University of Warsaw

Heavy Ion Laboratory

Annual Report

2011

Warszawa, July 2012

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Annual Report of the
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Introduction

In 2011 construction work on new buildings for the Faculties of Physics, Biology and Chemistry in the immediate neighbourhood of our laboratory entered into such a phase that the unexpected cuts in the power and water supplies were much less critical for us than in a previous. Thus, for the first time since 2005, the number of beam time hours devoted to experiments raised above 2500 hours/year. This is a very good sign for the future.

The EAGLE gamma array was equipped with the twenty high purity Compton suppressed germanium detectors, owned by the European GAMMAPOOL. The array will be intensively used in the 2012 experimental campaign.

For the first time in our laboratory a beam of ^{15}N was accelerated and used in a nuclear physics experiment. The ^{15}N isotope in a gaseous form was obtained from ammonium nitrate supplied by our Ukrainian collaborators from the Institute of Nuclear Physics in Kiev.

Among the scientific highlights it is worth mentioning the result obtained in a wide international collaboration, with contributions from our colleagues led by dr. M. Palacz, and published in Nature. This happened for the first time in the history of our laboratory. Every publication in this very prestigious journal is a great achievement and gives a high rank to our scientific staff.

Medical applications were an important part of our activity. The construction of the Radiopharmaceuthicals Production and Research Centre accelerated significantly and in July the PETtrace GE proton/deuteron cyclotron was installed. The centre will produce radiopharmaceuticals for Positron Emission Tomography (PET). Production of long-lived radiopharmaceuticals for other medical and life-sciences applications is also foreseen. Furthermore, due to the initiative of prof. J. Jastrzębski, some efforts were undertaken in order to produce ^{211}At, an isotope that could be used in cancer therapy. The first test irradiations of a bismuth target with the alpha internal beam from the U-200 cyclotron were performed.

Following the success of the Polish Workshop on the Acceleration and Applications of Heavy Ions, a one week event for undergraduate students from Polish universities organised for a few years, a two-week workshop for students from abroad was organised for the first time in February/March. This initiative has received the necessary funding from the Polish National Agency for LLP Erasmus - the Foundation for the Development of the Educational System. The workshop was organised jointly with the University of Sofia, Bulgaria, and the University of Huelva, Spain and gathered 19 students from those universities and a few Polish institutions. Next year we plan to repeat it, adding the Akdeniz University of Antalya, Turkey, to the list of partner institutions.

Summarising, it was a very busy and productive year . I would like to thank all the scientific and engineering staff of our laboratory for their very hard work and wish that their efforts will be recognised by the authorities responsible for the financing of science in Poland.

Prof. Krzysztof Rusek, Director of HIL

Part A

Laboratory overview

A.1 General information

K. Rusek, J. Choiński, M. Zielińska

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

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

The first beam was extracted in 1993 and since that time HIL has been an effective "user facility", serving up to the present time over 350 scientists from Poland and abroad and becoming a recognised element of the European Research Area. Beam time is allocated by the Director based on the recommendation of the international Programme Advisory Committee (see Sec. D.7). The only criteria are the scientific merit of the project and its technical feasibility. The research programme (see Part B) is mostly focused on nuclear and atomic physics, but materials science, biological and applications studies also play an important role and a significant amount of the beam time is allocated for these purposes.

Experimental teams may take advantage of permanent set-ups installed on the beam lines or use their own dedicated equipment. Available apparatus includes IGISOL — a Scandinavian type on-line separator, CUDAC — a PIN-diode array particle detection system, JANOSIK — a multi-detector system consisting of a large NaI(Tl) crystal with passive and active shields and 32-element multiplicity filter and ICARE, a charged particle detector system used for particle identification and energy measurements, moved to HIL from IReS Strasbourg. The most recent experimental tool, still being developed and improved, is the EAGLE array (Sec. A.7) – a multi-detector γ-ray spectrometer, which can be easily coupled to ancillary detectors like an internal conversion electron spectrometer, a charged particle 4 π multiplicity filter (Si-ball), a scattering chamber equipped with 100 PIN-diode detectors, a 60-element BaF_2 gamma-ray multiplicity filter, a sectored HPGe polarimeter and a plunger.

HIL is currently in a transition period and will shortly become an accelerator centre, operating two cyclotrons (Sec. A.3). Installation of a commercial proton-deuteron cyclotron (E_p = 16.5 MeV) is under way in the HIL building. This accelerator will be used for the production of and research with radiopharmaceuticals for Positron Emission Tomography (PET). Production of long-lived radiopharmaceuticals for other medical and life-science applications is also foreseen.

A.2 Tasks carried out in 2011 in order to improve the cyclotron infrastructure and efficiency

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In 2011, 2656 hours of beam were successfully delivered by the HIL cyclotron for different experiments. The total amount of time of beam on target increased compared to previous years. This was possible because several important problems, affecting the work of the cyclotron, were solved. Nevertheless, the most important issue — the very old vacuum equipment — still remains to be solved. Figure 1 shows the total number of beam hours delivered over the last eleven years.

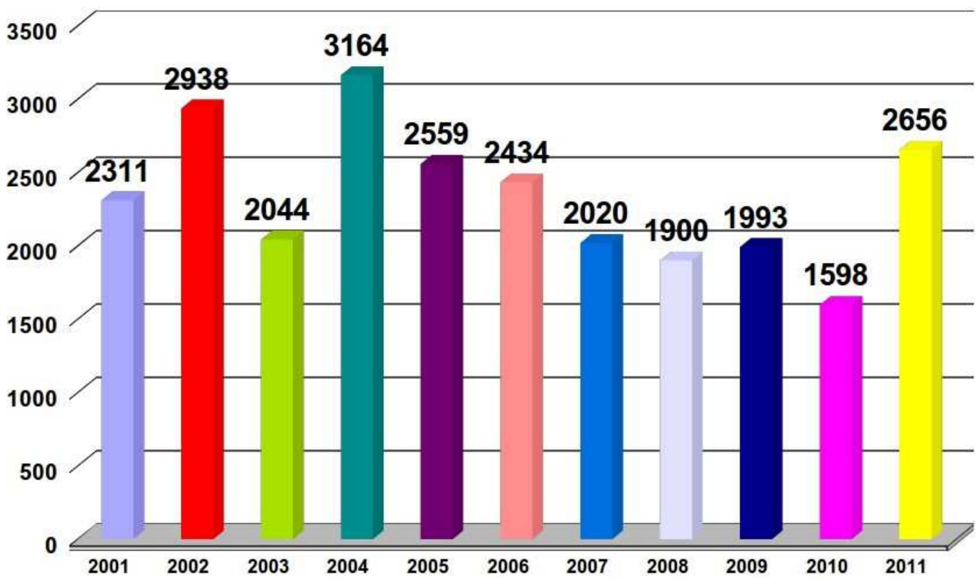

Figure 1: Total cyclotron beam time in the years 2001–2011

The first order amelioration of the inner part of the central region was made at the beginning of 2011 and "live" tests of this solution were carried out over the summer. This allowed the beam to be brought from the new ECR ion source to the median plane of the cyclotron and also to extract it. However, the intensity of the beam was much lower than the corresponding intensity from the old ECR and was not satisfactory. Thus, further work on the reconstruction of the central region was needed. This required measurements of the magnetic field in the injection channel and in the median plane of the cyclotron.

The equipment for the vertical measurements was constructed and programmed after the summer holiday break, and the measurements were performed in December. The measurements will be the basis for the design of a spiral inflector which will be developed in collaboration with JINR, Dubna in 2012.

The equipment necessary for the measurements in the median plane has also been designed. The assembly of the measurement system is planned for the first half of 2012. In the mean time, control software for the system will be developed.

An additional quadruplet of electrostatic quadrupoles for the axial beam line was built at the end of 2011 and the first trial of this focusing system was carried out in December. The first results of these trials, although promising, were not conclusive regarding their impact on accelerated beam current. Further work on this system is planned for 2012.

In autumn 2011, after several high frequency amplifier breakdowns, a system to protect against the ingress of water into the amplifier compartment was developed and built. A tender for the new RF amplifiers was also lunched, but unfortunately no offers were submitted.

The monthly distribution of beam time in 2011 is presented in Fig. 2 and the diversity of the experiments performed during 2011 is illustrated in Fig. 3. Lower experimental activity during July, August and September is correlated with the traditional summer vacation. Main topics of the experiments are related to nuclear physics research, biological research, machine development and beam tests. Beam time was also allocated to national and international student workshops, as in the last few years. This was the first year when we began the production of Astatine 211 in close collaboration with the Institute of Nuclear Chemistry and Technology and the Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences. In all the experiments, the involvement of young researchers, graduate and undergraduate students is traditionally large, which is illustrated in Fig. 4. Detailed descriptions of the experimental set-ups available at HIL can be found on the laboratory web page: `www.slcj.uw.edu.pl`.

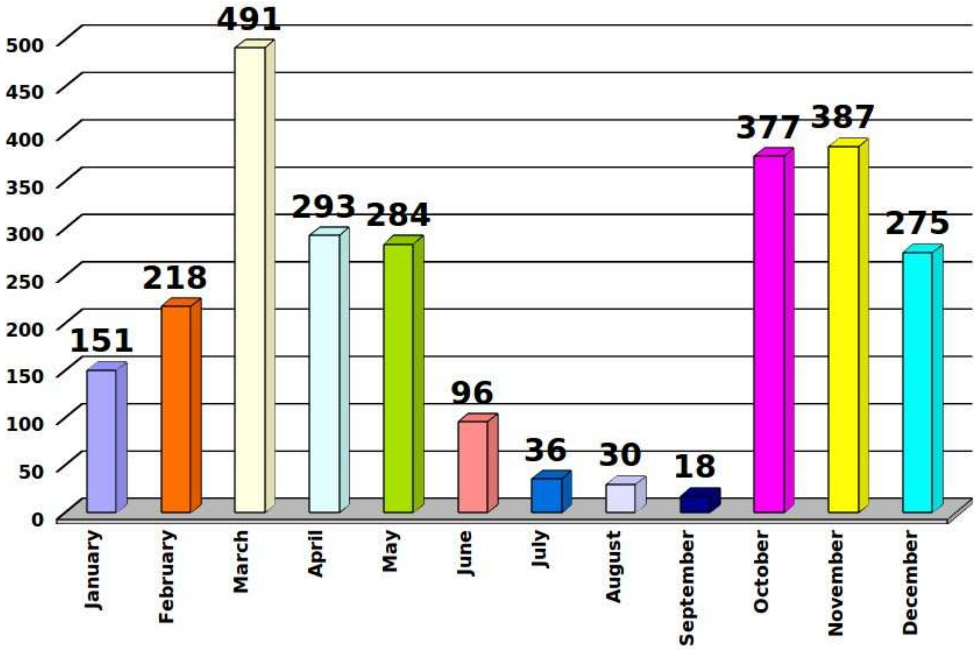

Figure 2: Beam time distribution (hours) in 2011 per month

A list of the experiments performed in 2011 is presented in Tables 1 and 2. The following acronyms are used in the table:

- AMU Poznań —- Adam Mickiewicz University, Poznań
- IB JKU Kielce – Institute of Biology, Jan Kochanowski University, Kielce
- HCC, Kielce – Holycross Cancer Centre, Kielce
- IEP UW — Institute of Experimental Physics, University of Warsaw, Warsaw

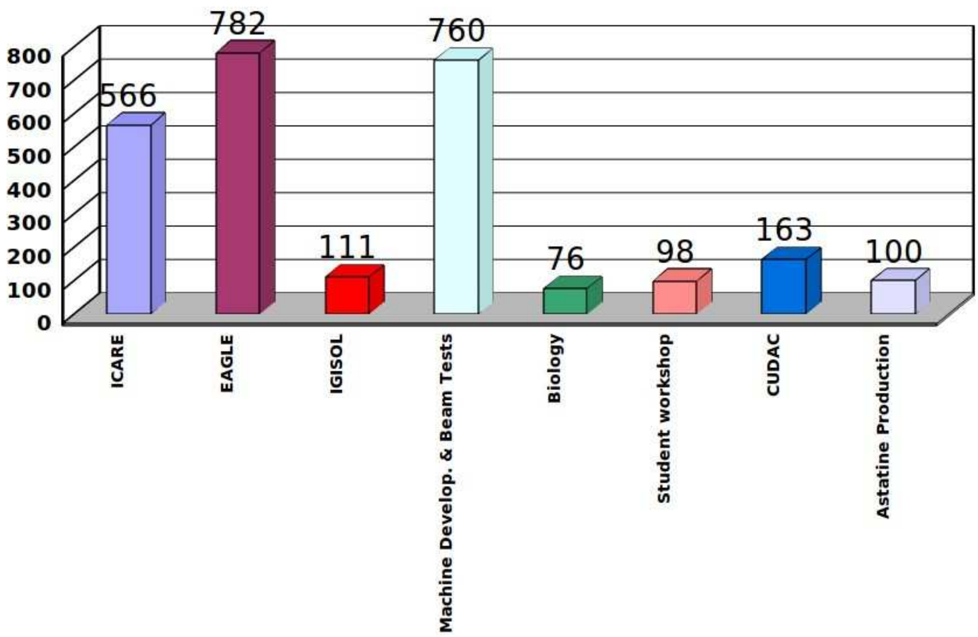

Figure 3: Distribution of beam-time (in hours) among different experiments

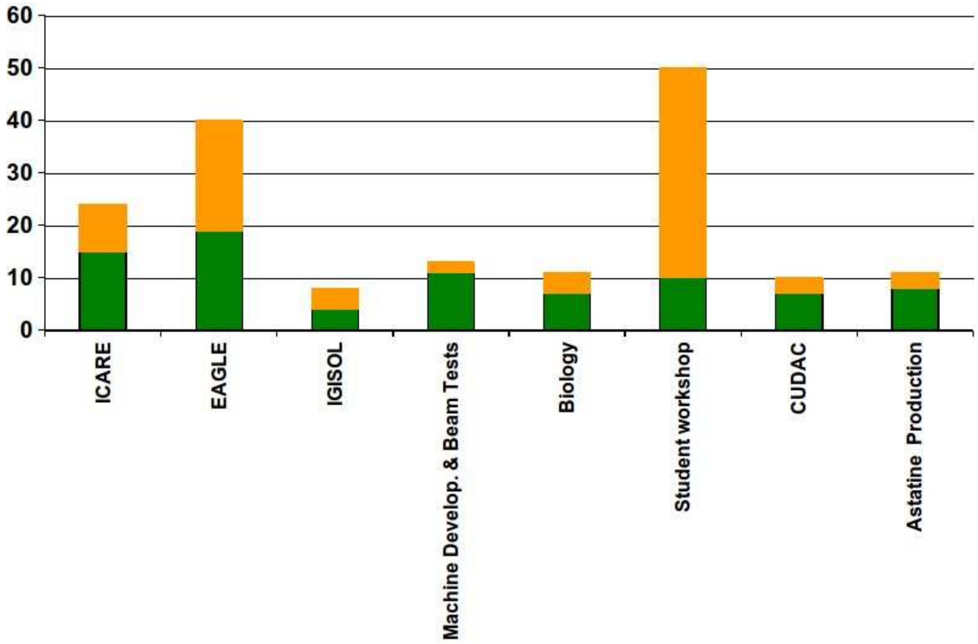

Figure 4: Number of users of Warsaw cyclotron beams in 2011

- INP Kraków — The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków
- IPN Orsay — Institut de Physique Nucléaire, Orsay, France
- NCNR Świerk — The National Centre for Nuclear Research, Świerk
- NCNR Łódź — The National Centre for Nuclear Research, Łódź
- UŁ — Faculty of Physics and Applied Computer Science, University of Lodz, Łódź
- MCSU Lublin — Maria Curie-Skłodowska University, Lublin
- NU Kharkiv — National University, Kharkiv, Ukraine
- NCU Toruń — Nicolaus Copernicus University, Toruń

- UI Ioannina — University of Ioannina, Greece
- UL Liverpool — University of Liverpool, Liverpool, UK
- US Katowice — University of Silesia, Katowice

