University of Warsaw

Heavy Ion Laboratory

Annual Report

2013

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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 22 May 2014

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Contents

Introduction

Despite the number "13" , the last year, 2013, was extremely successful for our laboratory. Cyclotron operated for record number of hours, 3346, split between experiments that used the ICARE chamber system and the EAGLE gamma-ray array, with significant involvement of young scientists.

A two year campaign with the EAGLE array consisting of 20 HPGe gamma ray detectors (15 had anti-Compton shields) from the European GAMMAPOOL came to its successful conclusion with the completion of 15 experiments that will form the basis for 8 PhD theses and multiple MSc and BSc projects. A new conversion electron spectrometer produced at the University of Łódź was coupled to the EAGLE array allowing for the study of the violation of K selection rules in nuclei. It was possible with this setup to determine the properties of a very weak highly hindered transition in ^{184}Pt.

Among other research highlights, the ground breaking experiments performed at REX-ISOLDE by an international collaboration with the active participation of our colleagues specialising in Coulomb excitation studies revealed evidence for strong octupole deformation of a short-lived isotope of radium. Such a "pear shape" nucleus was predicted by theory but never observed experimentally. This discovery was published in the prestigious journal NATURE.

Medical physics work in the laboratory continued through the ongoing development for the production of the isotope ^{211}At which is used for the alpha particle irradiation of tumors and feasibility studies for the accelerator production of ^{99m}Tc were carried out. The important research of our radio-chemist colleagues working in the Centre of Production and Research on Radiopharmaceuticals that is a part of our laboratory is described in section B.

In 2013 for the first time our laboratory co-organised the Mazurian Lakes Conference on Physics, the 33rd event in a series dating back to 1968. It was held in the remote resort of Piaski from the 1st to the 7th of September. The title "Frontiers in Nuclear Physics" allowed a broad scope for the conference that included talks on the physics of super-heavy nuclei, nuclear structure and reactions, nuclear astrophysics and different aspects of applications. It was a very successful event and in two years time we shall again be among the organisers.

Considerable staff effort went into preparing for the installation and bringing into operation the ECR ion source that will be carried out in 2014.

The community of European nuclear physicists is preparing the project ENSAR2 (European Nuclear Science and Applications Research 2) for the coming call in HORIZON 2020, the EU Framework Programme for Research and Innovation. Our laboratory, together with the Institute of Nuclear Physics of the Polish Academy of Sciences in Cracow, is applying within this project for trans-national access to both our research infrastructures. The first meeting of the ENSAR2 consortium took place in Warsaw on 17th–21st of June 2013. Our common proposal received a warm welcome. The call in HORIZON 2020 for submission of the ENSAR2 project should be issued in September 2014.

Prof. Krzysztof Rusek, Director of HIL

Part A

Laboratory overview

A.1 Cyclotron operation in 2013 and tasks carried out in order to improve the infrastructure and efficiency

J. Choiński, P. Gmaj, O. Steczkiewicz, A. Bednarek, M. Kopka, Ł. Standyło, M. Antczak, M. Budziszewski, T. Bracha, P. Czwarnok, M. Figat, B. Filipiak, A. Górecki, A. Jakubowski, P. Jasiński, W. Kalisiewicz, W. Kozaczka, Z. Kruszyński, P. Krysiak, K. Łabęda, K. Makowski, I. Mazur, J. Miszczak, Z. Morozowicz, B. Paprzycki, A. Pietrzak, K. Pietrzak, B. Radomyski, M. Sobolewski, K. Sosnowski, J. Sura, R. Tańczyk

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Operation

In order to broaden the range of available beams — both in terms of the type of ions as well as their energy definition and beam intensity — in 2013, a number of preparatory operations for the implementation of the new ECR ion source were conducted. Its implementation requires a substantial upgrading of the structure of the cyclotron. The primary goal was to maintain the interchangeability of the old and new structures. This assumption was motivated by the necessity to maintain the cyclotron in operation during the preparatory work. Therefore, although the normal operation and preparatory actions were carried out in parallel, as a result of the above approach the availability of the cyclotron for experiments in 2013 not only did not decrease, but increased by 30% compared to 2012 and 100% compared to 2010 (see Fig. 1).

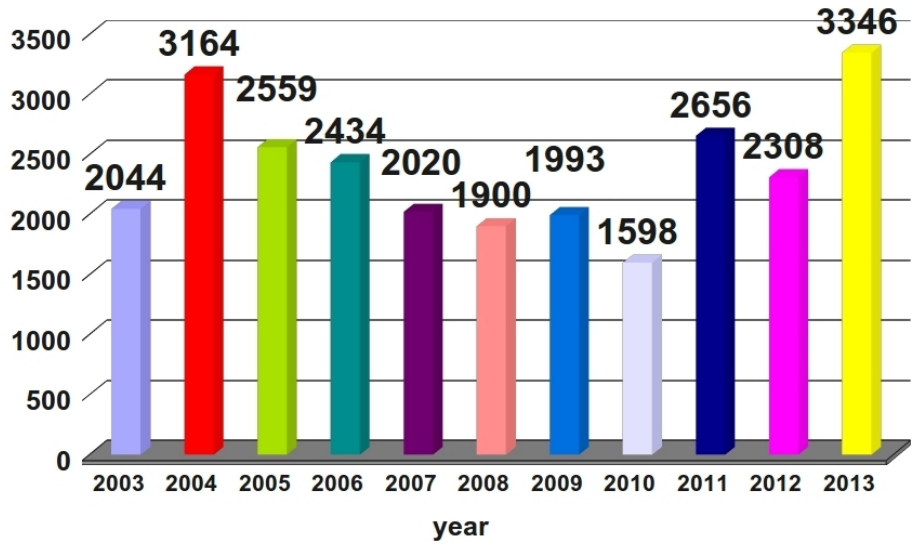

Figure 1: Total cyclotron beam time in the years 2004–2013.

With insufficient means available from the SPUB grant, the above increase was possible thanks to Polish-Russian cooperation and substantial assistance given by the employees of JINR, Dubna. However, installation of the new central part of the cyclotron and the new inflector was postponed from December 2013 to the beginning of 2014 — simply to give the maximum availability of the experimental time.

The monthly distribution of beam time in 2013 is presented in Fig. 2. During half of July, August and September the cyclotron was closed for the summer vacation.

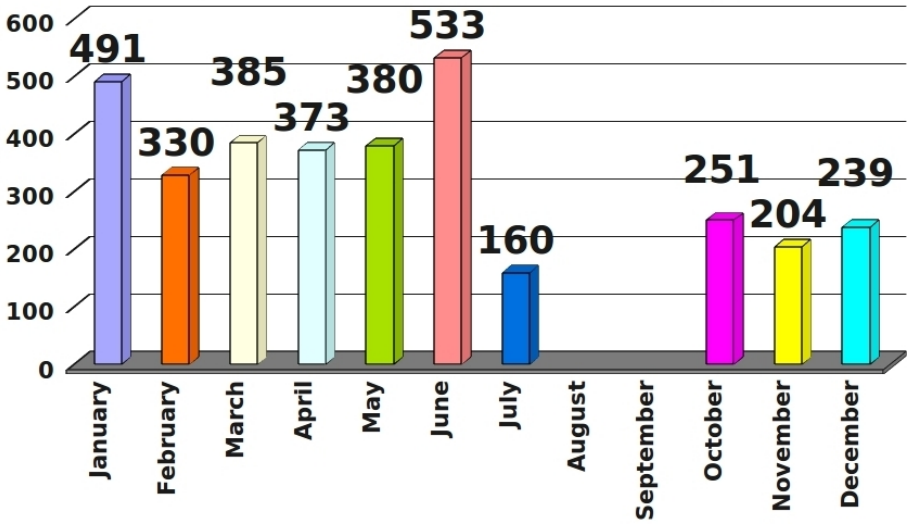

Figure 2: Beam time distribution (hours) in 2013 per month.

The main experiments were related to nuclear physics research, biological and medical research (including ^{211}At production in collaboration with the Institute of Nuclear Chemistry and Technology and the Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences), machine maintenance and beam tests. Beam time was also allocated to national and international student workshops, as in the last few years. The diversity of the experiments performed during 2013 is illustrated in Fig. 3.

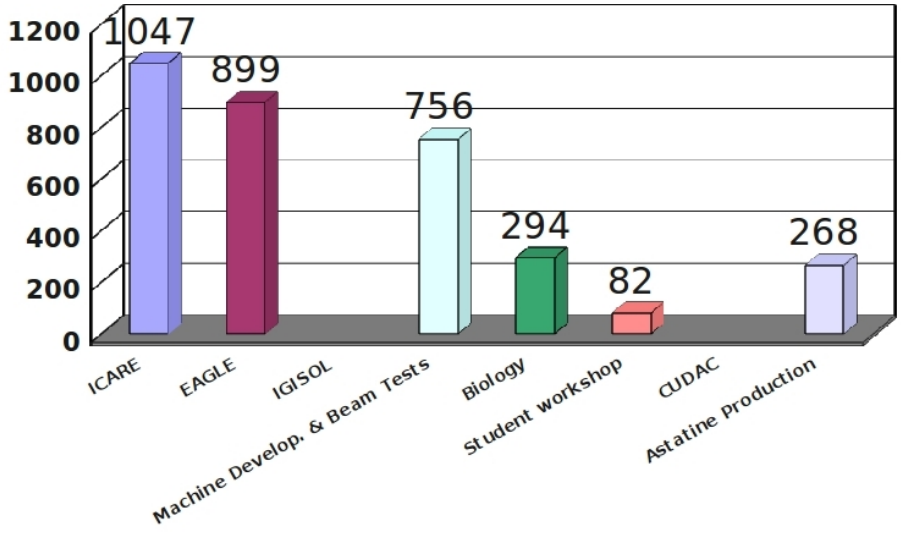

Figure 3: Distribution of beam-time (in hours) among different experiments.

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

A list of the experiments performed in 2013 is presented in Tables 1 and 2. The following acronyms are used in the table:

- HIL — Heavy Ion Laboratory
- CEA — French Alternative Energies and Atomic Energy Commission, Saclay, France
- HCCC Kielce — Holycross Cancer Center, Kielce, Poland
- IEP UW — Inst. of Experimental Physics, Univ. of Warsaw
- INP Kraków — The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
- NCNR Świerk — National Centre for Nuclear Research, Otwock, Świerk, Poland
- NNC — Institute of Nuclear Physics of National Nuclear Center, Almaty, Kazakhstan
- PTB — PTB, Braunschweig, Germany
- UŁ — Faculty of Physics and Applied Computer Science, University of Lodz, Łódź, Poland
- U.Huelva — University of Huelva, Huelva, Spain
- U.Sofia — Sofia University "St. Kliment Ohridski", Sofia, Bulgaria
- U.Oslo — University of Oslo, Norway
- US — University of Silesia, Katowice, Poland

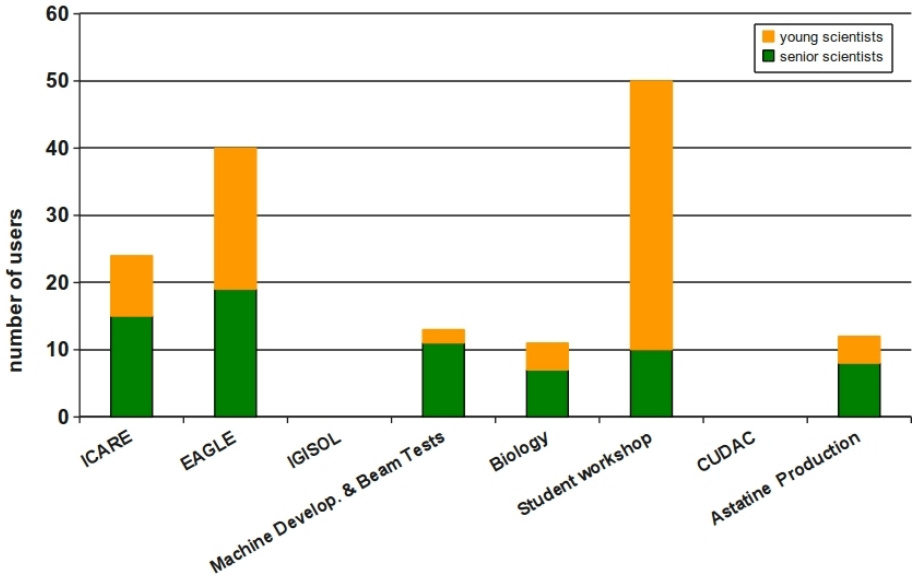

Figure 4: Number of users of Warsaw cyclotron beams in 2013.

Maintenance

ECR Source

The new ECR source was tested for stable production of beam from volatile and non-volatile compounds. For non-volatile compounds two types of micro ovens were tested. The original Pantechnik one and the type used in Dubna (Russia). The maximum current of $^{24}Mg^{4+}$, obtained at the first Faraday cup after the analysing magnet, amounted to 80 μA. The stability of this intensity was maintained for 12 hours of continuous work. Unreliable operation of the control system of the ECR significantly reduced the possibility

Table 1: Experiments performed in 2013 — part 1

Dates	Ion and Energy	Experiment	Leading institution	Collaborating institutions
3.01	$^{12}C^{+3}$ 90 MeV	Biology	HIL, NCNR Świerk	IEP UW
07.01 – 11.01	$^{16}O^{+3}$ 73 MeV	EAGLE	IEP UW	HIL, NCNR Świerk, UŁ
14.01 – 18.01	$^{20}Ne^{+4}$ 96 MeV	EAGLE	U.Oslo	HIL, NCNR Świerk
23.01 – 26.01	$^{12}C^{+3}$ 90 MeV	Biology	PTB, NCNR Świerk	HIL, IEP UW
28.01 – 08.02	$^{20}Ne^{+3}$ 50 MeV	ICARE	NNC	HIL, NCNR Świerk, INP Kraków
11.02 – 15.02	$^{4}He^{+1}$ 30 MeV	Astatine production	HIL	US
18.02 – 22.02	$^{12}C^{+2}$ 48 MeV	Biology	IEP UW	HIL, NCNR Świerk, HCCC Kielce
26.02 – 01.03	$^{20}Ne^{+3}$ 54 MeV	Students' workshop	HIL	U.Huelva, U.Sofia
6.03	$^{15}N^{+4}$	Test of the cyclotron	HIL	
11.03 – 15.03	$^{12}C^{+3}$ 90 MeV	Biology	NCNR Świerk	HIL, IEP UW
18.03 – 29.03	$^{15}N^{+3}$ $^{14}N^{+3}$ 84, 88 MeV	ICARE	NNC	HIL, NCNR Świerk, INP Kraków
08.04 – 12.04	$^{4}He^{+1}$ 30 MeV	Astatine production	HIL	US
15.04 – 26.04	$^{16}O^{+3}$ 73 MeV	EAGLE	IEP UW	HIL, NCNR Świerk, UŁ

of a trial production of beams from non-volatile compounds. Making the ion source more reliable required significant changes in the control software and forced the replacement of a few weak points in the control system hardware. Figure 5 shows the charge distribution of Mg for the best result received up to now, but further tests are planned in 2014.

RF system

In May 2013 several significant RF system failures were recorded and removed. These failures indicate the need for replacement as soon as possible of the original Russian RF generators with new ones (see plans). Namely:

Table 2: Experiments performed in 2013 — part 2

Dates	Ion and Energy	Experiment	Leading institution	Collaborating institutions
06.05 – 17.05	$^{14}N^{+3}$ 89 MeV	EAGLE	UŁ	HIL, NCNR Świerk, UŁ, IEP UW
20.05 – 24.05	$^{4}He^{+1}$ 30 MeV	Astatine production	HIL	US
27, 28.05	$^{15}N^{+4}$	Test of the cyclotron	HIL	
03.06 – 14.06	$^{20}Ne^{+4}$ 96 MeV	EAGLE	U.Oslo	HIL, NCNR Świerk
17.06 – 21.06	$^{16}O^{+4}$ 91 MeV	EAGLE	HIL	NCNR Świerk, UŁ, IEP UW
24.06 – 05.07	$^{20}Ne^{+4}$ 70 MeV	ICARE	HIL	NCNR Świerk, NNC, INP Kraków
08.07 – 10.07	$^{20}Ne^{+3}$ 54 MeV	Students' workshop	HIL	
07.10 – 10.10	$^{4}He^{+1}$ 30 MeV	Astatine production	HIL	US
14.10 – 18.10	$^{32}S^{+5}$ 91 MeV	ICARE	HIL, CEA	NCNR Świerk, UŁ, IEP UW
21.10 – 25.10	$^{20}Ne^{+3}$ 54 MeV	Students' workshop	HIL	
18.11 – 22.11	$^{12}C^{+3}$ 90 MeV	Biology	HIL, NCNR Świerk	IEP UW
25.11 – 06.12	$^{20}Ne^{+3}$ 46 MeV	ICARE	LNS Catania	HIL, NCNR Świerk, NNC, INP Kraków
09.12 – 13.12	$^{20}Ne^{+3}$ 46 MeV	ICARE	LNS Catania	HIL, NCNR Świerk, NNC, INP Kraków

- one of two RF power tubes (channel A) was repaired provisionally (the power tubes of the GK-11A type have been out of production for years and we had to search for the remaining examples in storage in Russia;
- the contactor in channel B failed and was replaced with a recycled one;
- channel A preamplifier failed and was repaired;
- the harmonic oscillations (channel B) were subjected to service and the tubes grid voltages, interlock and safety switches were regulated during the summer break;

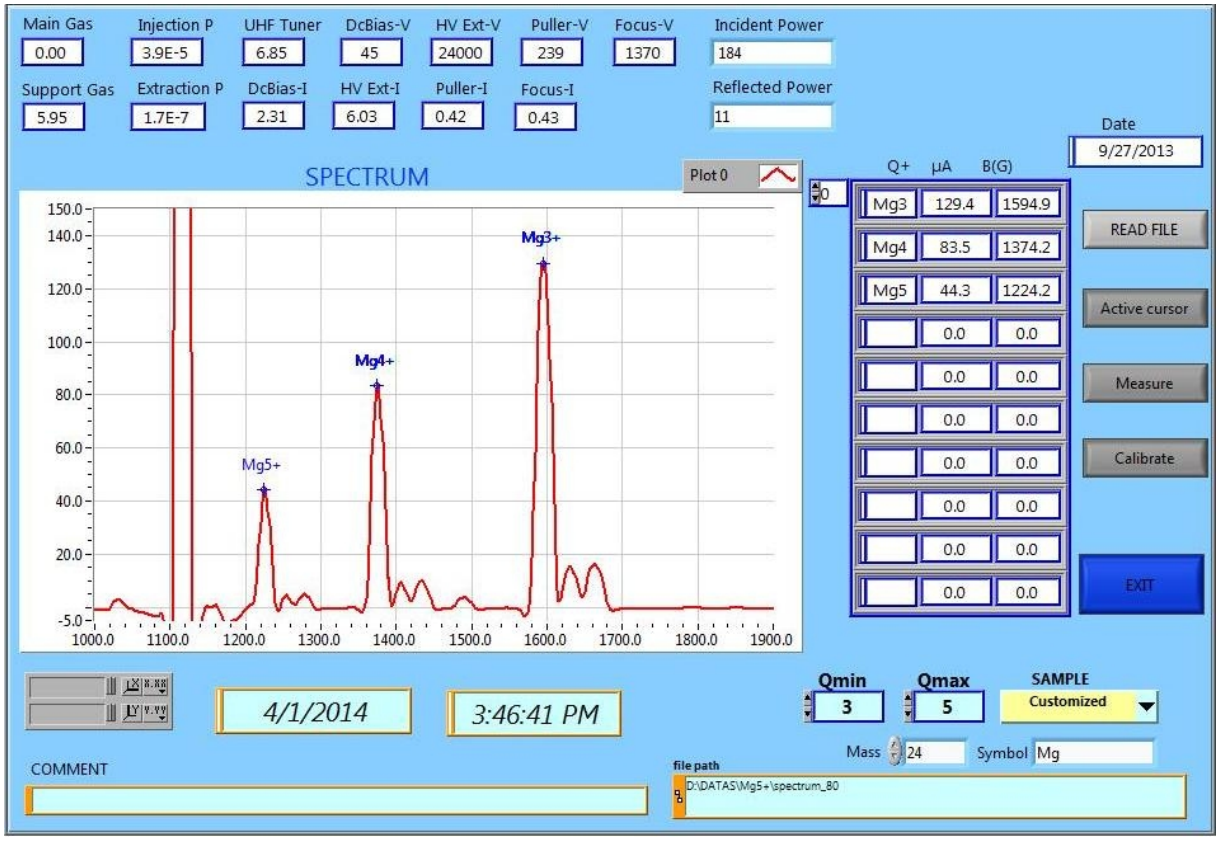

Figure 5: Charge distribution of Mg.

- the water cooling system was improved by installation of fast switched caps on the ends of the elastic water leads.

Power infrastructure

In 2013, other than routine service work, following a major failure of the power system of the old ECR source the system was completely rebuilt, allowing for possible further use of this source. This included reconstruction of the control and automation systems of the ECR ion source and adding a fire breaker to the power distribution system. Apart from that, the replacement of power amplifiers for the beam distribution lines was begun in 2013. This replacement is absolutely necessary due to the exhaustion of the routine repair possibilities of these amplifiers and their outdated control system.

Development and projects

Central Part, Spiral Inflector

As mentioned at the outset, a number of important changes designed to extend the types and intensity of the ion beams will be carried out at the beginning of 2014. These changes require modifications to the central part of the cyclotron, installation of the spiral inflector and introduction of the new ECR ion source to permanent operation.

In 2013 all the mechanical parts (see Fig. 6) needed for the modification of the central region of the cyclotron and to install the spiral inflector were designed and constructed. The high voltage power supplies of the inflector were installed and its remote control

was created (LabView environment) and tested. The new structure will be installed in January-February 2014.

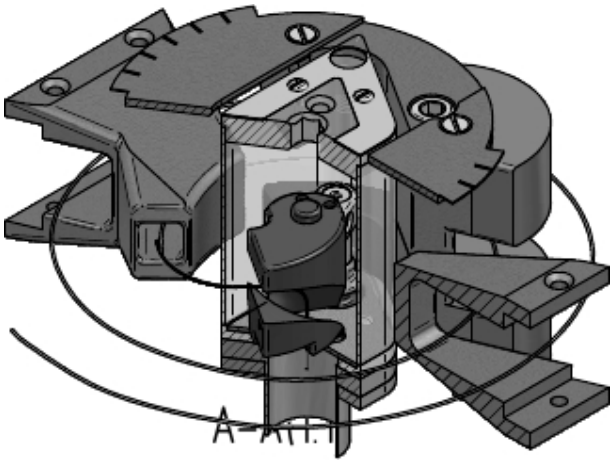

Figure 6: The new central part of the cyclotron and spiral inflector.

New power supplies (beam line active elements)

Due to the technical wear and tear of the power supplies which support the beam lines, part of them will be replaced in 2014 with new ones. This will require the development and implementation of a new power supply control system, coherent with the control system of the ECR source.The new control system will be based on the NI LabView platform and will be implemented in 2014 for powering steering magnets and quadrupoles. As mentioned above, some elements of this system were created in 2013 but development will continue in 2014. The system will significantly improve the reliability of the cyclotron.

RF system

In 2013 a series of tenders were let for the purchase of the new RF system. These tenders were not successful, therefore it was decided to change the purchase order and buy the power stages of RF amplifiers with power sources, interlocks and safety switches in one tender and independently arrange other tenders for the missing parts of the RF system (frequency sources, stabilisation system, control system). It will be decided in 2014 which parts of the system have to be bought and which parts must be sourced by our own manpower at the HIL.

Power infrastructure

The replacement of the power amplifiers for the beam distribution lines requires some major changes in the power supply infrastructure. For this reason, in 2013 a new electrical switchgear RDK has been developed and partially implemented. The full implementation of the project will be executed in the current (2014) year.

Cyclotron magnet

It is planned to replace the old system for lifting the upper part of the cyclotron with a new one, which will allow for much faster operation related to the reconstruction of the central part. This change is needed before we can proceed to the measurement of the magnetic field, which in turn is necessary to improve the transmission of the accelerated ions.

Vacuum system

The vacuum system was partially renewed in 2013 but it still needs some investment to replace the old vacuum pumps on the beam lines.

EMILIE project

The Heavy Ion Laboratory has joined the European EMILIE project which aims to improve the charge breeder efficiency. The purpose of participating in this project is to increase knowledge and practices concerning ion sources of the ECR type. In 2013 the HIL participated in several experiments. The role of HIL for 2013 (as defined in WP3 of the EMILIE project) consisted of:

- Taking part in experiments related to optimisation of the multiple frequencies heating of charge breeders. HIL has been involved in two batches of experimental tests carried out on the LPSC charge breeder. The first one was concentrated on the coupling between double frequency heating and support gas effects on charge breeding (Ar, Kr) and the second one was more focused on charge breeding efficiency for metallic ions (Na and Rb) and +1 ions capture efficiency. The results of the first set of tests were presented at the EURISOL Topical Meeting (Kraków, Poland) which took place in July. Generally the experiment has shown a beneficial effect of gas mixing and 2-frequency plasma heating (Fig. 7) pointing to different mechanisms of increased efficiency in both cases (additive effects). The results of the second set of experiments are still being analysed.

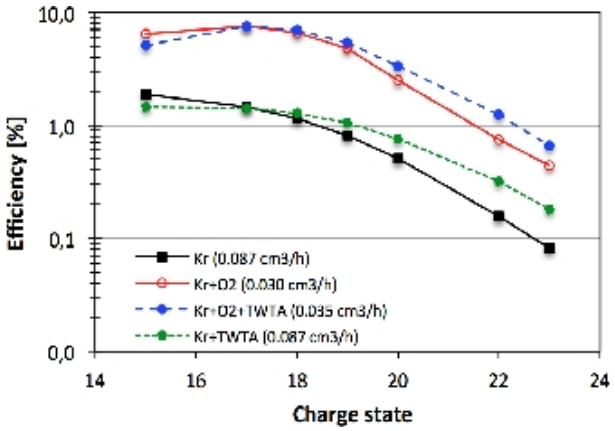

Figure 7: Additive effect of 2-frequency plasma heating and gas mixing

- Mechanical design and construction of the new, versatile plasma chamber for the PHOENIX booster which is a part of the task "Optimisation of the breeding efficiency of the PHOENIX booster". The design was to be performed on the basis of a concept coming from numerical optimisation of microwave coupling to the PHOENIX booster and numerical simulation of the +1 beam capture and further ion charging due to interaction with the plasma. The calculations and conceptual work which are to be made by LNL are still in course.

