algorithms for the digital determination of signal arrival times, design of prototype detectors, tests of the digitisers, experimental verifications of the conclusions obtained in computer simulations [3] on the two types of scintillators considered, as well as simulations of NEDA performance in fusion-evaporation reactions. A series of tests of neutron detectors purchased by the NEDA collaboration were performed at the Legnaro National Laboratory, providing data to accomplish the above mentioned tasks and goals. Analysis of the data is in progress.

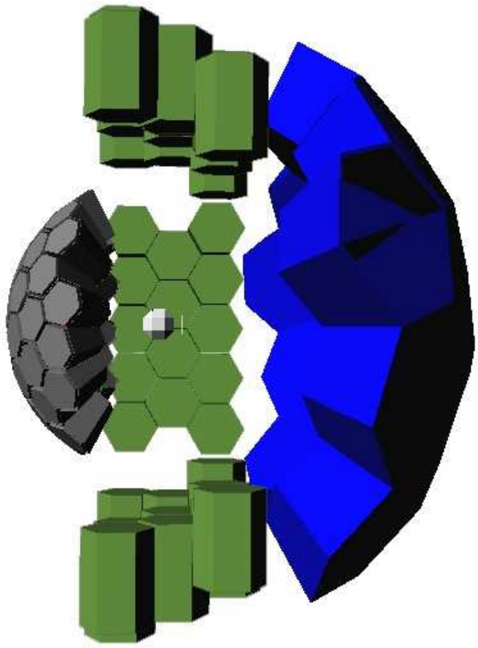

Figure 1: The setup for studying exotic neutron-deficient nuclei, consisting of a 1 Π AGATA γ spectrometer, 1 Π Neutron Wall, 1 Π NEDA and 4 Π DIAMANT charged particle detector.

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Part E

Appendices

E.1 Degrees and theses completed in 2012 or in progress

E.1.1 PhD theses of students affiliated to HIL and of HIL staff members

Jan Mierzejewski
Mechanizm niekompletnej fuzji badany z wykorzystaniem EAGLE i SiBall
Mechanism of incomplete fusion studied with EAGLE and SiBall
Supervisor: prof. dr hab. T. Matulewicz. Expected completion time: 2013.

Grzegorz Jaworski, Faculty of Physics, Warsaw University of Technology
Detekcja neutronów prędkich w badaniach egzotycznych jąder atomowych
Fast neutron detection in the investigations of the structure of exotic nuclei
Supervisor: prof. dr hab. J. Kownacki. Expected completion time: 2013.

Katarzyna Hadyńska-Klęk
Badanie struktury kolektywnej w izotopach wapnia metodą wzbudzeń kulombowskich
Studies of collective structure in calcium isotopes using the Coulomb excitation method
Supervisor: prof. dr hab. M. Kicińska-Habior. Expected completion time: 2013.

Daniel Piętak, Institute of Radioelectronics, Warsaw University of Technology
Metoda oceny jakości wyników z eksperymentów wzbudzeń kulombowskich z wykorzystaniem algorytmu genetycznego
Evaluation method based on a genetic algorithm for results of Coulomb excitation experiments
Supervisor: prof. dr hab. J. Wojciechowski. Expected completion time: 2013.

Izabela Strojek, The National Centre for Nuclear Research, Otwock, Świerk, Poland
Wpływ struktury jądra ^{20}Ne na reakcje z jego udziałem
Influence of the structure of ^{20}Ne on reactions with this nucleus
Supervisor: prof. dr hab. K. Rusek. Expected completion time: 2013.

Anna Pękal, Faculty of Chemistry, University of Warsaw
Wpływ doboru procedury analitycznej na wyznaczanie właściwości antyutleniających próbek żywności
Influence of analytical procedure on antioxidant properties of food samples
Supervisor: prof. dr hab. Krystyna Pyrzyńska. Expected completion time: 2013.

Łukasz Standyło, The National Centre for Nuclear Research, Otwock, Świerk, Poland
Badanie oddziaływania ^{6}He z jądrami ^{206}Pb przy energiach blisko bariery kulombowskiej
Study of the interaction of ^{6}He with ^{206}Pb nuclei at energies close to the Coulomb barrier
Supervisor: prof. dr hab. K. Rusek. Expected completion time: 2014

Tomasz Marchlewski
Supervisor: prof. dr hab. K. Rusek. Expected completion time: 2017

E.1.2 Other PhD theses based on experiments performed at HIL

Łukasz Janiak, University of Łódź
Supervisor: prof. dr hab. J. Andrzejewski. Expected completion time: 2014.

Justyna Samorajczyk, University of Łódź
Supervisor: prof. dr hab. J. Andrzejewski. Expected completion time: 2014.

E.1.3 PhD, MSc and BSc theses supervised by HIL staff members

Urszula Kaźmierczak, Faculty of Physics, University of Warsaw
Supervisor: dr hab. Z. Szefliński. PhD thesis, expected completion time: 2014.

Ilona Głowacka, Faculty of Physics and Applied Computer Science, University of Łódź
Skuteczność biologiczna jonów węgla w zastosowaniu do terapii nowotworów
Biological effectiveness of carbon ions applied to cancer therapy
Supervisor: dr hab. Z. Szefliński. MSc thesis defended in March 2012

Jakub Pietrzak, Faculty of Physics, University of Warsaw
Rekonstrukcja obrazu w tomografii SPECT z wykorzystaniem technologii programowalnych procesorow graficznych
Image reconstruction in Single Photon Emission Computed Tomography using CUDA capable graphics cards
Supervisor: dr hab. Z. Szefliński. MSc thesis defended in September 2012

Michał Czerwiński, Faculty of Physics, University of Warsaw
Wpływ dawki lokalnej na przeżywalność kolonii komórkowych *Survival of cell lines under influence of local dose*
Supervisor: dr hab. Z. Szefliński. MSc thesis defended in June 2012

Elżbieta Gajewska-Dendek, Faculty of Physics, University of Warsaw
Symulacje Monte Carlo dawki terapeutycznej w technologii CUDA Nvidia
Monte Carlo simulations of the therapeutic dose in NVIDIA CUDA technology
Supervisor: dr hab. Z. Szefliński. MSc thesis defended in June 2012

Bartłomiej Chabecki, Faculty of Physics, University of Warsaw
Oznaczanie czystości radiochemicznej radiofarmaceutyków metodą TLC (chromatografii cienkowarstwowej)
Determination of radiochemical purity of radiopharmaceuticals using TLC (thin layer chromatography)
Supervisors: dr hab. Z. Szefliński, dr K. Kilian. BSc thesis defended on 25 July 2012