Table 1: Experiments performed in 2011 — part 1

Dates	Ion Energy [MeV]	Experiment	Leading institution	Collaborating institutions
04.01–15.01	$^{20}Ne^{+3}$	Test of new ion source and injection line	HIL	
17.01–23.01	$^{20}Ne^{+3}$ 44, 54, 57	CUDAC	HIL	NCNR Świerk, NU Kharkiv, US Katowice, INP Kraków
14.02–16.02	$^{12}C^{+2}$ 50	Biology	IEP UW, IB JKU Kielce	HIL, HCCC Kielce, NCNR Świerk, NCU Toruń
17.02–21.02	$^{20}Ne^{+3}$ 47, 53, 56	CUDAC	HIL	NCNR Świerk, NU Kharkiv, US Katowice, INP Kraków
23.02–24.02	$^{4}He^{+1}$ 125	Astatine Production	HIL	HIL, US Katowice
01.03–04.03	$^{20}Ne^{+3}$ 54	Student workshop	HIL	
09.03–18.03	$^{14}N^{+3}$ $^{10}B^{+2}$ 72, 53	EAGLE	IEP UW	HIL, NCNR Świerk
21.03–25.03	$^{18}O^{+4}$ 102	IGISOL	IEP UW	HIL, NCNR Świerk, NCNR Łódź, US Katowice, IPN Orsay
28.03–01.04	$^{32}S^{+6}$ 140	EAGLE	HIL	IEP UW, NCNR Świerk, UŁ
04.04–15.04	$^{20}Ne^{+3}$ 50, 54	ICARE	HIL	NCNR Świerk, NU Kharkiv, US Katowice, INP Kraków
09.05–20.05	$^{12}C^{+3}$ $^{16}O^{+4}$ 69, 86	EAGLE	UŁ	HIL, NCNR Świerk, IEP UW
30.05–31.05	$^{40}Ar^{+6}$	Test of new ion source and injection line	HIL	
06.06–10.06	$^{4}He^{+1}$ 125	Astatine Production	HIL	US Katowice

Table 2: Experiments performed in 2011 — part 2

Dates	Ion Energy [MeV]	Experiment	Leading institution	Collaborating institutions
01.07–29.07	$^{20}Ne^{+3}$ $^{20}Ne^{+4}$ $^{20}Ne^{+5}$ $^{40}Ar^{+6}$	Test of new ion source and injection line	HIL	
02.08–16.08	$^{4}He^{+1}$ $^{40}Ar^{+6}$ $^{40}Ar^{+8}$	Test of new ion source and injection line	HIL	
22.09–23.09	$^{32}S^{+5}$ 75	Test of the cyclotron	HIL	
27.09	$^{40}Ar^{+6}$	Test of new ion source and injection line	HIL	
03.10–04.10	$^{4}He^{+1}$	Test of new ion source and injection line	HIL	
10.10–14.10	$^{32}S^{+5}$ 75	EAGLE	HIL	IEP UW, NCNR Świerk, UŁ
17.10–24.10	$^{20}Ne^{+3}$ $^{20}Ne^{+4}$ 50, 73	ICARE	UI	HIL, IEP UW, NCNR Świerk
24.10–27.10	$^{20}Ne^{+3}$ 54	Student workshop	HIL	
14.11–27.11	$^{14}N^{+3}$ 72	EAGLE	IEP UW	HIL, IEP UW, NCNR Świerk
28.11–01.12	$^{18}O^{+4}$ 102	IGISOL	IEP UW	HIL, NCNR Świerk, NCNR Łódź, US Katowice, IPN Orsay
14.12–23.12	$^{15}N^{+3}$ 82	ICARE	NU Kharkiv	HIL, NCNR Świerk, NU Kharkiv, US Katowice, INP Kraków

A.3 The Warsaw PET Project — Radiopharmaceuticals Production and Research Centre at HIL

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In 2011 the University of Warsaw invested additional funds of its own to finish the second production laboratory, which is an integral part of the investment, keeping the same standard as the basic lab for the production of FDG. The agreement was signed on 25 July 2011. The project was extended to the design and execution of clean-rooms, equipped with hot cells for labelling with ^{18}F, ^{11}C and ^{15}O isotopes. This shifted the final date of completion to 28 February 2012.

This year, the main effort was focused on design and building execution works. In parallel the equipment was installed and tested: on 15 July 2011, the cyclotron was installed at the site. By December, all the hot cells, clean rooms, and technical areas with respective systems were finished.

Despite the serious problems with which we had to deal in this project, it will be completed in the first half of 2012.

The completion of the project will be celebrated with an international conference: "Positron Emission Tomography in Research and Diagnostics" organised in May 2012, by the Heavy Ion Laboratory in collaboration with the Department of Nuclear Medicine, Medical University of Warsaw and the International Atomic Energy Agency.

A.4 Electrostatic quadrupoles of the HIL cyclotron injection line

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Beams of ions from the ECR ion source are transported to the central region of the cyclotron by an ion-optical system called the "injection line". The purpose of the line is to form the beam so it is accepted by the cyclotron high frequency RF accelerating system, with the lowest possible losses. The beam is shaped in time by a buncher to reach the RF system at the proper phases. The space form of the beam is formed by magnetic and electrostatic ion-optical elements.

In this report we describe a set of electrostatic quadrupoles installed to match the beam emittance and the cyclotron acceptance. This function is illustrated in Fig. 1.

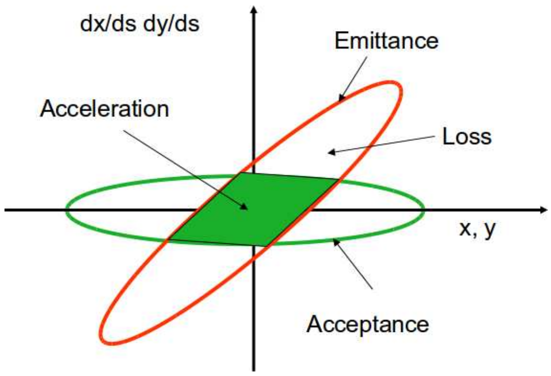

Figure 1: If the cyclotron acceptance in a given plane is like the green ellipse and the emittance of the beam is like the red ellipse, then only particles having the deviation-inclination coordinates within the overlapped green region will be accepted by the accelerating system.

Since the focusing power of the cyclotron is different in the horizontal and vertical planes (the betatron frequencies are different by a factor of around three), we need four free parameters to match both planes [1, 2]. We chose a set of four quadrupole lenses assembled in two doublets. A single lens is schematically shown in Fig. 2, and a picture of a doublet is presented in Fig. 3.

The electrodes are made of oxygen-free copper to increase their spark resistance. They are approximately hyperbolically shaped using the data given in Ref. [3]. The insulators are made of teflon plates. The voltage for each electrode is supplied by a separate voltage source through a vacuum insulator. The whole system is shown schematically in Fig. 4. The geometrical parameters are: beam aperture $2a = 75$ mm, radius of the electrode curvature $RE = 43$ mm, length of electrodes $L = 100$ mm, distances $s = 50$ mm, $s_3 = 200$ mm. The optical parameters k_1, k_2 result from the transport analysis. The polarisation voltages on each of the electrodes are shown in Fig. 5.

The analysis of the beam transport starts with the assumption that at the entrance to the system $s_1 = 0$, the beam being formed by the previous elements to a cross-over in both planes. In our case we need the focus placed in the central post at $s_2 = s_x = 1500$ mm and $s_2 = s_y = 1000$ mm. The distances of the focus in terms of the transport matrix elements are:

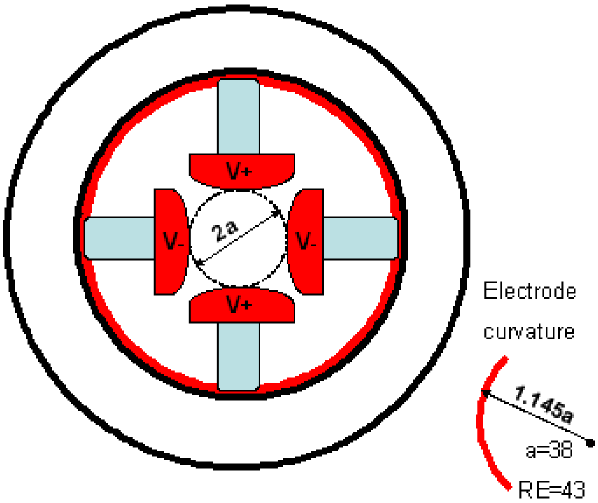

Figure 2: Schematic drawing of a single lens

Figure 3: Photo of one of the two doublets installed in the cyclotron injection line.

$$s_x(k_1, k_2) = -\frac{T_x(k_1, k_2)_{0,0}}{T_x(k_1, k_2)_{1,0}} \qquad s_y(k_1, k_2) = -\frac{T_y(k_1, k_2)_{0,0}}{T_y(k_1, k_2)_{1,0}}$$

Here the indices of the matrix elements follow the convention used in the MATHCAD program.

For the above requirements and for ions with a mass to charge ratio $A/Q = 5$, with an ECR extraction voltage of $V_{ecr} = 24$ kVolt, we get the values of the lens parameters $k_1 = 4.504$, $k_2 = 4.204$, and consequently the lens voltages:

$$V_1 = k_1^2 \cdot V_{ecr} \cdot a^2 \quad V_2 = k_2^2 \cdot V_{ecr} \cdot a^2$$

Hence, $V_1 = 684.543$ V and $V_2 = 596.612$ V.

The system is regularly used and it increases the cyclotron beam intensity. The amplifying factor depends on the type of ion and the settings of all the other line elements. It is also used as a steering system when some values of a single lens voltages are changed, introducing the first harmonics in the quadrupole field distribution. The first harmonics shift the centre of the lens and it results in a steering effect.

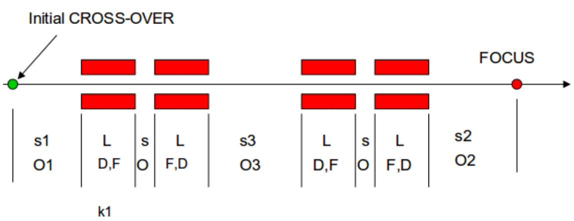

Figure 4: Schematic drawing of the whole system.

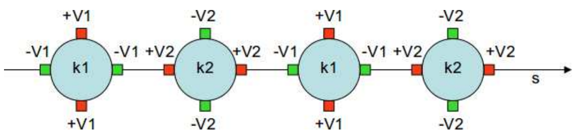

Figure 5: The signs of voltages fed to each electrode.

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A.5 RF team activity report

A. Bednarek, K. Sosnowski, M. Budziszewski, T. Bracha , J. Miszczak, P. Gmaj

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In 2011 modernisation of the RF power system (Fig. 1) used for the acceleration of particles inside the cyclotron was initiated. A grant from the Fund for Polish Science and Technology made it possible to open a tender for the supply and commissioning of a complete RF system. The complete system consists of a synthesiser-exciter, a pair of identical amplifier chains and phase and amplitude stabilisation circuits. The tender procedure is currently on-going.

Figure 1: Front panel of the existing RF power system.

In collaboration with members of the vacuum team, we developed and launched a prototype vacuum pump controller. The heart of the controller is the LOGO, PLC controller from the Siemens company. Two RF power tubes (Fig. 2) for the RF power stage were purchased from the Joint Institute of Nuclear Research, Dubna, Russia The assistance of the Dubna Institute in arranging this transaction is gratefully appreciated, as the tubes, made in the USSR, have not been on the market for many years.

Routine maintenance work and repairs were also performed by the RF group. In December 2011, modernisation of the existing emergency cooling water leakage drain was carried out. Corroded and clogged pipes were removed. The old pipes were replaced with new ones made of plastic, with a larger cross section. The new system is equipped with a electro-mechanical water leakage sensor (Fig. 3) and a flashing lamp indicating leakage. Early detection of water leaks in the RF power compartment allows serious damage of expensive elements of the final RF power stage, powered by a high voltage of 10 kV, to be avoided. Before the installation of the water leakage warning system, we had to replace the high voltage insulator supporting tunable resonant circuit of the RF power stage, which was damaged by water spray coming from the holes in the cooling system. We also tested and introduced new fast on/off connectors for elastic pipes with cooling water. The new connectors significantly decrease the time needed to replace a ruptured pipe.

Figure 2: RF system power vacuum tube GK-11A from Dubna.

Figure 3: Water leakage sensor (left) and water leakage indicator lamp (right).

A.6 Activity report of the electrical support group

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In 2011 the electrical support group designed and implemented several projects:

1. Construction of three new magnetic coils for the magnetic trap of the ECR ion source, repair of one coil.
2. Measurements of the electric parameters of two transformers and two choke coils of the high frequency generators.
3. Repair and adjustment of the power supply UZ1.
4. Replacement of fans in the main power supply ZM1.
5. Measurement of the reserve capacitors for the reactive power compensation.
6. Participation in the design of a new power switching station RGW to power the high frequency generators and PET Laboratory.

The following routine measurements and maintenance procedures were also performed:

1. Measurements and maintenance of power supplies, electromagnets and wiring of the laboratory equipment.
2. Measurements and maintenance of the electrical power system and the electrical installations, including lighting, inside and outside, of the HIL building.

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

A.7 Ge Detector Laboratory and status report on Phase I 20 HPGe from GAMMAPOOL

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2) The National Centre for Nuclear Research, Otwock, Świerk, Poland

The central European Array for Gamma Levels Evaluations (EAGLE) [1, 2] was designed to host 20 high purity Compton suppressed germanium detectors as part of a collaboration with the European GAMMAPOOL. In preparation for forthcoming experiments a new Detector Laboratory was set up. This Laboratory is equipped with two setups for regeneration of HPGe detectors (Fig. 1), and another for testing detectors (Fig 2). The detector laboratory was ready for use before the detectors arrived in June 2011.

Figure 1: HPGe detector regeneration setups at HIL

The newly obtained detectors were tested and regenerated during summer 2011 to be ready for experiments in September and November 2011. Out of the total number of 20 detectors obtained only 10 had satisfactory performance parameters. The other ten had problems which were repaired in 6 cases. One detector with neutron damage was annealed and two others with bad vacuum were restored by pumping. Two detectors with broken high voltage filters and one with a broken preamplifier were repaired. The last four detectors were beyond repair in our laboratory due to the following problems: vacuum leak, high detector current in two cases and bad pulse shape. In this last case, the detector can not be used with pile up rejection, which disqualifies the detector from experiments in the EAGLE setup. Our evaluation was confirmed during a two weeks' visit to HIL of Pete Jones from the University of Jyväskylä.

Finally 16 Germanium detectors with 70% efficiency and 15 anti-Compton shields were ready for use in the EAGLE spectrometer. This means 15 detectors may be used at a time in an experiment (limited by the number of anti-Compton shields). The detectors have energy resolutions ranging from 2 to 3 keV at the 1333 keV ^{60}Co line. The detector

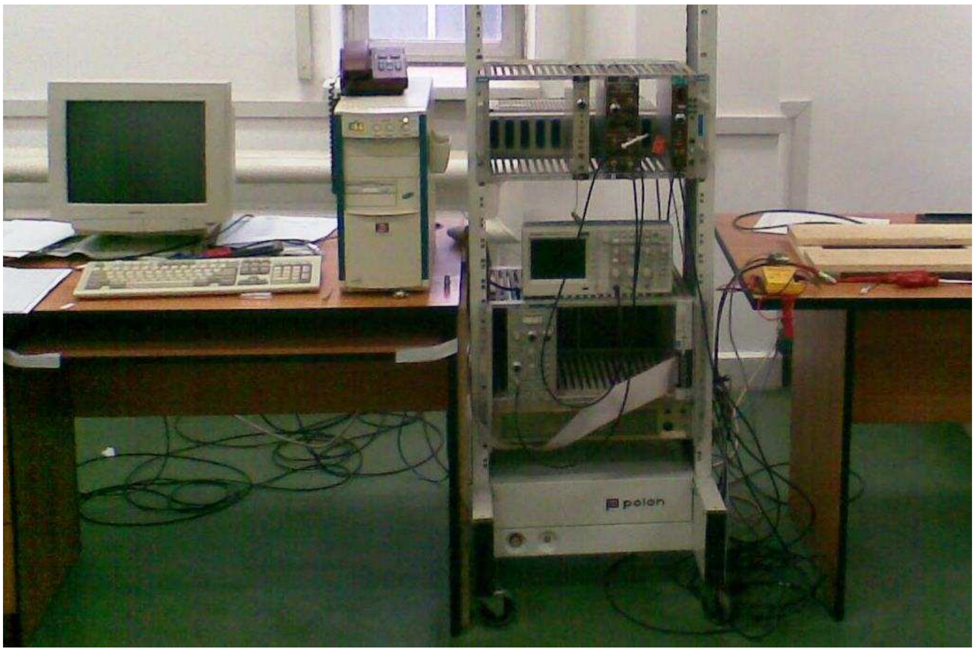

Figure 2: HPGe detector testing setup at HIL

laboratory with two regeneration setups operational is able to regenerate fully all 16 detectors in 8 weeks.

The work done in the new detector laboratory combined with the efforts of engineers in the EAGLE project encouraged the laboratory in the physics department of the University of Jyväskylä (Finland) to lend HIL five high purity Compton suppressed germanium detectors for use from December 2011 to April 2012.

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A.8 Quality control of FDG

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Molecular imaging with radiopharmaceuticals uses short-lived isotopes (usually ^{18}F, ^{11}C, ^{13}N, ^{15}O). One of the most important aspects of working with radiopharmaceuticals is the short time (about 40 minutes) that can be spent on quality control and release procedures, thus the speed, simplicity and reliability of the analytical methods are critical factors. For radiopharmaceuticals the general requirements are listed in the European Pharmacopoeia and these parameters have to be checked before application for human use.