  While awaiting the results of the above mentioned calculations the HIL is considering building a small test stand that models phenomena occurring when a +1 ion is injected in to the charge breeder and then passes through the plasma. The model is currently being developed and when finished can be used as a test device for studying experimentally some aspects of charge breeder design.

A.2 EAGLE campaign with GAMMAPOOL detectors 2011–2013

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on behalf of the EAGLE collaboration[a]

1) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
2) Faculty of Physics, University of Warsaw, Warszawa, Poland

Introduction

Twenty PHASE I HPGe detectors of 70% efficiency and 15 anti-Compton shields from GAMMAPOOL were at our disposal during the EAGLE campaign between October 2011 and June 2013. A configuration with 15 shielded detectors of a total photo-peak efficiency of 1.8% at 1.3 MeV was assembled. Over 1500 hours of beam time were scheduled for 15 experiments. The data collected form the basis of 8 on-going PhD theses and several MSc and BSc projects, numerous conference presentations and 7 peer reviewed publications so far. The operation of the EAGLE array during the 2011–2013 campaign was funded by the Polish Ministry of Science and Higher Education in the frame of the "Experimental study of spontaneous symmetry breaking in nuclear excited states using gamma and gamma-electron spectroscopy on beams of the Warsaw Cyclotron at the Heavy Ion Laboratory, University of Warsaw" project.

The scientific programme included:

- the experimental study of spontaneous chiral symmetry breaking by DSAM lifetime measurements of partner bands in ^{122,124}Cs nuclei.
- the shape coexistence and shape evolution of ^{42}Ca, ^{70}Zn, ^{107}Ag, ^{125}Cs and ^{140}Sm nuclei studied by measurements of transition probabilities using Coulex and RDDS methods.
- studies of K-isomers as a test of K-quantum number conservation, by the combined gamma and internal conversion electron spectroscopy of ^{134}Nd and ^{184}Pt nuclei.

Experiments Performed

The experiments performed are listed in Table 1. In addition, during the EAGLE campaigns more than 80 students took part in one of the three major training programs at the HIL: International Workshop on Acceleration and Applications of Heavy Ions (II and III edition, 2 weeks each), I Summer School on Acceleration and Applications of Heavy Ions (one week) and Polish Workshop on Acceleration and Applications of Heavy Ions (VII and VIII editions, one week each). During the workshops EAGLE was operated by a group of maximum of 4 students, supervised by an experienced nuclear physicist, who performed a short in-beam experiment.

New ICE spectrometer

During the last EAGLE campaign with GAMMAPOOL detectors, the new Internal Conversion Electron spectrometer was designed, built and tested (see Fig. 1).

[a]The EAGLE collaboration Web page: `http://www.slcj.uw.edu.pl/en/97.html`

Table 1: Experiments performed with EAGLE between October 2011 and June 2013

No.	Date	Beam hours	Spokesman	Title
1	10–14.10.2011	96h ^{32}S	K. Hadyńska-Klęk	Determination of the low spin level scheme in ^{42}Ca for the Coulex analysis of the first AGATA experiment
2	14–25.11.2011	216h ^{14}N ^{10}B	E. Grodner	DSA lifetime measurements of the excited states belonging to partner bands of ^{124}Cs
3	9–13.12.2011		J. Kownacki	Decay chains investigation of ^{238}U and ^{235}U natural sample
4	13–24.02.2012	216h ^{16}O	J. Perkowski	The investigation of the role of triaxiality in the K quantum number violation in decay of K isomer in ^{134}Nd
5	27–29.02.2012	48h ^{14}N	D. Karpiński	Test of ^{14}N beam focusing for the future plunger experiment
6	11–22.06.2012	216h ^{40}Ar	J. Perkowski	The investigation of the triaxiality role in decay paths of K-isomer in ^{184}Pt produced in the ^{40}Ar+^{148}Nd reaction.
7	9–13.07.2012	96h ^{14}N	D. Karpiński	Lifetimes measurements of the excited states of ^{125}Cs and question of triaxial deformation — with Koln-Bucharest plunger
8	5–18.11.2012	216h ^{32}S	K. Wrzosek-Lipska	Quadrupole moments of excited states in ^{107}Ag
9	19–25.11.2012	96h ^{32}S	M. Zielińska	Transition probabilities in ^{70}Zn
10	7–13.01.2013	96h ^{16}O	T. Marchlewski, E. Grodner	DSA lifetime measurements in ^{122}Cs — excitation functions of chiral bands population
11	14–20.01.2013	96h ^{20}Ne	A. Görgen	Oblate nuclear shapes and shape transitions in neutron-deficient rare earth isotopes: the test of ^{124}Te target and beam energy for the population of low spin levels in ^{140}Sm
12	15–28.04.2013	216h ^{16}O	T. Marchlewski, E. Grodner	DSA lifetime measurements in ^{122}Cs — search for the chiral phase transition
13	06–19.05.2013	216h ^{14}N	J. Perkowski	Testing the new conversion-electron spectrometer on and off beam by ^{14}N + ^{175}Lu — decay paths of K-isomer in ^{184}Pt.
14	20–25.05.2013		J. Kownacki	Fission of ^{252}Cf — off beam test of a new target chamber
15	3–16.06.2013	216h ^{20}Ne	A. Görgen	Oblate nuclear shapes and shape transitions in neutron-deficient rare earth isotopes : the lifetimes in ^{140}Sm measured with Koln-Bucharest plunger
16	17–23.06.2013	96h ^{20}Ne	P. Sibczyński	Investigation of a neutron-rich fission fragments isomers induced by heavy ions

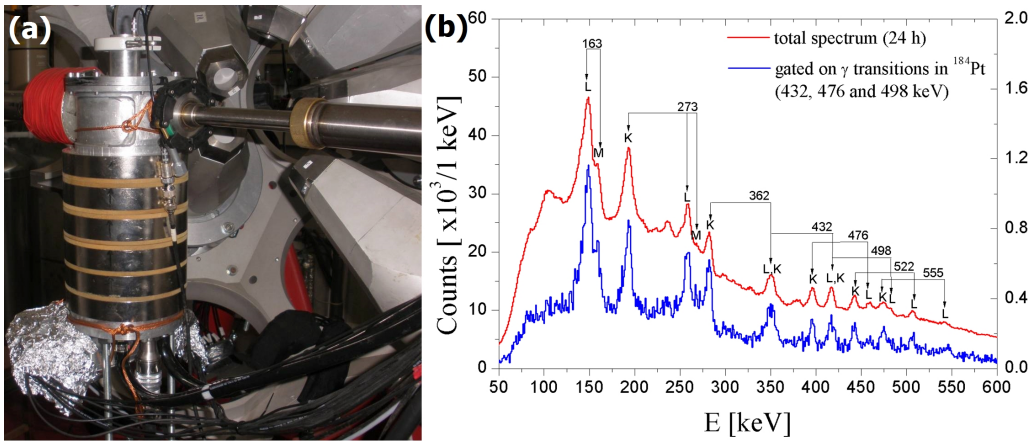

Figure 1: The first experiment with the new ICE spectrometer. (a) the spectrometer inside the EAGLE array (b) in-beam electron spectra: inclusive (red line) and exclusive (blue line) gated on γ-transitions in ^{184}Pt. The transition energies and corresponding electron lines are labelled.

Digital electronics

The prototype of a new acquisition module for 4 ACS Ge detectors was designed, built and tested (see Fig. 2). The module gives full control over the acquisition hardware and low level software, allowing the system to be adapted for cooperation with external devices. The module was tested using both calibration sources and during in-beam measurements with EAGLE array coupled with the ICE spectrometer (see Fig. 1a). The energy linearity obtained with the module presented is better than that of a standard ORTEC analogue amplifier and ADC (see Fig. 2b).

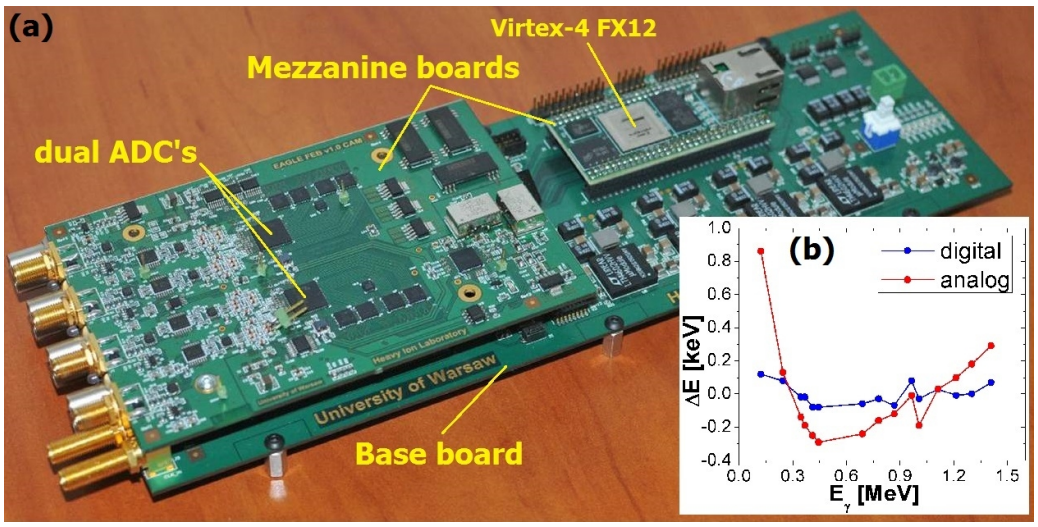

Figure 2: (a) The new acquisition module for 4 ACS Ge detectors; the most important components are labelled. (b) The energy difference between actual γ-ray energy and that calculated with linear calibration using ^{152}Eu source for the presented digital module (blue) and a standard ORTEC analogue amplifier and ADC (red). The lines are drawn only to guide the eye.

Seven papers directly connected to the experiments performed have been published. Many other are in preparation as well as in the data analysis stage. 22 invited talks and presentations were given on international conferences and workshops. Three PhD theses were completed based on data collected with EAGLE and the EAGLE predecessor OSIRIS II. Five PhD theses (of T. Marchlewski, J. Samorajczyk, Ł. Janiak, F.L. Bello Garrote, M. Klintefjord) are in progress based on experiments performed with the use of GAMMAPOOL equipment.

A.3 Maintenance of HPGe detectors

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During the first half of 2013 experiments on the European Array for Gamma Levels Evaluations (EAGLE) set-up [1, 2] were carried out using the 20 HPGe Compton suppressed detectors borrowed from GAMMAPOOL for the period from July 2011 till June 2013 [3].

In 2013 the detectors were used in 7 experiments for 47 in-beam days before shipment to Orsay, France. In order to obtain satisfactory data the detectors had to be regenerated by the process of annealing [4, 5]. During the first six months of 2013 the process of annealing was applied to 18 HPGe GAMMAPOOL detectors.

After the detectors from GAMMAPOOL left HIL the HPGe detectors from the HIL's own pool were prepared for upcoming experiments. The process of annealing was used 20 times in order to restore the detectors. By the end of the year 19 detectors were ready to be used out of total number of 23, further 3 detectors were found to be broken beyond repair, and the last one was away in another laboratory.

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A.4 Overhaul of the beam diagnostic system

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The beam diagnostic system was commissioned about 15 years ago, and it consists of beam-stops covered with photo-luminescent paint observed by analogue CCD cameras. The beam current at the beam-stop is also measured. The beam-stop movement in and out of the beam-line is controlled by a microprocessor based local control unit, in turn controlled by the cyclotron control system [1]. The cameras are turned on all the time, and the image to be viewed in the control room is selected by an 18-input / 1-output analogue multiplexer. The diagnostic system performed well in the past, but changes in the cyclotron and beam-stations setup [2,3] increased the number of cameras to 21. As a stop-gap measure a second beam diagnostic display monitor with a manual video switch was added in the control room to display images from the additional cameras. Since, over the years the cabling used to connect the cameras to the multiplexer was at some points damaged (and of course repaired, but the quality of the video degraded) it was decided to build a new video multiplexer and install a new cabling for the cameras. The new multiplexer is a direct replacement of the old one, but it can accommodate up to 32 cameras, so there is a lot of room for the beam diagnostic system to grow. The work was done during the cyclotron's summer shutdown of 2013.

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A.5 Linux computers at HIL

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The cluster of Linux computers at HIL consists of about 15 workstations and servers. These computers have been running the Linux 10.04 LTS operating system since 2011 [1]. In 2013 the operating system was upgraded to version 12.04 LTS on two of the machines (the backup server and the firewall-gateway computer). At the same time the disk space on the backup server was increased by 3 TB (amounting to 5 TB in total). A general upgrade of the operating system on all the machines to the newest available long-term support version (Ubuntu 14.04 LTS) is planned in 2014.

In the second half of 2013 a system for monitoring the Linux computers was implemented. This system is based on the Nagios software. Configuration files have been created for each of the computers, depending on the number of installed disks and on running services. The system sends a notification e-mail in case the amount of data on any of the monitored disks exceeds the threshold, CPU load is critical or just a proper response from a computer or service is missing. In addition, in order to improve the security of data stored on the HIL computers, all Linux machines which have hard drives with the S.M.A.R.T. firmware have been configured to monitor the HDD status by performing a quick scan each night. Once a week a more detailed scan is performed to detect and report possible disk errors.

Security of the network was improved by blocking the possibility of querying HIL DNS servers from outside the University of Warsaw network, which prevents the use of our systems to carry out a DDoS attack on a selected network infrastructure.

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A.6 XXXIII Mazurian Lakes Conference on Physics: Frontiers in Nuclear Physics

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The 33$^{\text{rd}}$ Mazurian Lakes Conference on Physics was held at Piaski, Poland, from the 1$^{\text{st}}$ till the 7$^{\text{th}}$ of September 2013. The history of Mazurian meetings dates back to 1968. This traditional conference is now organised every two years by the University of Warsaw, the National Centre for Nuclear Research and the Pro-Physica Foundation. Its goal is to bring together scientists to discuss the hottest topics in nuclear physics, in an environment facilitating contacts between the participants staying at a remote location.

Over 140 physicists from 17 countries all over the world enjoyed lively discussions on the latest developments in the fields of low-energy nuclear physics, both experimental and theoretical. The scientific program included about 80 oral presentations The number of excellent contributed abstracts was so large that a crowded poster session included the presentation and discussions of almost 50 posters.

Scientific topics discussed at the conference ranged from nuclear structure to nuclear reactions, from nuclear astrophysics to the synthesis of new elements, from results from just commissioned powerful detector arrays to new facilities under construction and the applications of nuclear physics research. All facilities contributing to the discovery and spectroscopic studies of new chemical elements and super heavy isotopes beyond the recently named $Z = 112$ Copernicium were presented.

The long term future of the Mazurian Conferences is justified by the number of talks presenting the status of new laboratories and powerful detector arrays. These new and expensive constructions will continue to benefit the physics community and our society in general. The latter may be deduced from several talks at the Mazurian Conference

presenting the applications of nuclear physics. Hadron therapy, radioisotopes for diagnostics and, medical imaging and biological response to radiation are evident outcomes of earlier nuclear physics developments and are helping thousands of patients every day. New detector techniques may keep us safer from terrorist attacks and prevent smuggling of nuclear materials. Cultural Heritage research profits from non-destructive inspection of art objects offered by nuclear techniques.

We should not forget the social aspect of the conference. With the aid of excellent weather, in between the lectures, the participants could continue scientific discussions while enjoying outdoor activities offered by the Piaski venue: kayaking, canoeing, cycling, and of course sailing with the traditional Regatta, this year won by Juha Äystö and his "Team Finland". Everybody enjoyed the vocal skills of several national teams at the campfire.

The 34^{th} Mazurian Lakes Conference on Physics will be held in September 2015, not surprisingly in the Mazurian Lakes Region.

A.7 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], M. Sitarz[2], O. Steczkiewicz[1], A. Stolarz[1], I. Strojek[4], Z. Szefliński[1]

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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 cycle 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. Recently medical applications of nuclear physics have also been included in the programme of the Workshop.

Since 2012 the Workshop has been organised as a general university course. This status attracts students both from the University of Warsaw and from other Polish universities. In 2013 twenty students attended the lectures and the practical training. Five persons came from the University of Warsaw, 3 from the University of Silesia, 3 from the Jagiellonian University in Kraków, 3 from the University of Science and Technology in Kraków, 2 from the University of Łódź, 2 from the Gdańsk University of Technology, 1 from the Adam Mickiewicz University in Poznań, and 1 student from the University of Wrocław.

In 2013, the programme of lectures was as follows:

- HIL in a nutshell (K. Rusek);
- Radioprotection at the HIL (R. Tańczyk);
- Introduction to heavy ion acceleration and elements of ion optics (O. Steczkiewicz);
- Detection of gamma radiation, charged particles and neutrons (M. Palacz);
- In-beam gamma spectroscopy (P. Napiorkowski);
- Nuclear reactions (A. Stolarz);
- Targets for nuclear physics (A. Stolarz);
- Radiopharmaceuticals for Positron Emission Tomography (K. Kilian);
- Impact of external conditions on the timescale of radioactive decays (Z. Janas).

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 — gamma spectroscopy with the EAGLE setup;
- Thin target production and thickness control;
- Measurement of ^{137}Cs activity in environmental samples;
- Gamma camera image reconstruction.

For the very first time students could use for training the gamma camera in the newly established Medical Imaging Laboratory. The advanced medical equipment installed at the HIL is a gift from the General Electric company. The students got acquainted with the novel numerical techniques used in medical applications of nuclear physics.

A.8 International Workshops on the Acceleration and Applications of Heavy Ions

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3) Akdeniz University, Antalya, Turkey
4) University of Huelva, Huelva, Spain
5) Sofia University "St. Kliment Ohridski", Sofia, Bulgaria

Nuclear physics students, especially in countries where no accelerator facilities are available, often have quite limited possibilities to become acquainted with modern scientific apparatus. Existing teaching laboratories usually offer basic equipment and students are required to carry out standard experiments, which do not stimulate independent thinking and creativity. To help fill this gap in student training, student workshops and summer schools on the acceleration and applications of heavy ions are organised every year at the Heavy Ion Laboratory of the University Warsaw, giving students a unique opportunity to gain hands-on 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.

The Polish edition of the workshop has been organised every year since 2005. In 2010 the HIL obtained EU funding to organise three international editions of the Workshop on the Acceleration and Applications of Heavy Ions as an LLP Erasmus Intensive Programme (IP) in 2011-2013. This project was carried out jointly by the HIL, University of Huelva (Spain), St Kliment Ohriidski University in Sofia (Bulgaria) and Akdeniz University (Antalya, Turkey). In order to be eligible for this type of funding 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 at partner institutions forming the consortium could benefit from the ERASMUS financial support that we received. The workshop was integrated in the teaching programmes at the partner institutions: students from Warsaw, Huelva and Antalya received 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.

The workshop was extended to two full weeks: the first week was used for setting up the experimental apparatus and carrying out in-beam measurements, while during the second week participants analysed the collected data, performed additional off-beam measurements (if needed) and prepared final presentations. The scope of the lectures was also broadened as compared to the one-week Polish edition thanks to the complementarity of the partner institutions' areas of competence and important contributions by numerous scientists from other research centres in Poland and abroad.

In 2013, 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. P. Olko, K. Mazurek (Institute for Nuclear Physics, Kraków), M.-D. Salsac, 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 S. Lalkovski (St Kliment Ohriidski Uni-

Figure 1: Participants in the international student workshop in 2013.

versity in Sofia, Bulgaria) were among the lecturers along with several researchers from the HIL (K. Hadyńska-Klek, K. Kilian, M. Palacz, L. Próchniak, K. Rusek, O. Steczkiewicz, A. Stolarz) and the Institute of Experimental Physics, University of Warsaw (Z. Janas, U. Kaźmierczak, T. Matulewicz, P. Olbratowski).

18 students from four countries took part in the following experimental tasks:

A. Rutherford scattering (supervisors: J. Iwanicki, K. Hadyńska-Klek);
B. Gamma-ray spectroscopy (supervisors: M. Palacz, T. Abraham, Y. Kucuk);
C. Nuclear reactions — experimental (supervisors: I. Martel, K. Kemper, I. Strojek);
D. Nuclear reactions — theory (supervisors: K. Rusek, I. Boztosun, N. Keeley, Y. Kucuk);
E. Fast timing (supervisors: S. Lalkovski, P.J. Napiorkowski);
F. Ion optics (supervisor: O. Steczkiewicz) + gamma-ray detection (supervisors: T. Marchlewski, M. Zielińska)
G. Measurements of activity in biological samples (supervisor: A. Trzcińska) + preparation of targets for nuclear physics (supervisors: A. Stolarz, A. Trzcińska)

The 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. Two editions of the Summer School on the Acceleration and Applications of

Figure 2: Student presentation session.

Heavy Ions have been already organised. In the second one, which took place in July 2013, 11 students from Germany, Greece, Italy, Spain, Ukraine and the UK took part in lectures and experimental projects at the HIL supervised by researchers from the HIL and the University of Ioannina. The school was very well received by the participants and we hope it will become part of the regular teaching effort at the HIL.

More information on the Workshop and Summer School can be found at the Web pages: `http://www.slcj.uw.edu.pl/workshop` and `http://www.slcj.uw.edu.pl/summerschool`.

Part B

Research for medical and biological applications at HIL

B.1 Determination of metallic and radiometallic impurities in the ^{18}F-Fludeoxyglucose production process

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The aim of this study was to synthesise ^{18}FDG in several consecutive runs and check the quality of manufactured radiopharmaceuticals and to determine the distribution of metallic impurities in the synthesis process.

Standard methods for determination of the basic characteristics of the radiopharmaceuticals were used. Additionally, high resolution γ spectrometry was used for the assessment of nuclidic purity and inductively coupled plasma with mass spectrometry to evaluate the metallic content. ^{18}FDG was synthesized in six independent runs using the standard method from mannose triflate with alkaline hydrolysis.

Radionuclidic purity and radionuclidic impurities were determined using gamma spectroscopy with a high resolution germanium detector (GMX-20190-P) with a digital signal processor (DSPEC, Ortec) and GammaVison software. The spectra were recorded in 10800 s each for the final product and purification cartridges used during the synthesis of 2-[^{18}F]FDG: ion exchange columns Accel Plus QMA Sep-Pak^{TM}, used for preconcentration and separation of ^{18}F from the target, reverse phase separation columns Sep-Pak^{TM} C-18 RP used in the basic hydrolysis and purification process of the FDG, alumina columns Sep-Pak^{TM} N Plus for ionic impurities. Inductively coupled plasma with mass spectrometry (ICP-MS, Perkin Elmer Elan 9000) was used for determination of Cu, Fe, Pb, Ag, Co, Mn, Cd, Zn, Cr levels in the ^{18}FDG and enriched water samples. Calibration curves in the range up to 100 μg/L with four transitive points were prepared. The internal standard, ^{103}Rh, was used to minimise interference.

In this work 15 radioisotopes were identified in the QMA column. ^{96}Tc, ^{56}Co and ^{56}Ni were the main contributors of residual activity with a 70% share in the total column activity (3.120 MBq). Only 6 isotopes were found in ^{18}O water after passing the QMA: ^{51}Cr, ^{52}Mn, ^{54}Mn, ^{56}Co, ^{57}Co, ^{58}Co with ^{58}Co dominant and significant contributions from ^{52}Mn, ^{56}Co and ^{57}Co. Tc and Re isotopes were not observed, which could be easily explained by their chemical properties, where negatively charged perrhenate and pertechnetate ions are immobilized on the QMA cartridge. Activity of ^{18}O water was 1.400 MBq (44% of QMA, 30% total activity) but the individual activities of the dominating isotopes were higher than in the QMA column, due to formation of Mn and Co cationic complexes. Presence of these isotopes in QMA, which is an anionic exchanger, can be explained by the formation of hydroxycomplexes in close to neutral pH.

The spectra of the other purification columns (carbon and aluminum) during the production process show $<$5 Bq peaks of ^{51}Cr, ^{52}Mn and ^{56}Co. This is the result of significant purification based on cationic and anionic properties of radiometallic impurities, where the cations are collected in recovery water and anions are trapped on the QMA column. Residual radionuclidic impurities are separated and collected in further purification steps, resulting in only ^{51}Cr, ^{52}Mn and ^{56}Co with activity in the range 1–2 Bq being recorded in the final product.

Heavy metal content was determined in six ^{18}FDG samples and respective recovery water from each run. First, the quantitation limit was determined as an average blank ± 6 standard deviation. Then determination of 9 heavy metals: Cu, Fe, Pb, Ag, Co, Mn, Cd, Zn and Cr in samples was conducted. Summarised values of quantitation limit are presented in Table 1. The presented results clearly indicate that the metal impurities are not a serious threat for the quality of the FDG produced and are significantly lower than set by the regulatory office. Most of the metallic impurities are concentrated in the ion exchange column in the inlet or migrate with enriched water to recovery and do not influence significantly the synthesis process. A slight increase in the concentration of copper, zinc and chromium in the final product is observed. The first two are common trace contaminants and are difficult to remove, thus their probable source is the saline solution, used for the final formulation. Increasing concentration of chromium can be explained by the presence of elements of stainless steel in the dispensing line.

Concluding, all impurities were efficiently eliminated from the final product and met radionuclidic purity tests set in Pharmacopoeia.

Table 1: Heavy metal content in recovery water and ^{18}FDG samples. EMEA Guidelines Parenteral limit.

	LOQ [µg/L]	Recovery water [µg/L]	^{18}FDG [µg/L]	EMEA Guidelines limits [µg/L]
Cu	0.09	1.63±0.09	4.6±0.4	5000
Fe	21	<LOQ	<LOQ	150
Pb	0.13	14.7±1.3	0.42±0.18	100
Ag	0.18	19.0±0.9	<LOQ	N/A
Co	0.11	5.2±0.1	<LOQ	10000
Mn	0.08	0.52±0.04	0.48±0.10	70000
Cd	0.15	<LOQ	<LOQ	250
x Zn	1.1	59±3	250±50	150000
Cr	0.7	3.8±0.4	27.6±1.5	1500

B.2 Synthesis of ^{11}C-methionine

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^{11}C-methionine increased its clinical significance when methionine uptake was identified as one of critical factors in tumor growth and began to be a standard method for visualization of gliomas in neurooncology.