Maciej Wójcik, Faculty of Physics, University of Warsaw
Oznaczanie czystości radioizotopwej radiofarmaceutyków znakowanych ^{18}F
Determination of radionuclide purity of ^{18}F labelled radiopharmaceutical
Supervisors: dr K. Kilian, dr hab. Z. Szefliński. BSc thesis defended on 28 September 2012

Barbara Panas, Faculty of Physics, University of Warsaw
Wytwarzanie radiofarmaceutyków do Pozytonowej Tomografii Emisyjnej, znakowanych ^{18}F
Production of Radiopharmaceuticals Positron Emission Tomography Labelled ^{18}F
Supervisors: dr K. Kilian, dr hab. Z. Szefliński. BSc thesis defended on 28 September 2012

Agnieszka Kunka, Faculty of Physics, University of Warsaw
Oznaczanie czystości radiofarmaceutyków metodą chromatografii gazowej
Determination of purity of radiopharmaceuticals using gas chromatography
Supervisors: dr K. Kilian, dr hab. Z. Szefliński. BSc thesis defended on 25 September 2012

Marta Wardzińska, Faculty of Physics, University of Warsaw
Osłabienie wiązki fotonów o energii 662 keV w fantomie wodnym
The attenuation of the photon beam with an energy of 662 keV in a water phantom
Supervisor: dr hab. Z. Szefliński. BSc thesis defended in June 2012

Piotr Warzybok, Faculty of Physics, University of Warsaw
Konstrukcja fantomu wodnego i pomiary rozkładu dawki na źródle kobaltowym
Water phantom and dose distribution on ^{60}Co source
Supervisor: dr hab. Z. Szefliński. BSc thesis defended in June 2012

Maria Pręgier, Faculty of Chemistry, University of Warsaw
Badanie i optymalizacja reakcji kompleksowania jonów Ga porfirynami do zastosowań w technikach obrazowania medycznego
Optimization of Ga complexation reaction with porphyrins for applications in molecular imaging
Supervisor: prof dr hab. K. Pyrzyńska, associate supervisor: dr K. Kilian.
MSc thesis, expected completion time: June 2013

Michalina Komorowska, Faculty of Physics, University of Warsaw
Eksperymentalne wyznaczanie względnych przekrojów czynnych reakcji $^{122}Sn(^{20}Ne,xnypz\alpha)$ z wykorzystaniem spektrometru EAGLE
Experimental determination of the relative cross sections in reaction $^{122}Sn(^{20}Ne,xnypz\alpha)$ using EAGLE array
Supervisors: prof. dr hab. M. Kicińska-Habior, dr J. Srebrny.
Expected completion time: 2013

E.1.4 Other BSc and MSc theses based on experiments performed at HIL

Tomasz Marchlewski, Faculty of Physics, University of Warsaw
Pomiar koincydencji γ-γjako metoda badań poziomów wzbudzonych jądra atomowego
Study of γ-γ coincidences as a method to investigate nuclear excited states
Supervisor: dr Ernest Grodner. MSc thesis defended in September 2012

Alicia Ariza, University of Huelva, Huelva, Spain
Estudio de las reacciones directas y fusión-evaporación en la dispersión de ^{20}Ne + ^{12}C
Study of direct and fusion-evaporation reactions in the scattering of ^{20}Ne on ^{12}C
Supervisor: dr Ismael Martel. MSc thesis defended in December 2012

Justyna Chudyka, Faculty of Mathematics, Physics and Chemistry, University of Silesia
Analiza możliwości wytwarzania źródeł promieniotwórczych dla celów medycznych przy pomocy cyklotronu U200-P
Analysis of the possibility to produce radioactive sources for medical applications using the U200-P cyclotron
Superisor: prof. dr hab. W. Zipper. MSc thesis defended in 2012

Katarzyna Tworek, Faculty of Mathematics, Physics and Chemistry, University of Silesia
Wyznaczanie prądu wiązki cząstek alfa przyspieszanych w cyklotronie warszawskim podczas produkcji radioizotopu ^{211}At
Determination of the beam current of αparticles in Warsaw cyclotron during the ^{211}At production
Superisor: prof. dr hab. W. Zipper. MSc thesis defended in 2012

E.2 Seminars

E.2.1 Seminars co-organised by HIL

Nuclear Physics Seminars

Seminars organised jointly by the divisions of Nuclear Physics, Nuclear Spectroscopy and Nuclear Structure Theory of the Faculty of Physics, University of Warsaw, and the Heavy Ion Laboratory, University of Warsaw

H.O.U. Fynbo — Dep. of Phys. and Astr., Aarhus U., Denmark 12 January 2012
Cluster structure and 3α-decay of ^{12}C studied by β-decay and γ-decay

J. Bartke — Instytut Fizyki Jądrowej PAN, Kraków 19 January 2012
Maria Skłodowska-Curie w filatelistyce, numizmatyce i medalierstwie
Maria Skłodowska-Curie in philately, numismatics and art medals

G. Wrochna — NCNR, Świerk, Poland 16 February 2012
Narodowe Centrum Badan Jadrowych — powstanie i plany rozwoju
National Centre for Nuclear Research — the creation and development plans

R. Kotte — FZ Rossendorf, Germany 22 February 2012
Strangeness and Femtoscopy Results with HADES

I. Martel — University of Huelva, Hiszpania 01 March 2012
The Linac Research Facility at the University of Huelva (Spain)

C. Simenel — CEA, Saclay, Francja 08 March 2012
Descriptions of multi-nucleon transfer reactions with quantum microscopic approaches

H. Białkowska — NCNR, Świerk, Poland 15 March 2012
Zderzenie jąder ołowiu w akceleratorze LHC
Collision of led nuclei in the LHC accelerator

J. Dobaczewski — Inst. of Theoretical Physics, Univ. of Warsaw 22 March 2012
Rotational and vibrational states in heavy nuclei described within the energy density functional methods

L. Próchniak — UMCS, Lublin, Poland 29 March 2012
Kolektywne stany kwadrupolowe w teorii średniego pola
Collective quadrupole states in the mean field theory

M. Palacz — HIL 12 April 2012
Wzbudzenia rdzenia N=Z=50 badane w jądrze ^{96}Pd
Excitations of the N=Z=50 core studied in ^{96}Pd

P. Bednarczyk — Institute of Nuclear Research, Kraków, Poland 19 April 2012
Badania eksperymentalne kolektywnej struktury nuklidów z pobliża jąder magicznych ^{40}Ca and ^{56}Ni
Experimental investigations of the collective structure of nuclei in the vicinity of ^{40}Ca and ^{56}Ni

K. Czerski — University of Szczecin, Szczecin, Poland 26 April 2012
Reakcje jądrowe przy ekstremalnie niskich energiach — czy zimna fuzja jądrowa jest możliwa?
Nuclear reactions at extremely low energies — is the cold fusion possible?