To ensure the smooth realisation of the whole project of the Radiopharmaceuticals Production and Research Centre, the development of quality control methods for FDG has to be performed in advance for testing and qualification of modules and systems. In 2011 a set of analytical methods has been developed, covering:

- Nuclidic purity,
- Chemical and radiochemical purity,
- Isotonicity and pH,

and applied to reference samples obtained from other laboratories.

A.9 The ^{11}C and ^{15}O Laboratory

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An important task and organisational investment in 2011 was the purchase of equipment for and commissioning of the Laboratory dedicated to research on radiopharmaceuticals labeled with short-lived isotopes. The laboratory was equipped with two hot cells, a wide range of synthesisers for ^{11}C labelling of molecules (3 synthesisers) and ^{15}O (1 shielded synthesiser for ^{15}O-H_2O). The equipment allows common radiopharmaceuticals used in diagnostic practice to be synthesised as well as developing innovative labelled compounds.

In addition, the targetry for ^{11}C and ^{15}O was installed in the cyclotron bunker. The chemistry lab was equipped with a microwave synthesiser for development of new procedures and a liquid chromatograph with mass spectrometry (LC-MS) for structural studies and identity check of the compounds obtained.

The ^{11}C and ^{15}O Laboratory was equipped in the framework of the Preclinical Research and Technology Centre under the Innovative Economy project.

A.10 Unix Computers at HIL

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Modernisation and unification of all the Unix computer systems at HIL, begun in 2009 [1] and continued in 2010 [2], was successfully completed at the beginning of 2011. All workstations and servers in the HIL computer network were upgraded to Ubuntu Linux v.10.04 LTS. In the middle of 2011 the disk space of the HIL mail server was extended approximately four times. In the third quarter of 2011 the HIL backup server was also updated, which included doubling its disk space.

As already reported [2], advanced shell scripts are used for the administration of the linux cluster at HIL. These scripts can be divided into two groups. The first is designed to keep the Ubuntu hosts configuration coherent. The second makes the process of system re-installation easier and faster (after hardware failures for example). In 2012 the scripts were significantly improved and extended.

Linux and other Unix-like computer operating systems are generally regarded as very well-protected against malicious programs, but they are not absolutely immune. The number of viruses, Trojans, and other computer contaminant programs — specifically written for Linux — has been on the rise in recent years. In addition, files that are stored in Linux hosts, and later distributed, could be infected by malicious software written for Windows. Taking all these aspects into account, a decision was taken to improve the security of the HIL computer network by installing anti-virus packages on crucial Unix hosts. A number of available anti-virus packages were evaluated. Finally avast! for Linux was chosen and installed at HIL on WWW and file servers.

The Collaborative SPIRAL2 Preparatory Phase web site that is hosted and maintained by HIL was moved to the new WWW server in the first quarter of 2011. Despite the fact that the SPIRAL2 Preparatory Phase project terminates in March 2012, the web site will be active at the HIL WWW server till April 2021. The validity of the spiral2pp.eu domain was prolonged till this date.

The following activities are scheduled for the next year: modernisation of the HIL WiFi network system (Q1, Q2), modernisation (hardware and software updates) of the HIL mail server (Q2, Q3), operating system update (to Ubuntu Linux 12.04 LTS) for all Unix computers actually running under Ubuntu Linux 10.04 LTS (Q3, Q4).

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[1] HIL Annual Report 2009, page 20

[2] HIL Annual Report 2010, page 28

A.11 Computers and networks at HIL

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In 2010 there were two failures of the Air Conditioning (AC) system in the Laboratory's server room (one in summer and one in winter). The failures were quickly fixed, so there was no interruption to the Laboratory's computer services. It was however found out, that the problems were caused by the borne dust from the neighbouring construction sites, and by the fact, that the AC system operated near its maximum cooling capacity. Since the server room was rather small (3.1 m by 3.1 m), a decision was taken to convert one room in the basement of the Laboratory building into a second server room, instead of upgrading (or in fact replacing) the AC unit in the old one. The new room was outfitted with a 12kW AC system, a raised floor, and a dual 1 Gb/s fiber optics link to the Laboratory LAN. Most of the existing servers were moved to the new room in the spring. Additional space is available there and can in future be used to accommodate new computers. With the exception of the installation of the AC unit, all the conversion work in the new server room was done by the Laboratory staff.

A.12 Educational and science popularisation activities at HIL

A. Trzcińska[1], O. Steczkiewicz[1], M. Zielińska[1], M. Palacz[1], J. Choiński[1], K. Hadyńska-Klęk[1,2], G. Jaworski[1,3], K. Kilian[1], J. Mierzejewski[1,2], P.J. Napiorkowski[1], L. Pieńkowski[1], J. Srebrny[1], K. Wrzosek-Lipska[1,2],

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

In 2011, 33 groups (almost 1000 people) visited our Laboratory. High-school classes were the largest category of our visitors, but we also welcomed students from faculties of the University of Warsaw: Physics and Biology, as well as from the Maria Curie-Skłodowska University in Lublin, the Cardinal Stefan Wyszyński University in Warsaw, the Jan Kochanowski University in Kielce and the Warsaw University of Technology. Physics Student Clubs from different universities, finalists of the Interschool Competition in Physics and Chemistry "EUREKA", finalists of the Polish Competition "Looking for talents", participants of the Summer School of Physics organised by the Faculty of Physics, University of Warsaw, and groups of physics teachers were also among our visitors.

In September HIL participated in the annual Festival of Science 201 for the 15th time. We prepared a series of panel discussions on subjects related to nuclear physics and its applications in technology and medicine. These meetings took place on 24 September and were accompanied by guided tours of the cyclotron. During the preceding week we also organised so-called Festival Lessons for secondary school classes. These simple lectures, addressed to youths of age 14–15, attracted large attention.

In 2011, the Laboratory for the first time took part in the "Museum Night" organised in Warsaw. In this event, not only museums, but also other institutions were opened up to the public in the late evening of 14 May. Our facility was then visited by more than 500 guests of different ages and backgrounds. In turn on 26 May, we participated in the inauguration of the so called "Maria Skłodowska-Curie educational path", a historical and educational establishment located in the park in front of the HIL building, and in the nearby oncological hospital — the former Radium Institute which at its opening in 1932 received 1 g of radium as a gift from M. Skłodowska-Curie.

The Seventh Polish Workshop on Acceleration and Applications of Heavy Ions was organised at HIL in October 2011 (see Sec. A.13 of this Report), and for the first time we also hosted an international version of the workshop (Sec. A.14). HIL staff members are also engaged in supervising MSc and PhD theses — see Sec. D.1. In the summer a four-week training course was organised for several students from the Warsaw University of Technology.

A.13 Polish Workshop on the Acceleration and Applications of Heavy Ions

P.J. Napiorkowski[1], *A. Trzcińska*[1], *T. Abraham*[1], *K. Hadyńska-Klęk*[1,2], *G. Jaworski*[1,3], *M. Komorowska*[1,2], *M. Kowalczyk*[1,2], *J. Mierzejewski*[1,2], *M. Palacz*[1], *J. Srebrny*[1], *O. Steczkiewicz*[1], *A. Stolarz*[1], *I. Strojek*[4], *K. Wrzosek-Lipska*[1,2]

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

The number of participants has been increasing every year, reaching nineteen in 2008. This number is limited by the capacity of the HIL guest house, in which students are accommodated. Participation in the workshop, including the accommodation, is free of charge. After the success of the first editions, we usually receive over twice as many applications as the number of places available. It should also be noted that almost every year new institutions join the list of universities interested in sending their students to the Workshop. The participants are often willing to continue the collaboration with HIL in the form of a summer internship or at the MSc stage. So far three MSc theses prepared at HIL by former Workshop participants have been defended: one in 2008 at the Adam Mickiewicz University in Poznań and two in 2009 at the University of Silesia in Katowice.

The 14 students participating in the Workshop in 2011 came from the following universities: 3 from the Jagiellonian University in Kraków, 4 from the University of Lodz, 4 from the University of Silesia and 3 from Szczecin University. During the Workshop they attended a series of lectures on subjects related to heavy ion physics. The experimental tasks allowed them to get acquainted with HIL infrastructure by performing measurements using dedicated apparatus available in the Laboratory. The Workshop was concluded by student presentations — each group prepared a 20 minute talk on their measurements and results.

In 2011, the programme of the lectures was as follows:

- Presentation of HIL (K. Rusek);
- Radioprotection at HIL (R. Tańczyk);
- Introduction to heavy ion acceleration and elements of ion optics (O. Steczkiewicz);
- Detection of gamma radiation, charged particles and neutrons (M. Palacz);
- In-beam gamma spectroscopy (P. Napiorkowski);
- Nuclear-coal synergy (L. Pieńkowski),
- Targets for nuclear physics (A. Stolarz),

- Radioactive decays as a source of nuclear structure information (Z. Janas),
- Radiopharmaceuticals for Positron Emission Tomography (K. Kilian).

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.
- Measurements of ^{137}Cs activity in environmental samples.

A.14 International Workshop on the Acceleration and Applications of Heavy Ions

M. Zielińska[1,2] for the Warsaw-Huelva-Sofia-Antalya collaboration

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

To meet the needs of Polish nuclear physics students, the Heavy Ion Laboratory organised the first Workshop on the Acceleration and Applications of Heavy Ions in 2005, which, after the success of the first edition, has been repeated every year since (see Sec. A.13 of this Report). In general the workshops were very well received by participants, who appreciated especially the possibility of performing nuclear physics measurements using real scientific equipment, used every day for research, and the experience of work in an accelerator laboratory. The evaluation showed, however, that the participants judge the time allocated for the workshop (6 working days) as being too short to fully benefit from it. Larger working groups (4 persons and more) were also disfavoured.

These remarks were taken into account when organising in March 2011 the first International Workshop on the Acceleration and Applications of Heavy Ions [1] based on this concept. The workshop obtained significant financial support from the ERASMUS LLP Programme as a so-called Intensive Programme (grant agreement ERA_IP_18_2010). 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. An Intensive Programme also has to be organised by a consortium of at least three universities from three different European countries. Only students affiliated at these partner institutions can benefit from the ERASMUS financial support that we received. The consortium was formed by the University of Warsaw, University of Huelva (Spain) and University of Sofia (Bulgaria) and 19 students from Bulgaria, Spain and Poland took part in the first edition of the workshop. In 2011, Akdeniz University in Antalya, Turkey, joined the list of partner institutions co-organising the workshop and starting from 2012, students and scientists from this university will take part in it. The workshop becomes more and more integrated in the teaching programmes at the partner institutions: students from Warsaw, Huelva and Antalya receive ECTS credits upon successful completion of the course, and in Huelva it has become a mandatory course for the second cycle of studies in the field of nuclear engineering.

In 2011, the programme of lectures included subjects such as target preparation, ion optics, presentation of various experimental techniques as well as applications of nuclear methods in other fields, for example medicine and nuclear energy. I. Martel (University of Huelva, Spain), S. Lalkovski (Sofia University "Sveti Kliment Ohridski", Bulgaria), N. Keeley (The National Centre for Nuclear Research, Świerk), L. Próchniak (Maria Curie-Skłodowska University in Lublin), K.W. Kemper (Florida State University, Tallahassee, USA), P. Decowski (Smith College, Northampton, USA), M. Kmiecik (Institute for Nuclear Physics, Kraków) were among the lecturers along with several researchers from HIL (K. Rusek, O. Steczkiewicz, A. Stolarz, J. Kownacki, L. Pieńkowski, K. Kilian).

Students took part in the following experimental tasks:

A. Ion optics (supervisors: O. Steczkiewicz, P. Gmaj, J. Sura, A. Trzcińska);
B. Rutherford scattering (supervisors: J. Iwanicki, J. Srebrny, I. Strojek);
C. Gamma-ray spectroscopy (supervisors: M. Palacz, J. Mierzejewski);
D. Nuclear reactions — experimental (supervisors: I. Martel, I. Strojek);
E. Nuclear reactions — theory (supervisors: K. Rusek, N. Keeley, K. Kemper) and detector tests (supervisor: A. Kordyasz);
F. Fast timing (supervisors: S. Lalkovski, P.J. Napiorkowski).

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 jury consisting of three nuclear physics professors.

To the best of our knowledge, apart from the Polish Workshop on the Acceleration and Applications of Heavy Ions and its international successor, there is no other training of this kind offered by European accelerator centres. Existing training programmes and summer schools do not provide accelerator beam time and sophisticated equipment for teaching purposes only: common practice is incorporating students in research groups and assigning them routine and sometimes unskilled tasks. In this aspect, our project is unique and innovative: it offers a real hands-on experience with modern equipment and an opportunity to work in an international group on an open problem. In addition to specific knowledge on methods of data acquisition and analysis, in operating the cyclotron including beam diagnostics measurements and in charged particle and gamma-ray detection techniques, participation in the workshop enables the students to develop their teamwork and communication skills as well as their ability to deal with open questions and to think critically. The project encourages both student and teacher mobility and strengthens the existing collaboration between participating institutions.

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Part B

Experiments at HIL

B.1 Study of the $I^\pi = K^\pi = 8^-$ isomeric state in N=74 nuclei by combined conversion-electron and γ-ray spectroscopy

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The violation of the K selection rule for electromagnetic transitions in nuclei is not yet well understood [1–4]. One possible reason for the phenomenon is the Coriolis interaction, which is responsible for an admixture of wave function components characterised by K values higher than the main one. However, non-axial deformation may cause the same experimental effects. The nuclei with mass number close to A=130, with large triaxiality γ around 20–30°, are an excellent testing ground to study this phenomenon. The interesting $I^\pi = K^\pi = 8^-$ isomeric state appears in nuclei in this mass number area.

The conservation of the K-number was studied in the decay of the isomeric state in ^{130}Ba. The interesting isomer was populated using the ^{122}Sn(^{12}C,4n)^{130}Ba reaction. The measurement was carried out in electron-γ and γ-γcoincidence modes using an electron spectrometer coupled to the EAGLE γ-ray array. The spectroscopy of internal conversion electrons together with gamma studies allow multipolarities and furthermore absolute values of the transitions probabilities to be determined. It can help in clarifying the mechanism of violation the K-selection rule. The de-excitation of the $I^\pi = K^\pi = 8^-$ isomeric state in ^{130}Ba has already been investigated [5, 6] but with large differences between the results. The authors of Ref. [5] report that the value of the internal conversion coefficient of the K-line for the 882 keV transition is equal to 0.0075(8). For the same coefficient, in the publication of Ref. [6] a value of 0.0052(5) is given. The total electron spectrum and a spectrum gated by the 691 keV γ-ray transition obtained in our experiment are shown in Fig. 1. One may note the presence of electron lines from the de-excitation of the $I^\pi = K^\pi = 8^-$ isomeric state. The experimental values of the conversion coefficients for the K and L+M+... lines for the 462, 882 keV transitions were obtained, while for the 1004 keV transition, only the K-line value could be measured [8].

A test experiment to study the $I^\pi = K^\pi = 8^-$ isomeric state in the next N=74 nucleus was also performed. The nucleus ^{134}Nd was produced in the reaction: ^{122}Te(^{16}O,4n)^{134}Nd. A total γ-ray spectrum recorded during the two-day experiment is shown in Fig. 2. The gamma lines characteristic for the decay of the $I^\pi = K^\pi = 8^-$ isomeric state in ^{134}Nd are observed in the spectrum.

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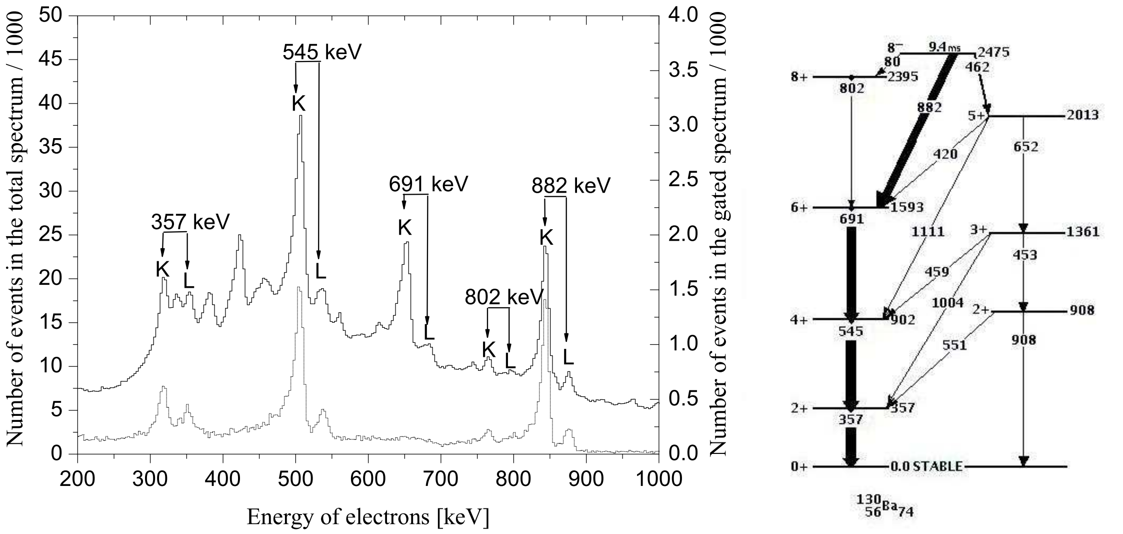

Figure 1: The "beam-off" total electron spectrum (solid line), and a spectrum gated by the 691 keV γ-ray transition (dashed line), collected during an 8-day experiment with an average beam current of 40 enA. The strongest transitions belonging to the decay of the isomeric state in ^{130}Ba are labeled. The decay scheme of the isomeric state $I^{\pi} = K^{\pi} = 8^{-}$ is shown in the left-hand side of the figure [7].