^{11}C-methionine was synthesized via ^{11}C methylation from L-cysteine thiolactone (ABX, Radeberg, Gemany) in solution using the bubbling method. ^{11}C was produced in a GE high performance target with total activity *ca.* 1000 mCi (37 GBq) by the ^{14}N(p,α)^{11}C reaction after 10 minutes irradiation. ^{11}C-methyliodide was then synthesized in a Synthra MeIPlus module (Hamburg, Germany) by converting CO_2 to methane (H_2/Ni, 400°C), passing the ^{11}C-CH4 over iodine in a triplicate loop at elevated temperature (720°C) and trapping on a Porapak column (dry method). Thermically desorbed $^{11}CH_3I$ was bubbled into the reactor with L-homocysteine thiolactone (2 mg) in a 300 µl solution of 2:1:1 (v/v) 1M NaOH, ethanol and water at ambient temperature (85°C, 6 min.). The product was then purified by semipreparative HPLC (C18 column, 0.05M NaH_2PO_4 + 2% EtOH as mobile phase) with a total wet-synthesis time of 20 min.

B.3 The evaluation of polyphenolic compound antioxidant properties in the presence of digestive enzymes

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Dietary polyphenols have attracted considerable interest because of their associated health properties [1]. Studies have demonstrated that polyphenolic compounds possess strong antioxidant activity, thus they may protect cells and tissues against reactive oxygen and nitrogen species. The antioxidative properties of polyphenols are manifest particularly by their ability to inhibit free radical generation, scavenge free radicals and chelate transition metal ions, mainly iron and copper, which are catalysts of free radical reactions. They also prevent free radical generation by inhibiting the activity of oxidizing enzymes or by increasing the activity of enzymes with antioxidative properties. It has been shown that the regular intake of food with a high content of polyphenols improves the antioxidant status in vivo and helps lower the risk of certain types of cancer and coronary heart disease [2].

Polyphenolic compounds are secondary metabolites of plants and are highly diverse in terms of structure and chemical properties. Derivatives of 4-hydroxybenzoic and cinnamic acid derivatives and flavonoids have been investigated (Fig. 1).

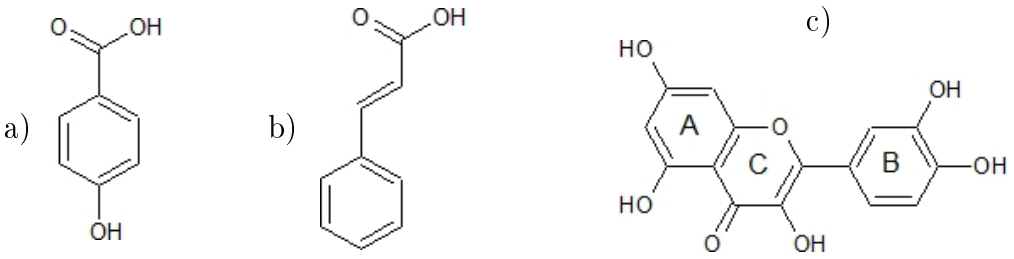

Figure 1: Structures of some polyphenols a) 4-hydroxybenzoic acid b) cynnamic acid c) quercetin.

The measured antioxidant activity is closely related to the structures of phenolics as compounds with two or more electron donating groups have higher antioxidant abilities than monosubstituted phenols. Cinnamic acid derivatives have greater scavenging ability than benzoic acid derivatives due to the presence of a double bond, which increases the acidity of the protons of the hydroxyl groups [3]. The flavonoids which have two hydroxyl groups located at the ortho position (catechol moiety) have high antioxidant properties. The presence of a ketone group and a double bond between C_2 and C_3 carbons in the C ring is also important.

The aim of this project is to evaluate the antioxidant properties of polyphenols in the presence of salivary enzymes. The DPPH radical method was used to investigate the antioxidant activity of model solutions with and without saliva. Radical scavenging activity was assessed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay. The sample (0.1 mL) was mixed with DPPH solution (2.4 mL, 30 μM) in methanol and immediately the change of absorbance at 539 nm was recorded over time against the blank. The

results were expressed as the percentage of reduction (inhibition) of the DPPH according to expression: $(A_0 - A_t)/A_0 \times 100$, where A_0 is the initial absorbance and A_t is the absorbance after 20 minutes.

The human saliva was collected by mechanical stimulation of the salivary glands. Saliva was then diluted with water in a 1:1 (w:w) ratio, centrifuged and filtered. This solution was mixed with the polyphenol solution in a 1:1 (v:v) ratio and incubated at 37°C for 10, 90, 130/170 and 3600 minutes.

When caffeic acid is mixed with saliva a slight increase is observed after the first 3 hours from the start of incubation and a decrease after 24 hours (Fig. 2). The incubation with saliva causes steady growth in the antioxidant properties of protocatechuic acid. Both ferulic and vanillic acid possess hydroxyl and methoxy groups in ortho position in the aromatic ring. However, only ferulic acid showed the ability to scavenge DPPH. After addition of saliva to the ferulic acid solution, the antioxidant capacity is higher than without saliva solution and constant during incubation. Vanillic acid does not show antioxidant activity and a rise of the signal after the addition of saliva occurs due to the ability of the saliva itself to scavenge DPPH radical. Comparing the results obtained for gallic and ellagic (dimer of gallic acid) acids it can be seen that the antioxidant capacity of gallic acid is lowered slightly in the first 3 hours of incubation with a solution of saliva. After the first 170 minutes ellagic acid showed constant antioxidant properties. For both of these acids it can be observed that after 24 hours of incubation with saliva solution, the ability to scavenge DPPH has been significantly reduced. Phenolic acids were stable when incubated with water.

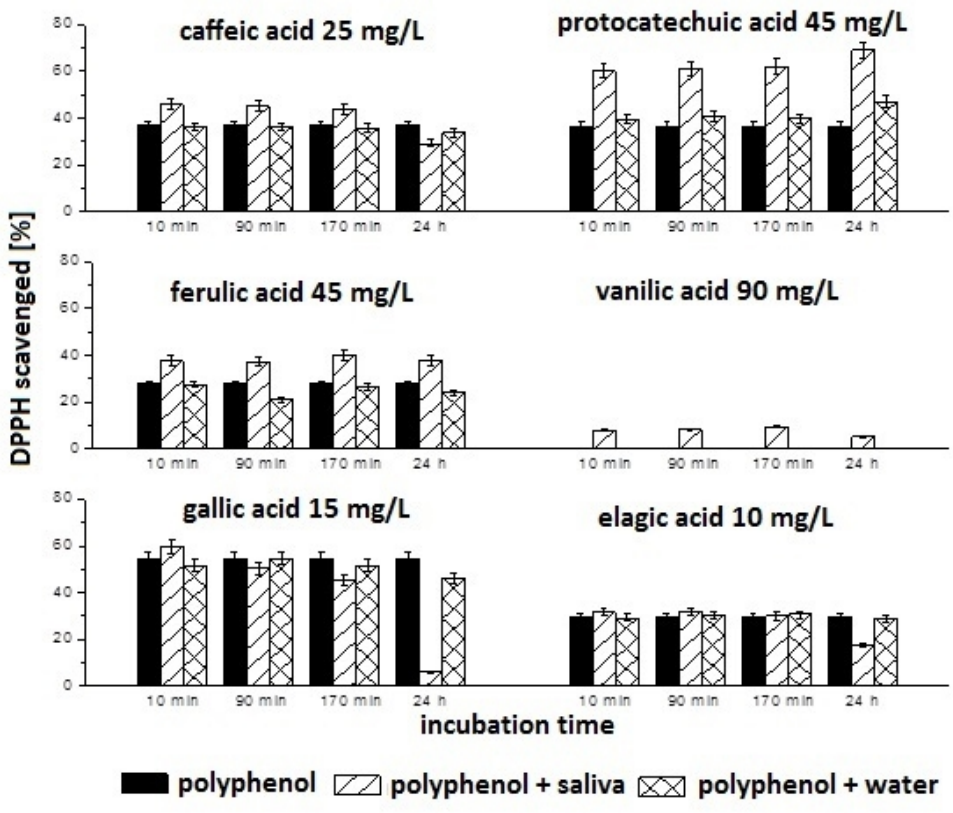

Figure 2: The ability to scavenge DPPH for some polyphenolic acids.

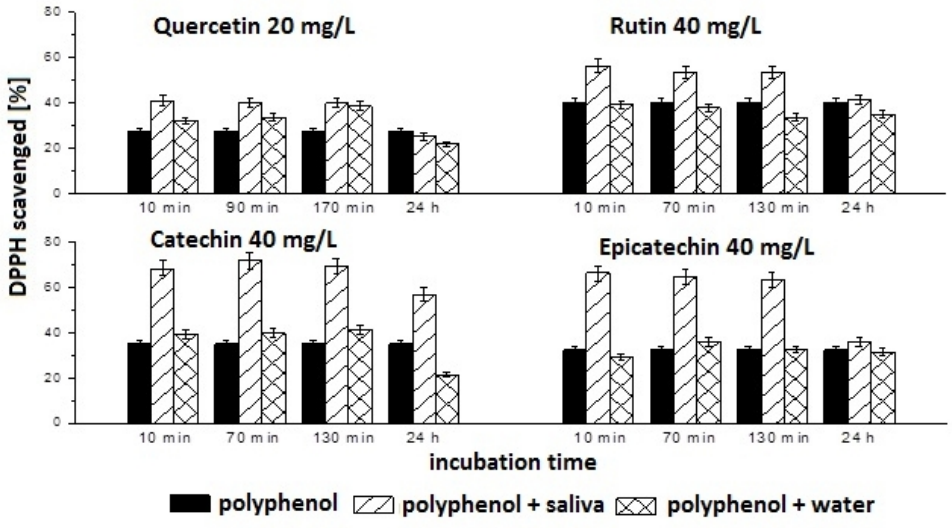

Figure 3: The ability of scavenging DPPH for some flavonoids.

Incubation with saliva solution increase the scavenging of DPPH for all the investigated flavonoids (Fig. 3). For all of them a positive change is observed after over two hours of incubation and then the signal drops after 24 hours. However, for catechin and epicatechin the increase of antioxidant activity is much higher than for quercetin and rutin. It is also worth mentioning that rutin and catechin are not stable in aqueous medium after 24 hours.

The study demonstrated that certain polyphenolic compounds are not stable in the presence of salivary enzymes and their antioxidant activity changes during incubation with human saliva solution. Differences in the ability of DPPH scavenging are assorted for the various polyphenols. Research has shown that the form of some polyphenolic acids changes during incubation with a saliva solution.

Acknowledgment

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B.4 Hydrophilic interaction chromatography (HILIC) in the speciation analysis of selenium

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Selenium in trace amounts is necessary for cellular function in organisms, whereas an excess of this element is toxic. Selenium is a component of the antioxidant enzymes, such as glutathione peroxidase and thioredoxin reductase, that protect the body against free radicals and reactive oxygen species (ROS). Selenoamino acids, especially selenomethylocysteine, have anti-carcinogenic effects. It is essential to determine the various chemical forms of selenium, not only the total content due to the fact that inorganic and organic forms have different biological functions.

For the separation of selenium, ion ion-pair chromatography and reverse-phase nonpolar chromatography are the most often used [1]. A new type of chromatography — hydrophilic interaction chromatography (HILIC) has not yet been used in speciation analysis of selenium. HILIC is a complementary technique to both normal and reversed-phase chromatography for the analysis of polar and ionic compounds. HILIC retention is controlled primarily by a partition between the mobile phase eluent and a water-enriched layer in the hydrophilic stationary phase. Other interactions such as ion-exchange, hydrogen bonding and dipole–dipole could also influence the selectivity of the separation. High concentrations of organic solvents (usually acetonitrile), increase the efficiency of electrospray ionization and the sensitivity of mass spectrometry [2].

The aim of our studies was to evaluate the use of HILIC chromatography coupled with mass spectrometry for selective determination of selenium species. A Luna-CN column with an aliphatic chain and nitrile groups at the end of the chain was used. The composition and pH of the mobile phase were optimized. Single reaction monitoring (SRM) mode was used to determine the concentration of the tested compounds. Selenite (Se(IV)), selenate (Se(VI)), selenomethionine (SeMet) and methyloselenocysteine were analyzed.

The effect of the percentage of acetonitrile in the mobile phase for the retention coefficients (k) of compounds in two pH values (7.0 and 3.2) was investigated. When the concentration of acetonitrile increases, the retention times and retention coefficients of the analytes are higher. At 95% content of acetonitrile in the mobile phase, retention times for all analyzed compounds are longer than 60 minutes. This occurs in both neutral and acidic media. When methanol was used instead of acetonitrile, the retention coefficients were lower. This is due to the fact that in the HILIC acetonitrile is a weaker eluent than methanol. In an acidic medium (pH 3.2) inorganic forms of selenium are protonated and eluted in the dead volume of the column.

Different concentrations of ammonium acetate in the mobile phase change the retention times and shapes of the peaks. Figure 1 shows the chromatograms obtained for selenomethionine.

It was observed that the addition of salt decreased the retention time of SeMet by about 1 minute. When 5 mM ammonium acetate solution was used the signal shape was improved. However, a higher concentration of salt did not improve the signal. For other compounds improvement of the peak quality was also observed only when a low

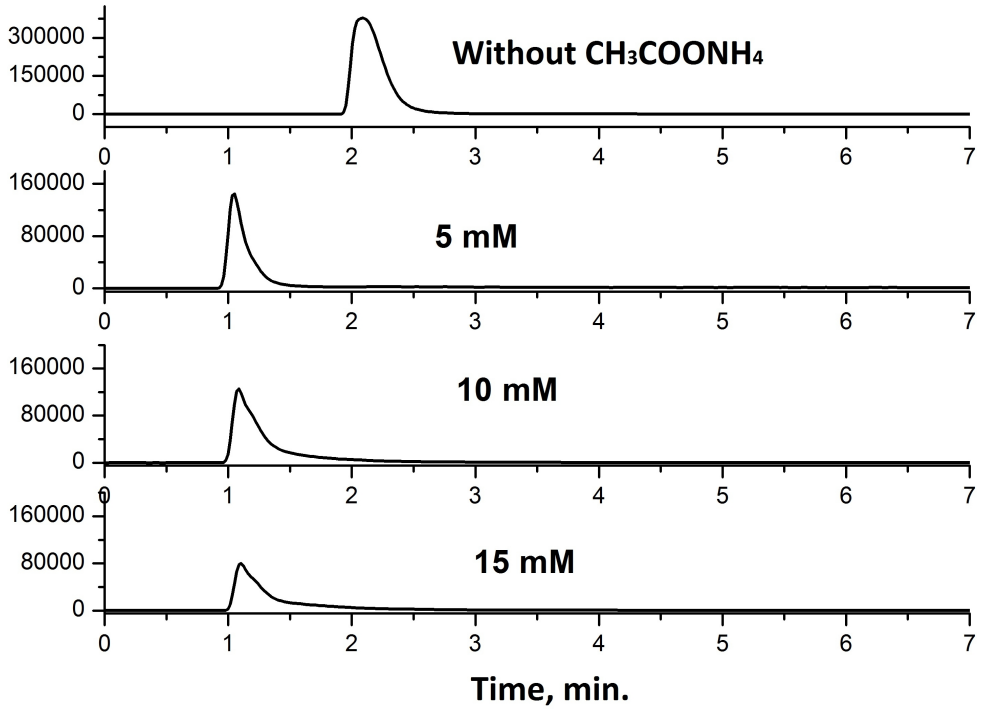

Figure 1: The influence of the concentration of ammonium acetate on the quality of selenomethionine peak. Mobile phase: acetonitrile 70% (v/v).

concentration (5 mM) of ammonium acetate was added. Four selenium species using a Luna CN column and a mixture of acetonitrile and ammonium acetate in different concentrations were analyzed. Isocratic elution was performed. It was found that the addition of ammonium acetate at a concentration of 5 mM may slightly improve the peak shapes. HILIC seems to be a technique with a great potential due to the high content of organic solvents in the mobile phase which can improve the sensitivity of mass spectrometry. This fact allowed compounds to be analysed at a trace level.

Acknowledgment

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B.5 ^{211}At production at the Warsaw Cyclotron

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In February 2011 the first samples of ^{211}At were produced using the internal He^+ beam of the U200P cyclotron at the Heavy Ion Laboratory of the University of Warsaw via the ^{209}Bi(α,2n)^{211}At reaction. Till the end of 2013 nine working weeks of irradiation runs were performed. During these weeks the cyclotron parameters were set and kept for the most efficient internal irradiation conditions. After the irradiation the ^{211}At activity was transported to the Institute of Nuclear Chemistry and Technology in Żerań. The rationale for the ^{211}At production and its chemical investigations was presented in our previous reports [1] and is briefly summarised below.

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 α 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 a few cells in dimension. They are very effective in destroying the small tumours of a few cells in dimension with much lower interaction with surrounding healthy cells, provided that a vector molecule which can effectively seek out the tumour cells is identified and the link between this molecule and the alpha-particle emitter is chemically established.

Currently two irradiations are performed during one working day, the longer one starting in the evening and the shorter one in the morning. The perpendicular, internal cyclotron beam of He^+ irradiates a 100–270 μm thick Bi foil, covered with a 20 μm Al foil and, monitoring the beam intensity, 10 μm Cu foil. More details about the Bi sample preparation were given in Ref. [1]. In favourable cases up to six ^{211}At samples are delivered for the chemical investigations during one working week. After the irradiation the sample activity is determined using a standard dose monitor and the gamma ray spectra are collected on a HPGe counter. Fig. 1 presents an example of such a spectrum, collected recently.

The yield of ^{211}At as a function of the He^+ bombarding energy was determined measuring the beam energy by the production ratio of ^{210}At/^{211}At. The Al was used as an energy degrader. This efficiency is shown in Fig. 2 and is compared with the theoretical curve calculated from the published cross section (σ) and stopping power (S) data using the formula:

$$Y = \frac{HN_A}{zq_eM}\int_{E_{min}}^{E_{max}}\frac{\sigma(E)}{S(E)}dE$$

where: Y — thick target yield, H — target material isotopic enrichment, N_A — Avogadro's number, z — projectile atomic number, q_e — electron charge, M — target atomic mass, S — stopping power, σ — cross sections.
The uncertainties were estimated by the propagation of the measurement uncertainties related to the beam (beam current, energy, etc.) and activities.

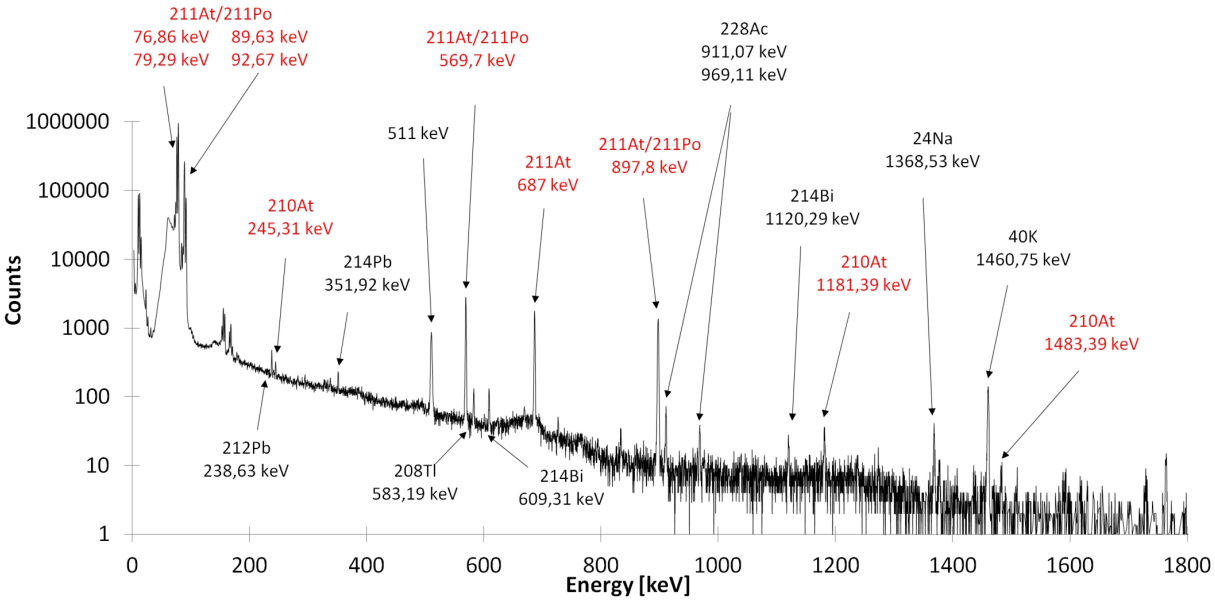

Figure 1: Gamma ray spectrum collected with a HPGe detector of 20 % efficiency placed at 86 cm from the bismuth target, irradiated with a 28.5 MeV He^+ beam of 530 nA intensity during 4.25 h. Measurement time 0.36 h. Beginning of the measurement 1 h after the EOB. The sample activity was 97.5 MBq and the corresponding gamma dose at 30 cm from the sample was 7 µSv/h at EOB.

After intensity and sample purity determination the irradiated samples are transported to the Żerań Laboratory, where the astatine is distilled at 650°C with nitrogen flow of 120 ml/min. and condensed in (PEEK-polyether ether ketone)-capillary trap. The capillary trap is immersed in an ethanol-liquid nitrogen cooling bath 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's irradiation. About 50% of this activity was extracted from the irradiated targets for chemical research.

In the Żerań Laboratory two methods of ^{211}At radiopharmaceutical preparation are investigated. In the first method binding the ^{211}At radioisotope to the substance P, a peptide with high affinity to receptors of glioma cancer cells, is studied, using the N-succinimidyl 3-[*I]iodobenzoate method and the "metal bridge" approach developed in the INCChT laboratory. The obtained radiobioconjugates will be examined for their stability and cell binding affinity. As a research result, it is expected to obtain a radiopharmaceutical for glioma cancer treatment after tumour resection. In the second method silver impregnated nanoparticles of titanium dioxide are used as carriers for ^{211}At. In a recent paper [2] we show that TiO_2/Ag nanoparticles can be successfully prepared using a simple method and can be quickly and easily labelled with ^{211}At. In the following research phase modification of the nanoparticle surface will be tested as well as their attachment to the tumour seeking agent investigated.

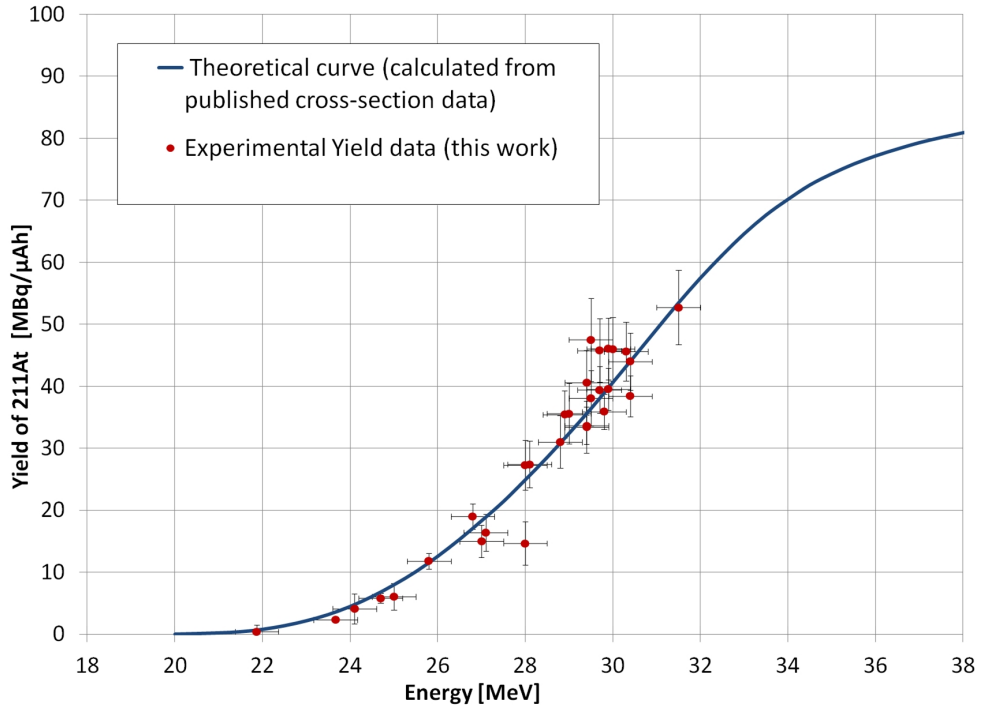

Figure 2: The yield of the ^{211}At production as a function of the He^{+} beam energy.

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B.6 Accelerator production of ^{99m}Tc

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The accelerator route for the production of the most popular radioisotope used in nuclear medicine, ^{99m}Tc, is currently investigated in a number of laboratories all around the world [1, 2]. The rationale for undertaking these researches in general, and in our laboratory in particular, was presented in Ref. [3]. In Warsaw, a consortium of three institutions was established to perform this programme: POLATOM at the National Centre for Nuclear Research, the Heavy Ion Laboratory at the University of Warsaw and the Institute of Nuclear Chemistry and Technology. This consortium is a member of the IAEA Coordinated Research Project [4] with a Research Contract recently extended for a second year of realization and was awarded a 3 years research grant by the Polish funding agency NCBiR (National Centre of Research and Development) [5].

The main activity of our team during the last year consisted in the preparations of materials and equipment for the studies of the ^{100}Mo(p,2n)^{99m}Tc reaction in the energy range between 25 MeV and 8 MeV. The calculations of this and parasitic reaction cross sections by the evaporation codes were also performed.

The natural Mo targets, both thick for estimation of the Tc production yield in a function of beam energy and thin foils for cross section measurement with 'stacked foil' technique were prepared and are presented in Fig. 1 and 2. Similar targets of the isotopically enriched material will be available in 2014.

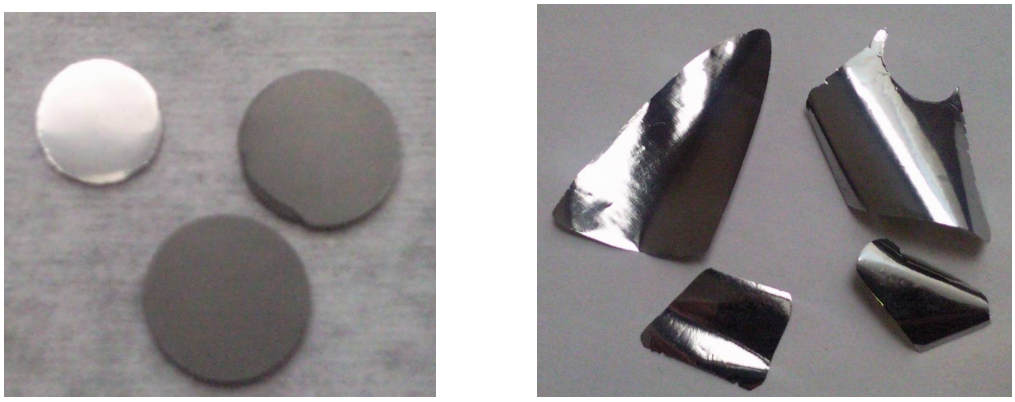

Figure 1: Left: Thick Mo-nat pellets of 500 to 2000 μm with density varying from 55 to 85% of the Mo volumetric mass density. Right: Thin Mo-nat foils (10 μm) prepared by rolling for assembling the "stacked foils" target.