Z. Janas — Inst. of Experimnental Physics, Univ. of Warsaw 10 May 2012
Wpływ warunków zewnętrznych na czas życia jąder ^{7}Be
Influence of the external conditions on the life-time of ^{7}Be

A. Trzcińska — HIL 24 May 2012
Co determinuje kształt rozkładu barier na fuzję?
The shape of the fusion barriers — what it depends on?

G. Odyniec — Lawrence Berkeley National Lab., Berkeley, USA 31 May 2012
Search for the Critical Point of the Nuclear Matter Phase Diagram. First results from the Beam Energy Scan Program at RHIC*

P. Moskal — Physics Dep., Jagiellonian U., Kraków, Poland 4 October 2012
Badanie symetrii dyskretnych w rozpadach mezonów za pomocą detektorów WASA oraz KLOE
Study discrete symnmetries in mezon decays by ATLAS and CMS experiments

M. Ostrowski — Astr. Obs., Jagiellonian U., Kraków, Poland 11 October 2012
Wszechświat w TeV'owym promieniowaniu gamma
The Universe in the TeV γ-ray radiation

A. Kalinowski — Inst. of Experimnental Physics, Univ. of Warsaw 18 October 2012
Obserwacja kandydata na bozon Higgsa przez eksperymenty ATLAS i CMS
Higgs candidate observation by the ATLAS and CMS experiments

K. Siegień-Iwaniuk — NCNR, Świerk, Poland 25 October 2012
Prawdopodobieństwo jonizacji ^{6}He^{+} w rozpadzie β^{-}
^{6}He jonization probability

T. Lesiński — Inst. of Theoretical Physics, Univ. of Warsaw 8 November 2012
Less-empirical nuclear density functional theory

K. Wiśniewski — Inst. of Experimnental Physics, Univ. of Warsaw 15 November 2012
Klasteryzacja cząstek dziwnych w gęstej materii jądrowej
Clasterisation of strange particles in dense nuclear matter

K. Grzelak — Inst. of Experimnental Physics, Univ. of Warsaw 22 November 2012
Oscylacje neutrin – najnowsze wyniki
Neutrino oscilations — the newest results

D. Tarpanov — Inst. of Theoretical Physics, Univ. of Warsaw 29 November 2012
Effect of polarization corrections on single-particle energies

Ł. Świderski — NCNR, Świerk, Poland 6 December 2012
Scyntylatory do detekcji neutronów
Neutron detection scintillators

E.2.2 External seminars given by the HIL staff

J. Kownacki 10 January 2012
OSIRIS-II activity at HIL
EAGLE 2012 Workshop, HIL, Warszawa, Poland

P. Napiorkowski 10 January 2012
Is the ^{208}Pb nucleus an ideal target for Coulomb excitation measurements? — A study of subbarrier neutron transfer reaction with ^{40}Ca beam
EAGLE 2012 workshop, HIL, Warszawa, Poland

L. Próchniak 11 January 2012
EAGLE experiments — testing nuclear structure theories
EAGLE 2012 workshop, HIL, Warszawa, Poland

P.J. Napiorkowski 22 February 2012
HIL for GANAS
GANAS Kick-off Meeting, Bormio, Italy

G. Jaworski 22–25 February 2012
How to build neutron multiplicity filter NEDA — simulations and experimental tests
1st Topical Workshop on Modern Aspects in Nuclear Structure, Bormio, Italy

P.J. Napiorkowski 5–7 March 2012
Nuclear Microscope at the Heavy Ion Laboratory — invited talk
Frontiers in Gamma Spectroscopy conference, New Delhi, India

L. Próchniak 29 March 2012
Dublety pasm rotacyjnych w jądrach nieparzysto-nieparzystych
Dublets of rotational bands in odd-odd nuclei
Maria Skłodowska-Curie University, Lublin, Poland

K. Rusek 26–29 March 2012
Scattering of ^{8}He on ^{208}Pb at energies around the Coulomb barrier
DREB 2012 Conference, Pisa, Italy

K. Rusek 19 April 2012
Fizyka Jądrowa i jej medyczne zastosowania
Nuclear Physics and its medical applications
National Centre for Nuclear Research, Świerk, Poland

J. Jastrzębski 15 May 2012
Historia Budowy "Radiopharmeceuticals Production and Research Centre"
The history of the construction of the Radiopharmeceuticals Production and Research Centre
Radiopharmeceuticals Production and Research Centre Openning Ceremony, HIL, Warszawa, Poland

J. Choiński 16–19 May 2012
Recently opened "Radipharmaceuticals Production and Research Centre" at HIL UW
PETRAD2012 Conference, HIL, Warszawa, Poland

J. Choiński 16–19 May 2012
Radiopharmaceuticals Production and Research Center at HIL UW — invited talk
PETRAD2012 Conference, HIL, Warszawa, Poland

J. Choiński 25 May 2012
Środowiskowe Laboratorium Ciężkich Jonów Uniwersytetu Warszawskiego jako przykład laboratorium typu "users facility"
Heavy Ion Laboratory of the University of Warsaw as an example of a "users facility"
Maria Skłodowska-Curie University, Lublin, Poland

M. Palacz 4–6 June 2012
NEDA (Neutron Detector Array)
COPIGAL Workshop, Kraków, Poland

E. Piasecki 4–6 June 2012
Barrier Height Distribution Studies at HIL
COPIGAL Workshop, Kraków, Poland

K. Rusek 4–6 June 2012
Structure of exotic halo nuclei
COPIGAL Workshop, Kraków, Poland

K. Rusek 18–21 June 2012
Nuclear Physics and its medical applications at the Polish National Cyclotron Laboratory (Warsaw/Cracow) — invited talk
ENSAR ECOS Workshop, Menaggio, Italy

K. Hadyńska-Klęk 25–28 June 2012
Coulomb excitation of the presumably superdeformed band in ^{42}Ca
EGAN 2012 Workshop, Orsay, France

A. Stolarz 25–28 June 2012
Targets for nuclear spectroscopy studies and not only — invited talk
EGAN 2012 Workshop, Orsay, France

J. Mierzejewski 25–28 June 2012
4π silicon ball — ΔE detectors for channel selection and full energy spectrum determination
EGAN 2012 Workshop, Orsay, France

G. Jaworski 28 June 2012
Neutron multiplicity filter NEDA – properties of BC501A and BC537 scintillators
EGAN 2012 Workshop, Ancillary Detectors Group Meeting, Orsay, France

G. Jaworski 28 June 2012
On the edge of neutron detection – innovative NEDA tests
EGAN 2012 Workshop, Ancillary Detectors Group Meeting, Orsay, France