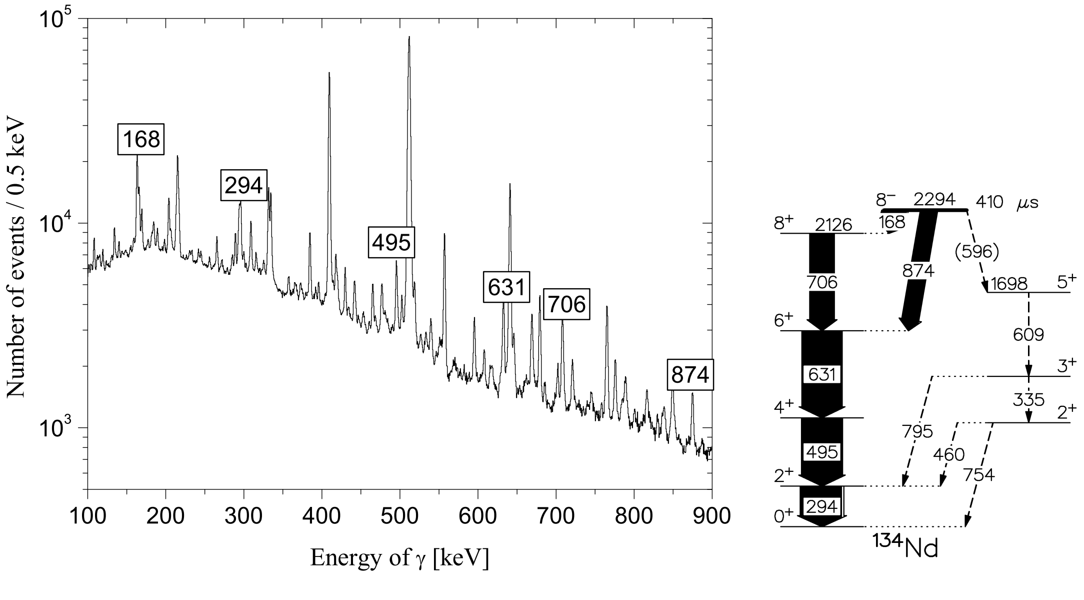

Figure 2: Gamma-ray lines observed with a ^{122}Te target after 2 days' exposure to a beam of ^{16}O ions. The arrows indicate γ-ray transitions below the $I^{\pi} = K^{\pi} = 8^{-}$ isomeric state in ^{134}Nd

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B.2 Investigation of the incomplete fusion reaction mechanism in the ^{20}Ne+^{122}Sn reaction

J. Mierzejewski[1], A. A. Pasternak[1,2], J. Srebrny[1], A. Stolarz[1], M. Kowalczyk[1,5], M. Komorowska[1,5], H. Mierzejewski[3], M. Kisieliński[1,6], J. Kownacki[1,6], A. Kordyasz[1], M. Zielińska[1], W. Perkowski[1], A. Jakubowski[1], M. Antczak[1], A. Pietrzak[1], P. Jasiński[1], B. Paprzycki[1], K. Wrzosek-Lipska[1], K. Hadyńska - Klęk[1], M. Palacz[1], G. Jaworski[1,7], J. Perkowski[4], Ch. Droste[5], J. Skalski[6], R. Anczkiewicz[8]

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The mechanism of the ^{20}Ne+^{122}Sn reaction was investigated using the EAGLE spectrometer [1]. Charged particle-γ coincidences were measured with 30 ΔE Si detectors of the Si-ball [2, 3], coupled to 12 Compton-suppressed Ge detectors. A 5.4 mg/cm^2-thick target of metallic ^{122}Sn was placed in a 70 μm thick aluminium tube, shielding the Si detectors from the scattered beam. The target was enriched to 95.4% of ^{122}Sn. Measurements were performed at two ^{20}Ne energies: 141 MeV and 150 MeV. The gamma and charged particle spectra for selected αxn and pxn channels were registered in the 4π solid angle. The aim of the experiment was to provide experimental results that might help to describe the dynamics of the incomplete fusion reaction [4] mechanism: the creation of compound nuclei and α-particle emission.

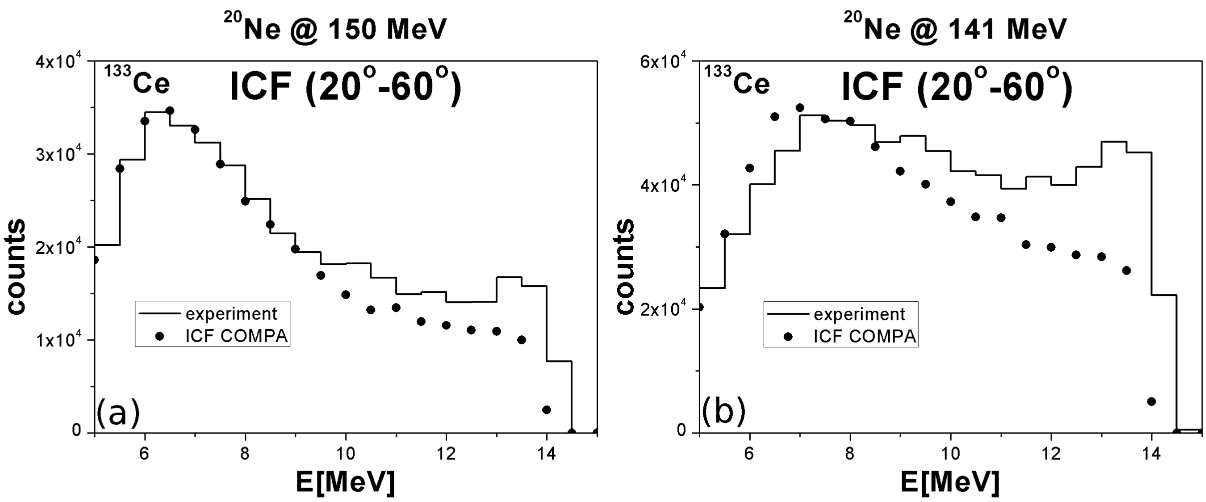

Figure 1: Incomplete fusion α-particle spectra (solid line) for the ^{122}Sn(^{20}Ne,α5n)^{133}Ce reaction at 150 MeV (a) and 141 MeV (b) ^{20}Ne beam energy, compared to incomplete fusion calculations performed with COMPA (points).

The charged particle spectra accompanying the production of ^{133}Ce were obtained by setting gates on the 190, 295, 357 and 620 keV transitions [5] observed in the γ spectra. Spectra measured in the 20°–60° ring of the Si-ball contained α particles originating from both complete and incomplete fusion. Spectra of evaporated α particles were calculated with the COMPA code [6] and subtracted from the spectra in the 20°–60° ring. The incomplete fusion spectra obtained are shown in Fig. 1 a and b. Alpha particles are visible at energies above 6 MeV. The lower part of the spectra is presumably dominated by protons, believed to be emitted in reactions with target admixtures. The difference between the presented spectra is easily noticeable.

We proposed a new model of an incomplete fusion reaction [6, 7], which was recently incorporated in COMPA. The model consists of seven semi-empirical parameters: R_0, D_{ICF}, F, e_f, σ_L, σ_R and δ. It is based on the assumption that the projectile breaks up while approaching the target. After breakup the α particle moves in some effective Coulomb potential and finally escapes from the compound nucleus. Fig. 1 presents the comparison of COMPA calculations and incomplete fusion spectra. The calculations were performed using the parameter set R_O=1.03, D_{ICF}=2, F=10, e_f=0.4, σ_L=σ_R=0.65 and δ=0.5. The calculations do not reproduce the spectra just below the edge observed at about 13.5 MeV. As described in [8], the simulations of the ΔE detectors are not accurate for this part of the spectra. Therefore, a comparison should only be made for energies below 12 MeV. Except for this, the data are rather well reproduced.

The calculated spectra of both complete and incomplete fusion in the 20°–60° ring can be presented in the centre of mass system. Such spectra, shown in Fig. 2, allow for a better overview of the model's performance. The difference between the incomplete fusion spectra is easily noticeable while the evaporation components are equal in the shape and position for both ^{20}Ne beam energies.

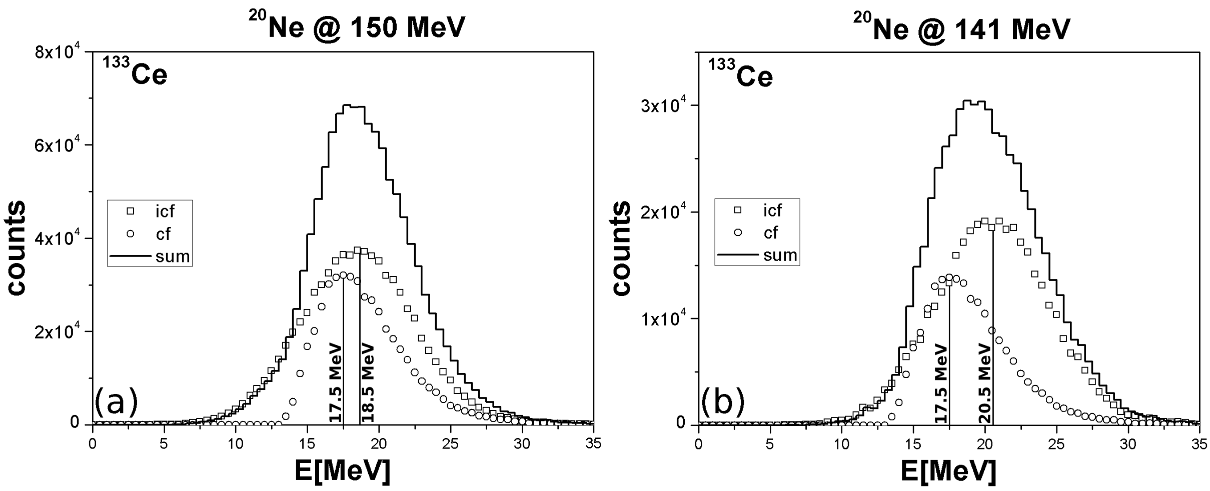

Figure 2: α particle spectra (solid histogram) in the centre of mass system corresponding to the spectra in the 20°–60° ring of the Si-ball for the ^{122}Sn(^{20}Ne,α5n)^{133}Ce reaction at 150 MeV (a) and 141 MeV (b) ^{20}Ne beam energy. The decomposition of the simulated spectra into the complete (open dots) and incomplete (open squares) fusion components is shown.

Alpha particle spectra from an incomplete fusion reaction carry information on the emission mechanism. Exclusive spectra attributed to αxn channels, in contrast to inclusive ones, carry an information on the spin and excitation energy of the compound nucleus as well. After the emission of an α particle, the subsequent evaporating neutrons have easily calculable angular momenta and energies. Therefore, the exclusive spectra provide indirect information on the compound nucleus state just before evaporation. Such spectra were measured before by Wilczyńska et al. [4] for the ^{160}Gd(^{12}C,αxn)$^{168-x}$Er reaction and by Arnell et al. [9] for the ^{118}Sn(^{12}C,αxn)$^{126-x}$Xe reaction. Both cases were analysed in terms of our incomplete fusion model [6, 7], but since the statistics were small, it was difficult to evaluate the quality of the comparison. Moreover, the spectra were measured only at θ=20^o in the laboratory frame. The experiment presented in this work provided exclusive α particle spectra with large statistics, registered over 4π solid angle, for the ^{122}Sn(^{20}Ne,α5n)^{133}Ce reaction at two beam energies: 141 and 150 MeV. The results were compared to the model predictions.

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B.3 DSA lifetime measurements of ^{124}Cs and the time-reversal symmetry

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The phenomenon of nuclear chirality was postulated in 1997 by S. Frauendorf and J. Meng in Ref. [1]. The most simple case of nuclear chirality relates to odd-odd triaxial nuclei, where the angular momenta of odd nucleons and the angular momentum of the even-even core can form either a left or right handed system. The laws of physics do not prefer either of the two possible systems, meaning that spin-chiral symmetry is fundamentally conserved. However, selection of one handedness minimises the energy and breaks the symmetry spontaneously. Actually, spin-chirality is equivalent to spontaneous time-reversal symmetry breaking since the symmetry operation that reverses handedness is a combination of π-rotation and time reversal. As stated in Ref. [2] observation of handedness through γ-radiation is not possible since the eigenstates are symmetric or antisymmetric combinations of the left- and right- handed systems. These combinations form chiral doublets on which two rotational bands – called chiral partner bands – develop. In the first experimental study of nuclear chirality only the chiral partner bands were searched for. It turned out that observation of the partner bands is not a sufficient argument to confirm the presence of chiral symmetry breaking and the measurement must be augmented by determination of the level lifetimes in the partner bands. DSA experiments [3, 4] revealed remarkable gamma-selection rules in the ^{128,126}Cs isotopes as the presence of specific B(M1) staggering confirming spin-chiral symmetry breaking. Here, the first DSA results for ^{124}Cs are presented.

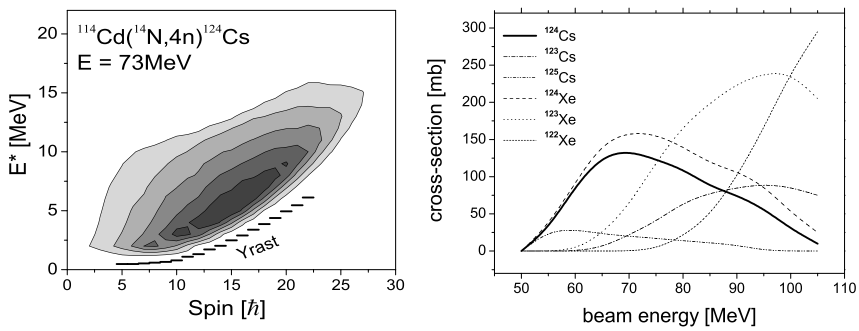

Figure 1: Entry-states population of ^{124}Cs (left) and cross-sections (right) as a function of ^{14}N beam energy bombarding a ^{114}Cd target calculated using the COMPA code.

The ^{124}Cs was produced in the ^{114}Cd(^{14}N,4n)^{124}Cs reaction at a beam energy of 73 MeV. The 34 mg/cm^2 thick ^{114}Cd target, also played the role of the stopper. The ^{14}N beam was provided by the U200P cyclotron. Fig. 1 shows the entry-states population of ^{124}Cs produced in the above reaction calculated using the COMPA code [5]. It is expected that levels close to the yrast (and also to the side-band) are mostly populated considering short feeding times. Calculated cross-sections of different reaction channels as a function of ^{14}N beam energy are also presented in Fig. 1. The $\gamma - \gamma$ coincidences were measured by the EAGLE array equipped with 12 ACS germanium spectrometers of around 25% efficiency each.

Fig. 2 shows the relevant part of the level scheme as observed in our experiment together with preliminary lifetime data and an example of the Doppler disturbed peak. Level spin and parity assignments follow Ref. [6]. The DSA analysis was performed with the COMPA, GAMMA and SHAPE codes described in detail in Ref. [7]. Fig. 3 presents B(M1) transition probabilities in the yrast band . The presence of two rotational bands, with almost degenerate spin and parity levels indicates spontaneous breakdown of chiral symmetry in ^{124}Cs. Though we report here the B(M1) staggering only in the yrast band, it agrees with the chiral scenario of ^{124}Cs due to the possible occurrence of S-symmetry [8]. According to Ref. [8], S-symmetry may appear together with chiral symmetry breaking and indicates a $\gamma \approx 30°$ triaxial deformation.