The project of the external irradiation station for solid state targets to be placed on the PETtrace cyclotron beam line is completed and the mechanical construction of this station is well advanced, see Fig. 3. The station will be controlled by the software, based on PLC controller, which has been written by our specialists and is currently implemented.

The targets irradiation with protons in energy range of 16 to 8 MeV will be done in our Laboratory. The irradiations of Mo targets with proton energies above energy available

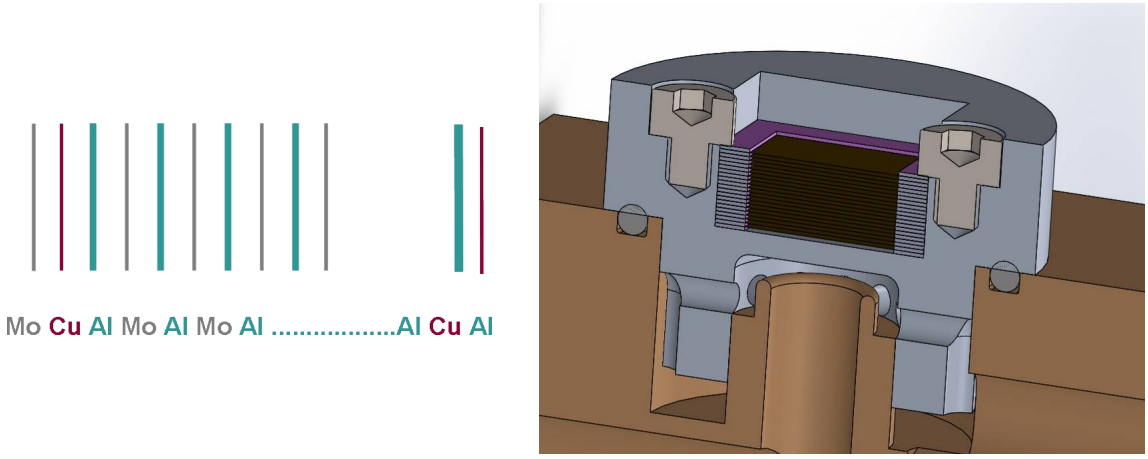

Figure 2: Composition of the stacked foils target (left) and drawing of its water-cooled holder (right).

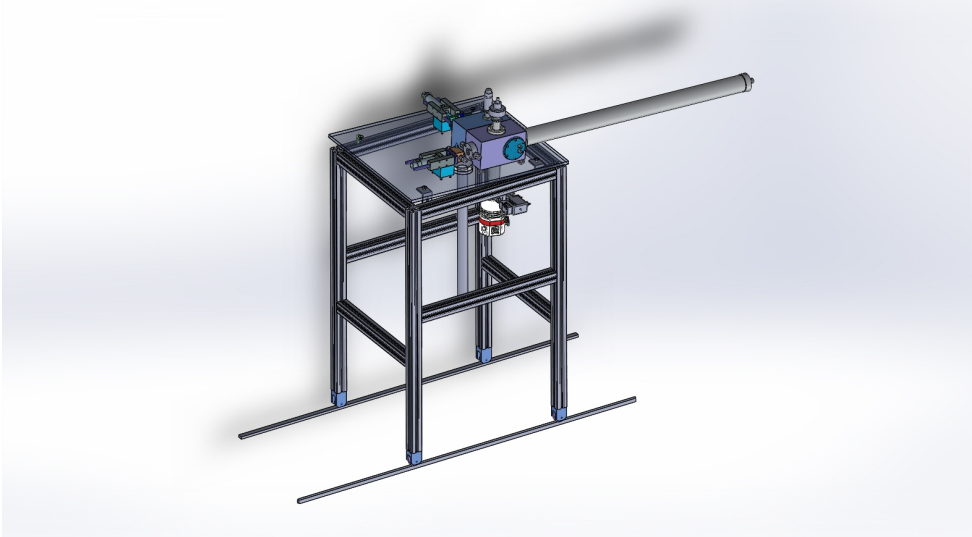

Figure 3: Drawing of the external irradiation station for solid state targets to be placed on the PETtrace cyclotron beam line.

in our PETtrace cyclotron are planned to be performed with proton beam provided by cyclotrons at other centres. The planning of these irradiations is in progress.

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B.7 ILITS experiment: first results

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Introduction

The object of investigation in nanodosimetry is the physical characteristics of the microscopic structure of ionising particle tracks, i.e. the sequence of the interaction types and interaction sites of a primary particle and all its secondaries, which reflects the stochastic nature of the radiation interaction. In view of the future radiation therapy with carbon ions, the ionisation structure of the carbon ion track is of particular interest.

ILITS is part of a European Joint Research Project approved in 2011 with the name "BioQuaRT" [1], which is an acronym for "Biologically weighted Quantities in Radio-Therapy", and which aims to lay the foundations for a new concept of radiation quality that is based on measurable physical characteristics of ionising particle track structure. Concerning experimental nanodosimetry, at present three types of nanodosimeter have been developed that are capable of measuring the track structure of ionising particles in a gas target equivalent to a nanometric site in condensed matter. Two of these nanodosimeters are involved in the ILITS project, namely the NCBJ Jet Counter and the PTB Ion Counter. ILITS is an acronym of "Investigation of Light-Ion Track Structure". The aim of the project is to contribute to the more fundamental investigations of BioQuaRT on the correlation between the characteristics of track structure for different target sizes by carrying out measurements using the PTB Ion Counter and the NCBJ Jet Counter for the same particles and energies. Up to now, measurements have been focused exclusively on carbon ion beams of various energies: during the previous beam time period in January 2013 ionisation cluster size distributions (ICSDs) in 1.2 mbar nitrogen produced by $^{12}C^{6+}$ ions of 45 MeV and 76 MeV were measured with the PTB Ion Counter at beam line A of the HIL cyclotron. As its parent project BioQuaRT, ILITS will last three years and will end in May 2015. This report presents the first results obtained with the PTB Ion Counter.

PTB Ion Counter setup

The PTB Ion Counter [2] detects positive ions created by ionising primary particles passing through or by the sensitive volume. The Ion Counter can work with different gases like propane, nitrogen and others. Within the ILITS experiment, ionisation cluster size distributions are measured in a target volume filled with 1.2 mbar nitrogen gas.

Basically, the setup of the PTB nanodosimeter for accelerator operation consists of two vacuum chambers (see Fig. 1): the scattering chamber (provided by the HIL) and the nanodosimeter itself, separated by a vacuum tight window of a Mylar foil 2.5 µ m in thickness. Both vacuum chambers have their own pumping system and they can be pumped independently. The purpose of the scattering chamber is to reduce the primary particle rate for the nanodosimeter that is inside the second chamber. A small number of primary ions are scattered and enter the second chamber passing through a series of slits after the Mylar foil. The slit before the extraction aperture defines the size of the radiation field, whose width and height above the extraction aperture are about 16 mm

and 2 mm, respectively. The slit before the trigger detector is larger than the radiation field and is needed for electrical shielding of the detector. The primary ions enter the low-pressure interaction chamber and create ions along their tracks; an electrode system extracts the ions from the interaction chamber into an evacuated acceleration stage with an ion detector at its end which registers the ions individually. The height of the sensitive volume is defined by the width of the drift time window, which is applied for the detected ions to be scored. The diameter of the sensitive volume is defined by the diameter of the extraction aperture, equal to 1 mm, and by the efficiency map for ion collection [3]. In a first approximation the geometry of the sensitive volume can be described by a cylinder with a diameter of 0.14 g/cm^2 when the nanodosimeter is operated with 1.2 mbar nitrogen.

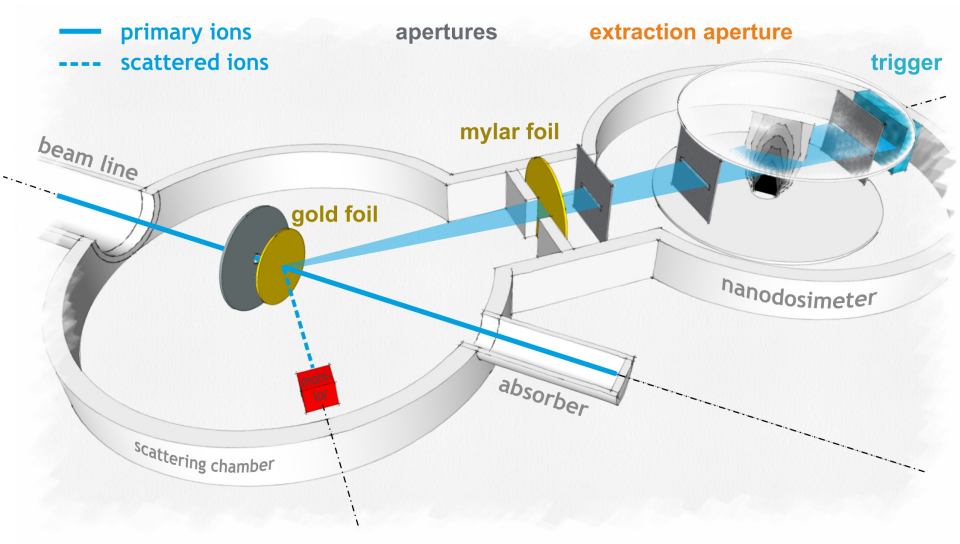

Figure 1: Schematic setup of the PTB nanodosimeter for measurements at an ion accelerator.

For triggering the data acquisition, the PTB Ion Counter uses a position sensitive detector to detect the arrival of the primary ions. This detector, 20 mm in width, records the position of the primary particles with respect to the centre of the sensitive volume. The number of ions collected in the sensitive volume is correlated to the primary particle's position; in this way it is possible to record ICSDs for different impact parameters d of the primary particles with respect to the centre of the sensitive volume without moving the ion counter.

Repeated measurements for a large number of single primary particles of radiation quality Q yield as the final result the relative frequency distribution $P\mu(d)$ of the ionisation cluster size of the detected ions.

First results

Figures 2 and 3 show the data measured with the PTB Ion Counter with 1.2 mbar nitrogen for 45 MeV $^{12}C^{6+}$ ions. Figure 2 shows the ICSDs for selected distances d and (in black) for the total detection area of the position sensitive detector, which corresponds to the ICSD of a larger beam having a geometry defined by the collimating slits. The shape of the cluster size distributions changes with the impact parameter d. It has a peaked shape when the primary particle passes the sensitive volume close to its centre ($d = 0$ mm and $d = 1$ mm), and monotonically decreases with cluster size when the primary particle passes the sensitive volume at larger distances. Figure 3 shows the mean ionisation cluster size,

i.e. the mean value of the ICSD measured at defined impact parameter d, as a function of d. The symmetry with respect to the centre of the sensitive volume is clearly visible. It can be seen that, as expected, the mean value of the ICSD decreases with increasing distance from the sensitive volume.

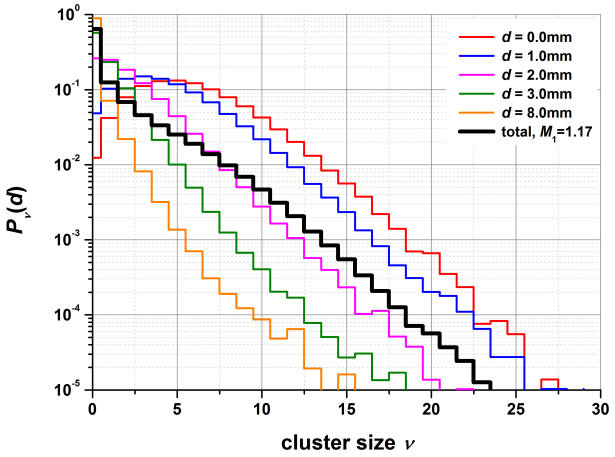

Figure 2: Ionisation cluster size distributions $P_\nu(d)$ at different impact parameters d and for the total detector size measured with the PTB Ion Counter with 45 MeV carbon ions in 1.2 mbar nitrogen.

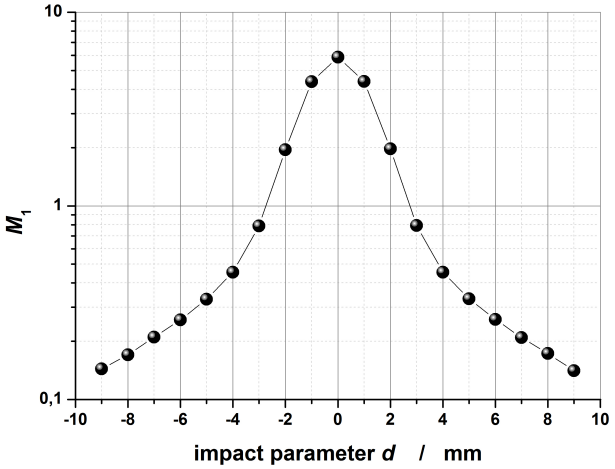

Figure 3: Mean ionisation cluster size M_1 for different impact parameters d measured with the PTB Ion Counter with 45 MeV carbon ions in 1.2 mbar nitrogen.

Acknowledgement

This work was carried out within the EMRP Joint Research Project SIB06 BioQuaRT. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

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B.8 Study of the biological response in cells to high LET radiation

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It has been accepted for a long time that the damaging effects of ionising radiation are the results of the direct ionisation of the cell nuclei. However, in addition to effects in cells directly targeted with heavy ions, there is evidence for non-targeted biological effects in cells that have not been directly irradiated [1, 2]. Non-irradiated cells placed in the neighbourhood of irradiated cells receive some signals influencing their survival, hence the term "bystander effect". The effect induced by irradiated cells and their progeny on neighbouring non-irradiated cells was studied.

The experimental set-up with a horizontal heavy ion beam designed for radiobiological research at the Heavy Ion Laboratory of the University of Warsaw (HIL) was used [3]. In February 2013 Chinese Hamster Ovary cells (CHO-K1) were irradiated with a 0.1 Gy dose of high LET ^{12}C . Immediately after irradiation, the cells were transferred into transwell culture insert dishes to enable a co-culture of irradiated and non-irradiated cells (Fig.1). Since the diameter of the pores in the membrane inserts was 1 μm cells from the membrane and the well shared medium but could not touch each other.

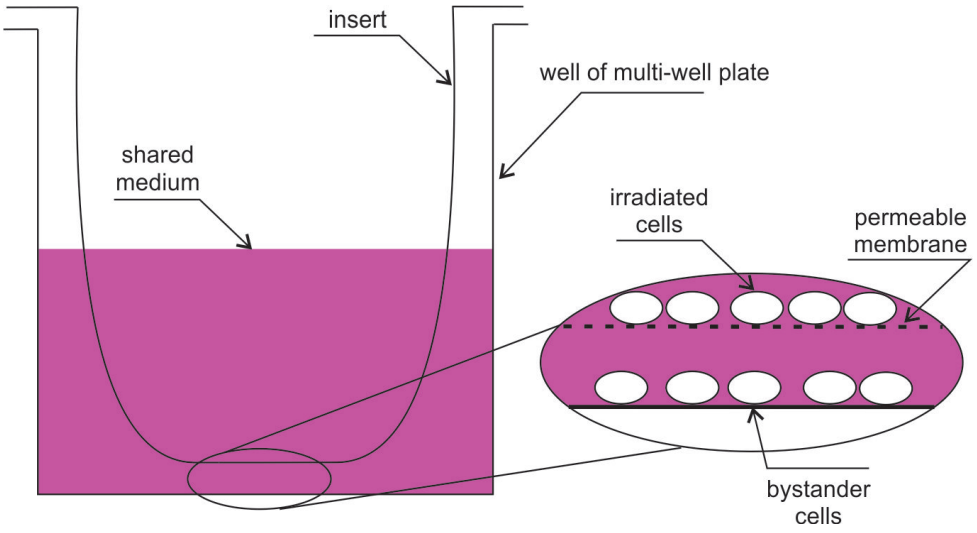

Figure 1: Scheme of transwell culture insert dish with permeable membrane.

To study biological response in cells two compatible radiobiology tests were used: the clonogenic survival assay and the micronucleus assay. The clonogenic survival assay allows

to be analysed the ability of cells to form colonies while micronucleus assay is one of the preferred methods for assessing chromosome damage that can be caused by exposure to ionising radiation [4].

For determination of bystander cell survival, cells were seeded at 150 cells/well, while irradiated cells were plated on membrane of the insert with different densities: 10^3, $5 \cdot 10^3$ and $25 \cdot 10^3$ cells/insert. After 7 days of incubation the medium was removed and the cells were fixed. The surviving fraction of CHO-K1 cells co-cultured with cells irradiated with ions was close to 1 within standard errors, regardless of the density of the irradiated cells plated on the inserts.

The frequency of micronuclei (MN) in binucleated cells (BNC) was scored according to the criteria proposed by Fenech [5]. The micronucleus assay results revealed that the frequency of MN in bystander cells co-cultured with irradiated cells was not significantly different than in the control cells [6].

Summarising the collected data, in the studies described here the bystander effect was not observed. The surviving fraction of cells co-cultured with irradiated cells was not reduced and the number of MN in 1000 BNC was not higher than in the control cells.

It is possible that the specific cell line, experimental design or the medium supplements may be critical for inducing bystander effects. To test our hypothesis, additional experiments with different cell lines are necessary.

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B.9 Jet Counter — experiment with carbon ions at HIL

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Carbon ion therapy is the therapy of choice for tumors because of the well-defined carbon ion range. A further benefit of carbon ions is that their biological effect is most pronounced in the Bragg peak and in the distal edge close to the Bragg peak. This enhanced biological effectiveness is related to the ionization structure of the carbon ion track at the nanometre level. In view of future radiation therapy with carbon ions, the ionization structure of the carbon ion track at the nanometre scale is of particular interest.

The Jet Counter [1] is capable of measuring the track structure of ionizing particles in a gas target equivalent to a nanometric site in condensed matter. These experiments —- namely the measurements of the ionization cluster size distribution, ICSD, created by carbon ions in a simulated nanometre sized (SNS) nitrogen volume were carried out at the HIL accelerator using 45 MeV and 76 MeV carbon ions. For more technical details of Jet Counter see Ref. [2].

The ICSDs for carbon ions of 45 MeV and 76 MeV were measured in N_2 for two cavity sizes with 0.16 μg/cm^2 and 0.32 μg/cm^2 diameters. The results are presented in Figures 1 and 2. These results are compared with the experimental data measured by the PTB group with the Ion Counter [3]. The ICSD results for carbon ions of 45 MeV measured by PTB Ion Counter [4] for cavity size have been compared with measurements by NCBJ for cavity size. The results of such a comparison are seen in Figure 3. It has been shown that the ICSD spectra measured by theJet Counter can be matched with the spectra of PTB Ion Counter by changing the gas cavity size. It has been shown that the effective diameters D of gas cavities of the two gas nanodosimeters which differ with the efficiency of single ion η collection are related by: $h_1 D_1 = h_2 D_2$. Further investigation is needed to elucidate the differences in ICSD spectra from both systems, especially for a larger cluster size region.

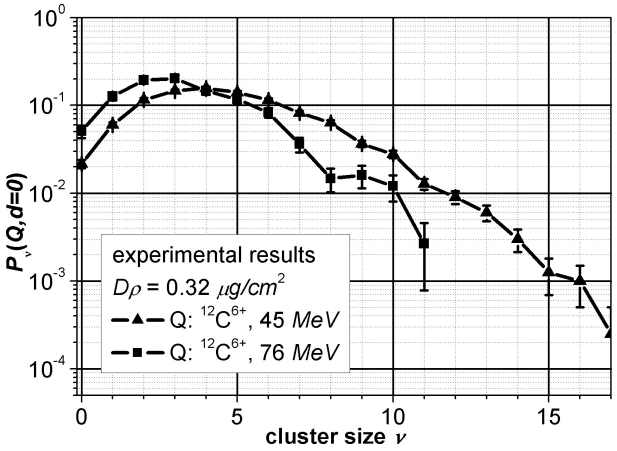

Figure 1: Ionization cluster size distributions produced by 45 MeV and 76 MeV carbon ions in 0.16 μg/cm^2 nitrogen nanometric target. NCBJ Jet Counter.

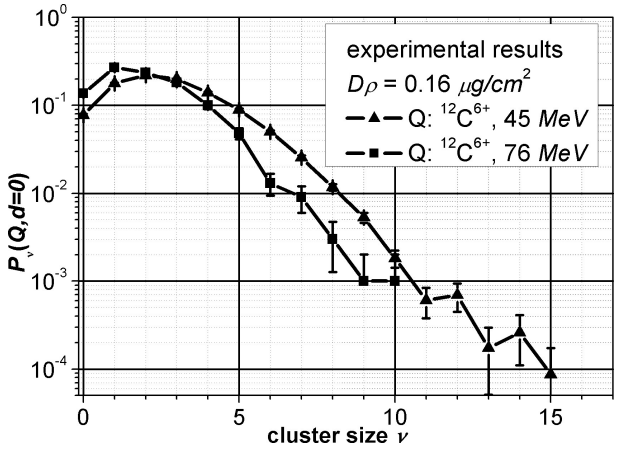

Figure 2: Ionization cluster size distributions produced by 45 MeV and 76 MeV carbon ions in 0.32 μg/cm^2 nitrogen nanometric target. NCBJ Jet Counter.

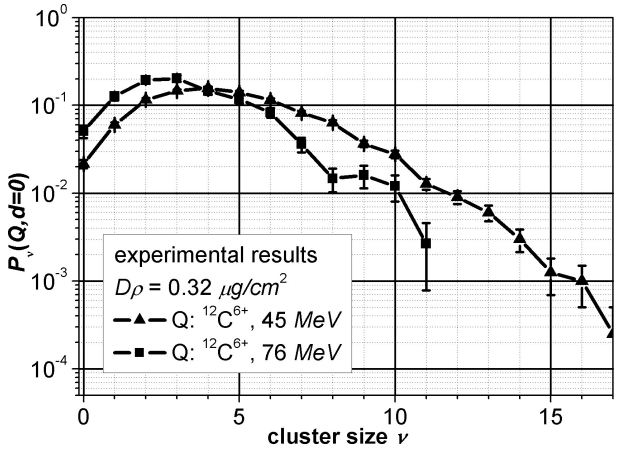

Figure 3: The comparison of ICSD spectra measured by the PTB Ion Counter with these measured with the NCBJ Jet Counter. Comparison performed for 45 MeV carbon ions in different targets area densities (see figure).

Acknowledgements

This work was carried out within the EMRP Joint Research Project SIB06 "BioQuaRT". The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

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Part C

Nuclear physics experiments at HIL

C.1 Study of the K-isomer in ^{184}Pt by electron and gamma spectroscopy

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Violation of the K selection rule for electromagnetic transitions in nuclei, in spite of being a subject of extensive investigations, is still an actual problem [1–3]. Electron-gamma coincidence measurements provide a powerful method to study this phenomenon.

The electron spectrometer (ULESE) for "in-beam" measurements designed and constructed at the University of Łódź is characterized by high efficiency up to 9% at an energy of 300 keV, good energy resolution (about 0.5% at 1 MeV) and, importantly, good suppression of delta electrons, positrons and photons emitted by the target [4]. Magnetic fields were used in two different layouts: perpendicular and parallel to the axis of the spectrometer, which is orthogonal to the beam line. The target is in the area where the vector of the magnetic field produced by a set of four square-shaped plate magnets is generally perpendicular to the initial direction of the emitted electrons or positrons. Conversion electrons leaving the target are bent towards the silicon detector; the positrons — in opposite directions and are eliminated. Electrons emitted from both sides of the target (forward and backward) can reach the detector after transmitting them by magnets in the form of coaxial rings which produce a longitudinal magnetic field. A significant reduction of delta electrons is achieved by suitable geometry of the magnetic field and the special shape of the target holder. The 16-segmented Si-detector is used for measuring the electron energy.

The conversion-electron spectrometer together with the EAGLE array [5] was successfully used to study the following reaction: ^{14}N + ^{175}Lu in which ^{184}Pt nuclei were mainly produced. The main goal of the measurement was to determine multipolarities of the gamma transitions de-exciting the $I^\pi = K^\pi = 8^-$ isomeric state in ^{184}Pt where the violation of the K selection rule for electromagnetic transitions is observed. These nuclei generally have a prolate shape and they are excellent objects to study this phenomenon.

The experiment was performed in electron-γ and γ-γ coincidence modes. The gamma and electron spectra gated by chosen gamma transitions from ^{184}Pt collected during the experiment are presented in Fig. 1.