G. Jaworski 28 June 2012
RFD simulations
EGAN 2012 Workshop, Simulations Group Meeting, Orsay, France

G. Jaworski 28 June 2012
NEDA simulations
EGAN 2012 Workshop, Simulations Group Meeting, Orsay, France

G. Jaworski 17–18 August 2012
NEDA – the future European neutron detector array
Low Energy Community Meeting, Argonne, National Laboratory, Argone, USA

A. Stolarz 19–24 August 2012
Targets for accelerator-based research — invited talk
INTDS Conference, Mainz, Germany

A. Stolarz 19–24 August 2012
Fine plastic foil as backing for sputtered nickel targets
INTDS Conference, Mainz, Germany

K. Hadyńska-Klęk 27 August – 2 September 2012
Study of the ^{42}Ca nuclear structure using AGATA and EAGLE spectrometers
Zakopane Conference on Nuclear Physics, Zakopane, Poland

M. Palacz 27 August – 2 September 2012
Odd-parity excitations of the N=Z=50 core
Zakopane Conference on Nuclear Physics, Zakopane, Poland

L. Próchniak 27 August – 2 September 2012
Superdeformed oblate superheavy nuclei within self-consistent approach
Zakopane Conference on Nuclear Physics, Zakopane, Poland

K. Rusek 27 August – 2 September 2012
Preliminary results of the scattering of ^{8}He with heavy targets
Zakopane Conference on Nuclear Physics, Zakopane, Poland

K. Hadyńska-Klęk 17–21 September 2012
Study of the ^{42}Ca nuclear structure using AGATA and EAGLE spectrometers
EuNPC 2012 - the Second European Nuclear Physics Conference, Bucharest, Romania

P.J. Napiorkowski 24 September 2012
ŚLCJ UW dla HTPRL
HIL UW for HTPRL
HTRPL Consorcium meeting, AGH University of Science and Technology, Kraków, Poland

J. Mierzejewski 25–28 September 2012
Conference on nuclear science and its applications, Samarkanda, Uzbekistan
Modeling incomplete fusion reactions

J. Mierzejewski 9–13 July 2012
Nuclear Structure and Dynamics, Opatija, Croatia
Modeling incomplete fusion reactions

J. Kownacki 8–10 November 2012
Delayed neutrons investigation
PROMETEO Workshop on NEDA Detectors: Mechanical and Electronic Design, Valencia, Spain

A. Trzcińska 13 November 2012
Od czego zależy rozkład barier kulombowskich?
What does the Coulomb barrier distribution depends on?
The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland

K. Hadyńska-Klęk 3–7 December 2012
Recent results from the ^{42}Ca COULEX@AGATA experiment
2nd EGAN School, GSI Darmstadt, Germany

E.2.3 Poster presentations

A. Kordyasz 22–27 January 2012
Model of vacuum, dark matter and charge
Spiral2 Week, GANIL, Caen, France

A. Stolarz 26–29 August 2012
^{211}At production on the inner beam of the Warsaw Cyclotron
4th International Wprkshop on Targetry and Target Chemistry, Playa del Carmen, Mexico

A. Pękal 26–29 April 2012
Radiopharmaceuticals Production and Research Centre in Warsaw
16th Eurp. Symp. on Radiopharmacy and Radiopharmaceuticals Nantes, France

A. Pękal 12–13 May 2012
Wykorzystanie metody headspace GC do oznaczania pozostałości rozpuszczalników organicznych w radiofarmaceutykach
Application of the headspace GC method for the determination of residual organic solvents content in radiofarmaceuticals
Polish Radiofarmaceuticals Conference, Łódź, Poland

G. Jaworski 13–18 August 2012
Building the neutron multiplicity filter NEDA
Nuclear Structure 2012 Conference, Argonne National Laboratory, Argonne, USA

M. Łyczko, A. Bilewicz, J. Jastrzębski, J. Choiński, A. Stolarz, A. Trzcińska, D. Szczepaniak, B. Wąs, J. Chudyka, K. Tworek 19–22 September 2012
Otrzymywanie kompleksów rodu z bifunkcyjnym ligandem makrocyklicznym jako linkerów do znakowania biomolekuł astatem-211
Preperation of rhodium complexes with bifunctional macrocycle ligand as linkers for labelling of biomolecules with astatine-211
XIII Congress of the Polish Society of Nuclear Medicine, Kielce, Poland

S.Krajewski, I.Cydzik, K.Abbas, A.Bulgheroni, F.Simonelli, U.Holzwarth, A.Majkowska-Pilip, A.Bilewicz 27–31 October 2012
Simple and fast procedure of labelling DOTATATE with ^{86}Y and ^{44}Sc
EANM 2012, Milan, Italy

E.2.4 Lectures for students and student laboratories

K. Kilian Winter semesters of academic years 2011/2012, 2012/2013, 30 hours each
Metody izotopowe i chemia farmaceutyków
Radiochemistry and radiopharmacy
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński Summer semester of academic year 2011/2012, 30 hours
Fizyka promieniowania jonizującego
Physics of the ionising radiation
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian Summer semester of academic years 2011/2012, 2012/2013, 60 hours each
Pracownia radiofarmaceutyków
Laboratory of radiopharmaceuticals
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński Winter semester of academic year 2012/2013, 45 hours
Fizyka I – Mechanika
Physics I – Mechanics
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński January 2012, 4 hours
Fizyka Jądrowa w diagnostyce i terapii medycznej
Nuclear Physics in the medical diagnostics and therapy
Open University, Warszawa, Poland

M. Palacz Winter semesters of academic years 2011/2012, 2012/2013, 30 hours each
Pracownia ochrony radiologicznej
Radioprotection Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

A. Trzcińska Winter semesters of academic years 2011/2012, 2012/2013, 30 hours each
Pracownia ochrony radiologicznej
Radioprotection Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

E.2.5 Science popularisation lectures

Z. Szefliński 15 March 2012
Radon w naszym otoczeniu
Radon in our environment
Secondary School, Pruszków, Poland

Z. Szefliński 2 April 2012
Radon w naszym otoczeniu
Radon in our environment
LXVII High School, Warszawa, Poland

Z. Szefliński 15 March 2012
Tomografia Pozytonowa - narzędzie diagnostyki medycznej i badań wysiłkowych
Positron Emission Tomography —-a tool for the medical diagnostics and exercise stress tests
Carolina Medical Center, Warszawa, Poland

P.J. Napiorkowski 16 March 2012
Fizyka Jądrowa nie taka straszna
Nuclear Physics is not so scary
Day of science in the Middle School at Celestynów, Poland