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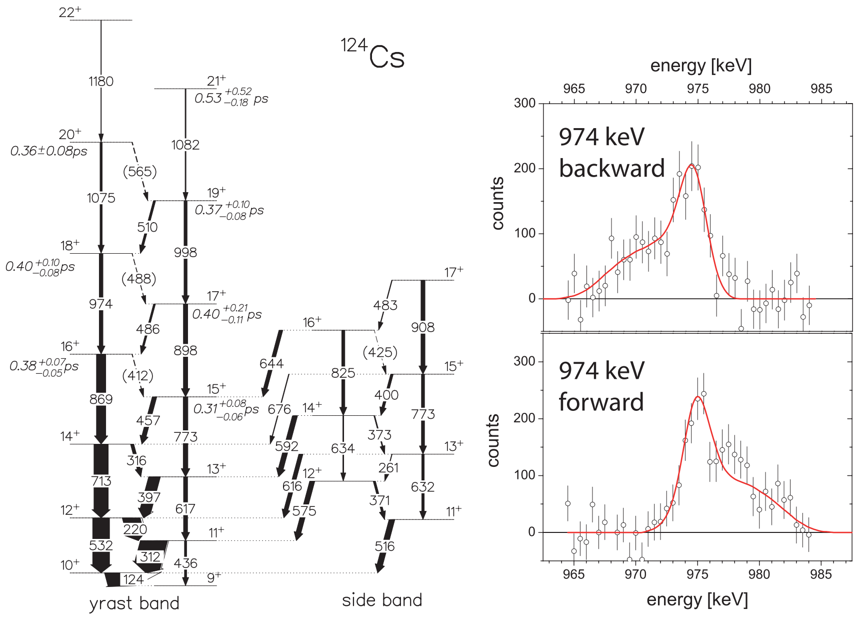

Figure 2: Left: The relevant part of the level scheme of ^{124}Cs observed in the present experiment. Spin and parity assignments follow Ref. [6]. Preliminary lifetimes are given in italics under the spins of the corresponding levels. Right: Doppler broadened line shapes of the 974 keV γ-transition registered by detectors placed at 143° and at 47° with respect to the beam direction. Solid lines show a fit of the line-shape to the experimental data.

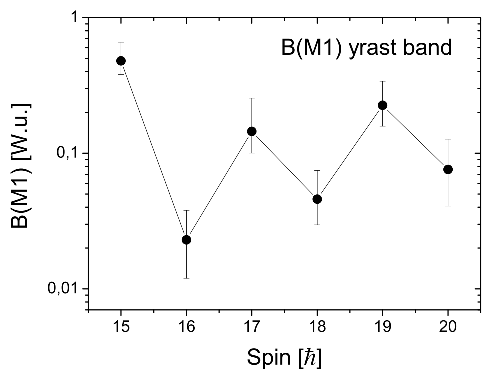

Figure 3: B(M1) reduced transition probabilities in the yrast band of ^{124}Cs.

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B.4 Decay chains and photofission investigation based on nuclear spectroscopy of a uranium sample

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The aim of the present investigation was to find the origin the γ rays which occur in the thorium, neptunium, uranium/radium, and uranium/actinium natural decay series, headed by ^{232}Th, ^{237}Np, ^{238}U, and ^{235}U, respectively. Measurements of such γ rays may give information on the presence, localisation and quantity of nuclear fission materials and may be used in security related applications. Detailed knowledge of all possible emitted γ rays is thus essential, and an especially interesting task is to identify characteristic high energy and high intensity γ-ray lines.

Many experimental and theoretical efforts have been devoted to the study of radioactive decay chains of heavy nuclei (see e.g. [1]). In the present work, relative yields of the members of the main decay chains (4n, 4n+1, 4n+2 and 4n+3) of an uranium sample were determined from intensities of γ rays feeding the ground states of the respective nuclei. Measurements were performed for a 100 g uranium sample. Single γ rays and $\gamma\gamma$ coincidences were registered with the use of the EAGLE array [2], consisting of 15 HPGe detectors, located at HIL. Two amplifications of γ-ray energies were used, to allow measurements up to 2 and 4 MeV (see Fig. 1).

Based on the $\gamma\gamma$ coincidence measurements, the origin of most of the observed γ rays was established. Important practical information was obtained: in the γ-ray spectrum of an uranium sample, strong 2.614 MeV γ line is always seen, which is the famous $3^- \rightarrow 0^+$ transition from ^{208}Pb, the final member of the ^{232}Th decay chain (4n).

Measurements of the γ rays emitted by uranium also made it possible [3] to determine the enrichment of the sample. The enrichment can be expressed as a function of the activity of ^{238}U and ^{235}U (the abundance of ^{234}U is small compared to the other uranium isotopes). The efficiency of HPGe detectors and the photon emission intensity for the chosen transition (usually 185 keV from ^{235}U) and 111 keV X rays (^{238}U) has to be taken into account in order to determine the respective activity values. The activity values were computed according to the formula $\Lambda = A/(ts\epsilon)$, where A is the net area of the peak corresponding to a γ ray or X-ray emission of the nuclide, t is the measurement time, s is the photon emission intensity and ϵ stands for the detection intensity of the full absorption peak considered. Our estimate gave the ^{235}U enrichment of our uranium sample (100 g uranium rod of 0.8 cm diameter and 10 cm length) equal to $89 \pm 10\%$.

In another experiment the same uranium sample was irradiated with 15 MeV photons (bremsstrahlung radiation) from the Siemens Mevatron linear accelerator located in NCBJ at Świerk, inducing photo-fission. Single γ-ray spectra were collected after 10 minutes of irradiation and 30 minutes of cooling time, and were continued for 24 hours. Each measurement lasted 10 minutes and the next one was automatically started after a 10 seconds break. As a result, several decays of fission fragments were identified, with the most prominent γ rays due to heavy fragments $^{138}\mathrm{Xe} \rightarrow ^{138}$ Cs ($T_{1/2}$ = 14 min., $E_\gamma = 258, 396, 434, 1768, 2015$ keV) and $^{138}\mathrm{Cs} \rightarrow ^{138}$ Ba ($T_{1/2}$ = 33 min., E_γ =

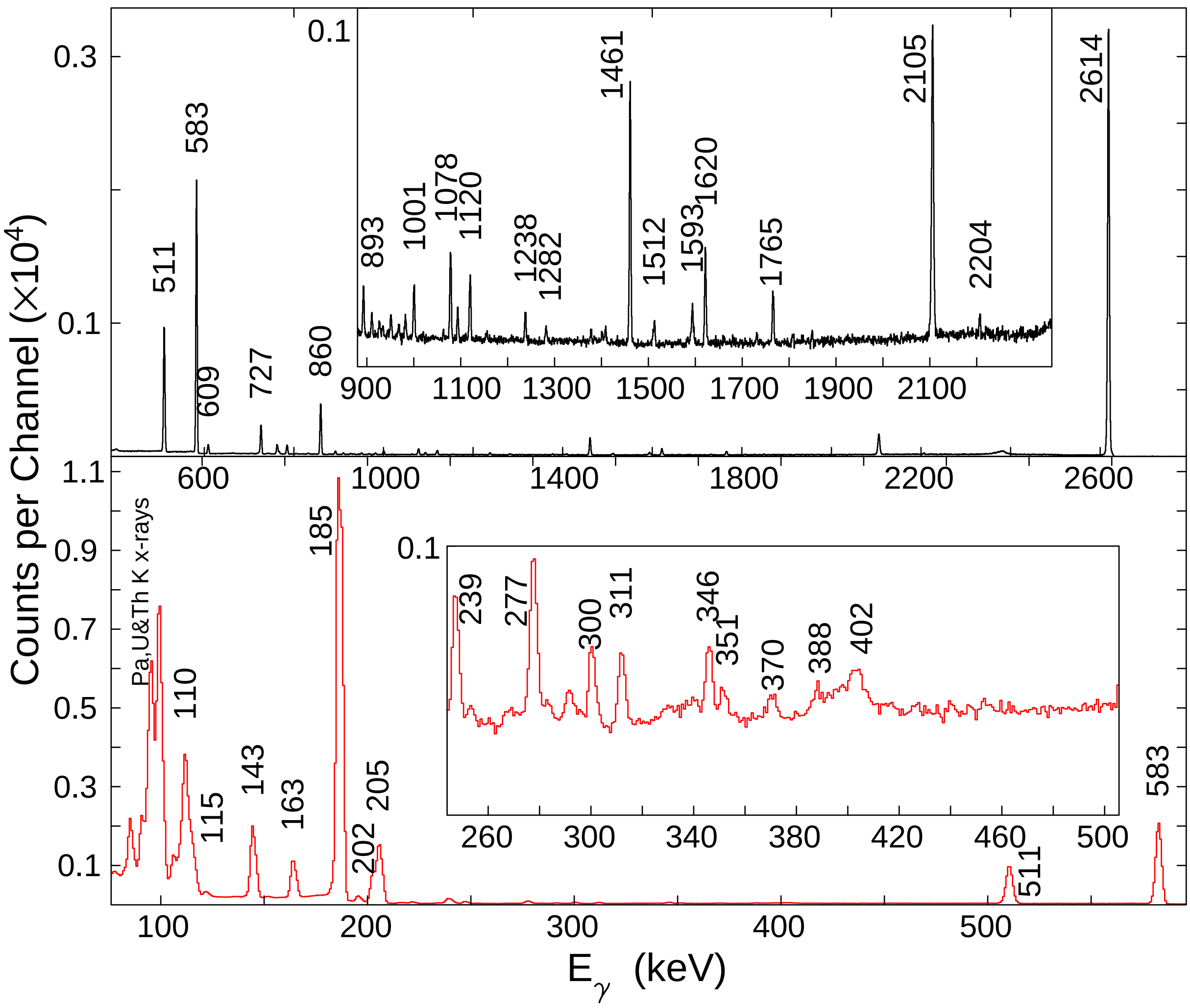

Figure 1: Example of $\gamma\gamma$ efficiency corrected coincidence spectrum of 100 g Uranium sample, measured with 15 HPGe detectors.

462, 546, 1009, 1435, 2218, 2693 keV), as well as light fragment decay $^{89}\mathrm{Rb} \rightarrow ^{89}\mathrm{Sr}(T_{1/2} =$ 15 min, $E_\gamma = 657, 947, 1031, 1248, 2570, 2707, 2196$ keV). We conclude that even after a short irradiation of a given sample with 15 MeV photons, one can easily recognise the origin of the observed γ rays, ascribing them to fissionable material. Especially important is the observation of the high energy lines which can penetrate thick shields.

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B.5 Coulomb barrier height distribution of the ^{20}Ne + ^{58,60,61}Ni systems

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Studies of the fusion barrier height distribution were continued by the Barrier Collaboration. A series of measurements for the ^{20}Ne + ^{58,60,61}Ni system were completed.

A beam of ^{20}Ne was delivered by the Warsaw Cyclotron. We measured quasi-elastic backward scattering using the CUDAC chamber equipped with 30 PIN diodes of 1x1 cm^2 surface placed at 130, 140 and 150 degrees with respect to the beam axis. Two PIN diodes placed at 35 degrees measured the "Rutherford" scattering. Ni targets of about 100 μg/cm^2 thickness were prepared from isotopically separated materials.

The barrier distribution D_{qe} was obtained as the first derivative of the quasi-elastic excitation function σ_{qe} divided by the Rutherford cross section [1–3] for the systems under study. The results are shown in Figure 1.

According to Coupled Channel calculations, taking into account collective effects only, the shape of all three distributions should be virtually the same. We observe that for ^{58}Ni, where the level density is low, the barrier distribution is structured, whereas for ^{61}Ni, where the level density is higher, the structure at 37 MeV is smoothed out. It seems that smoothing is caused by non-collective excitations of the target nuclei.

The results were reported during the Fusion11 conference [4]

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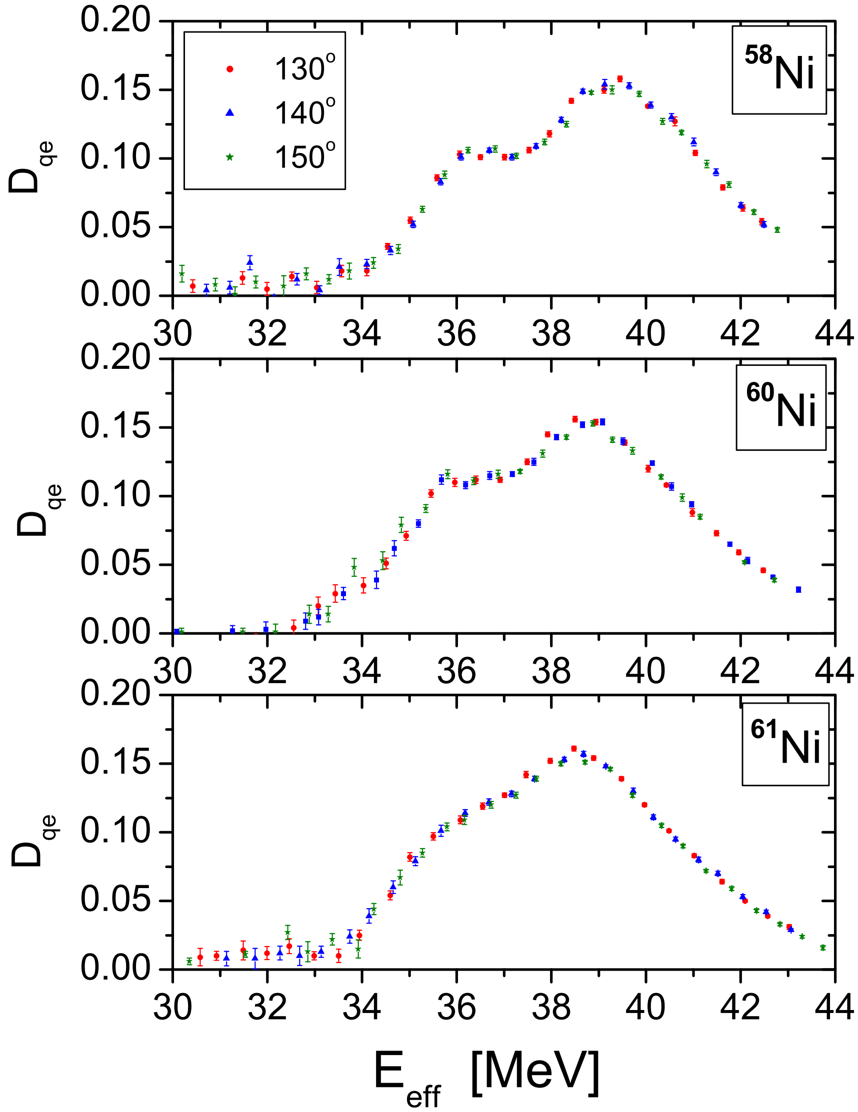

Figure 1: Barrier height distributions for the $^{20}Ne+^{58,60,61}Ni$ systems.

B.6 Transfer probabilities in the ^{20}Ne + ^{58,60,61}Ni systems

A. Trzcińska[1], A. Amar[2], W. Czarnacki[3], M. Kisieliński[1,3], S. Kliczewski[4], P. Koczoń[5], M. Kowalczyk[1,6], B. Lommel[5], M. Mutterer[7], M. Palacz[1], E. Piasecki[1,3], R. Siudak[4], I. Strojek[3], A. Stolarz[2], G. Tiourin[8], W. Trzaska[8]

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An experiment completing studies of the ^{20}Ne + ^{58,60,61}Ni systems at near barrier energies was performed.

We have shown that non-collective excitations can change the shape of the barrier height distribution (see Ref. [1]). Comparison of differential transfer cross sections at near barrier energy for these systems was the subject of recent experiments. The measurements were performed at HIL using the multi-detector 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 the four 20x20 mm Si detectors placed at a laboratory angle of 142° with respect to the beam. These detectors measured the energy of the reaction products. The base length of the ToF system was 82 cm.

Figure 1 shows examples of spectra collected for ^{58}Ni and ^{61}Ni. The quasielastically scattered ^{20}Ne ions dominate the spectra, α transfer probability is 2% for both Ni isotopes. In the case of ^{61}Ni we also observe products of 3 nucleon stripping (A=17) and 1 nucleon pick-up (A=21).

The data analysis is in progress. Preliminary results show that the transfer probabilities for ^{58}Ni,^{60}Ni and ^{61}Ni do not differ significantly.

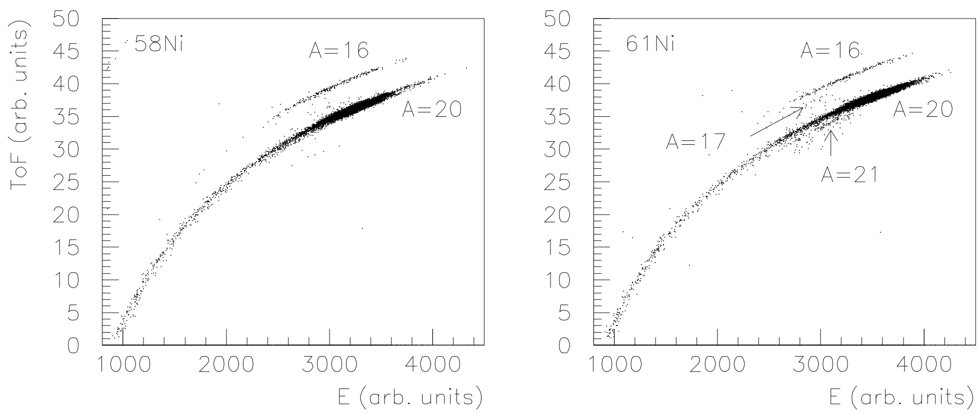

Figure 1: Mass identification of the ^{20}Ne + ^{58}Ni reaction (left panel) and ^{20}Ne + ^{61}Ni at near barrier energies.