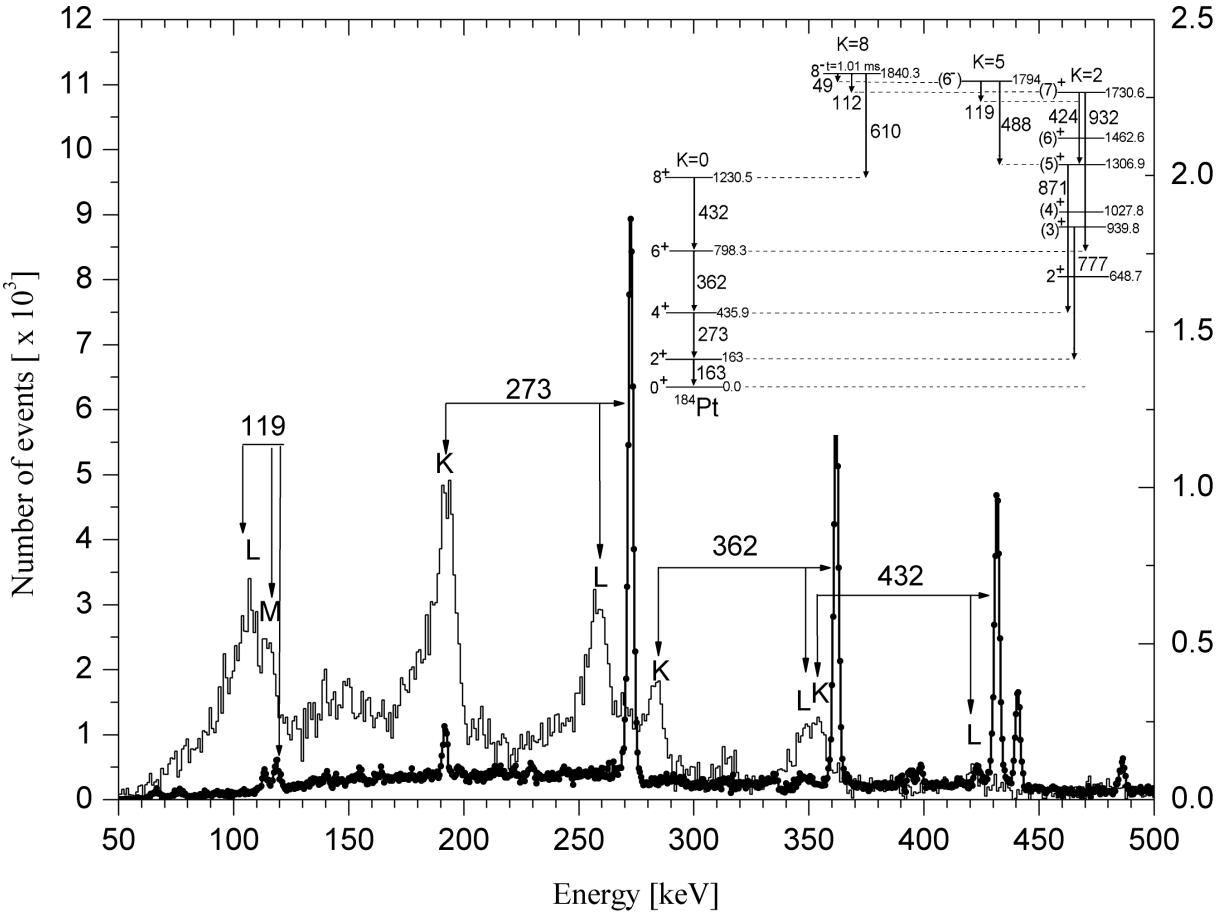

Figure 1: The electron and gamma spectra gated by the gamma transition at 163 keV are denoted by the solid line and the solid line with symbols, respectively. The partial decay scheme of the isomeric state in ^{184}Pt is presented in the insert.

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C.2 DSA lifetime measurements in ^{122}Cs — search for the chiral phase transition

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In the last few years many theoretical papers (see [1, 2] for instance) have called attention to odd-odd nuclei in the mass $A = 130$ region. In the quoted papers, a new phenomenon — spontaneous chiral symmetry breaking — was predicted and explored. This phenomenon is connected with fundamental rules of quantum mechanics, where time-reversal symmetry plays a significant role. Our previous DSA experiments (for example see Ref. [3]) have proven that the U200P cyclotron together with the EAGLE [4] array provides excellent conditions for detailed exploration of the nuclear chirality phenomenon. These previous lifetime measurements of the chiral nuclei made a significant contribution to the study of this phenomenon by providing the first experimental confirmation of spontaneous time-reversal (also called chiral) symmetry breaking. Although there are only a few nuclei so far whose properties meet all the theoretical predictions of strong chiral symmetry breaking the chirality phenomenon seems to be well established.

The goal of the experiment was to search for the phase transition between two configurations of the nucleus: the configuration where the time-reversal symmetry is conserved and that where the symmetry is spontaneously broken. It is expected that the transition between the two configurations happens rapidly as a function of total angular momentum at some critical rotational frequency. We expect characteristic M1 and E2 chiral γ-selection rules along the partner bands of ^{122}Cs above the critical frequency and their absence below. The critical frequency is expected around $I = 18\hbar$ in ^{122}Cs. This expectation is based on the energy staggering, see Fig. 1. It has been suggested in Ref. [5] that such an energy staggering should not appear in the chiral scenario. For lifetime measurements in the ^{122}Cs nucleus we used the EAGLE array equipped with 15 anti–compton spectrometers with around 70% efficiency each. The excited states belonging to partner bands were populated in the ^{109}Ag(^{16}O,3n)^{122}Cs reaction at a beam energy of 73 MeV. We used a 30mg/cm2 thick ^{109}Ag target. The ^{122}Cs cross section production reached around 80 mb at 73 MeV ^{16}O beam energy. Based on a COMPA code calculation we expect the yrast states in the I=10-22 region to be well populated.

The data are still being analysed. Lifetimes of the excited levels will be determined by means of line-shape analysis of the Doppler disturbed gamma peaks. We used this technique in previous measurements [6, 7]. Data analysis will be performed with the

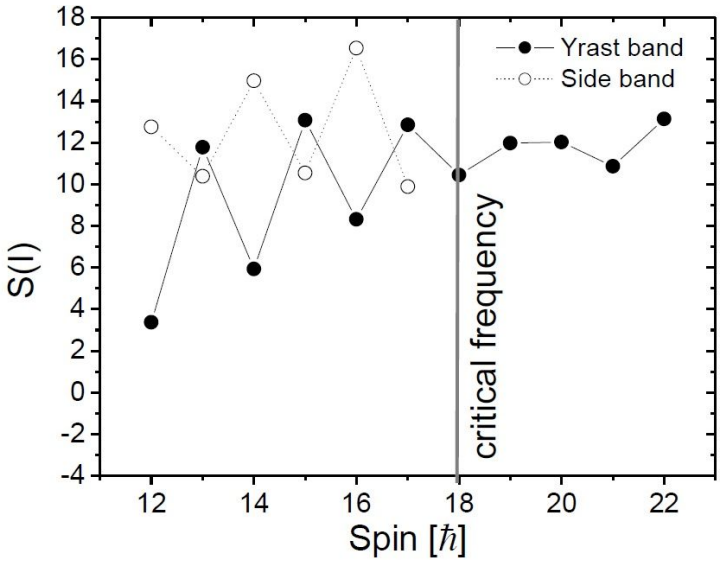

Figure 1: Energy levels staggering $S(I) = E(I) - E(I-1)/2I$ in the chiral partner bands of ^{122}Cs

help of COMPA, GAMMA and SHAPE computer codes developed by A. Pasternak. Phenomena affecting determination of the lifetimes, like the side-feeding process, are taken into account in the data analysis procedure. In this way all systematic uncertainties are incorporated in the final uncertainties of the level lifetimes, see [8].

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C.3 Investigation of the incomplete fusion reaction mechanism in the ^{20}Ne + ^{122}Sn system through experimental determination of the relative cross sections

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The mechanism of the ^{20}Ne + ^{122}Sn reaction was investigated through the analysis of singles gamma spectra measured at a ^{20}Ne beam energy of 150 MeV [1, 2]. This experiment [4, 5] was performed using the EAGLE [3] spectrometer equipped with 12 Compton-suppressed HPGe detectors. The acquired data were compared with results of a simulation performed with the COMPA program, a Monte-Carlo code based on the statistical model.

Nine channels of the ^{122}Sn(^{20}Ne,xnypzα) reaction were identified based on gamma-radiation observed in the spectra. To ensure that a chosen gamma-line is indeed emitted from a residual nucleus of the studied reaction and not a product of long-lived isotope activity the macro-structure of the beam produced by the HIL U200-P cyclotron was used. Among the identified nuclei were the following isotopes: ^{136}Nd, ^{135}Nd, ^{134}Nd that arose from the compound nucleus ^{142}Nd through emission of neutrons only; ^{136}Pr, ^{135}Pr, ^{134}Pr that are products of single proton and several neutrons emission; ^{133}Ce, ^{132}Ce, ^{131}Ce that could be produced by the emission of two protons and several neutrons or an alpha particle and neutrons.

The relative cross sections were determined from the intensity of selected gamma-ray lines which correspond to the feeding of the ground states. Because of the complexity of the spectra obtained the relative cross section was evaluated only for five of the identified products. Also, the use of a single g.s. feeding transition was not possible in every case. If such a problem occurred the intensity was estimated on the basis of other lines emitted from a given nucleus. Part of the singles gamma spectrum is shown in Fig. 1.

Before comparing the experiment with the simulation, the cross sections were normalised to the data for ^{136}Nd. The normalisation was performed for two reasons. One being the fact that in the studied reaction it can only be produced as a result of a complete fusion between ^{20}Ne beam and ^{122}Sn target (through the emission of 6 neutrons from the compound nucleus ^{142}Nd). The second is the fact that the intensity of the g.s. feeding transition for this particular nucleus was obtained with better accuracy than for the other evaluated neodymium isotope: ^{134}Nd.

With the assumption that the statistical model based COMPA code correctly reproduces cross sections for the products of complete fusion the results of the experiment analysis and simulation for the ^{122}Sn(^{20}Ne,xnypzα) reaction channels: *6n, 8n, 5n1α, 6n1α, 7nα* were compared as shown in Fig. 2. The difference between the theoretical extrapolation and experiment is very noticeable for all of the isotopes produced with α particle emission from the compound nucleus: for ^{133}Ce it is about 2.5 times larger, for ^{132}Ce — 1.6 times and for ^{131}Ce — 6.3 times. This could be interpreted as a sign of a huge contribution of incomplete fusion with α particle emission before compound nucleus formation and needs to be investigated further.

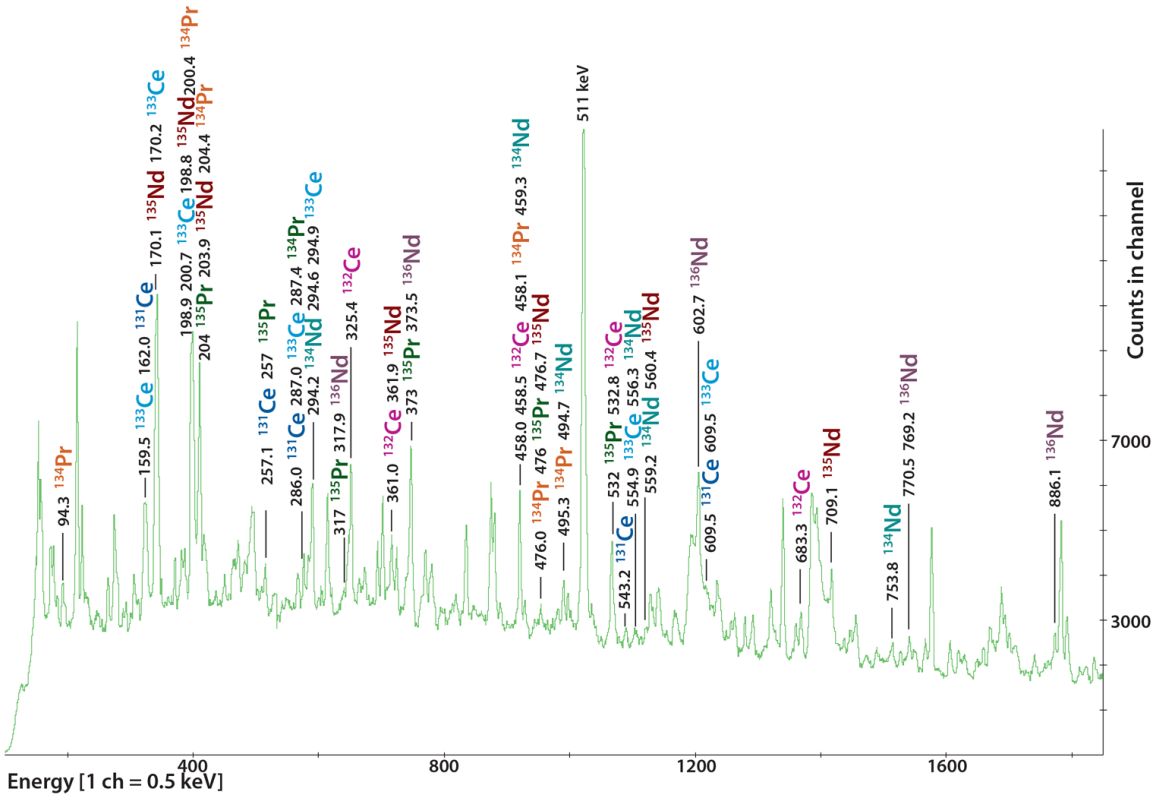

Figure 1: Singles γ-ray spectrum from the ^{20}Nd + ^{122}Sn reaction. Transitions identified in the analysis are marked in the plot.

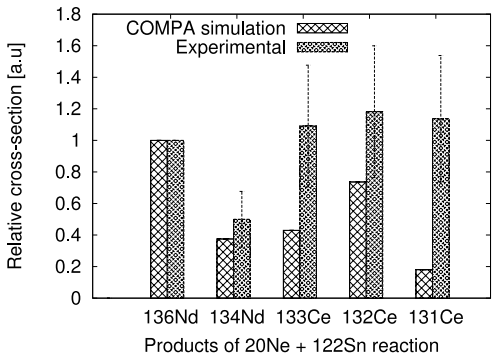

Figure 2: Relative cross sections for selected channels of the ^{20}Ne + ^{122}Sn reaction – a comparison of the experimental data and theoretical simulation with the statistical model of the complete fusion. Data were normalised to the results for ^{136}Nd.

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C.4 The E2/M1 mixing ratios in the chiral bands of ^{124}Cs

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The mixing ratios $\delta(E2/M1)$ have been measured for γ transitions belonging to the chiral partner bands in ^{124}Cs. In this experiment excited states of ^{124}Cs (see Fig. 1 and Ref. [1]) were populated in the ^{114}Cd(^{14}N, 4n)^{124}Cs reaction at a beam energy of 73 MeV. The ^{14}N beam was provided by the U200P cyclotron at the Heavy Ion Laboratory of the University of Warsaw. Twelve ACS HPGe detectors from the EAGLE array [2] registered γ–γcoincidences. For DCO analysis the following detectors were used: one detector at 79° (with respect to the beam direction), one detector at 101° and 8 detectors placed in the 37° and 143° rings.

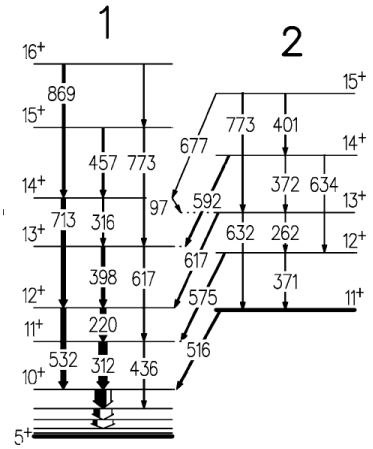

Figure 1: Chiral partner bands in the ^{124}Cs nuclei [1].

Due to the low statistics and because of the differences in detector efficiencies we used, instead of the standard definition of the RDCO ratio [3] we use the RNDCO ratio defined as:

$$RN_{DCO}^{exp} = \frac{\sum_{ij} N(\gamma_1 \to \theta_i, \phi_i; \gamma_2 \to \theta_j, \phi_j)}{\sum_{ij} N(\gamma_1 \to \theta_j, \phi_j; \gamma_2 \to \theta_i, \phi_i)}$$

$$RN_{DCO}^{theory} = \frac{\sum_{ij} W(\gamma_1 \to \theta_i, \phi_i; \gamma_2 \to \theta_j, \phi_j) \cdot \epsilon_{\gamma_1}(\theta_i, \phi_i) \cdot \epsilon_{\gamma_2}(\theta_j, \phi_j)}{\sum_{ij} W(\gamma_1 \to \theta_j, \phi_j; \gamma_2 \to \theta_i, \phi_i) \cdot \epsilon_{\gamma_1}(\theta_j, \phi_j) \cdot \epsilon_{\gamma_2}(\theta_i, \phi_i)}$$

where:
γ_1 and γ_2 — coincidence photons,
θ and ϕ -– detector position in the EAGLE array,
$N(\gamma_1 \to \theta_i, \phi_i; \gamma_2 \to \theta_j, \phi_j)$ — number of coincidence events when γ_1 was registered in i-th detector whereas γ_2 was registered in j-th detector,

$W(\gamma_1 \to \theta_i, \phi_i; \gamma_2 \to \theta_j, \phi_j)$ — DCO angular correlation function,
$\epsilon(\theta, \phi)$ — efficiency of the detector located at θ, ϕ in the EAGLE array.

The spin alignment parameter δ/I (which is the argument of the angular correlation function W) was taken as 0.3 in agreement with the results of similar reactions (see e.g. Fig. 2 of Ref [4]). Preliminary results are collected in Table 1. In Fig. 2 the example of analysis for the $15 - 14 - 12$ cascade (band 1 in Fig. 1) is presented.

$E\gamma$ (keV)	$I_i^\pi \to I_f^\pi$	bands	δ	multipolarity
220	$12^+ \to 11^+$	$1 \to 1$	$-0,21 \pm 0.03$	5%E2+95%M1
316	$14^+ \to 13^+$	$1 \to 1$	$-0,17 \pm 0.05$	3%E2+97%M1
398	$13^+ \to 12^+$	$1 \to 1$	$-0,23 \pm 0.03$	5%E2+95%M1
457	$15^+ \to 14^+$	$1 \to 1$	$-0,14 \pm 0.04$	2%E2+98%M1
617	$13^+ \to 12^+$	$2 \to 1$	$-0,14 \pm 0.06$	2%E2+98%M1
713	$14^+ \to 12^+$	$1 \to 1$	∞	100% E2

Table 1: Mixing ratios E2/M1 measured in the present experiment.

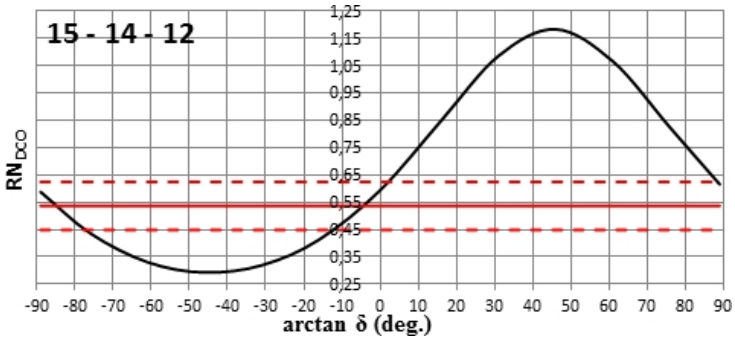

Figure 2: Comparison of the experimental value of RN_{DCO} with theoretical predictions for the $15 - 14 - 12$ cascade in band 1. The geometry of the DCO experiment: one detector at 79° against 4 detectors from the 37° ring. The alignment parameter δ/I was taken as 0.3. The horizontal line denotes the experimental value, while the red curve presents the theoretical prediction.

It follows from Table 1 that studied $\Delta I = 1$ transitions have nearly pure M1 character (the E2 component is of the order of 3%). This value can be compared with the results of the Core–Particle–Hole Coupling model where the electromagnetic properties of chiral bands were calculated [5]. The result ($\delta^2 \approx 1\%$) is in reasonable agreement with our experimental value.

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C.5 The E3/M2 mixing ratio of the $8^- \rightarrow 6^+$ transition in ^{130}Ba measured using the γ-γ angular correlation method

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The $\delta(E3/M2)$ mixing ratio for the $8^- \rightarrow 6^+$ transition (Fig. 1) accompanying decay of the isomeric state ($I^\pi = 8^-$, $E_{exc} = 2475$ keV, $T_{1/2} = 9.4$ ms) in the ^{130}Ba nucleus was studied in this experiment using the γ-γ angular correlation method.

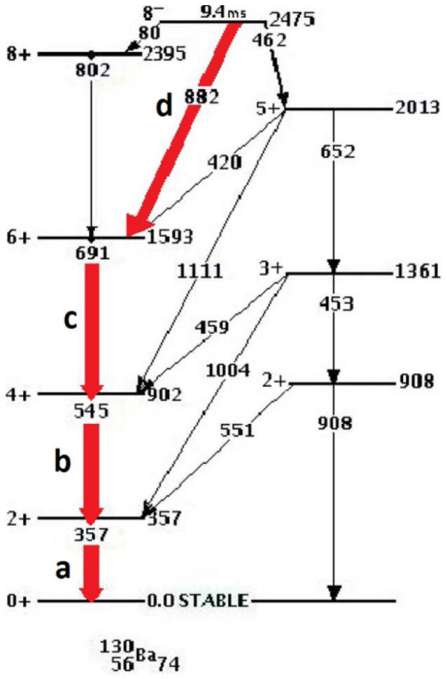

Figure 1: The decay of the $I^\pi = 8^-$ isomeric state in ^{130}Ba [2]. Red arrows mark the transitions studied.

The isomeric state in ^{130}Ba was populated via the ^{122}Sn(^{12}C, 4n)^{130}Ba reaction at a beam energy of 68 MeV. The EAGLE array [1] consisting of 12 Compton – suppressed HPGe detectors was used for collecting γ-γ coincidences. More experimental details were presented in Ref. [2].

Figure 1 shows the decay scheme of the isomeric state in ^{130}Ba [3]. The strong transitions "a", "b", "c" and "d" were used to study the directional angular correlation of the "d" photon (the $8^- \rightarrow 6^+$ transition, $E\gamma = 882$ keV) with "a", "b" and "c" photons. This correlation was normalized to well known correlations between "a", "b" and "c" photons

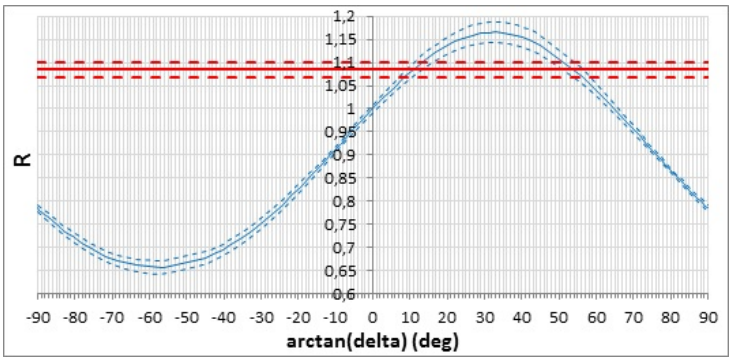

Figure 2: Comparison of the R_{exp} ratio (red horizontal lines) with the R_{theory} ratio (blue curves).

($6^+ \rightarrow 4^+ \rightarrow 2+ \rightarrow 0^+$ cascade). It is worth noting that the "a", "b" and "c" transitions are pure E2 stretched transitions, therefore these correlations are identical.

The experimental ratio R_{exp} defined as:

$$R^{exp} = \frac{N_{da}(\theta_1)}{N_{da}(\theta_2)} / \frac{N_{ba}(\theta_1)}{N_{ba}(\theta_2)}$$

was measured. In this equation: θ is the angle between two detectors ($\theta_1 = 180°$ and $\theta_2 = 71°$ or $\theta_2 = 109°$), N_{da} — number of coincidences between "a" and "d" photons with a gate set on the "d" line. We received 12 results for different detector combinations and different lines belonging to the $8^- \rightarrow 6^+ \rightarrow 4^+ \rightarrow 2^+ \rightarrow 0^+$ cascade. The preliminary analysis gave the average value $\langle R_{exp} \rangle = 1.09(2)$. The theoretical value R_{theory} (being a function of $\delta(E3/M2)$) is equal to:

$$R^{theory} = \frac{W_{da}(\theta_1)}{W_{da}(\theta_2)} / \frac{W_{ba}(\theta_1)}{W_{ba}(\theta_2)}$$

where $W_{da}(\theta)$ is the angular correlation function for the "d" and "a" photons [4].

A comparison of the experimental value (R_{exp}) with the theoretical one (R_{theory}) gave two solutions for the $8^- \rightarrow 6^+$ transition (see Fig. 2), namely:$\delta_1(E3/M2) = 0.19(10)$ and $\delta_2(E3/M2) = 1.4(3)$. The first solution suggests that the multipolarity of the 882 keV transition is M2 with a small ($\approx 3\%$) admixture of E3 transition while the second solution implies a strongly mixed E3/M2 transition (35%M2+65%E3).

The value of $\delta^2(E3/M2) = 0.5(4)$ is known from Ref. [2] where the ICC was measured. The relatively large error does not allow the determination which solution (δ_1 or δ_2) is the proper one. One may expect that the new improved version of the electron magnetic spectrometer (ULESE [5]) coupled to the EAGLE array will allow ICC to be determined with sufficient precision to solve this problem.

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C.6 Indirect study of the astrophysical ^{16}O+^{16}O fusion reaction by the Trojan Horse Method

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The ^{16}O+^{16}O fusion reaction is important in terms of the explosive oxygen burning process during the late evolution stage of massive stars. The astrophysical S-factor of such a heavy-ion fusion strongly depends on the energy at corresponding stellar temperatures far below the Coulomb barrier. There are large discrepancies between different experiments [1–4] and among theoretical predictions [5, 6], and there is a lack of data below $E_{\rm cm} = 7$ MeV. We aimed to determine the excitation function of the most important exit channels, α+^{28}Si and p+^{31}P, of the ^{16}O+^{16}O reaction at stellar energies by means of the Trojan Horse Method (THM) [7]. This is an indirect technique with the advantage of measuring an astrophysical two-body reaction approaching the Gamow-peak energy region through a three-body reaction performed at a beam energy which allows us to overcome the Coulomb barrier in the reaction entrance channel as well as the electron screening due to atomic electrons. At the Heavy Ion Laboratory, we performed THM measurements via the ^{16}O(^{20}Ne, α^{28}Si)α and ^{16}O(^{20}Ne, p^{31}P)α three-body reactions in the centre-of-mass energy range below 15 MeV approaching 8 MeV with a ^{20}Ne beam at 45 MeV, searching the quasi-free condition with coincident pairs of α-α and α-proton within a momentum range of the spectator $\alpha < 100$ MeV/c. This measurement was mainly for normalisation purposes of the THM by comparing to the better-known excitation functions in the higher part of this energy range, in advance of a lower energy measurement below 10 MeV to be done also by the THM in a further experiment.