K. Kilian 20–29 September 2012
Zastosowanie fizyki jądrowej w diagnostyce medycznej
Applications of nuclear physics in medicine
XVI Festival of Science, Warszawa, Poland

K. Kilian 20–29 September 2012
Tomografia emisji pozytonu (PET). Nowe możliwości dla nauki, ochrony zdrowia i przemysłu
Positron emission tomography (PET). New opportunities for science, health care and industry
XVI Festival of Science, Warszawa, Poland

P.J. Napiorkowski 20–29 September 2012
Fizyka jądrowa w walce z fałszerzami win
Nuclear physics against wine forgers
XVI Festival of Science, Warszawa, Poland

P.J. Napiorkowski 20–29 September 2012
Fizyka dla bramkarzy
Physics for goalkeepers
XV Festival of Science, Warszawa, Poland

E.3 Publications

E.3.1 Publications in journals of the Journal Citation Reports (JCR) list

Publications resulting from work performed with HIL facilities

E. Piasecki, W. Czarnacki, N. Keeley, M. Kisieliński, S. Kliczewski, A. Kordyasz, M. Kowalczyk, S. Khlebnikov, E. Koshchiy, T. Krogulski, T. Loktev, M. Mutterer, A. Piorkowska, K. Rusek, M. Sillanpaa, A. Staudt, I. Strojek, S. Smirnov, W. H. Trzaska, and A. Trzcinska.
Weak channels in backscattering of ^{20}Ne on ^{nat}Ni, ^{118}Sn, and ^{208}Pb.
Phys. Rev. C 85 (2012) 054604.

E. Piasecki, L. Swiderski, N. Keeley, M. Kisieliński, M. Kowalczyk, S. Khlebnikov, T. Krogulski, K. Piasecki, G. Tiourin, M. Sillanpaa, W. H. Trzaska, and A. Trzcinska.
Smoothing of structure in the fusion and quasielastic barrier distributions for the ^{20}Ne + ^{208}Pb system.
Phys. Rev. C 85 (2012) 054608.

I. Strojek, W. Czarnacki, W. Gawlikowicz, N. Keeley, M. Kisieliński, S. Kliczewski, A. Kordyasz, E. Koshchiy, M. Kowalczyk, E. Piasecki, A. Piorkowska, K. Rusek, R. Siudak, A. Staudt, and A. Trzcinska.
Structure Effects in ^{20}Ne + ^{208}Pb Quasi-elastic Scattering.
Acta Phys. Pol. B 43 (2012) 339.

J. Perkowski, J. Andrzejewski, T. Abraham, W. Czarnacki, C. Droste, E. Grodner, L. Janiak, M. Kisieliński, M. Kowalczyk, J. Kownacki, J. Mierzejewski, A. Korman, J. Samorajczyk, J. Srebrny, A. Stolarz, and M. Zielinska.
Isomeric State 8^- in ^{130}Ba Studied by Conversion-electron and Gamma-ray Spectroscopy.
Acta Phys. Pol. B 43 (2012) 273.

J. Mierzejewski, A. A. Pasternak, J. Srebrny, and R. M. Lieder.
Modeling incomplete fusion reactions.
Physica Scripta T150 (2012) 014026.

K. Wrzosek-Lipska, L. Prochniak, M. Zielinska, J. Srebrny, K. Hadynska-Klek, J. Iwanicki, M. Kisieliński, M. Kowalczyk, P. J. Napiorkowski, D. Pietak, and T. Czosnyka.
Electromagnetic properties of ^{100}Mo: Experimental results and theoretical description of quadrupole degrees of freedom.
Phys. Rev. C 86 (2012) 064305.

J. Samorajczyk, J. Andrzejewski, L. Janiak, J. Perkowski, J. Skubalski, and A. Stolarz.
Preparation and Tests of the Target for Production of ^{134}Nd Nuclei.
Acta Phys. Pol. B 43 (2012) 325.

G. Jaworski, M. Palacz, J. Nyberg, G. de Angelis, G. de France, A. D. Nitto, J. Egea, M. Erduran, S. Ertürk, E. Farnea, A. Gadea, V. González, A. Gottardo, T. Hüyük, J. Kownacki, A. Pipidis, B. Roeder, P.-A. Söderström, E. Sanchis, R. Tarnowski, A. Triossi, R. Wadsworth, and J. V. Dobon.

Monte Carlo simulation of a single detector unit for the neutron detector array NEDA.
Nucl. Inst. and Meth. A 673 (2012) 64 .

P. Delahaye, A. Galata, J. Angot, G. Ban, L. Celona, J. Choinski, P. Gmaj, A. Jakubowski, P. Jardin, T. Kalvas, H. Koivisto, V. Kolhinen, T. Lamy, D. Lunney, L. Maunoury, A. M. Porcellato, G. F. Prete, O. Steckiewicz, P. Sortais, T. Thuillier, O. Tarvainen, E. Traykov, F. Varenne, and F. Wenander.
Prospects for advanced electron cyclotron resonance and electron beam ion source charge breeding methods for EURISOL.
Review of Scientific Instruments 83 (2012) 02A906.

Publications resulting from work performed with external facilities

M. Albers, N. Warr, K. Nomura, A. Blazhev, J. Jolie, D. Mucher, B. Bastin, C. Bauer, C. Bernards, L. Bettermann, V. Bildstein, J. Butterworth, M. Cappellazzo, J. Cederkall, D. Cline, I. Darby, S. Das Gupta, J. M. Daugas, T. Davinson, H. De Witte, J. Diriken, D. Filipescu, E. Fiori, C. Fransen, L. P. Gaffney, G. Georgiev, R. Gernhauser, M. Hackstein, S. Heinze, H. Hess, M. Huyse, D. Jenkins, J. Konki, M. Kowalczyk, T. Kroll, R. Krucken, J. Litzinger, R. Lutter, N. Marginean, C. Mihai, K. Moschner, P. Napiorkowski, B. S. Nara Singh, K. Nowak, T. Otsuka, J. Pakarinen, M. Pfeiffer, D. Radeck, P. Reiter, S. Rigby, L. M. Robledo, R. Rodriguez-Guzman, M. Rudigier, P. Sarriguren, M. Scheck, M. Seidlitz, B. Siebeck, G. Simpson, P. Thole, T. Thomas, J. Van de Walle, P. Van Duppen, M. Vermeulen, D. Voulot, R. Wadsworth, F. Wenander, K. Wimmer, K. O. Zell, and M. Zielinska.
Evidence for a Smooth Onset of Deformation in the Neutron-Rich Kr Isotopes.
Phys. Rev. Lett 108 (2012) 062701.