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B.7 Coulomb excitation of ^{42}Ca. The possibility of a sub-barrier transfer reaction

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A Coulomb excitation experiment to study the electromagnetic properties of low-lying states in ^{42}Ca with a focus on a presumably super-deformed band was performed at the Laboratori Nazionali di Legnaro in Italy in 2010 using the γ-ray spectrometer AGATA Demonstrator coupled to the DANTE position sensitive charged particle detector array. First results were presented in [1].

In order to resolve the existing ambiguities concerning the deformation of the presumably super-deformed band, a Coulomb excitation measurement was performed to extract the B(E2) values in ^{42}Ca. The experiment took place in February 2010 at the Laboratori Nazionali di Legnaro. For this measurement, the γ-ray spectrometer AGATA Demonstrator [2] coupled to the charged particle detection set-up DANTE [3] was used for the first time ([4]).

Transitions de-exciting the highly deformed band were observed, as well as γ rays depopulating low-lying states in the yrast band. In both the ground state band and the highly deformed band it was possible to Coulomb excite levels of spin up to 4^+ (the left-hand panel of Fig. 1).

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

Unexpectedly, two unknown γ lines were observed in the spectrum at energies of 2048 and 376 keV. Particularly strong and clearly visible was the 2048 keV transition. The widths of these γ rays indicate that they could be emitted from the scattered ^{42}Ca projectile.

There are several options, which were taken into consideration regarding the origin of these γ lines.

Calculations of various transition probabilities performed using the GOSIA code [5] excluded the attribution of the 2048 keV line to the known level scheme of ^{42}Ca. Observation of the 376 keV γ line, however, supported the scenario that both 376 and 2048 keV transitions could be related to a new state located at 2048 keV in ^{42}Ca and populated in the Coulomb excitation experiment. In such a case, the 2048 keV γ ray would just deexcite this new level while the 376 keV γ-transition would be a branch from the 2424 keV level.

A dedicated fusion-evaporation experiment aiming at the determination of the low spin level scheme in ^{42}Ca was performed at the Heavy Ion Laboratory, University of Warsaw, using the EAGLE-II spectrometer in the configuration with 16 HPGe detectors in anti-

Compton shielding. A ^{32}S beam with an energy of 86 MeV bombarded a very thick ^{12}C target.

Analysis of both experiments is in progress. The possibility of a sub-barrier neutron transfer reaction occurring together with Coulomb excitation of ^{42}Ca should be taken into consideration. To prove this scenario, analysis of the angular distributions of γ rays related to scattered ^{42}Ca projectiles was performed. The angular range of the DANTE detector was divided into three bins: 110°–118°, 119°–126°, 127°–136° (laboratory frame). Angular distributions of the yields for the 1525 keV and 2048 keV transitions were compared with the results of calculations performed using the GOSIA code based on the COULEX formalism. In the first approach, the assumption was made that the 2048 keV line is an E2 transition that de-excites a 2^+ state at 2048 keV energy.

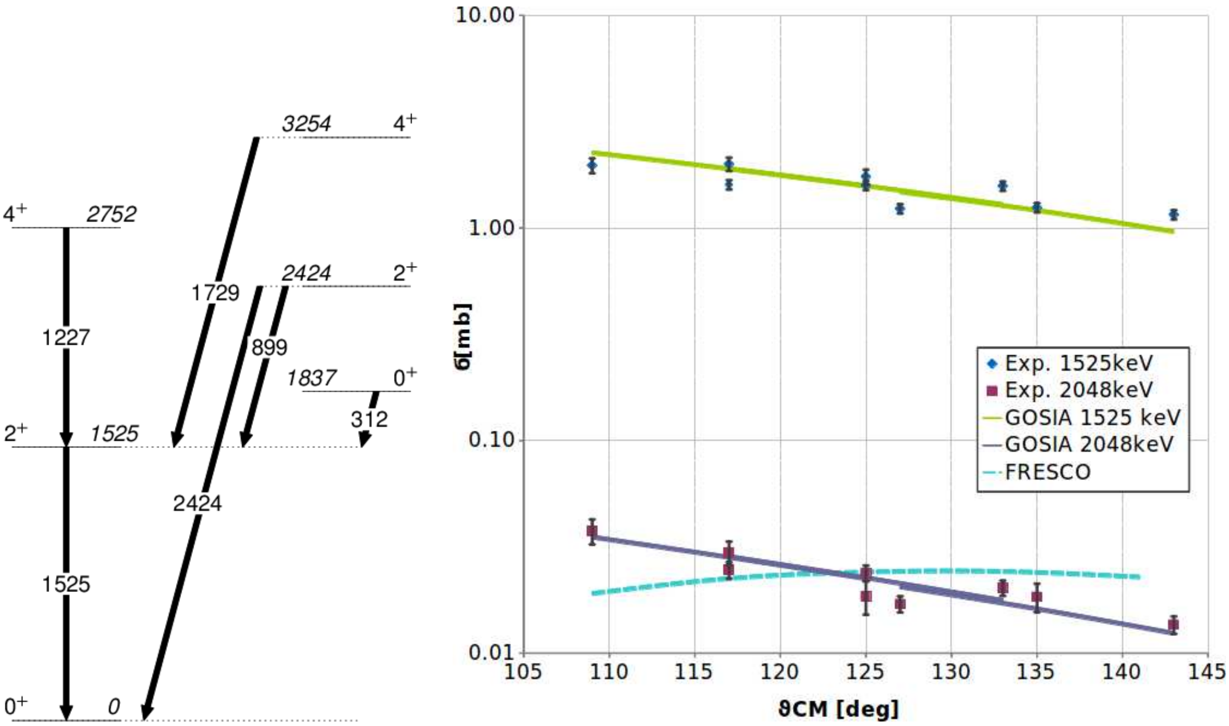

Figure 1: The level scheme of ^{42}Ca showing transitions observed in the Coulomb excitation experiment (left). The comparison of experimental yields with cross-sections calculated using the GOSIA and FRESCO codes (right).

The GOSIA code gives absolute cross-section values. Since diagonal and transitional matrix elements are well known for the 1525 keV state, and the 1524 keV γ transition [6], the normalisation coefficient was determined and the measured 1525 keV transition yield was scaled to the calculated cross section. Subsequently, the same normalisation factor was used to rescale the observed yield of the 2048 keV transition to the absolute scale.

In the meantime it was noticed that a transition with an energy of 2048 keV is present in the decay scheme of ^{43}Ca and de-excites the $p_{3/2}$ state of single particle character. Even though it seemed that the probability of exciting this state in the studied reaction (below the Coulomb barrier) was negligible, calculation of the one neutron transfer probability was performed.

The reaction cross section leading to this state in ^{43}Ca was calculated using the FRESCO code [7] and compared with the cross-section obtained from the Coulomb excitation formalism and experimental yields (the right panel of Fig. 1).

It turns out that the observed intensity of the 2048 keV transition can also be explained in the frame of one neutron sub-barrier transfer theory. In this particular case, it might also indicate that both Coulomb and nuclear forces contribute to the excitation process in the reaction investigated. The influence of neutron transfer on the observed γ-ray yields will be the subject of further careful analysis.

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B.8 Elastic scattering of ^{20}Ne+^{28}Si at near barrier energies

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Elastic scattering angular distributions were measured for the reaction ^{20}Ne+^{28}Si at near barrier energies (E_{beam} = 43 ,53 and 73 MeV). The results were analysed in the coupled channel framework. It was found that elastic transfer is a fundamental mechanism to describe these data. More elaborate calculations are in progress as well as the simultaneous analysis of transfer data.

Introduction

The elastic scattering of light systems with a cluster structure continues to attract attention, as the pronounced oscillatory patterns together with a cross section rise at backward angles, present a challenge to different models of the underlying mechanism. Many different interpretations have been offered in recent years and are presented in a comprehensive way in [1]. However, the lack of a general simultaneous description of such data leaves the subject open. The target mass dependence of the elastic scattering cross section has been studied via excitations functions at $\theta_{c.m.}$=180° for the systems ^{16}O+^{28}Si, ^{16}O+^{40}Ca, ^{16}O+^{58}Ni [2]. An interesting aspect was underlined in these measurements. While for the lighter targets a common oscillatory structure occurs, no oscillation pattern is observed for the heavier target but a rather fast fall off. A question then can be raised relatively to the projectile dependence.

In this context, we present a study of the elastic scattering for the system ^{20}Ne+^{28}Si at near barrier energies ($\sim$ 1.2 to 2 $V_{C.b.}$). Previous studies on ^{16}O+^{28}Si underline a strong oscillatory structure with backward rise of the cross section. Studies on ^{12}C+^{28}Si have been performed at sub-barrier energies, while those at near barrier energies do not extend to large enough backward angles to draw firm conclusions. It will be interesting to see the behaviour of elastic cross sections by utilising a heavier projectile such as ^{20}Ne as well as to identify the type of mechanism in case that the oscillatory patterns and the cross section rise is present.

Experimental details and theoretical analysis

A ^{20}Ne beam with an intensity of a few electrical nA, delivered by the Warsaw Cyclotron, bombarded a 200 μg/cm^2 ^{28}Si target set mainly perpendicular or for some angles tilted by 30° degrees to the beam direction. Three telescopes positioned 9 cm from the target on the two platforms of the ICARE target chamber were used to collect the elastically scattered neon nuclei, well discriminated from other reaction products via the conventional

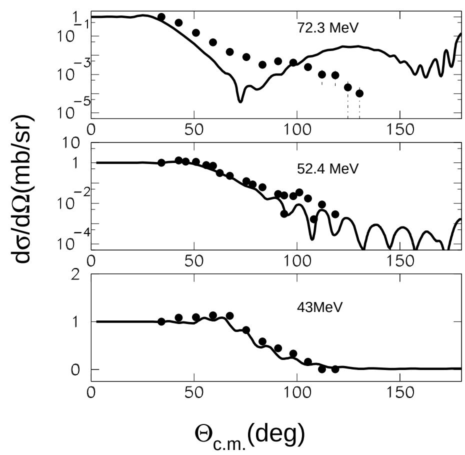

Figure 1: Elastic scattering data for ^{20}Ne+^{28}Si at three bombarding energies : 72.3, 53.4 and 43 MeV are compared with coupled channel calculations.

ΔE-E technique. The platforms were rotated, one in the angular range θ_{lab}=25° to 85°, and the other in θ_{lab}=40° to θ_{lab}=65°. Two single silicon detectors were positioned at fixed angles of ± 20°, 25.9 cm from the target, for normalisation purposes. Experimental results are presented in Figure 1 and are compared with coupled channel calculations performed with the code Fresco. For the calculation, the central potential was taken in the standard form, $V = (1 + 0.5i)V_{DF}$, where V_{DF} is a double folded potential. The calculation included couplings to the 2^+ excited states in ^{20}Ne and ^{28}Si, assuming them to be conventional rotational states, and also elastic transfer of a ^{8}Be cluster between all the possible combinations of states with the spectroscopic factor for ^{28}Si = ^{20}Ne + ^{8}Be taken as 1.0.

Conclusions

From the comparison of the data with the theory it is noted that at backward angles the anomalous increase of the cross sections persists even with a heavy projectile like ^{20}Ne. The oscillatory patterns disappear however as we proceed to higher energies. As a first observation, we can conclude that this behaviour can be described in a first approximation by the elastic transfer of ^{8}Be from the target to the projectile in accordance with previous findings [3] for different systems. More elaborate calculations and the analysis of transfer channels are in progress and should give a better understanding of the subject, while experimental data at more backward angles are necessary to interpret fully the proposed scenario. New measurements in inverse kinematics are planned in that direction.

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B.9 Comparison of the ^{7}Li(^{18}O, ^{17}N)^{8}Be and ^{18}O(d, ^{3}He)^{17}N reactions

A.T. Rudchik[1], Yu.M. Stepanenko[1], K.W. Kemper[2], A.A. Rudchik[1], O.A. Ponkratenko[1], E.I. Koshchy[3], S. Kliczewski[4], K. Rusek[5,6], A. Budzanowski[4], S.Yu. Mezhevych[1], I. Skwirczyńska[4], R. Siudak[4], B. Czech[4], A. Szczurek[4], J. Choiński[6], L. Głowacka[7]

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New angular distributions for the ^{7}Li(^{18}O, ^{17}N)^{8}Be reaction at an ^{18}O energy of $E_{lab}(^{18}O) = 114$ MeV, for the ground states of ^{8}Be and ^{17}N, as well as for the excited states of ^{17}N, were measured. These data and the ^{18}O(d, ^{3}He)^{17}N reaction data taken at $E(d) = 52$ MeV were analysed within the coupled-reaction-channels method using ^{7}Li + ^{18}O and ^{18}O + d optical potentials deduced from previous elastic and inelastic scattering results. Shell-model spectroscopic amplitudes were used in the analysis. Both reactions are dominated by the single proton transfer. Calculations show that heavy-ion reactions of the type studied in this work can be used to identify final-state spins, when measurements are extended to small angles [1].

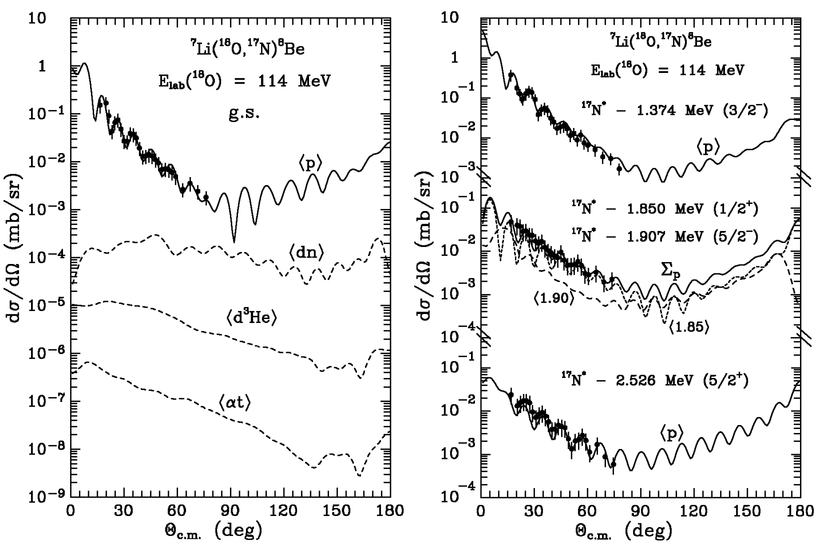

Figure 1: Angular distribution of the ^{7}Li(^{18}O, ^{17}N)^{8}Be reaction at $E_{lab}(^{18}O) = 114$ MeV. Left panel: distributions for the transition to the ground states of ^{8}Be and ^{17}N, the curves show the CRC calculations for different transfers. Right panel: distributions for transitions to the 1.374 MeV, 1.85 MeV + 1.907 MeV, and 2.526 MeV states of ^{17}N, the curves show the CRC calculations for proton transfers.

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B.10 Nuclear processes in the interactions of ^{15}N ions with ^{6,7}Li, ^{10}B and ^{12}C

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Angular distributions for the ^{6,7}Li, ^{10}B, ^{12}C(^{15}N, X) reaction were measured by bombarding self-supporting 900 and 450 μg/cm^2 foils of natural Lithium (^{7}Li abundance 92.5%) and Carbon (^{12}C — 98.90%) with a ^{15}N beam. The beam energy was 81.2 MeV, and the beam energy spread was about 0.5%. Eighty percent enriched self-supporting foils of 900 and 960 μg/cm^2 were used as targets for ^{6}Li and ^{10}B, respectively. The experiment was performed at the Warsaw University C-200P cyclotron using the ICARE experimental set-up. The reaction products were detected by ΔE − E Si telescopes. Fig. 1 shows a typical $\Delta E(E)$ spectrum for the ^{12}C(^{15}N, X) reaction products, with $Z = 3 - -8$ identified.