The experiment was performed in the ICARE experimental chamber on Beam Line D of the experimental hall of the Heavy Ion Laboratory. A ^{20}Ne^{3+} beam was provided from the $K = 160$ cyclotron at 45 MeV with an average intensity of around 20 enA on target on average, and the production run was performed for about 180 hours in total. The experimental setup is illustrated in Fig. 1. For the beam collimator, a ϕ6-, a ϕ3- and a ϕ2-mm hole are laid straight on the beam axis within a distance of 380 mm upstream, respectively. We utilised WO_3 evaporated onto a Au backing as a solid oxygen target with a typical thickness of 116 mg/cm^2 of WO_3 and 193 mg/cm^2 of Au. We also arranged CH_2, CD_2 and Au targets on the target ladder for calibration purposes and a system check. Three silicon beam monitoring detectors were installed at 30°. For the reaction product

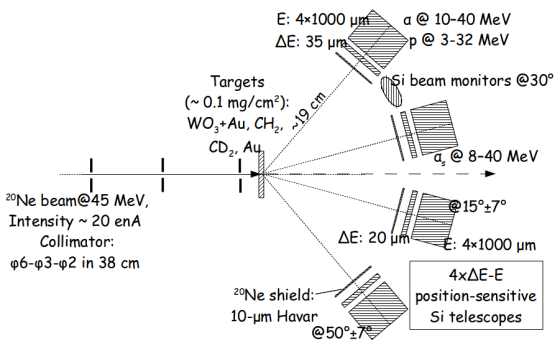

Figure 1: Schematic view of the experimental setup.

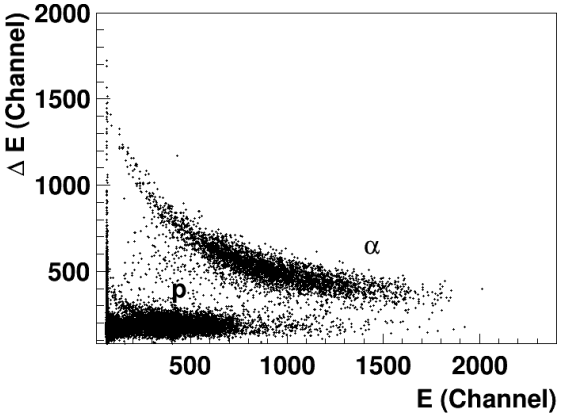

Figure 2: Example of the ΔE-E particle identification of the 15° telescope.

measurement, we mounted four ΔE-E silicon telescopes symmetrically with respect to the beam axis at 15° and 50°. The thickness of each ΔE layer at 15° was 20 μm in order to measure low-energy spectator α, while that at 50° was 35 μm focusing on higher energy (up to 40 MeV) α of the coincidence pair. Each E layer consisted of a stack of four 1-mm-thick silicon detectors for high-energy protons up to 32 MeV. The first E layer was position-sensitive by charge division, and the distances from the target were typically 190 mm. We placed a 10-μm Havar foil in front of each ΔE layer in order to prevent the detectors from beam scattering on W and Au in the target.

The beam monitors were calibrated using a single energy peak of a ^{241}Am α source and the linearity was checked with a pulsar. We are currently dealing with some variations of the gain among the detectors and among the runs. The angle and the energy of the PSDs will be well calibrated with the α source and proton scattering data with slotted masks mounted in front of each telescope face to observe defined angles and kinematically known energies. The $d(^{20}\mathrm{Ne}, p)^{21}\mathrm{Ne}$ reaction with the CD_2 target was also helpful for the calibration as it shows at least 7 kinematic loci corresponding to the excited states of ^{21}Ne. From the ΔE-E method, most of the events were well identified as either proton or α as shown in Fig. 2. The total count rate of the valid coincident events of α-α and α-p pairs was about 0.013 pps/pnA in the whole energy region, while we expected it one order of magnitude higher before the experiment. This discrepancy may originate from the unknown three-body reaction cross section. Further data analysis is in progress.

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C.7 Identification of the $^{16}O + ^{208}Pb$ reaction products

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The products of the $^{16}O + ^{208}Pb$ reaction at 85 and 90 MeV of beam energy were studied in order to observe the isomeric decays also in the region of neutron-rich nuclei. This reaction was already successfully employed e.g. by Astier et al. [1] to study high spin states in $^{119-126}Sn$ isotopes. The $^{16}O + ^{208}Pb$ reaction leading to the compound nucleus ^{224}Th at beam energies of 85 and 90 MeV was investigated with the OSIRIS and EAGLE arrays equipped with 12 and 16 HPGe Compton suppressed spectrometers in two experiments, respectively. The beam was provided by the cyclotron of the Heavy Ion Laboratory, University of Warsaw. In the OSIRIS experiment the 1 mg/cm^2 ^{208}Pb target was backed by 23 mg/cm^2 of ^{197}Au. The backing was thick enough to stop the recoil nuclei produced in the reaction. In the EAGLE experiment a $^{16}O^{+3}$ ion beam with energy of 90 MeV bombarded ^{208}Pb target with thickness of about 6 mg/cm^2. Taking advantage of the beam pulse structure of the HIL cyclotron one could measure the γ-γ coincidence spectra in off-beam and in-beam modes. The spectra measured at the beginning and at the end of the beam-off period show the existence of isomers in the time region of ms and several tens of microseconds. In order to identify isomeric states in the fission fragments Si detectors were used to trigger the EAGLE array and isolate the delayed γ-ray cascades. Delayed γ rays observed in the beam-off region are due to beta decays of the long-lived states (often with high spins) of fission fragments produced, as well as from directly produced isomers.

In the reaction considered at least about 80 products of fission were created. The relative yields for various reaction channels were deduced from the intensity of the γ-γ coincidence peaks. The most intensely populated were isotopes of $^{108,110,112}Pd$, $^{98,100}Mo$ and $^{118,120,122}Sn$. There are still several delayed γ rays which are very difficult to ascribe to a proper nucleus and this subject will be studied in forthcoming experiments. Several n-rich nuclei were also observed, and some of them are in the scope of planned measurements with higher statistics.

In the off-line analysis the sorting procedures were based on M. Kowalczyk's [2] multi-purpose program, while multi-gated γ-γ coincidence spectra were analysed with the RADWARE package [3].

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C.8 Search for the $h_{11/2}$ isomer in the ^{105}Ru nucleus produced in the ^{16}O + ^{208}Pb induced fission reaction

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The fission products of the ^{16}O+^{208}Pb reaction were studied in order to establish the properties of their excited states especially associated with isomeric behaviour. The detector array equipped with 12–16 Compton suppressed HPGe detectors, located at the Heavy Ion Laboratory (HIL) of the University of Warsaw was employed. The existence of a new $h_{11/2}$ isomer in the ^{105}Ru nucleus is considered. The region of the neutron rich nuclei with $A \approx 80 - 130$ is expected to possess rich isomerism due to the simultaneous existence of high and low j-orbitals in the low energy structure, i.e. $2p_{1/2}$, $1g_{9/2}$ for protons and $1g_{7/2}$, $3s_{1/2}$, $2d_{3/2}$, $1h_{11/2}$ for neutrons. The collective nuclear structure aspects also favour isomerism in this region [1].

Fig. 1 displays an example of the low energy part of the γ-γ coincidence spectra measured at the beginning and at the end of the beam-off period showing the existence of isomers in the time region of ms and several tens of μs. Inspecting Fig. 1 one can see many delayed γ rays, among them lines belonging to ^{105}Ru nucleus, suggesting the existence of an isomeric state at the 209 keV level energy. The level scheme based on the present data obtained in the ^{208}Pb (^{16}O, fγ) reaction is shown in Fig. 2.

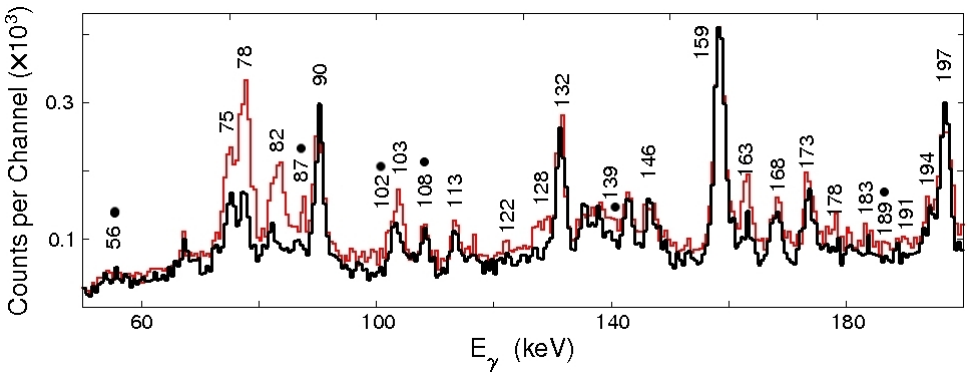

Figure 1: Example of two partial γ-ray spectra collected for a time of 300 μs at the beginning (red line) and at the end (black line), 5.8 ms later, of the beam-off period, respectively. The lines marked with black dots indicate the γ lines appearing below the 209 keV, $11/2^-$ state of ^{105}Ru.

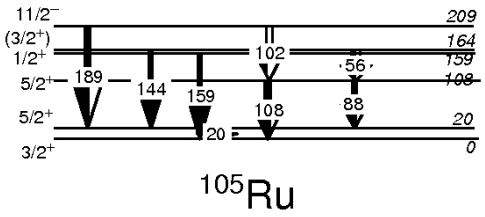

Figure 2: Partial level scheme of low spin states in ^{105}Ru. The 189 keV and 102 keV lines being candidates for isomeric transitions were proposed in the present investigation. Other lines were previously observed, Refs. [2,3].

The coincidence relations of γ rays placed below the 209 keV state were inspected. Especially interesting for the present consideration were the coincidences between the 102 and 108 keV lines. There is a visible coincidence relation between these two lines.

It is possible that the newly proposed 189 keV and 102 keV lines are isomeric transitions. From an examination of a background subtracted time spectra, deduced from the γ-time matrices, a half-life of a few microseconds for 209 keV level was obtained.

From the data gathered in this experiments one can presume that this isomeric state might exist, however the final estimation of the half-life needs more beam time in order to increase the statistics in a better geometry.

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C.9 Weak couplings in the back-scattering of ^{20}Ne on ^{118}Sn — excitation energy measurement

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The Barrier Group continued its project of the study of barrier height distributions.

It was observed for the Zr + ^{20}Ne and Ni + ^{20}Ne systems 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} [1, 2].

Interpretation of this phenomenon within the framework of the conventional coupled channels method is difficult since the form factor of non-collective excitations is not known. A theoretical interpretation of the results for ^{90}Zr and ^{92}Zr was presented in [3] where the excitations were described in a random-matrix model.

In 2012 we performed the measurements allowing us to study the evolution of the Q spectrum (distribution of system excitation energy) with scattering angle for the system: ^{20}Ne + ^{118}Sn [4]. In 2013 the next experiment was carried out in order to study the evolution of the Q spectrum with projectile energy for the same system. The experimental system was similar to the one used in 2012. A ^{20}Ne beam was delivered by the Warsaw Cyclotron and the measurements were performed using the multidetector system ICARE. The ToF (Time of Flight) technique was used to identify the masses of backscattered 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.

An improvement to the ToF system was applied in order to reduce the background: an Al shielding was installed around the MCP detector in order to avoid false signals from electrons emitted from the target and randomly scattered ions.

The data analysis is in progress.

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C.10 Breakup effects in ^{6}Li + ^{18}O elastic scattering

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Measurements of the elastic scattering of ^{6}Li + ^{18}O at the HIL in inverse kinematics [1] at an ^{18}O beam energy of 114 MeV revealed a strong rise in the differential cross section at backward scattering angles. This short report presents the results of an investigation into whether this rise could be caused by strong coupling effects due to the loosely-bound cluster structure of ^{6}Li.

Analyses of many ^{6}Li elastic scattering data have proved that the continuum-discretized coupled-channel (CDCC) method accounts well for the measured observables, including polarisation [2]. Thus, we have performed CDCC calculations for the studied system using the $\alpha + d$ cluster model of ^{6}Li [3]. All the interactions, including the bare optical model (OM) potential and the coupling potentials between the ground, resonant and non-resonant states of ^{6}Li were generated from empirical OM potentials describing elastic scattering of α-particles and deuterons from ^{18}O [4, 5] so that the CDCC calculations did not contain any adjustable parameters.

The results of the CDCC calculations are shown by the solid curve in Fig. 1. The forward scattering data up to $\theta_{\rm c.m.} = 100^{\circ}$ are well described by the calculations but the backward scattering data are a few orders of magnitude above the model predictions. Similar results were obtained by much simpler OM calculations with the optical potential constructed from the sum of the bare potential and the trivially equivalent dynamic polarisation potential [6] (DPP, dotted curve in Fig. 1).

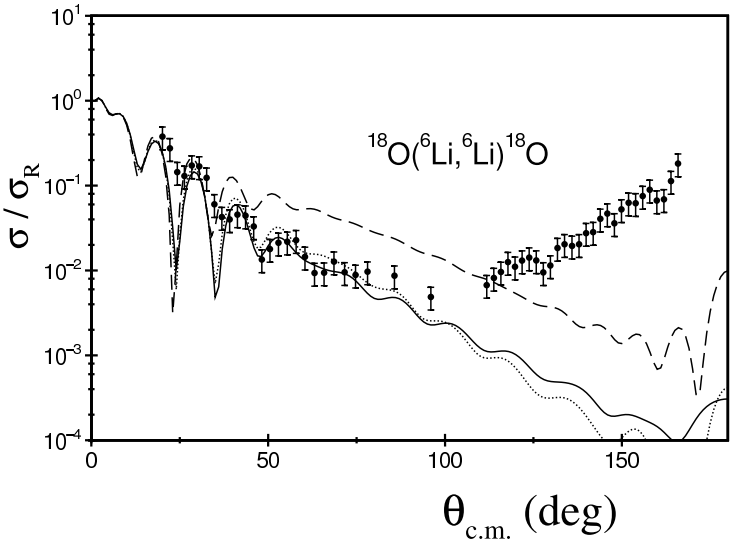

Figure 1: Comparison of model calculations with the elastic scattering data. The solid curve denotes the result of a microscopic CDCC calculation that includes the effect of ^{6}Li breakup. The dashed and the dotted curves show the results of OM calculations with the bare and bare + DPP optical potentials, respectively.

The effect of the ^{6}Li breakup is presented by the difference between the solid and the dashed curves, as the dashed curve shows the results of an OM calculation with the bare potential only, without any couplings to the ^{6}Li excited states.

In summary, the strong internal projectile coupling of ^{6}Li could not account for the observed rise of the ^{6}Li + ^{18}O elastic scattering at backward angles, although its effect at forward scattering angles is found to be substantial. The backward rise must be attributed to other reaction channels observed in the experiment and this will be the subject of subsequent studies.

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C.11 Exit channel interaction potential from the ^{18}O(^{6}Li,^{7}Li)^{17}O reaction

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The strongest transfer reaction channel induced in ^{6}Li + ^{18}O scattering measured at the HIL [1] was found to be the one-neutron transfer from the target to the projectile leading to the ground and first excited states of ^{17}O [2]. The elastic scattering data were described at forward angles by an effective optical model (OM) potential constructed from a sum of the bare potential and the dynamic polarisation potential, the latter derived from a microscopic continuum-discretized coupled channel-calculation (see the dotted curve in Fig. 1 in Ref. [3]). The spectroscopic factors for the $^{18}O_{g.s.} = {}^{17}O_{g.s.} + n$ and the $^{18}O_{g.s.} = {}^{17}O_{1exc} + n$ are known [4]. Thus, the only missing information needed to perform standard coupled-reaction-channel (CRC) calculations for the measured reactions is the OM potential in the ^{7}Li + ^{17}O exit channel. This creates an opportunity to check if the global ^{7}Li OM potential of Cook [5] could be used to describe the interaction of this nucleus with the isotope of oxygen, ^{17}O.

The coupling scheme applied in the CRC calculations included, apart from the entrance and the two exit channels, excitation of ^{18}O to its first excited state (2^+, 1.98 MeV, deformation parameter β_2=0.365 from the NNDC database) as well as neutron transfer from this excited state. The spectroscopic factor for the $^{18}O_{2+}$ was assumed to be the same as for the $^{18}O_{g.s.}$. The effect of this transfer on the measured ^{18}O(^{6}Li,^{7}Li)$^{17}O_{g.s.,1exc}$ cross sections was found to be negligible.

The model CRC calculations performed with the ^{7}Li + ^{17}O optical model potential derived from the global prescription of Cook [5] were unable to describe the measured angular distributions at backward angles (dashed curves in Fig. 1) generating cross sections a few orders of magnitude below the measured values. The calculations are free of any adjustable parameters. Better results were obtained with an optical potential of the following W-S parametrisation:

$$V_o = 183 \text{ MeV}, W = 6 \text{ MeV}, R = 3.587 \text{ fm}, R_i = 6.502 \text{ fm}, a = a_i = 0.740 \text{ fm},$$

with the imaginary part more extended than the real. This extended imaginary potential reflects the effect of couplings to the other strong channels not explicitly included in the present calculation.

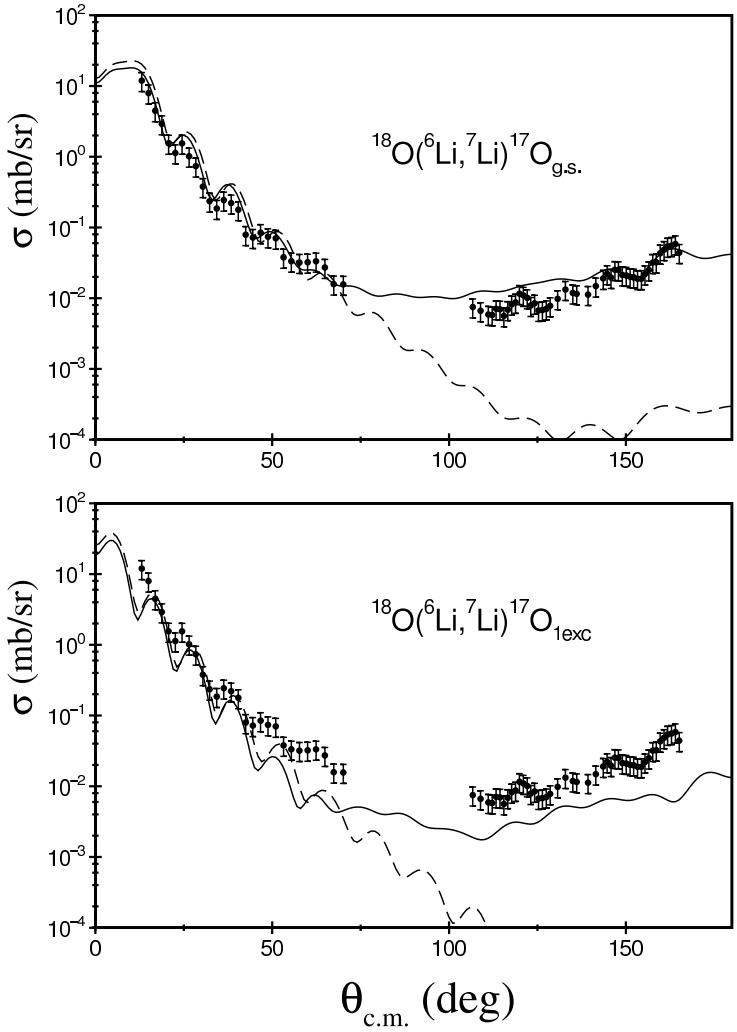

Figure 1: Angular distributions of one-neutron transfer reactions leading to the ground (upper panel) and first excited states (lower panel) of ^{17}O. The curves represent the results of model calculations with two different OM potentials in the exit channel, see text for details.

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C.12 Strong coupling effects of the transfer reactions in ^{6}Li + ^{18}O scattering

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The rise of the ^{6}Li + ^{18}O elastic scattering cross section at backward angles could not be attributed to the weakly bound $\alpha + d$ cluster structure of the projectile (see Ref. [1]). In an experiment performed at the HIL, apart from elastic and inelastic scattering other strong reaction channels were observed [2,3], in particular the one-neutron transfers leading to the ground and the first excited states of ^{17}O. The measured angular distributions for these transfer reactions were described by coupled-reaction-channel (CRC) calculations with the exit channel interaction potential containing a long range absorption (see contribution [4]). In this contribution the effect of these transfer reactions on elastic and inelastic scattering is studied.

The experimental data for the ^{6}Li + ^{18}O elastic scattering (the experiment was performed in inverse kinematics, with an ^{18}O beam energy of 114 MeV) and the inelastic scattering leading to the excitation of ^{6}Li to its 3^{+} resonant state and the excitation of ^{18}O to its first excited state are plotted in Fig. 1 [2]. The excited states could not be resolved experimentally. The results of a CRC calculation that included couplings to the one-neutron transfer reactions are plotted by the solid curves. Comparison with the calculation where these couplings were omitted (dashed curves) shows that these transfer reaction channels strongly affect the backward cross sections for elastic and inelastic scattering. In order to simulate the effect of other reaction channels observed in the experiment, CRC calculations with artificially enlarged values of the ^{18}O spectroscopic amplitudes were performed - the spectroscopic amplitudes from [5] were multiplied by two. The results of a CRC calculation with such enlarged amplitudes are plotted by the dotted curves.

In summary, the complex analysis of the experimental data obtained at the HIL by means of CRC calculations strongly suggests that the backward rise of the ^{6}Li + ^{18}O scattering cross sections could be attributed to the strong transfer reaction channels observed in the experiment.

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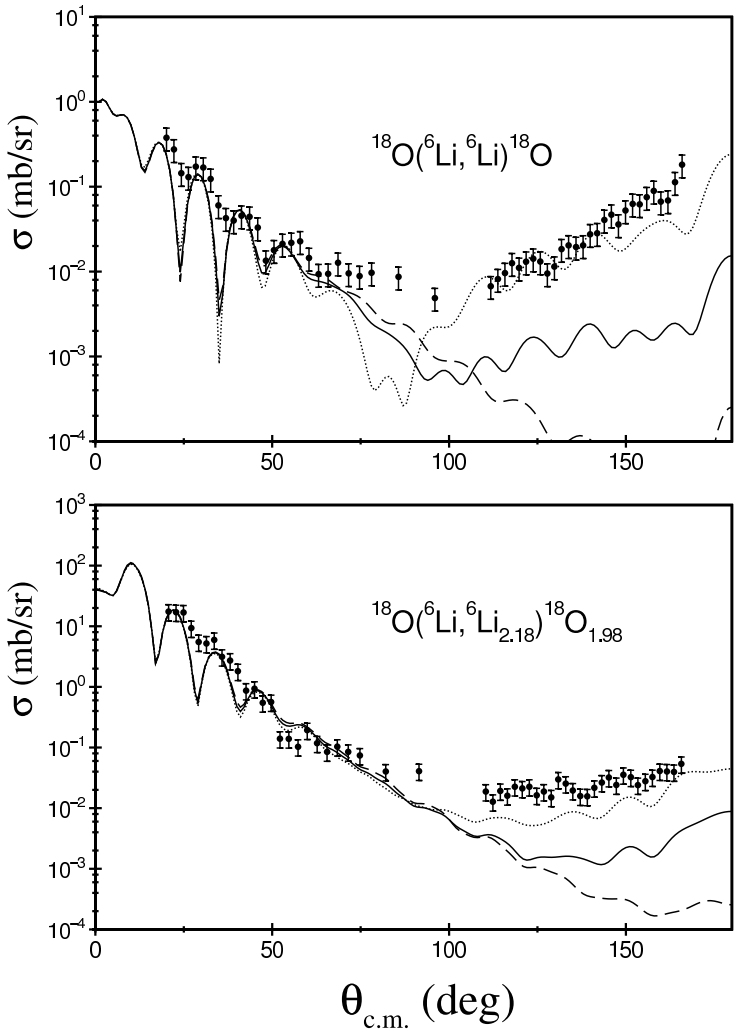

Figure 1: Angular distributions of elastic and inelastic scattering of ^{6}Li from ^{18}O. The dashed curves represent results of a calculation without couplings to the one-neutron transfer channels. The solid curves denote the results of a CRC calculation including these couplings, while the dotted curves represent a similar CRC calculation but with the spectroscopic amplitudes of $^{18}O_{g.s.}$ multiplied by two.

C.13 Elastic and inelastic scattering of ^{12}C ions by ^{7}Li at 115 MeV

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The interaction of ^{7}Li + ^{12}C was studied experimentally in inverse kinematics using an E_{lab} = 115 MeV ^{12}C beam from the Warsaw U-200P cyclotron [1].

A typical $\Delta E(E)$-spectrum is shown in Fig. 1. Due to the very good mass and charge resolution of the detection system the events corresponding to the elastic scattering could be well resolved from the other isotopes of carbon and lithium. The measured angular distribution of the ^{7}Li + ^{12}C elastic scattering is shown in Fig. 2.

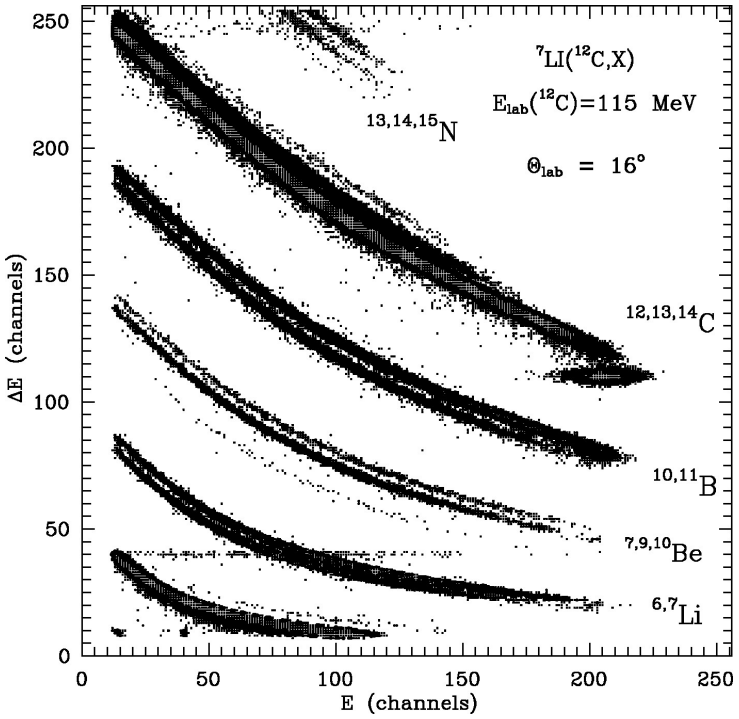

Figure 1: Typical $\Delta E(E)$-spectrum of the ^{7}Li(^{12}C, X) reaction products.

The data were analysed within direct reaction theory using standard Woods-Saxon optical model potentials in the entrance and exit channels. The elastic and inelastic scattering, reorientation of ^{7}Li in its ground state and one and two-step transfer reactions were included in the coupling-scheme.