D. D. DiJulio, J. Cederkall, C. Fahlander, A. Ekstrom, M. Hjorth-Jensen, M. Albers, V. Bildstein, A. Blazhev, I. Darby, T. Davinson, H. De Witte, J. Diriken, C. Fransen, K. Geibel, R. Gernhauser, A. Gorgen, H. Hess, J. Iwanicki, R. Lutter, P. Reiter, M. Scheck, M. Seidlitz, S. Siem, J. Taprogge, G. M. Tveten, J. Van de Walle, D. Voulot, N. Warr, F. Wenander, and K. Wimmer.
Coulomb excitation of ^{107}Sn.
Eur.Phys.J. A 48 (2012) 105.

D. D. DiJulio, J. Cederkall, C. Fahlander, A. Ekstrom, M. Hjorth-Jensen, M. Albers, V. Bildstein, A. Blazhev, I. Darby, T. Davinson, H. De Witte, J. Diriken, C. Fransen, K. Geibel, R. Gernhauser, A. Gorgen, H. Hess, J. Iwanicki, R. Lutter, P. Reiter, M. Scheck, M. Seidlitz, S. Siem, J. Taprogge, G. M. Tveten, J. Van de Walle, D. Voulot, N. Warr, F. Wenander, and K. Wimmer.
Excitation strengths in ^{109}Sn: Single-neutron and collective excitations near ^{100}Sn.
Phys. Rev. C 86 (2012) 031302.

N. Patronis, A. Pakou, D. Pierroutsakou, A. M. Sanchez-Benitez, L. Acosta, N. Alamanos, A. Boiano, G. Inglima, D. Filipescu, T. Glodariu, A. Guglielmetti, M. La Commara, G. Lalazissis, I. Martel, C. Mazzocchi, M. Mazzocco, P. Molini, C. Parascandolo,

M. Sandoli, C. Signorini, R. Silvestri, F. Soramel, E. Stiliaris, M. Romoli, A. Trzcinska, K. Zerva, E. Vardaci, and A. Vitturi.
Probing the ^{17}F+p potential by elastic scattering at near-barrier energies.
Phys. Rev. C 85 (2012) 024609.

E. De Filippo, A. Pagano, P. Russotto, F. Amorini, A. Anzalone, L. Auditore, V. Baran, I. Berceanu, B. Borderie, R. Bougault, M. Bruno, T. Cap, G. Cardella, S. Cavallaro, M. B. Chatterjee, A. Chbihi, M. Colonna, M. D'Agostino, R. Dayras, M. Di Toro, J. Frankland, E. Galichet, W. Gawlikowicz, E. Geraci, A. Grzeszczuk, P. Guazzoni, S. Kowalski, E. La Guidara, G. Lanzalone, G. Lanzano, N. Le Neindre, I. Lombardo, C. Maiolino, M. Papa, E. Piasecki, S. Pirrone, R. Planeta, G. Politi, A. Pop, F. Porto, M. F. Rivet, F. Rizzo, E. Rosato, K. Schmidt, K. Siwek-Wilczynska, I. Skwira-Chalot, A. Trifiro, M. Trimarchi, G. Verde, M. Vigilante, J. P. Wieleczko, J. Wilczynski, L. Zetta, and W. Zipper.
Correlations between emission timescale of fragments and isospin dynamics in ^{124}Sn+^{64}Ni and ^{112}Sn+^{58}Ni reactions at 35 A MeV.
Phys. Rev. C 86 (2012) 014610.

N. Keeley, K. W. Kemper, and K. Rusek.
Bound state form factors from knockout in ^{10}Be(d, t) neutron pickup.
Phys. Rev. C 86 (2012) 014619.

G. Marquinez-Duran, A. M. Sanchez-Benitez, I. Martel, R. Berjillos, J. Duenas, V. V. Parkar, L. Acosta, K. Rusek, M. A. G. Alvarez, J. Gomez-Camacho, M. J. G. Borge, C. Cruz, M. Cubero, V. Pesudo, O. Tengblad, A. Chbihi, J. P. Fernandez-Garcia, B. Fernandez Martinez, J. A. Labrador, A. H. Ziad, J. L. Flores, N. Keeley, L. Standylo, I. Strojek, M. Marques, M. Mazzocco, A. Pakou, N. Patronis, D. Pierroutsakou, R. Silvestri, R. Raabe, N. Soic, and R. Wolski.
Scattering of ^{8}He on ^{208}Pb at Energies Around the Coulomb Barrier.
Acta Phys. Pol. B 43 (2012) 239.

X. Mougeot, V. Lapoux, W. Mittig, N. Alamanos, F. Auger, B. Avez, D. Beaumel, Y. Blumenfeld, R. Dayras, A. Drouart, C. Force, L. Gaudefroy, A. Gillibert, J. Guillot, H. Iwasaki, T. Al Kalanee, N. Keeley, L. Nalpas, E. C. Pollacco, T. Roger, P. Roussel-Chomaz, D. Suzuki, K. W. Kemper, T. J. Mertzimekis, A. Pakou, K. Rusek, J. A. Scarpaci, C. Simenel, I. Strojek, and R. Wolski.
New excited states in the halo nucleus ^{6}He.
Phys.Lett. B 718 (2012) 441.

K. Rusek, I. Martel, A. M. Sanchez-Benitez, and L. Acosta.
^{10}Be Yield from ^{11}Be + ^{120}Sn Interaction at the Coulomb Barrier.
Acta Phys. Pol. B 43 (2012) 233.

K. Zerva, A. Pakou, N. Patronis, P. Figuera, A. Musumarra, A. Di Pietro, M. Fisichella, T. Glodariu, M. La Commara, M. Lattuada, M. Mazzocco, M. G. Pellegriti, D. Pierroutsakou, A. M. Sanchez-Benitez, V. Scuderi, E. Strano, and K. Rusek.
Quasi-elastic backscattering of ^{6,7}Li on light, medium and heavy targets at near- and sub-barrier energies.
Eur.Phys.J. A 48 (2012) 102.

M. Palacz, J. Nyberg, H. Grawe, K. Sieja, G. de Angelis, P. Bednarczyk, A. Blazhev, D. Curien, Z. Dombradi, O. Dorvaux, J. Ekman, J. Galkowski, M. Gorska, J. Iwanicki, G. Jaworski, J. Kownacki, J. Ljungvall, M. Moszynski, F. Nowacki, D. Rudolph, D. Sohler, D. Wolski, and M. Zieblinski.
N=50 core excited states studied in the $^{96}_{46}$***Pd***$_{50}$ ***nucleus.***
Phys. Rev. C 86 (2012) 014318.

M. Sugawara, T. Hayakawa, M. Oshima, Y. Toh, A. Osa, M. Matsuda, T. Shizuma, Y. Hatsukawa, H. Kusakari, T. Morikawa, Z. G. Gan, and T. Czosnyka.
Possible antimagnetic rotational band and neutron alignment in ^{101}***Pd.***
Phys. Rev. C 86 (2012) 034326.