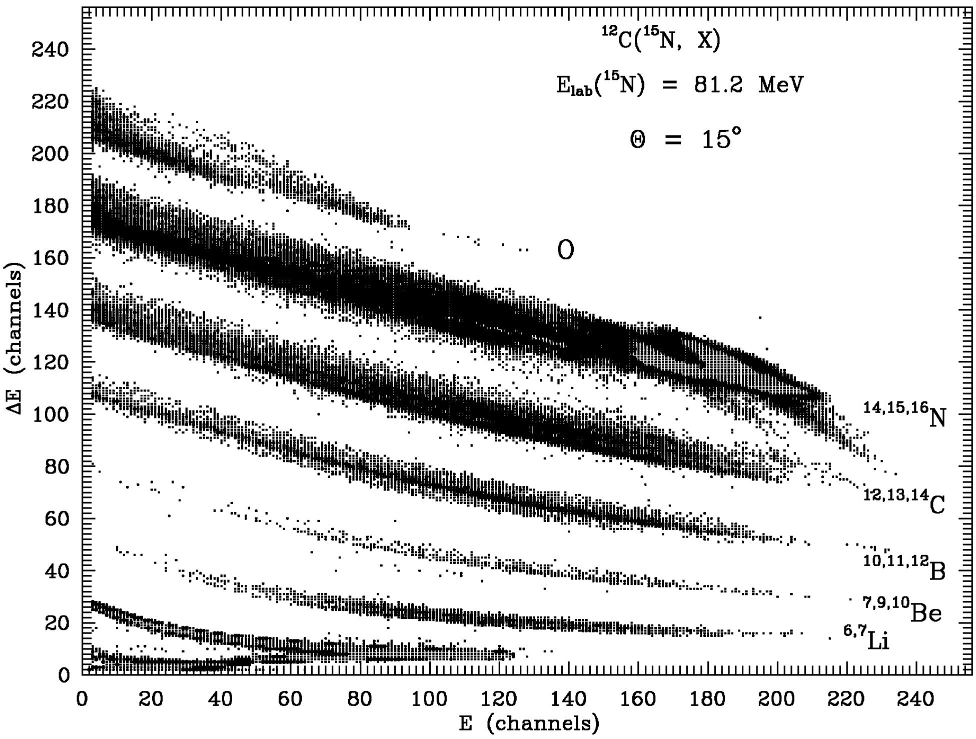

Figure 1: Typical $\Delta E(E)$ spectrum from the ^{12}C(^{15}N, X) reactions at a ^{15}N beam energy of 81.2 MeV.

B.11 ^{211}At production at the Warsaw Cyclotron

J. Choiński[1], A. Jakubowski[1], J. Jastrzębski[1], B. Paprzycki[1], A. Pietrzak[1], R. Tańczyk[1], A. Stolarz[1], D. Szczepaniak[1], A. Trzcińska[1], J. Chudyka[2], K. Tworek[2], W. Zipper[2], B. Petelenz[3], B. Wąs[3], A. Bilewicz[4], M. Łyczko[4]

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The labelling of biomolecules with ^{211}At was studied for many years at the Institute of Nuclear Chemistry and Technology (INCT) in collaboration with Duke University Medical Centre at Durham (NC) [1]. For the investigations performed in Poland the ^{211}At isotope was produced using the ^{4}He particle beam from the AIC-144 cyclotron at the Institute of Nuclear Physics in Kraków (IFJ) [2]. However, in recent years this cyclotron has been adapted for particle therapy of eye tumours and its radioisotope production programme was stopped. Therefore, having as objective the continuation of the ^{211}At labelling studies at INCT, we extended the spectrum of beams available at the Warsaw heavy ion cyclotron, and $^{4}He^{+}$ ions were accelerated.

The first irradiation experiments were performed using a 31.0 MeV $^{4}He^{+}$ beam from the home-made ECR ion source. The ions impinged on an internal Bi target fixed to a water-cooled holder, painted black. The targets were prepared by direct melting of the Bi material onto aluminium backing. The backing with Bi grains spread over the target spot was heated on a hot plate and Bi, when melted, was evenly distributed over the spot with the help of a graphite "spatula" (see Fig. 1). The Bi target, 0.3 mm thick, fixed tightly to its holder (to assure good thermal contact) was wrapped with a 0.017 mm Al foil.

The $^{4}He^{+}$ beam intensity was between 200 and 300 pnA, as measured by the beam intensity monitor and verified by the radioactivity induced in a Cu target under the same conditions. The γ-ray energies and intensities were determined using standard γ-ray spectrometry methods.

Till now four series of Bi irradiations have been performed — each series consisting of up to four full-night irradiations. The irradiated Bi samples were transported to INCT, where the ^{211}At was extracted and labelling processes studied. In the near future the second, commercial ECR ion source will be employed for the more efficient production of $^{4}He^{+}$ ions, and a new, better cooled, internal target assembly will be designed.

The measured and evaluated γ-ray spectra (see Fig. 2) of the irradiated Bi targets and ^{nat}Cu monitors were used as a basis of the M.Sc. degree theses of Justyna Chudyka and Katarzyna Tworek. These data were also presented in Ref. [3]

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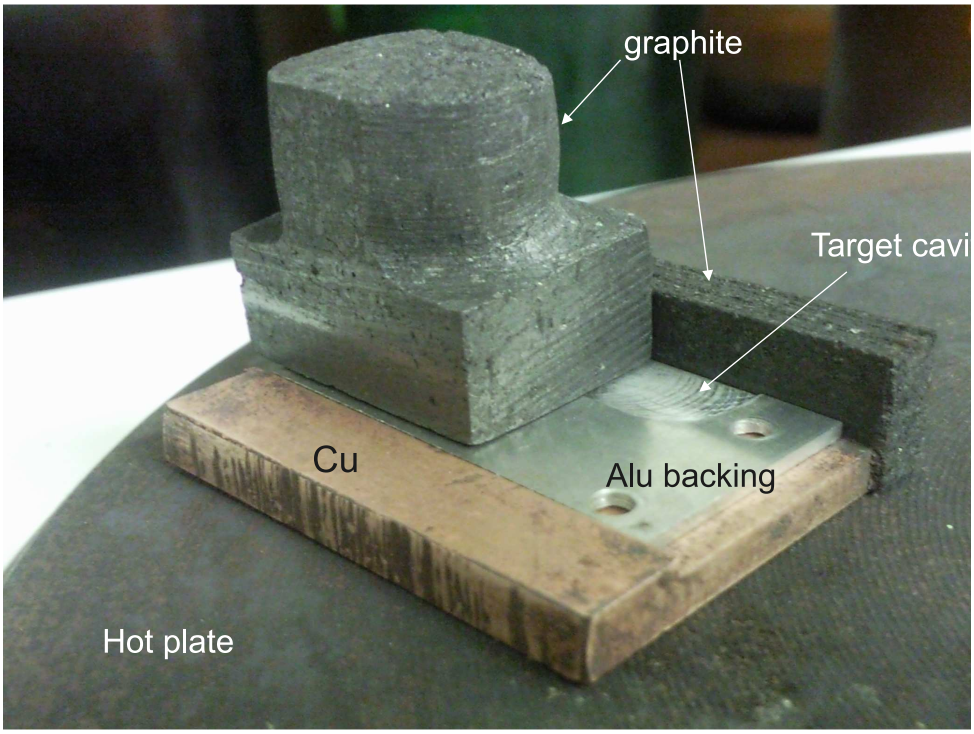

Figure 1: Production of the Bi target.

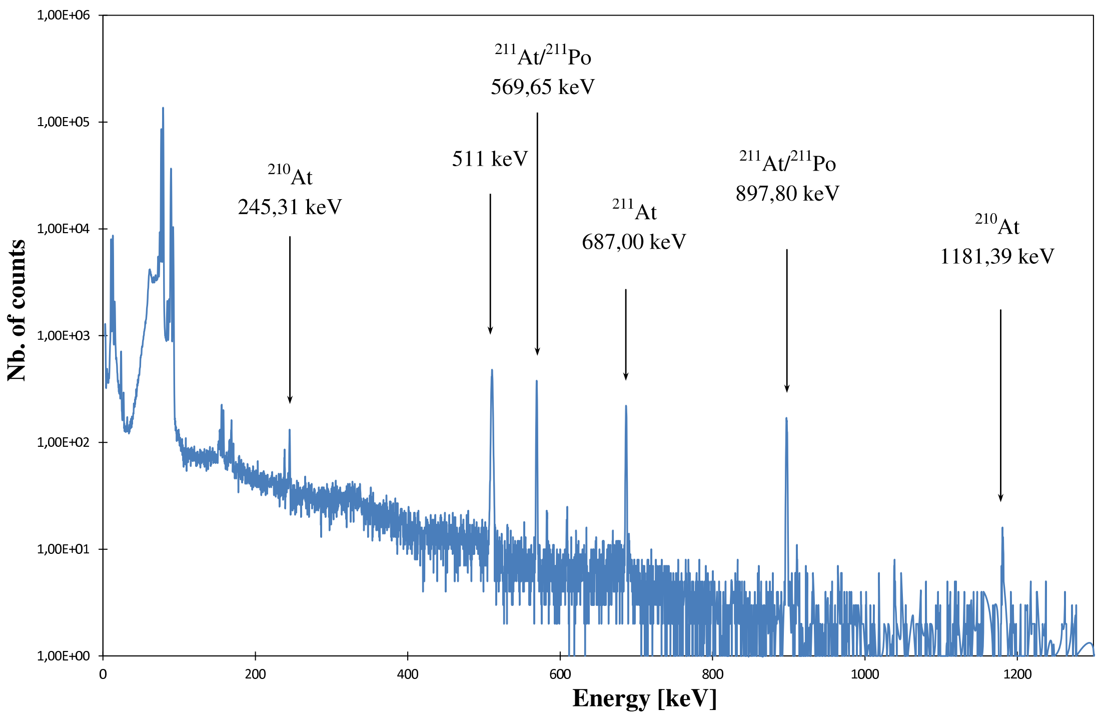

Figure 2: Gamma rays emitted from the ^{209}Bi target shortly after irradiation with the 30 MeV ^{4}He beam.

B.12 Isotopic nitrogen production by ammonia nitrate decomposition

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The ^{15}N isotope in gaseous form was produced at the target laboratory of HIL. This was needed to provide beams of nitrogen ions to study the ^{6,7}Li(^{15}N,X) and ^{12}C(^{15}N,X) transfer reactions. Beams of $^{15}N^{+3}$ can be obtained with the HIL cyclotron ion-source starting with gaseous nitrogen compounds or with pure nitrogen.

The ^{15}N isotope was available in the form of ammonium nitrate $NH_4^{15}NO_3$. According to the common information, simple thermal decomposition carried out at 170–200 °C, if performed with careful heating, should result in with nitrous oxide:

$$NH_4NO_3 \rightarrow N_2O + 2H_2O$$

Rapid heating should be avoided as the decomposition process may be explosive:

$$2NH_4NO_3 \rightarrow 4H_2O + 2N_2 + O_2$$

However, according to Berthold [2], the ammonium nitrate decomposition process is much more complex. When ammonium nitrate is heated to a temperature higher than its melting point (170 °C) the following series of reactions occur:

$$NH_4NO_3 \leftrightarrow NH_3 + HNO_3 \text{ (starting at 170°C)}$$
$$NH_4NO_3 \rightarrow N_2O + 2H_2O \text{ (at about 200°C)}$$
$$NH_4NO3 \rightarrow 2N_2 + O_2 + 4H_2O \text{ (above 300°C)}$$

A few other reactions are also possible when the procedure is carried out at temperatures above 300 °C.

Although it is often advised to avoid rapid heating due to the danger of explosion, taking into account the first reaction listed by Berthold, a temperature close to 200 °C must be achieved in a short time, to avoid the decomposition of the nitrate to ammonia and nitric acid as significant contributions to the final product.

In the process carried out in our laboratory, a vessel with ammonium nitrate was heated in a sand-bath to ensure even distribution of the heat. Initially, the vessel was placed close to the surface of the sand and remained in this position until the sand reached a temperature above 250 °C. Then the vessel was immersed in the sand while heating of the sand-bath continued to 270–300 °C. Figure 1 shows the production setup composed of the sand-bath, the vessel with NH_415NO_3, the water steam trap filled with $CaCl_2$, a pressure sensor and a gas-bottle (1.5 l volume).

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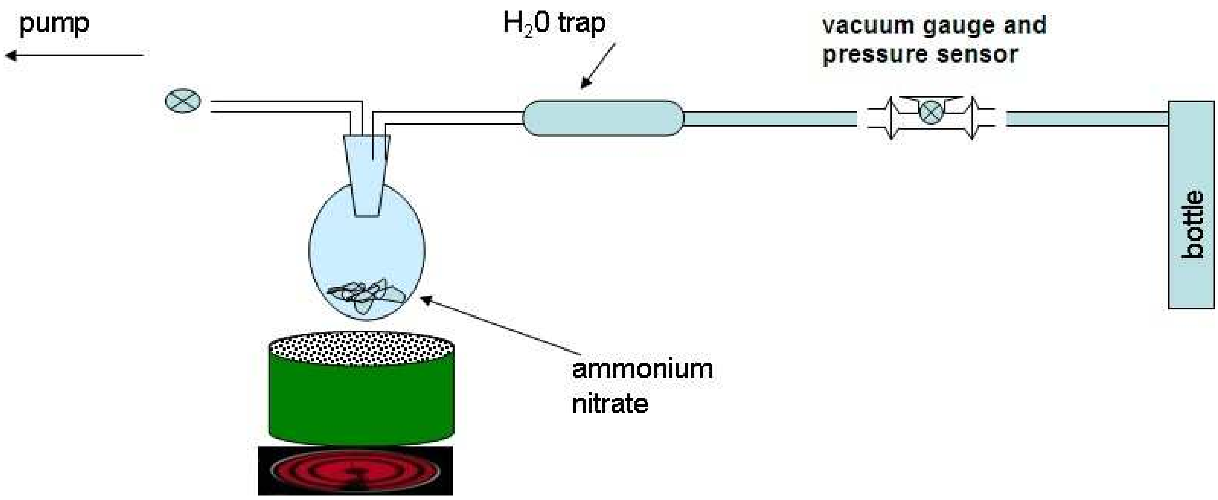

Figure 1: N-15 production set up.

B.13 A Te-122 target for ^{134}Nd production in reaction with an ^{16}O beam

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A ^{122}Te target, needed for studies of K-selection rule violation in N=74 nuclei [1], was prepared at the HIL target laboratory. One of the nuclei of interest in these investigations, ^{134}Nd, may be produced in the reaction of ^{122}Te with ^{16}O ions delivered by the HIL cyclotron: $^{16}\mathrm{O} + {}^{122}\mathrm{Te} \rightarrow {}^{138}\mathrm{Nd}^{*} \rightarrow {}^{134}\mathrm{Nd}+4\mathrm{n}$. The best results are expected with a ^{122}Te target of 3 mg/cm^2 thickness. Such a target thickness is a compromise between the energy loss of the electrons in the target material at the interesting energy range (300–1000 keV) and the production rate of the required nuclei.

Preparation of the target

Preparation of a self-supporting tellurium target of the required thickness is not feasible because of its properties. Due to the high brittleness of tellurium [2], the rolling technique, very useful for preparation of metallic targets in this thickness range, can not be applied. It was thus decided to prepare the target by deposition on a backing. Among the few materials considered as backing, Au seemed to be the best choice, assuring good mechanical properties and stability of the Te layer in-beam [3]. The thickness of the Au backing, 1.3 μm (2.5 mg/cm^2), was chosen to stop the products of the reaction. The foil was prepared in-house by rolling the gold material between stainless steel sheets. The target material was deposited by the procedure of evaporation-condensation in a high vacuum. To save the expensive isotopic target material the deposition was performed with the vapour source placed at a short distance from the backing. To enhance the vapour condensation efficiency, the backing was mounted on a water-cooled copper block. Details of the procedure are described in Ref. [4]. The target produced in this way had a spot of 14 mm in diameter (Fig. 1).

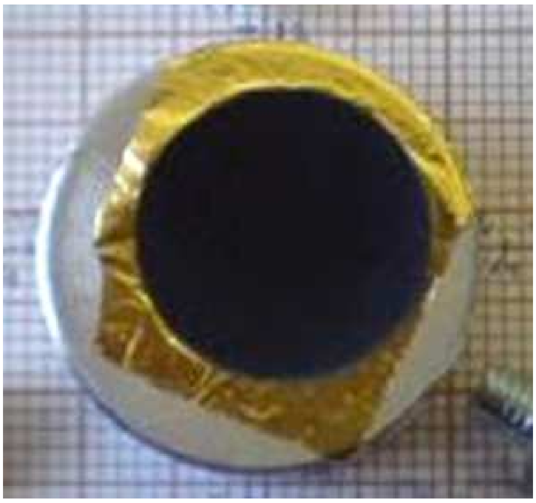

Figure 1: The ^{122}Te target on gold foil backing mounted on the target holder.

Determination of the target thickness

The layer deposited from a vapour source placed at a short distance builds up in a kind of stalactite shape. The distribution of the thickness of the target spot layer was determined by measuring the energy loss of α particles emitted by the triple source (^{241}Am+^{239}Pu+^{244}Cm). The configuration of the set-up used for the α-particle energy measurement is presented in Fig. 2.