The solid curve in Fig. 2 shows the sum of contributions to the elastic scattering coming from potential scattering, <pot>, reorientation of the ^{7}Li ground state, <reor>, and transfer reactions. As one might expect, the main contribution is due to potential scattering. The real part of the potential used to calculate this contribution is very close

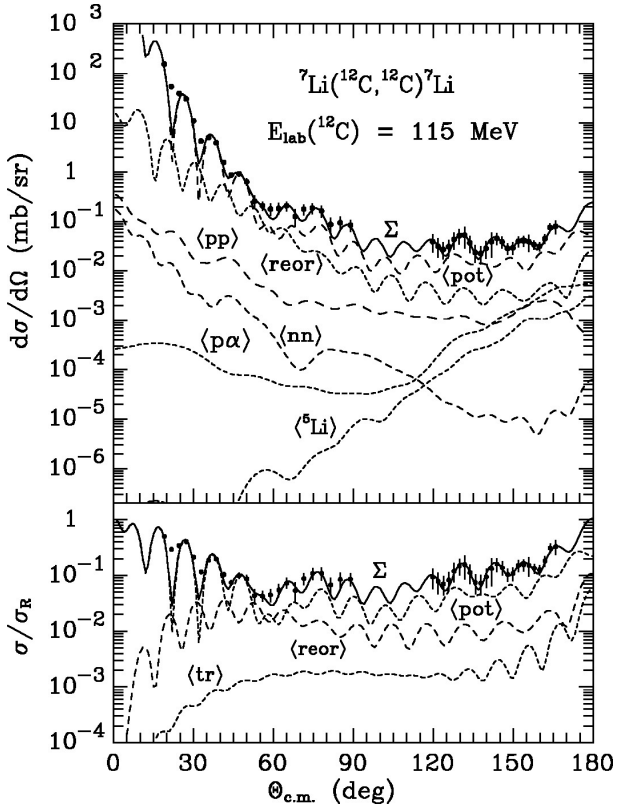

Figure 2: Angular distribution of the ^{7}Li + ^{12}C elastic scattering at $E_{lab}(^{12}\mathrm{C}) = 115$ MeV.

to the potential derived from ^{7}Li and ^{12}C ground state densities by means of the double-folding method.

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C.14 The ^{14}C(^{11}B, ^{9}Be)^{16}N reaction and the ^{9}Be + ^{16}N optical potential

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5) National Research Center "Kurchatov Institute", Moscow, Russia

The angular distribution of the ^{14}C(^{11}B, ^{9}Be)^{16}N reaction leading to the ground and excited states of ^{9}Be and ^{16}N, unresolved in the experiment, was measured simultaneously with the ^{11}B + ^{14}C elastic and inelastic scattering using an E_{lab} = 45 MeV, ^{11}B beam from the Warsaw U-200P cyclotron [1]. The experimental data are plotted in Fig. 1.

The data were analysed within the direct reaction theory, assuming a deuteron transfer mechanism. In the entrance channel, the ^{11}B + ^{14}C optical potential of Wood-Saxon type deduced from an analysis of the ^{11}Be + ^{14}C elastic scattering data was used. Spectroscopic amplitudes required in the reaction calculations were calculated using the nuclear shell-model code DESNA. The ^{9}Be + ^{16}N optical potential was assumed to be of Woods-Saxon shape, with the parameters fitted in order to describe the ^{14}C(^{11}B, ^{9}Be)^{16}N reaction data. The ^{9}Be + ^{16}N optical potential parameters are listed in Table 1, and the potential is plotted in Fig. 2.

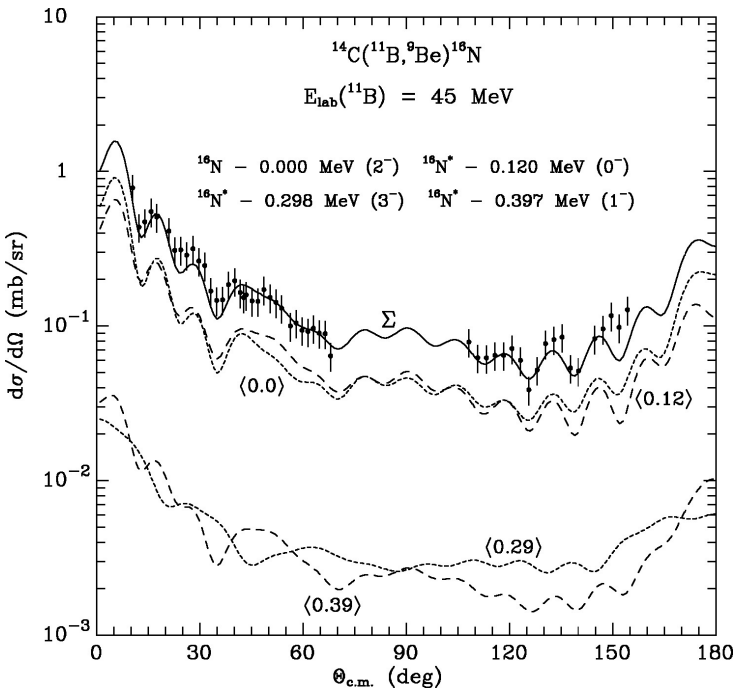

Figure 1: Angular distribution of the ^{14}C(^{11}B, ^{9}Be)^{16}N reaction. Curve Σ presents the incoherent sum of the different contributions due to deuteron transfer to the different states of ^{9}Be and ^{16}N.

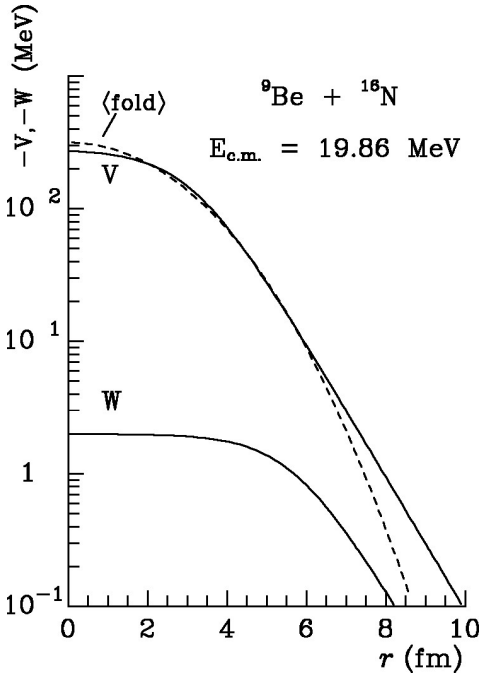

Figure 2: The ^{9}Be + ^{16}N potential.

Nuclear system	E_{cm} (MeV)	V_0 (MeV)	r_V (fm)	a_V (fm)	W_S (MeV)	r_W (fm)	a_W (fm)	Ref.
^{9}Be + ^{16}N	19.86	164.5	0.800	0.900	3.0	1.250	0.900	[1]
^{9}Be + ^{16}N	29.02	174.5	0.800	0.900	5.0	1.250	0.900	[2]
^{11}B + ^{14}C	25.20	266.6	0.750	0.740	7.5	1.345	0.740	[3]

Table 1: Parameters of the nucleus-nucleus potentials

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C.15 Single crystal diamond films grown by MWCVD homo-epitaxy on [100] HPHT diamond substrates

A.J. Kordyasz[1], M. Kowalczyk[1,2], J. Tarasiuk[2], A. Bednarek[1], B. Radomyski[1], Ł. Kordyasz[3]

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The best diamond detectors are produced using diamond single-crystals. Such crystals can be obtained by growing diamond on single-crystal diamond High Pressure High Temperature (HPHT) substrates. For growing the diamond crystals we used the Microwave Chemical Vapour Deposition (MWCVD) process with a MWCVD reactor [1–4]. Synthetic single-crystal diamonds are obtained on a silicon substrate, see Fig. 1.

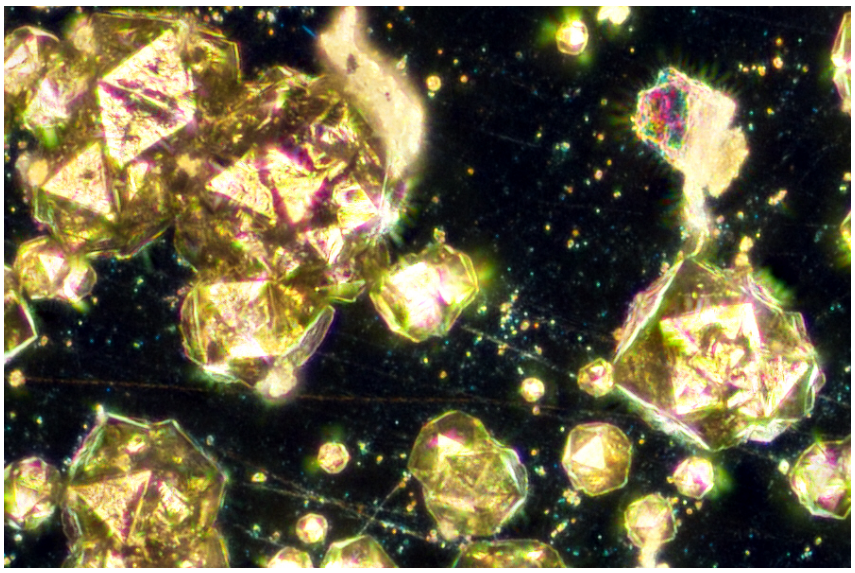

Figure 1: Single-crystal diamonds are grown during 8 days on a silicon substrate using 2% concentration of butane in hydrogen at a temperature of about 800°C and a pressure of 70 Th. Randomly oriented diamond crystals of diameter about 0.2 mm are obtained in the hetero-epitaxy process.

The MWCVD homo-epitaxy process is performed on a single-crystal Sumimoto 3x3x0.3 mm^3 diamond substrate HPHT crystal, [100] oriented at a temperature of about 800°C and 1.4% of butane/hydrogen concentration with a pressure of 69 Th. After 11 days single-crystal diamonds, oriented with the [100] direction in the shape of square pyramid are obtained, see Fig. 2.

After increasing the concentration from 1.4% to 2.6% of butane/hydrogen with MWCVD process lasting 4 days, a diamond film of thickness 50 μm is obtained, see Fig. 3. Similar results were obtained with compositions of methane/hydrogen and hexane/hydrogen.

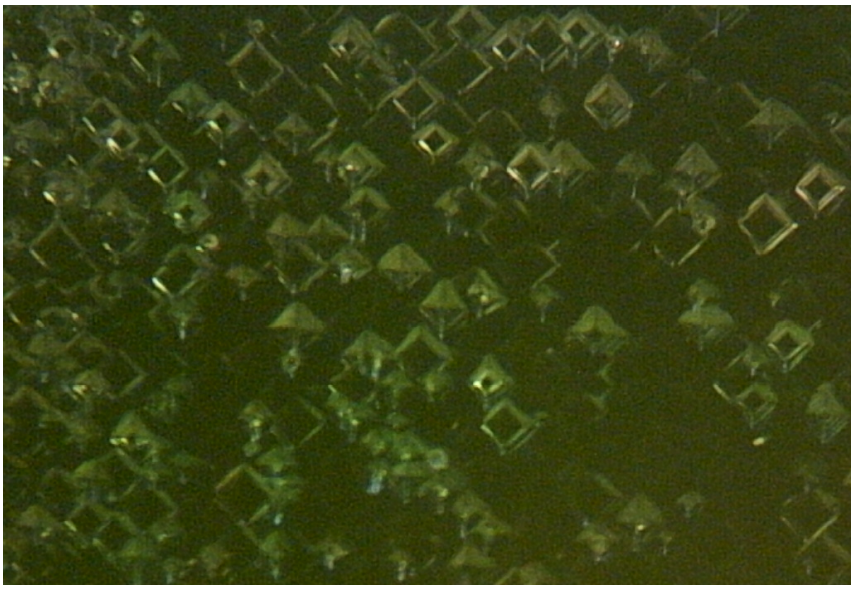

Figure 2: [100] oriented diamond single-crystals, grown by MWCVD in the homo-epitaxy process on a [100] diamond Sumimoto substrate. Parallel oriented diamond square pyramids (some of them are without a peak) are visible.

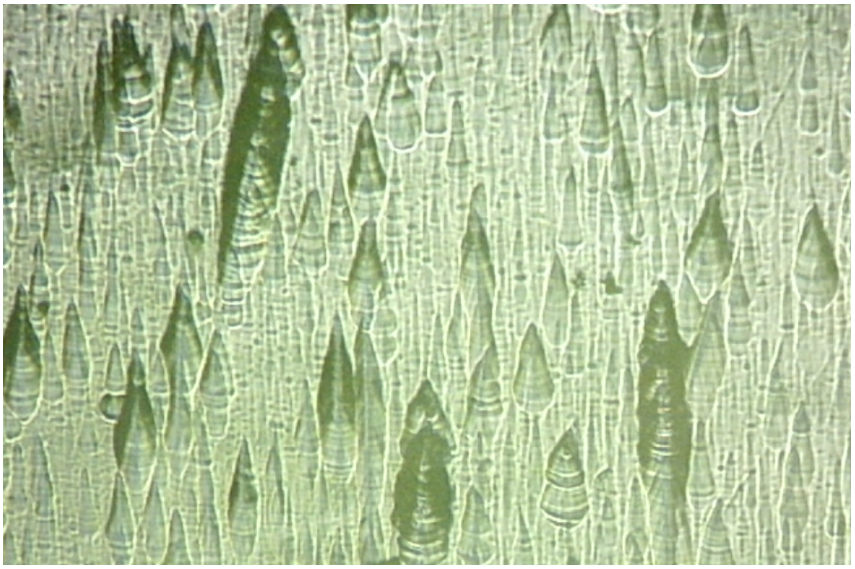

Figure 3: Single crystal diamond film of thickness 50 μm grown in 4 days by the MWCVD homo-epitaxy process on a [100] HPHT diamond single crystal Sumimoto substrate.

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C.16 Thickness distribution of large-area thin silicon detectors

A.J. Kordyasz[1], M. Kowalczyk[1,2], A. Bednarek[1], Z. Khabanowa[3], J. Sarnecki[4], D. Lipoński[4], H. Wodzińska[4]

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The thickness uniformity of thin transmission detectors is very important for the proper identification of heavy ions by the $E - \Delta E$ method. The detector (20×20 mm^2) thickness distribution (with 1 mm steps in X and Y directions) was measured by transmission of α particles with a stop PIN diode collimated to diameter of 3 mm. The thickness distribution was calculated using range-energy tables of α particles in silicon. We have used α particles from ^{241}Am ($< E_\alpha >= 5.48$ MeV). The ΔE detector thickness distribution is shown in Fig. 1.

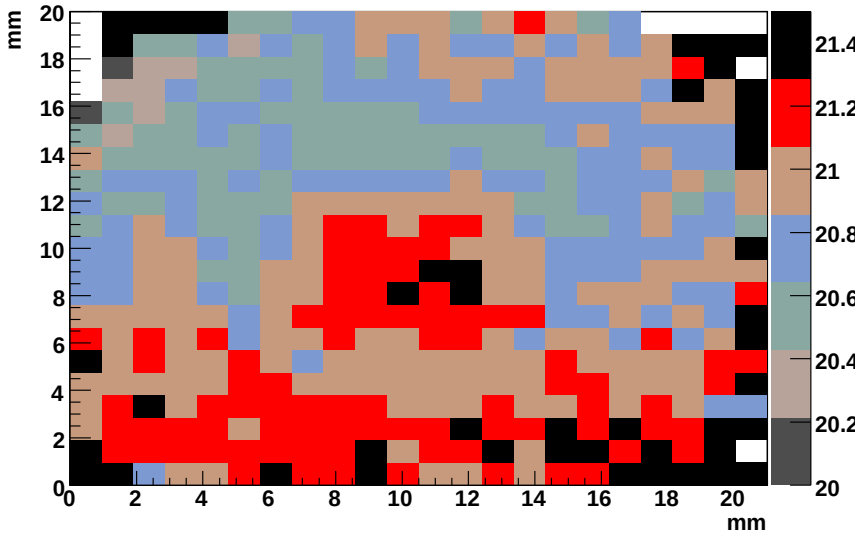

Figure 1: Thickness distribution of the epitaxial thin ΔE silicon detector. Average value resulting from the map is 20.9 μm and the nonuniformity is within 1 μm. The colour scale is in μm on the right-hand side of the picture.

Preliminary tests of a $E - \Delta E$ telescope with this thin ΔE detector were conducted at the CS cyclotron in the INFN-LNS in Catania (Italy) using fragments produced in the heavy-ion reaction ^{84}Kr (E=35MeV/A) + ^{112}Sn. The PI distribution (PID) is presented in Fig. 2 and shows Z identification from He to manganese [1].

A silicon vertex detector for superheavy elements consists of a system of large-area thin silicon strip detectors [2]. For proper working of the silicon vertex detector the thickness distribution of such large thin strip detectors should be exactly determined. The thickness distribution of 5 μm of a large-area, 4 in silicon membrane is presented in Fig. 3.

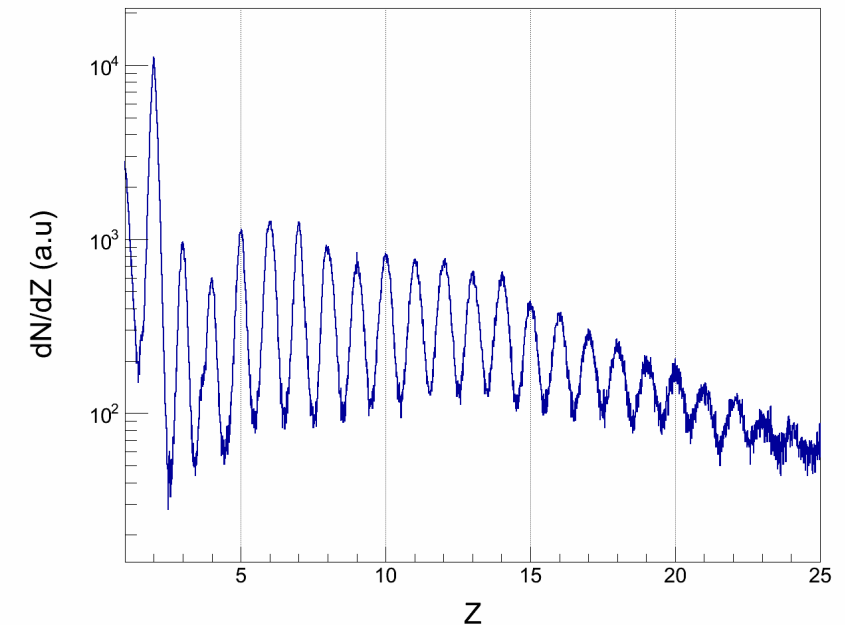

Figure 2: Charge distribution of measured ions obtained after linearization of the $\Delta E - E$ matrix [1].

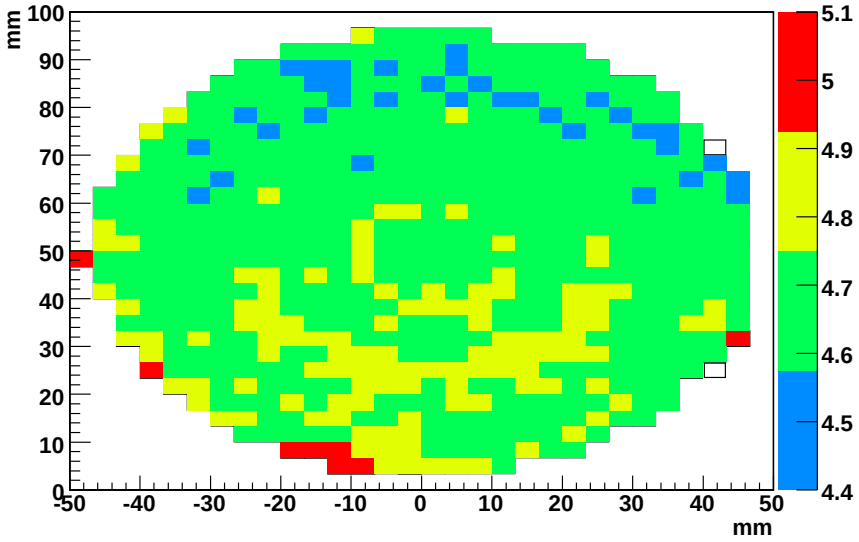

Figure 3: Thickness distribution of a 4 in epitaxial silicon layer of thickness below 5 µm. The colour scale is in µm on right-hand side of the picture.

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Part D

Experiments using external facilities

D.1 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], A. Gadea[4], V. González[8], T. Hüyük[4], M. Jastrząb[11], J. Kownacki[2], M. Moszyński[12], Q. Nishada[13], J. Nyberg[13], E. Sanchis[7], P.-A. Söderström[14], A. Triossi[3], J.J. Valiente Dobon[3], R. Wadsworth[15], L. Xiaoliang[13]

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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) The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
12) National Centre for Nuclear Research, Otwock, Świerk, 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 future neutron multiplicity filter NEDA (NEutron Detector Array) (see earlier HIL Annual reports [1, 2] and Ref. [3]) will operate at stable and radioactive beam facilities together with state-of-the-art γ-ray spectrometers. It is designed to detect multiple neutrons with an efficiency a few times higher than existing neutron detectors arrays (e.g. the Neutron Wall [4, 5] and the Neutron Shell [6]). To reach this goal every part of the array has to be carefully optimised. The activities of the NEDA collaboration in 2013 are summarised below.

The properties of liquid scintillators of types BC501A and BC537 were earlier carefully compared (see [7, 8]) showing the definite superiority of the proton-based BC501A scintillator, which became the material of choice for the NEDA detectors. However, new materials were appearing in the market and their properties, as stated by the manufacturers, were promising. We tested the new commercially available plastic scintillator EJ-299-33 with neutron-γ discrimination capabilities [9] and its performance turned out to be significantly worse than that of BC501A [10]. Detailed analysis of the collected data is ongoing.

Choice of a photomultiplier type might significantly affect the time resolution and neutron-γ discrimination capabilities of NEDA. Several different photomultipliers were tested. Measurements showed [11, 12] that the Hamamatsu R11833-100 photomultiplier has largest photo-electron yield and gives a time resolution FWHM equal to 760(20) ps when the signal is probed with a 200 MS/s frequency. This fulfils the NEDA time resolution requirement which is set at 1 ns. The analysis of the influence of photomultiplier type on the neutron-γ discrimination capabilities of BC501A scintillator showed that the above mentioned photomultiplier type is among the two equally best ones, reaching FOM=1.67 at 320(20) keVee [13].

The processing of signals from the NEDA detectors will be realised in a fully digital manner. The digitiser will have frequency of 200 MS/s and a resolution of 14 bits (11.3 ENOB). Details of the design and results of tests of the digitiser have been published in Ref. [14]. Further measurements [15] validated the system, characterising it with a noise standard deviation in the range 1.4–2.0 ADC channels and energy resolution equal to 2.3 keV at 1.33 MeV for EXOGAM detectors. The production of 45 FADC Mezzanines for NEDA is ongoing.

The simulation calculations performed in 2013 were focused on planning the campaign with the combined NEDA and Neutron Wall array connected to the AGATA γ-ray spectrometer, which is foreseen at GANIL in 2016. Extensive work on a comparison of the simulation results to the experimental data collected earlier with the Neutron Wall allowed the Neutron Wall efficiency, the time of flight spectra and angular distributions of neutrons emitted in neutron-deficient fusion-evaporation reactions to be reproduced properly for the first time [16]. This makes possible reliable predictions for the efficiency of various possible geometries of the setup at GANIL.

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Part E

Appendices

E.1 Degrees and theses completed in 2013 or in progress

E.1.1 DSc (habilitation) degrees of HIL staff members

Leszek Próchniak
The degree was awarded in April 2013 by the Scientific Council of the Faculty of Mathematics, Physics and Computer Science, Maria Curie Skłodowska University, Lublin

Anna Stolarz
The degree was awarded in December 2013 by the Scientific Council of the Faculty of Physics, Warsaw University of Technology, Warszawa

E.1.2 PhD theses of students affiliated to HIL and of HIL staff members

Izabela Cydzik, Institute of Nuclear Chemistry and Technology, Warszawa
Radiolabelling of nanoparticles for biological studies
Supervisor: prof. dr hab. A. Bilewicz. Defended in January 2013.

Katarzyna Hadyńska-Klęk, Faculty of Physics, University of Warsaw
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. Defended in October 2013.

Izabela Strojek, 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. Defended in October 2013.

Jan Mierzejewski, Faculty of Physics, Warsaw University of Technology
Mechanizm niekompletnej fuzji badany z wykorzystaniem EAGLE i SiBall
Study of incomplete fusion in the $^{20}Ne+^{122}Sn$ reaction- in-beam measurements of the charged particle - γ correlations using the EAGLE spectrometer at the Warsaw Cyclotron
Mechanism of incomplete fusion studied with EAGLE and SiBall
Supervisor: prof. dr hab. T. Matulewicz. Defended in January 2014.

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: 2014.

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: 2014.

Łukasz Standyło, 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, Faculty of Physics, University of Warsaw
Supervisor: prof. dr hab. K. Rusek. Expected completion time: 2017.

E.1.3 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.

Frank Leonel Bello Garrote, University of Oslo
Supervisor: prof. Andreas Görgen. Expected completion time: 2016.

Malin Klientefjord, University of Oslo
Supervisor: prof. Andreas Görgen. Expected completion time: 2016.

E.1.4 PhD, MSc and BSc theses supervised by HIL staff members

Michalina Komorowska, Faculty of Physics, University of Warsaw
Eksperymentalne wyznaczanie względnych przekrojów czynnych reakcji ^{122}Sn(^{20}Ne,xnypzα) z wykorzystaniem spektrometru EAGLE
Experimental determination of the relative cross sections in reaction ^{122}Sn(^{20}Ne,xnypzα) using EAGLE array
Supervisors: prof. dr hab. M. Kicińska-Habior, dr J. Srebrny.
MSc thesis completed in January 2014.

Urszula Kaźmierczak, Faculty of Physics, University of Warsaw
Local dose and its role in biological response of mammalian cells in vitro
Supervisors: dr hab. Z. Szefliński, dr hab. A. Lankoff.
PhD thesis, expected completion time: 2015

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, defended in June 2013.

Justyna Kiec, Faculty of Physics, University of Warsaw
Badanie zanieczyszczeń radioiozotopowych w procesie produkcji ^{18}F
Studies of radionuclide impurities in the ^{18}F production
Supervisor: dr K. Kilian. BSc thesis defended in October 2013

Patryk Hejduk, Faculty of Physics, University of Warsaw
Optymalizacja procesu metylowania do znakowania ^{11}C Optimization of methylation process for ^{11}C labeling
Supervisors: dr K. Kilian, dr hab. Z. Szefliński
BSc thesis defended in September 2013

Mateusz Sitarz, Faculty of Physics, University of Warsaw
Interaction of ionizing radiation with cellular material in vitro
Supervisor: dr hab. Z. Szefliński
BSc thesis defended in September 2013.