S. Akkoyun, A. Algora, B. Alikhani, F. Ameil, G. de Angelis, L. Arnold, A. Astier, A. Ataç, Y. Aubert, C. Aufranc, A. Austin, S. Aydin, F. Azaiez, S. Badoer, D. Balabanski, D. Barrientos, G. Baulieu, R. Baumann, D. Bazzacco, F. Beck, T. Beck, P. Bednarczyk, M. Bellato, M. Bentley, G. Benzoni, R. Berthier, L. Berti, R. Beunard, G. L. Bianco, B. Birkenbach, P. Bizzeti, A. Bizzeti-Sona, F. L. Blanc, J. Blasco, N. Blasi, D. Bloor, C. Boiano, M. Borsato, D. Bortolato, A. Boston, H. Boston, P. Bourgault, P. Boutachkov, A. Bouty, A. Bracco, S. Brambilla, I. Brawn, A. Brondi, S. Broussard, B. Bruyneel, D. Bucurescu, I. Burrows, A. Bürger, S. Cabaret, B. Cahan, E. Calore, F. Camera, A. Capsoni, F. Carrió, G. Casati, M. Castoldi, B. Cederwall, J.-L. Cercus, V. Chambert, M. E. Chambit, R. Chapman, L. Charles, J. Chavas, E. Clément, P. Cocconi, S. Coelli, P. Coleman-Smith, A. Colombo, S. Colosimo, C. Commeaux, D. Conventi, R. Cooper, A. Corsi, A. Cortesi, L. Costa, F. Crespi, J. Cresswell, D. Cullen, D. Curien, A. Czermak, D. Delbourg, R. Depalo, T. Descombes, P. Désesquelles, P. Detistov, C. Diarra, F. Didierjean, M. Dimmock, Q. Doan, C. Domingo-Pardo, M. Doncel, F. Dorangeville, N. Dosme, Y. Drouen, G. D. ne, B. Dulny, J. Eberth, P. Edelbruck, J. Egea, T. Engert, M. Erduran, S. Ertürk, C. Fanin, S. Fantinel, E. Farnea, T. Faul, M. Filliger, F. Filmer, C. Finck, G. de France, A. Gadea, W. Gast, A. Geraci, J. Gerl, R. Gernhäuser, A. Giannatiempo, A. Giaz, L. Gibelin, A. Givechev, N. Goel, V. González, A. Gottardo, X. Grave, J. Gre¸bosz, R. Griffiths, A. Grint, P. Gros, L. Guevara, M. Gulmini, A. Görgen, H. Ha, T. Habermann, L. Harkness, H. Harroch, K. Hauschild, C. He, A. Hernández-Prieto, B. Hervieu, H. Hess, T. Hüyük, E. Ince, R. Isocrate, G. Jaworski, A. Johnson, J. Jolie, P. Jones, B. Jonson, P. Joshi, D. Judson, A. Jungclaus, M. Kaci, N. Karkour, M. Karolak, A. Kaşkaş, M. Kebbiri, R. Kempley, A. Khaplanov, S. Klupp, M. Kogimtzis, I. Kojouharov, A. Korichi, W. Korten, T. Kröll, R. Krücken, N. Kurz, B. Ky, M. Labiche, X. Lafay, L. Lavergne, I. Lazarus, S. Leboutelier, F. Lefebvre, E. Legay, L. Legeard, F. Lelli, S. Lenzi, S. Leoni, A. Lermitage, D. Lersch, J. Leske, S. Letts, S. Lhenoret, R. Lieder, D. Linget, J. Ljungvall, A. Lopez-Martens, A. Lotodé, S. Lunardi, A. Maj, J. van der Marel, Y. Mariette, N. Marginean, R. Marginean, G. Maron, A. Mather, W. Me¸czyński, V. Mendéz, P. Medina, B. Melon, R. Menegazzo, D. Mengoni, E. Merchan, L. Mihailescu, C. Michelagnoli, J. Mierzejewski, L. Milechina, B. Million, K. Mitev, P. Molini, D. Montanari, S. Moon, F. Morbiducci, R. Moro, P. Morrall, O. Möller, A. Nannini, D. Napoli, L. Nelson, M. Nespolo, V. Ngo, M. Nicoletto, R. Nicolini, Y. L. Noa, P. Nolan, M. Norman, J. Nyberg, A. Obertelli, A. Olariu, R. Orlandi, D. Oxley, C. Özben, M. Ozille, C. Oziol, E. Pachoud, M. Palacz, J. Palin, J. Pancin, C. Parisel, P. Pariset, G. Pascovici, R. Peghin, L. Pellegri, A. Perego, S. Perrier, M. Petcu, P. Petkov, C. Petrache, E. Pierre, N. Pietralla, S. Pietri, M. Pignanelli, I. Piqueras,

Z. Podolyak, P. L. Pouhalec, J. Pouthas, D. Pugnére, V. Pucknell, A. Pullia, B. Quintana, R. Raine, G. Rainovski, L. Ramina, G. Rampazzo, G. L. Rana, M. Rebeschini, F. Recchia, N. Redon, M. Reese, P. Reiter, P. Regan, S. Riboldi, M. Richer, M. Rigato, S. Rigby, G. Ripamonti, A. Robinson, J. Robin, J. Roccaz, J.-A. Ropert, B. Rossé, C. R. Alvarez, D. Rosso, B. Rubio, D. Rudolph, F. Saillant, E. Şahin, F. Salomon, M.-D. Salsac, J. Salt, G. Salvato, J. Sampson, E. Sanchis, C. Santos, H. Schaffner, M. Schlarb, D. Scraggs, D. Seddon, M. Şenyi it, M.-H. Sigward, G. Simpson, J. Simpson, M. Slee, J. Smith, P. Sona, B. Sowicki, P. Spolaore, C. Stahl, T. Stanios, E. Stefanova, O. Stézowski, J. Strachan, G. Suliman, P.-A. Söderström, J. Tain, S. Tanguy, S. Tashenov, C. Theisen, J. Thornhill, F. Tomasi, N. Toniolo, R. Touzery, B. Travers, A. Triossi, M. Tripon, K. Tun-Lanoë, M. Turcato, C. Unsworth, C. Ur, J. Valiente-Dobon, V. Vandone, E. Vardaci, R. Venturelli, F. Veronese, C. Veyssiere, E. Viscione, R. Wadsworth, P. Walker, N. Warr, C. Weber, D. Weisshaar, D. Wells, O. Wieland, A. Wiens, G. Wittwer, H. Wollersheim, F. Zocca, N. Zamfir, M. Ziębliński, and A. Zucchiatti.
AGATA Advanced GAmma Tracking Array.
Nucl. Inst. and Meth. A 668 (2012) 26 .

J. Mierzejewski, A. Pasternak, J. Srebrny, and R. Lieder.
Modelling Incomplete Fusion Reactions.
Physica Scripta T150 (2012) 014026.

I. Cydzik, A. Bilewicz, K. Abbas, A. Bulgheroni, F. Simonelli, U. Holzwarth, and N. Gibson.
A novel method for synthesis of ^{56}Co radiolabelled silica nanoparticles.
Journal of Nanoparticle Research 14 (2012) 10.

E.3.2 Other publications in journals and conference proceedings not included in the JCR list

J. Choiński, J. Jastrzębski
The Opening Ceremony of the Radiopharmaceuticals Production and Research Centre at the Heavy Ion Laboratory of the University of Warsaw, May 15, 2012, followed by an International Conference PETRAD2012
Nuclear Medicine Review 15 (2012) 2:85-86

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Technical and technological design of the radio-protection of a class III isotop laboratory for teaching and research with the Gamma Camera

E.4 Awards

Heavy Ion Laboratory Prize founded by Prof. T. Inamura

The prize was established by Professor Takashi Tom Inamura who worked in the Heavy Ion Laboratory in the years 1998–2002 and made a great contribution to its development. An award in the amount of 5.000 USD is granted every second year to recognise and support young researchers with outstanding experimental or technical achievements in the field of nuclear and atomic physics or related subjects. The results should be obtained using the Warsaw Cyclotron or other HIL apparatus. Candidates must be scientists or PhD students below the age of 36 on the day of application. The most important selection criterion is the candidate's academic achievement demonstrated by publications in international journals and presentations at international conferences. Achievements in the field of interdisciplinary applications of the HIL cyclotron are highly valued.
In the fifth edition, in 2012, the Heavy Ion Laboratory Prize was awarded to **Dr Joanna Czub** from the Jan Kochanowski University in Kielce, for her contribution to radiobiological studies pursued in-beam at the Warsaw Cyclotron.

The Rector of the University of Warsaw awards

E. Piasecki, A. Trzcińska
For a series of publications on fusion barrier height distributions

I. Mazur
For work on the PET project

Other awards granted to HIL staff and PhD students

Katarzyna Hadyńska-Klęk

Polish Ministry of Science and Higher Education scholarship for the best doctoral students for the academic year 2012/2013

Katarzyna Hadyńska-Klęk

"The Modern University" Scholarship for the best doctoral students, granted for the academic year 2011/2012 — a comprehensive support program for doctoral students and teaching staff of the University of Warsaw, Poland

Grzegorz Jaworski

Research and development scholarship for best PhD students, granted for the academic year 2012/2013 by the Faculty of Physics, Warsaw University of Technology

Grzegorz Jaworski

Scholarship for the academic year 2012/2013 within the project "Scientific potential as a support for the Mazovian economy" granted by the Marshal's Office of the Mazovian Voivodeship

E.5 Laboratory staff

Director: Krzysztof Rusek
Deputy director: Jarosław Choiński

Financial executive: Paweł Napiorkowski

Senior scientists:

Jerzy Jastrzębski[a], Jan Kownacki[a], Andrzej Kordyasz[a], Ernest Piasecki[a], Ludwik Pieńkowski[b], Krzysztof Rusek, Józef Sura, Zygmunt Szefliński[ac]

Scientific staff and engineers:

Tomasz Abraham, Andrzej Bednarek, Izabela Cydzik[d], Jarosław Choiński, Bohdan Filipiak[a], Przemysław Gmaj, Jędrzej Iwanicki[e], Andrzej Jakubowski, Krzysztof Kilian, Maciej Kisieliński[a], Marian Kopka, Michał Kowalczyk[a], Ireneusz Mazur, Jan Miszczak, Paweł Napiorkowski, Marcin Palacz, Daniel Piętak[f], Leszek Próchniak[g], Mateusz Sobolewski, Olga Steczkiewicz, Anna Stolarz, Julian Srebrny[a], Dorota Szczepaniak, Roman Tańczyk, Radosław Tarnowski, Agnieszka Trzcińska, Marzena Wolińska-Cichocka[e], Katarzyna Wrzosek-Lipska[e]

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Technicians:

Mariusz Antczak, Tomasz Bracha, Marek Figat, Andrzej Górecki, Piotr Jasiński, Wiesław Kalisiewicz, Wojciech Kozaczka, Zbigniew Kruszyński, Piotr Krysiak, Krzysztof Łabęda, Zygmunt Morozowicz, Bogusław Paprzycki, Wiesław Perkowski[a], Andrzej Pietrzak, Krzysztof Pietrzak, Irena Skrzeczanowska[a], Krzysztof Sosnowski

Administration and support:

Anna Błaszczyk-Duda, Marek Budziszewski, Przemysław Czwarnok[k], Rafał Klęk, Barbara Kowalska, Agnieszka Maciejewska, Ewa Sobańska, Lidia Strzelczyk, Krystyna Szczepaniak, Sylwester Świecicki, Iwona Tomaszewska[l], Joanna Wasilewska, Wanda Wesoły, Andrzej Wiechowski, Katarzyna Włodarczyk[a]

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[a] part time
[b] until 31 March 2012
[c] since 1 April 2012
[d] on long term leave until 15 December 2012
[e] on long term leave
[f] until 31 July 2012
[g] since 1 October 2012
[h] PhD student at the Institute of Experimental Physics, University of Warsaw
[i] PhD student at the Faculty of Physics, Warsaw University of Technology
[j] PhD student at the Faculty of Chemistry, University of Warsaw
[k] since 1 October 2012
[l] until 30 September 2012

E.6 Laboratory Council

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- Bogdan Fornal (Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków)
- Gilles de France (GANIL, Caen, France)
- Andres Gadea (University of Valenzia, Spain)
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- Nicholas Keeley (National Centre for Nuclear Studies, Warszawa)
- Rainer Lieder (University of Bonn, Germany)
- Piotr Magierski (Faculty of Physics, Warsaw University of Technology)
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- Brunon Sikora (Faculty of Physics, University of Warsaw)
- Władysław Trzaska (University of Jyväskylä, Finland)

The international Programme Advisory Committee of the Heavy Ion Laboratory meets usually twice a year, in spring and in autumn. The deadline for submitting proposals is three weeks before a PAC meeting. PAC approved experiments are scheduled at the meetings of the Users' Committee, which also serves as a link between cyclotron users and the Laboratory. The Users' Committee is chaired by Julian Srebrny (HIL UW).

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