Sylwia Przywóska, Faculty of Physics, Warsaw University of Technology
Pomiar okresu połowicznego radonu w wodzie
Measurement of half-life of radon in water
Supervisors: dr hab. A. Kordyasz, prof. dr hab. J. Pluta.
Engineering diploma thesis defended in March 2013.

E.1.5 Other BSc and MSc theses based on experiments performed at HIL

Klaudia Szpik, Institute of Physics, University of Silesia, Katowice, Poland
Producja radioizotopów selenu i arsenu dla celów medycyny nuklearnej na cyklotronie U-200P
Production of radioisotpes of selenium and arsenic for nuclear medicine, with the use of the U-200P cyclotron
Supervisors: dr hab. A Konewał, prof. dr hab. W. Zipper
MSc thesis, expected completion time: 2014.

Błażej Mleczko, Institute of Physics, University of Silesia, Katowice, Poland
Opracowanie metody wyznaczania aktywności radioizotopu At-211 za pomocą radiometru
Preparation of the method of determination of the At-211 activity using a radiometer
Supervisors: dr hab. A Konewał, prof. dr hab. W. Zipper
MSc thesis, expected completion time: 2014.

E.2 Publications

E.2.1 Publications in journals of the Journal Citation Reports (JCR) list

N. Burtebayev, J. T. Burtebayeva, N. V. Glushchenko, Z. K. Kerimkulov, A. Amar, M. Nassurlla, S. B. Sakuta, S. V. Artemov, S. B. Igamov, A. A. Karakhodzhaev, K. Rusek, and S. Kliczewski. *Effects of t- and α-transfer on the spectroscopic information from the $^{6}Li(^{3}He,d)^{7}Be$ reaction.* Nucl. Phys. A **909**, 20 (2013).

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E.3 Seminars

E.3.1 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

I. Cydzik — HIL 17 January 2013
Radioznakowanie nanocząstek dla badań biologicznych
Radiolabelling of nanoparticles for biological studies

C. Mazzocchi — Inst. of Experimental Physics, Univ. of Warsaw 21 February 2013
Beta decay studies of the most neutron-rich Ga, Ge and As isotopes at LeRIBSS (HRIBF, ORNL)

K.W. Kemper — Florida State University 28 February 2013
Recent nuclear physics planning in the US and some new projects

S. Lalkovski — Sofia University, Sofia, Bulgaria 7 March 2013
Isomeric decays in mass-separated neutron-rich silver nuclei

J. Czub — Jan Kochanowski University, Kielce, Poland 14 March 2013
Komórkowe efekty promieniowania o wysokim i niskim liniowym przekazywaniu energii: badania na pograniczu fizyki i biologii
Cellular effects of high and low LET radiation — research on the boundary of physics and biology

K. Hadyńska-Klęk — HIL 21 March 2013
Wzbudzenie kulombowskie pasma o dużej deformacji w ^{42}Ca
Coulomb excitation of highly deformed band in ^{42}Ca

A. Fijałkowska — Inst. of Experimental Physics, Univ. of Warsaw 4 April 2013
Badanie przemiany beta produktów rozszczepienia z wykorzystaniem spektrometru pełnej absorpcji
Beta decay studies of fission products by using total absorption spectrometer

A. Kisiel — Warsaw University of Technology, Warszawa, Poland 11 April 2013
Najnowsze wyniki analiz zderzeń AA i pA z eksperymentu ALICE
New results of the AA and pA events analysis from the ALICE experiment

P. Olko — Institute of Nuclear Research, Kraków, Poland 18 April 2013
Centrum Cyklotronowe Bronowice rozpoczęło działalność
The Cyclotron Centre Bronowice is operational

A. Staszczak — UMCS, Lublin, Poland 25 April 2013
Stabilność i własności superciężkich jąder atomowych w modelu średniego pola z funkcjonałem gęstości Skyrme'a
The stability and properties of super-heavy nuclei in the mean field model with the Skyrme density functional

W. Nazarewicz — Univ. of Tennessee, ORLN Oak Ridge, Inst. of Theoretical Physics, Univ. of Warsaw 9 May 2014
Jądro atomowe jako kwantowy układ otwarty
Atomic nucleus as an open quantum object

J. Dobaczewski — Inst. of Theoretical Physics, Univ. of Warsaw 16 May 2013
Oddziaływania efektywne niezależne od gęstości
Density independent effective interaction

S. Zemlyanoy — Joint Institute for Nuclear Research, Dubna, Russia 21 May 2013
New facility to study heavy neutron-rich nuclei formed in multi-nucleon transfer reactions

N.-V. Zamfir — Nat. Inst. of Phys. and Nucl. Eng., Bucurest, Romania 23 May 2013
Extreme Light Infrastructure - Nuclear Physics (ELI-NP). Status and Perspectives

W. Urban — Inst. of Experimental Physics, Univ. of Warsaw 6 June 2013
Deformacja jądrowa w pobliżu ^{78}Ni
Nuclear deformation in the vicinity of ^{78}Ni

W. Królas — Institute of Nuclear Research, Kraków, Poland 3 October 2013
Spektroskopia jąder neutrono-nadmiarowych w reakcjach głęboko nieelastycznych z wiązkami stabilnymi i radioaktywnymi
Spectroscopy of neutron-rich nuclei in deep-inelastic reactions with stable and aradioactive beams

P. Magierski — Faculty of Physics, Warsaw Univ. of Technology 10 October 2013
Dynamika układów nadciekłych: jąder atomowych i gazów kwantowych w ramach teorii funkcjonału gęstości
Dynamics of super-fluid systems: atomic nuclei and quantum gases in the density functional theory

S. Kowalski — Inst. of Physics, University of Silesia, Katowice, Poland 17 October 2013
Energia symetrii i skalowanie izotopowe w reakcjach zderzeń ciężkich jonów przy energiach Fermiego
Symmetry energy and isotope scaling in heavy-ion collisions at Fermi energies

M. Gai — Yale University 24 October 2013
Physics With Optical TPC and Gamma Beams

A. Schwenk — Darmstadt 7 November 2013
Three-body forces: from exotic nuclei to neutron stars

A. Šagátová — Slovak University of Technology, Bratislava, Slovakia 21 November 2013
Applied Nuclear Research at INPE SUT in Bratislava

C. Spitaleri — INFN Laboratori Nazionali del Sud, Catania, Italy 28 November 2013
The Trojan Horse method in nuclear astrophysics

A. Bravar — Université de Geneve 5 December 2013
The NA61 Experiment at CERN (current status and future prospects)

G. Zuzel — Inst. of Physics, Jagiellonian University, Kraków 12 December 2013
Eksperyment GERDA i najnowsze wyniki poszukiwań podwójnego bezneutrinowego rozpadu beta
The GERDA experiment and new results on search for a neutrino-less beta decay

E.3.2 External seminars given by the HIL staff

I. Cydzik 9 January 2013
Radioznakowanie nanocząstek dla badań biologicznych
Radiolabelling of nanoparticles for biological studies
Institute of Electronic Materials Technology, Warszawa, Poland

P. Napiorkowski 15 January 2013
Experimental challenges at the Heavy Ion Laboratory in Warsaw
Inter University Accelerator Centre, New Delhi, India

L. Próchniak 24 January 2013
Kolektywne kwadrupolowe stany jąder atomowych
Collective quadrupole states in atomic nuclei
Inst. of Physics, Maria Curie-Sklodowska Univ., Lublin, Poland

M. Palacz 18 February 2013
Neutron Wall and AGATA@GANIL
AGATA@GANIL Workshop, GANIL, Caen, France

J. Srebrny 20 February 2013
Nuclear Spectroscopy with the EAGLE spectrometer in-beam of the U200P cyclotron at HIL UW
Joint Institute for Nuclear Research Dubna, Russia

A. Trzcińska 20 February 2013
Studies of barrier heigh distributions at HIL UW
Joint Institute for Nuclear Research, Dubna, Russia

L. Próchniak 9 April 2013
Nuclear deformation as seen by a theorist
2nd GOSIA Workshop, Heavy Ion Laboratory, Warszawa

K. Hadyńska-Klęk 9 April 2013
Coulomb exitation of ^{42}Ca with Agata
2nd GOSIA Workshop, Heavy Ion Laboratory, Warszawa

P. Napiorkowski 9 April 2013
Coulex at HIL
2nd GOSIA Workshop, Heavy Ion Laboratory, Warszawa

A. Stolarz 18 April 2013
Metody przygotowywania tarcz do badań z cząstkami naładowanymi lub ciężkimi jonami
Methods of the target preparation for studies with charged particles or heavy ions
Faculty of Physics, Warsaw University of Technology

J. Choiński 25 April 2013
Ośrodek Produkcji i Badania Radiofarmaceutyków w Środowiskowym Laboratorium Ciężkich Jonów UW
Radiopharmaceuticals Production and Research Centre at the Heavy Ion Laboratory
Institute of Nuclear Chemistry and Technology, Warszawa, Poland

K. Kilian 18 May 2013
Tomografia Pozytonowa PET
Positron-electron tomography (PET)
Meeting of the Scientific Association of Electroradiology Technicians

K. Kilian 24 May 2013
Radiofarmaceutyki do PET
PET radiopharmaceuticals
Warsaw Medical Physics Meeting, HIL Warszawa

A. Stolarz 15 May 2013
Targets for accelerator-based nuclear research (invited talk)
Inter-University Accelerator Centre, New Delhi, India

J. Choiński 24–25 May 2013
Ośrodek Produkcji i Badania Radiofarmaceutyków w Środowiskowym Laboratorium Ciężkich Jonów – wytwarzanie izotopów i radiofarmaceutyków
Radiopharmaceuticals Production and Research Centre at Heavy Ion Laboratory — production of isotopes and radiopharmaceuticals
Medical Physics Meeting, Warszawa

P. Napiorkowski 19 June 2013
EWIRA —- New Developments of the GOSIA Code
ENSAR Town Meeting, Warszawa

J. Mierzejewski 23–27 June 2013
The summary of the first EAGLE campaign with GAMMAPOOL detectors at Heavy Ion Laboratory, University of Warsaw
EGAN 2013 Workshop, Liverpool, Great Britain

K. Hadyńska-Klęk 23–27 June 2013
The structure of ^{42}Ca Coulomb excited states
EGAN 2013 Workshop, Liverpool, Great Britain

J. Srebrny 23–28 June 2013
What should be a proper measure of the quadrupole deformation and triaxiality
EGAN 2013 Workshop, Liverpool, Great Britain

J. Choiński 23–28 June 2013
^{211}At - Targeted Alpha Therapy Research Program in Poland (invited talk)
Technical Meeting on Alpha Emitting Radionuclides and Radiopharmaceuticals for Therapy, IAEA, Wien, Austria

Ł. Standyło 7 July 2013
Optimization of multiple-frequency heating and gas mixiing in ECR charge breeding
EURISOL Topical Meeting 2013, Kraków

K. Hadyńska-Klęk 1–7 September 2013
Structure of ^{42}Ca Coulomb excited states
XXXIII Mazurian Lakes Conference on Physics Frontiers in Nuclear Physics, Piaski, Poland

A. Trzcińska 1–7 September 2013
The barrier-height distributions — influence of weak channels (invited talk)
XXXIII Mazurian Lakes Conference on Physics Frontiers in Nuclear Physics, Piaski, Poland

J. Jastrzębski 19–22 September 2013
Medical radioisotopes from the Heavy Ion Laboratory of the University of Warsaw — present status and future plans
Symposium on Positron Emission Tomography, Jagiellonian University, Kraków, Poland

A. Stolarz 7–11 October 2013
Preparation methods of thick molibdenum targets
Legnaro National Laboratory, Legnaro, Italy

K. Hadyńska-Klęk 15 November 2013
Deformacja jądrowa w sąsiedztwie podwójnie magicznego ^{40}Ca — przypadek ^{42}Ca
Nuclear deformation in the vicintiy of the doubly-magic ^{40}Ca — the ^{42}Ca case
National Cyclotron Laboratory Seminar, Inst. of Nuclear Physics, Kraków

M. Palacz 15 November 2013
NEDA (NEutron Detector Array)
National Cyclotron Laboratory Seminar, Inst. of Nuclear Physics, Kraków

J. Jastrzębski, A. Trzcińska 16 December 2013
Nuclear periphery study using antiprotons
Technische Universitat Munchen, Garching, Germany

E.3.3 Poster presentations

J. Choiński 4 June 2013
Silver modified TiO_2 nanoparticles as carriers for ^{211}At
The 8th International Symposium for Targeted Alpha Therapy Oak Ridge National Laboratory, USA

J. Jastrzębski 2–7 June 2013
The radiopharmaceuticals production and reserach centre established at the Heavy Ion Laboratory of the University of Warsaw
INPC 2013, Florence, Italy

K. Rusek 2–7 June 2013
Preliminary results on the elastic scattering of ^{8}He on ^{208}Pb at E=22 MeV
INPC 2013 Florence, Italy

A. Kordyasz 17–20 June 2013
New technology of a thin Si ion implanted epitaxial detector
ENSAR Town Meeting, Warszawa

K. Kilian 21 April 2013
Synteza, kontrola jakości w produkcji 18-fluorodeoksyglukozy
Synthesis and quality control in ^{18}FDG-production process
6th National Conference of Radiochemistry and Nuclear Chemistry

K. KIlian 9 May 2013
Synteza, kontrola jakości oraz charakterystyka zanieczyszczeń metalicznych w produkcji 18-fluorodeoksyglukozy
Synthesis, quality control and radiometalic impurities in ^{18}FDG-production process
II Radiopharmaceutical Conference, Łódź, Poland

L. Próchniak 25–29 September 2013
Quadrupole spectroscopic properties of medium heavy even-even nuclei within the Highly Truncated Diagonalization Approach
20th Nuclear Physics Workshop, Kazimierz Dolny, Poland

E.3.4 Lectures for students and student laboratories

K. Kilian winter semester of academic years 2012/2013, 2013/2014, 30 hours each
Metody izotopowe i chemia farmaceutyków
Radiochemistry and radiopharmacy
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of academic years 2012/2013, 2013/2014, 60 hours each
Pracownia radiofarmaceutyków
Laboratory of radiopharmaceuticals
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński lecture for 2nd year students, 30 hours
Energia w środowisku naturalnym
Energy in natural environment
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński lecture for 1st year students, 45 hours
Fizyka I dla fizyki medycznej
Physics I for medical physics
Faculty of Physics, University of Warsaw, Warszawa, Poland

M. Palacz academic year 2012/2013 (72 hours), and 2013/2014 (110 hours)
Pracownia ochrony radiologicznej
Radioprotection Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

A. Trzcińska academic year 2012/2013 (72 hours), and 2013/2014 (110 hours)
Pracownia ochrony radiologicznej
Radioprotection Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

E.3.5 Science popularisation lectures

Z. Szefliński lectures for high school pupils

Fizyka w biologii i medycynie (1 hour)
Physics in biology and medicine

Fizyka w diagnostyce radiologicznej (2 hours)
Physics in radiodiagnostics

Promieniowanie jonizujace — radon w środowisku naturalnym (1 hour)
Ionizing radiation — radon in the natural environment

Fizyka jądrowa w prostych doświadczeniach (4 hours)
Nuclear physics in simple experiments

E.4 Awards

University of Warsaw Medal

Jerzy Jastrzębski in May 2013 received the University of Warsaw Medal in recognition of his contribution to creating the Medical Imaging Laboratory at HIL

The Rector of the University of Warsaw awards

Michał Kowalczyk, Paweł Napiorkowski
For the paper published in Nature **497** (2013) 199, entitled *Studies of pear-shaped nuclei using accelerated radioactive beams*

Leszek Próchniak
For the contribution to the structure of atomic nucleus theory, summarised in the habilitation thesis entitled *Kolektywne wzbudzenia kwadrupolowe w teorii średniego pola jądrowego* (*Collective quadrupole excitations in the nuclear mean field theory*)

Krzysztof Rusek
For the series of publications on nuclear reactions

Marian Kopka, Wojciech Kozaczka, Piotr Krysiak, Zygmunt Morozowicz, Krzysztof Pietrzak
For the modernisation of the ECR ion source and of the electrical distribution unit

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

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 directors: Jarosław Choiński
Paweł Napiorkowski[a]
Financial executive: Paweł Napiorkowski[b]
Agnieszka Maciejewska[a]

Senior scientists:

Jerzy Jastrzębski[c], Jan Kownacki[c], Andrzej Kordyasz[c], Ernest Piasecki[c], Leszek Próchniak, Krzysztof Rusek, Józef Sura, Anna Stolarz, Zygmunt Szefliński[c]

Scientific staff and engineers:

Tomasz Abraham, Andrzej Bednarek, Izabela Cydzik[d], Jarosław Choiński, Bohdan Filipiak[c], Przemysław Gmaj, Andrzej Jakubowski, Krzysztof Kilian, Maciej Kisieliński[c], Marian Kopka, Michał Kowalczyk, Ireneusz Mazur, Jan Miszczak, Paweł Napiorkowski, Marcin Palacz, Bogdan Radomyski[e], Mateusz Sobolewski, Olga Steczkiewicz, Julian Srebrny[c], Dorota Szczepaniak[b], Roman Tańczyk, Radosław Tarnowski[b], Agnieszka Trzcińska, Andrzej Tucholski[f], Marzena Wolińska[g]

Doctoral candidates:

Katarzyna Hadyńska-Klęk[h], Grzegorz Jaworski[i], Tomasz Marchlewski[h], Jan Mierzejewski[h], Anna Pękal[j], Łukasz Standyło[k]

Technicians:

Mariusz Antczak, Tomasz Bracha, Marek Figat, Andrzej Górecki, Piotr Jasiński, Wiesław Kalisiewicz, Wojciech Kozaczka, Zbigniew Kruszyński, Piotr Krysiak, Kamil Makowski[l], Krzysztof Łabęda, Zygmunt Morozowicz, Bogusław Paprzycki, Mateusz Pęgier[mc], Andrzej Pietrzak, Krzysztof Pietrzak, Krzysztof Sosnowski, Łukasz Świątek[n]

Administration and support:

Anna Błaszczyk-Duda, Marek Budziszewski, Przemysław Czwarnok, Rafał Klęk, Barbara Kowalska[c], Agnieszka Maciejewska, Jolanta Osiecka[o], Piotr Piegat[pc], Joanna Strojek, Ewa Sobańska, Lidia Strzelczyk, Krystyna Szczepaniak, Joanna Wasilewska[q], Wanda Wesoły, Andrzej Wiechowski, Katarzyna Włodarczyk[c], Irena Żejmo[c]

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[a] since 1 September 2013
[b] until 31 August 2013
[c] part time
[d] on leave since 28 September 2013
[e] since 1 April 2013
[f] since 1 December 2013
[g] on long term leave
[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] PhD student at the National Centre for Nuclear Research, Otwock, Świerk
[l] since 6 May 2013
[m] since 15 November 2013
[n] since 1 August 2013
[o] since 1 November 2013
[p] since 4 November 2013
[q] until 27 September 2013

E.6 Laboratory Council

1. Prof. dr hab. Józef Andrzejewski
Nuclear Physics Division
University of Łódź
90-236 Łódź, ul. Pomorska 149/153

2. Prof. dr hab. Rajmund Bacewicz
Warsaw University of Technology
00-661 Warszawa, Plac Politechniki 1

3. Prof. dr hab. Janusz Braziewicz
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Jan Kochanowski University
25-406 Kielce, ul. Świętokrzyska 15

4. Prof. dr hab. Ewa Bulska
Biological and Chemical Research Centre
02-089 Warszawa, ul. Żwirki i Wigury 101

5. Prof. dr hab. Katarzyna Chałasińska-Macukow (Chairman of the Council)
Institute of Geophysics
University of Warsaw
02-093 Warszawa, ul. Pasteura 7

6. Prof. dr hab. inż. Andrzej Chmielewski
Institute of Nuclear Chemistry and Technology
03-195 Warszawa, ul. Dorodna 16

7. Przemysław Gmaj
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8. Prof. dr hab. Andrzej Góźdź
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9. Prof. dr hab. Zenon Janas
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10. Prof. dr hab. Jerzy Jastrzębski
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University of Warsaw
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11. Prof. dr hab. Marta Kicińska-Habior
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12. Prof. dr hab. Stanisław Kistryn
Jagiellonian University
31-007 Kraków, ul. Gołębia 24

13. Prof. dr hab. Adam Maj
The Henryk Niewodniczański
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14. Prof. dr hab. Wojciech Nawrocik
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Adam Mickiewicz University
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15. Dr hab. Sławomir Nazarewski
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16. Prof. dr hab. Paweł Olko
The Henryk Niewodniczański
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31-342 Kraków, ul. Radzikowskiego 152

17. Prof. dr hab. Ernest Piasecki
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18. Dr hab. Ludwik Pieńkowski
AGH University of Science and Technology
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19. Prof. dr hab. Krzysztof Rusek
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20. Prof. dr hab. Teresa Rząca-Urban
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21. Prof. dr hab. Adam Sobiczewski
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22. Prof. dr hab. Ryszard Sosnowski
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23. Prof. dr hab. Wiktor Zipper
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E.7 Programme Advisory Committee

PAC members

- Dimiter Balabanski (University of Sofia, Bulgaria)
- Konrad Czerski (Institute of Physics, University of Szczecin; Physics Department, Technical University of Berlin, Germany)
- 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)
- Zenon Janas (Faculty of Physics, University of Warsaw)
- Nicholas Keeley (National Centre for Nuclear Studies, Warszawa)
- Rainer Lieder (University of Bonn, Germany)
- Piotr Magierski (Faculty of Physics, Warsaw University of Technology)
- Leszek Próchniak (HIL)
- 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).

E.8 External participants in HIL experiments and HIL guests

A. Aimaganbetov	Gumilyov Eurasian National University, Astana, Kazakhstan
A. Dalelkhankyz	Kazakh National University, Almaty, Kazakhstan
A.A Amar	Faculty of Science, Tanta University, Tanta, Egypt
J. Andrzejewski	Fac. of Physics and Applied Computer Sci., U. of Lodz, Łódź, Poland
S.V. Artemov	Uzbek. Acad. Sci., Inst. Nucl. Phys., Tashkent, Uzbekistan
D. Banaś	Holycross Cancer Center, Kielce, Poland
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F.L. Bello Garrote	Department of Physics, University of Oslo, Oslo, Norway
G. Blazhenets	Kharkiv National University, Kharkiv, Ukraine
J. Braziewicz	Institute of Physics, Jan Kochanowski University, Kielce, Poland
N. Burtebayev	Inst. of Nucl. Phys. of National Nuclear Center, Almaty, Kazakhstan
J. Chudyka	Institute of Physics, University of Silesia, Katowice, Poland
J. Czub	Institute of Physics, Jan Kochanowski University, Kielce, Poland
Z. Denis	Inst. of Nucl. Phys. of National Nuclear Center, Almaty, Kazakhstan
Ch. Droste	Faculty of Physics, University of Warsaw, Warszawa, Poland
A. Dudziński	National Centre for Nuclear Research, Otwock, Świerk, Poland
T. Eriksen	Department of Physics, University of Oslo, Oslo, Norway
G. de France	GANIL, Caen, France
F. Giacoppo	Department of Physics, University of Oslo, Oslo, Norway
A. Görgen	Department of Physics, University of Oslo, Oslo, Norway
E. Grodner	Faculty of Physics, University of Warsaw, Warszawa, Poland
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G. Hilgers	PTB, Bundesallee 100, D-38116 Braunschweig, Germany
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M. Jastrząb	The H. Niewodniczański Inst. of Nucl. Physics PAN, Kraków, Poland
U. Kaźmierczak	Faculty of Physics, University of Warsaw, Warszawa, Poland
M. Kirejczyk	Faculty of Physics, University of Warsaw, Warszawa, Poland
G. Kiss	Institute of Nuclear Research (ATOMKI), Debrecen, Hungary
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M. Klintefjord	Department of Physics, University of Oslo, Oslo, Norway
A. Korman	National Centre for Nuclear Research, Otwock, Świerk, Poland
A. Kuc	Institute of Physics, University of Silesia, Katowice, Poland
R. Kumar	Inter University Accelerator Centre, New Delhi, India
H. Kutarük	Akdeniz University, Antalya, Turkey

M. La Cognata	INFN Laboratori Nazionali del Sud, Catania, Italy
B. Lambertsen	PTB, Bundesallee 100, D-38116 Braunschweig, Germany
M. Lattuada	INFN Laboratori Nazionali del Sud, Catania, Italy
O. Lebeda	Nuclear Physics Institute, Rez, Czech Republic
I. Maliyov	Kharkiv National University, Kharkiv, Ukraine
T. Marchlewski	Faculty of Physics, University of Warsaw, Warszawa, Poland
C. Mihai	H. Hulubei Nat. Inst. of Phys. and Nucl. Eng., Bucurest, Romania
I. Mitu	H. Hulubei Nat. Inst. of Phys. and Nucl. Eng., Bucurest, Romania
A. Młynarska	Faculty of Physics, University of Warsaw, Warszawa, Poland
B. Mleczko	Institute of Physics, University of Silesia, Katowice, Poland
M. Nassurlla	Kazakh National University, Almaty, Kazakhstan
M. Nasteruk	Faculty of Physics, University of Warsaw, Warszawa, Poland
T. Nowak	The H. Niewodniczański Inst. of Nucl. Physics PAN, Kraków, Poland
B. Panas	Faculty of Physics, University of Warsaw, Warszawa, Poland
A. Pausewang	PTB, Bundesallee 100, D-38116 Braunschweig, Germany
G.G. Rapisarda	INFN Laboratori Nazionali del Sud, Catania, Italy
S. Pascu	H. Hulubei Nat. Inst. of Phys. and Nucl. Eng., Bucurest, Romania
J. Perkowski	Fac. of Physics and Applied Computer Sci., U. of Lodz, Łódź, Poland
M. Pietrzak	Faculty of Physics, University of Warsaw, Warszawa, Poland
V. Pirnak	Inst. for Nuclear Research, Ukrainian Nat. Ac. of Sci., Kyiv, Ukraine
S. Pszona	National Centre for Nuclear Research, Otwock, Świerk, Poland
A.A. Rudchik	Inst. for Nuclear Research, Ukrainian Nat. Ac. of Sci., Kyiv, Ukraine
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