The average thickness of the tellurium spot determined by measurement of the α-particle energy loss across the target spot was estimated to be 2.7 ± 0.5 mg/cm^2, while the value obtained by the measurement of the energy attenuation of the electrons from an internal conversion electron source (^{133}Ba) was 2.27 ± 0.15 mg/cm^2. The thickness inhomogeneity calculated as a ratio of the difference between the highest and lowest measured thickness values versus the mean value amounted to 32%. The thickness distribution of the ^{122}Te deposit is presented in Fig. 2.

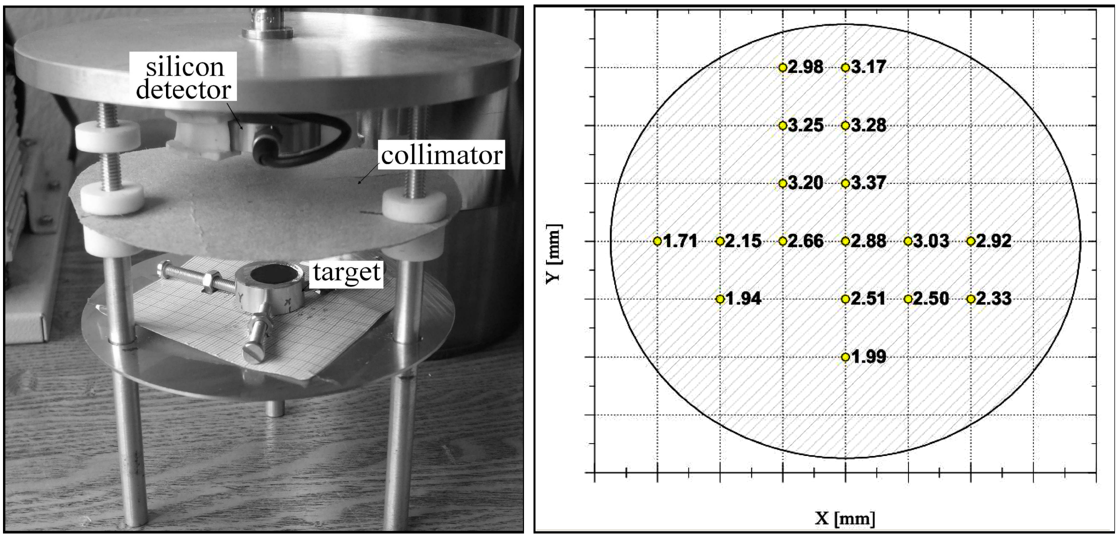

Figure 2: Right: set-up used for the determination of the energy loss of α particles. Left: the thickness distribution of ^{122}Te in the target.

The target was exposed to a beam of ^{16}O ions with an energy of 80 MeV and intensity of 10 pnA for two days. After this test experiment the tellurium deposit was investigated and its thickness was measured by the method described above. Neither peeling of the material nor changes in its thickness were noticed, proving the target stability under the beam. Thus, it may be concluded that the chosen "economical method" of Te target preparation resulted in a target suitable for the planned studies, having, however, a relatively high thickness inhomogeneity.

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B.14 Optical temperature stabilisation of a target heated by plasma in the MWCVD process

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The optimum temperature of creation of diamond by Microwave Chemical Vapour Deposition (MWCVD) is about 1073 K. The target for diamond layer deposition is heated by plasma in our MWCVD reactor [1, 2]. Target temperature is determined by investigation of the characteristic frequency distribution of light emitted from the target. The temperature stabilisation is performed by the registration of light emitted from a selected target area (see Fig. 1), using a WEB camera attached to a PC computer, and an automatic regulation system controlling the 2.45 GHz microwave power generated by the magnetron of the MWCVD reactor. This method is very efficient, since an increase of the target temperature of about 1% creates an increase of the light power emission of about 4%, according to the Stefan-Boltzmann law.

The idea of the temperature controlling regulation system is as follows. The decrease (increase) of microwave power is obtained by decrease (increase) of the magnetron 50 Hz AC power supply. This was performed by a system of inductances connected in series with the magnetron AC power supply and 50 Hz AC voltage source. The values of the inductances are proportional to 2n, where n denotes the number of bits (from 0 to 7). The combination of inductances connected in series is selected by a computer code to increase or decrease the microwave power. The total available inductances connected in series with the magnetron are proportional to the natural numbers selected from 0 to 255. In our practical applications we used 7 bits only, which gives the possibility to adjust the magnetron ac power supply with an accuracy of about 0.2V.

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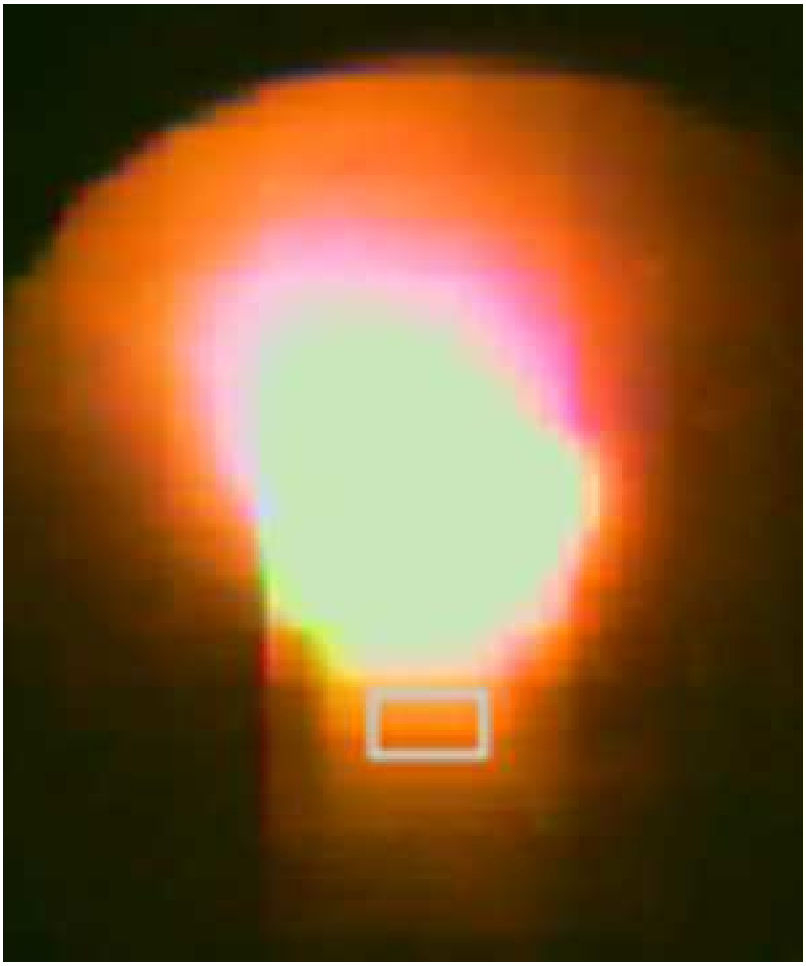

Figure 1: Picture registered by the WEB camera of the target heated to red colour by plasma during the Microwave Chemical Vapour Deposition process. The average value of light registered by pixels within the white rectangular frame is used for the temperature stabilisation of the target.

Part C

Experiments using external facilities

C.1 Parametrised form of the Dynamic Polarisation Potential

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We propose a parametrisation of the Dynamic Polarisations Potential (DPP) that was derived from a microscopic coupled-channel (CC) analysis of ^{6}He + ^{208}Pb elastic scattering [1]. DPP accounts for the effects of real and virtual processes that take place during scattering. It consists of real, V_{DPP}, and imaginary, W_{DPP}, terms. The real term is repulsive at the nuclear surface and has a long-range attractive tail that accounts for the virtual Coulomb couplings with states from the ^{6}He continuum.

Both components of the DPP can be parametrised at projectile-target separations larger than 10 fm with a sum of the standard Woods-Saxon (WS) and WS-derivative formfactors:

$$DPP_{real} = V_1 g(R) + a_2 V_2 \frac{df(R)}{dR}$$
$$DPP_{imag} = W_1 g(R) + a_2 W_2 \frac{df(R)}{dR} \quad (1)$$

where

$$g(R) = [1 + \frac{exp(R - R_0)}{a_1}]^{-1}$$
$$f(R) = [1 + \frac{exp(R - R_0)}{a_2}]^{-1} \quad (2)$$

with the parameters listed in Table C.1.

If the DPP is correctly parametrised, the optical model (OM) results with such an effective interaction should reproduce the original CC calculations. In Fig. 1 a comparison of the experimental data with the exact CC calculations is shown (solid curve). The simple OM calculation with the parametrised DPP gives results that are very close to the CC (dotted curve).

DPP_{real}	V_1 MeV	V_2 MeV	R_0 fm	a_1 fm	a_2 fm
	−0.265	−8.50	10.3	6.00	0.80
DPP_{imag}	W_1 MeV	W_2 MeV	R_0 fm	a_1 fm	a_2 fm
	−0.42	−6.50	9.9	3.00	0.50

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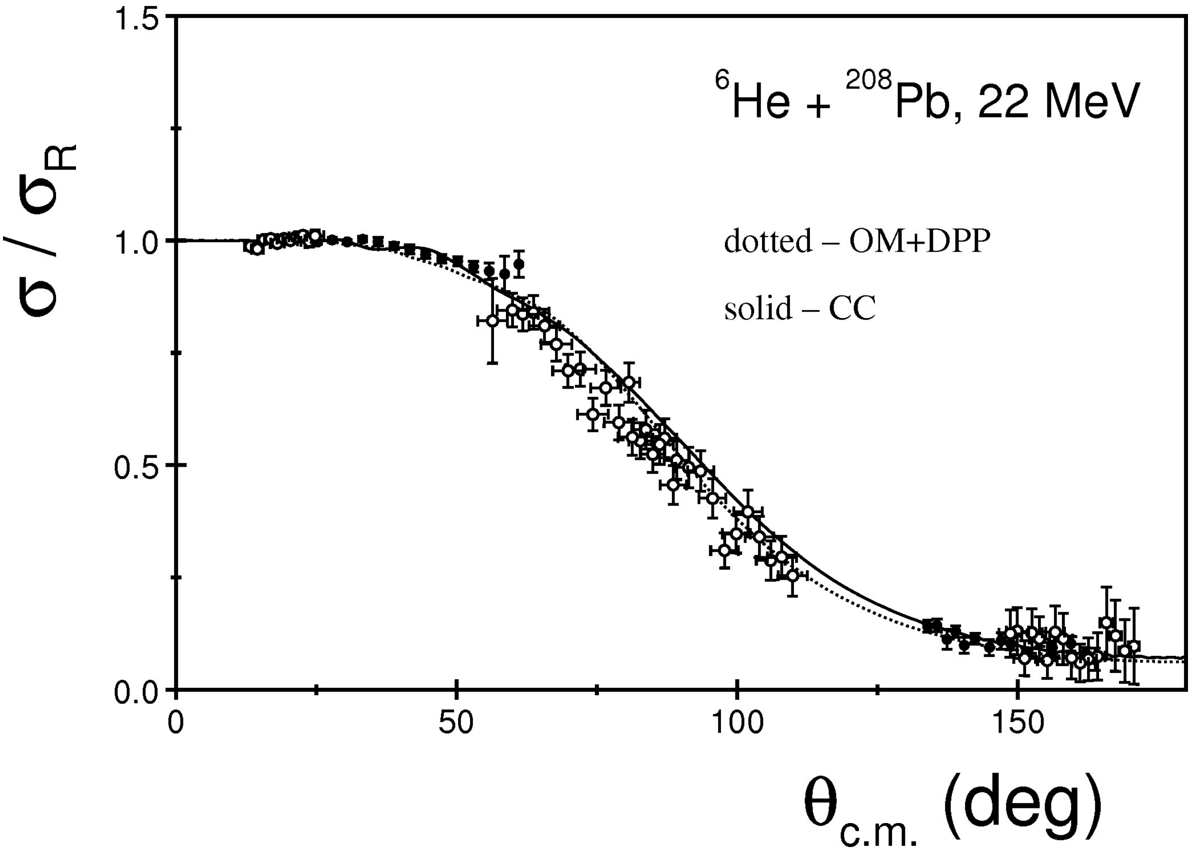

Figure 1: Comparison of the microscopic CC calculations (solid curve) with the simple OM calculations including the DPP in the parametrised form (dotted curve). Experimental data are from Ref. [2].

C.2 Evaluation of a single detector for the neutron multiplicity filter NEDA

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The NEutron Detector Array (NEDA), currently in its final design phase, will become a powerful neutron multiplicity filter, operating at stable and radioactive beam facilities, in conjunction with state of the art γ-ray detection arrays like AGATA [1], EXOGAM2 [2], GALILEO [3] or PARIS [4]. In this report, we present in a concise form results of a Monte Carlo evaluation of the size of a NEDA single detector and a comparison of two scintillators considered for NEDA. See Ref. [5] for more details.

Both single detector size and type of scintillator influence neutron detection efficiency, time resolution, probability that one neutron will generate a signal in more then one detector, and neutron-gamma discrimination capabilities. For the type of scintillator, in addition to a proton-based one, BC501A (chemical composition C_8H_{10}) commonly used in many neutron detection arrays, a deuterated scintillator (BC537, C_6D_6) is also considered. It was indicated, e. g. in ref. [6], that the deuterated scintillator may give signals which are more correlated with the energy of the incoming neutron, contrary to proton-based material. This is due to the anisotropic angular distribution of scattering of neutrons on deuterons. Such a property could make it possible to distinguish a single neutron scattering in more than one detector from multiple neutrons detected in the array.

In the simulations, a needle beam of monochromatic neutrons was shot into a scintillator cylinder with a 50 cm diameter and variable length. The efficiency to detect a neutron was analysed as a function of the detector length and the neutron energy. The results are shown in Fig.1a. The neutron detection probability as a function of the cylinder length reaches a maximum value of about 80 to 95%, at a cylinder length of 20 to about 40 cm, depending on the neutron energy and the type of scintillator. A further increase of the detector length does not lead to a significant increase of the detection probability. Reaching an efficiency of 100% is not possible, because in some events neutrons lose energy in reactions which do not produce enough light to exceed the threshold.

Neutrons undergo interactions mainly along the axis of their incoming direction. A scattered neutron may, however, produce another interaction, far away from the initial

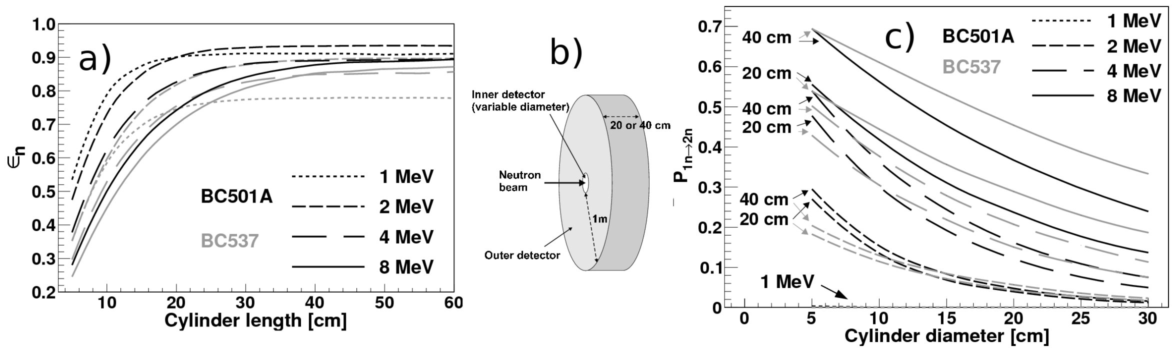

Figure 1: (a) Neutron detection efficiency as a function of detector length. (b) Setup used in the evaluation of the probability that one neutron generates a signal in more than one detector module. (c) Probability that a neutron shot onto the centre of the inner detector will generate signals in both detectors.

axis, often in another detector module. In order to study the distribution of such second interactions, a setup was evaluated consisting of two coaxial detectors, an inner and an outer detector, as shown in Fig. 1b. Such a setup is a good representation of a detector module surrounded by a number of other modules, with unimportant geometrical details omitted.

A needle beam of neutrons was shot onto the centre of the inner detector. The probability that one neutron will be detected in both detectors was studied as a function of the diameter of the inner detector. These simulations were run for both scintillator types, two detector lengths (20 cm and 40 cm), and four different energies (1, 2, 4, 8 MeV). Results of these studies are shown in Fig. 1c. The probability of generating signals in two detectors decreases rather slowly with the increase of the diameter of the inner detector. The values are significantly larger for longer detectors.

Our simulations show that the deuterated scintillator has significantly lower efficiency and worse time resolution than the proton-based one. As far as the $P_{1n\to 2n}$ probability is concerned, both detectors exhibit similar behaviour, except for situations when the efficiency of BC537 is too low to produce an above threshold signal for a second time. The anticipated good correlation of the light produced in the deuterated scintillator with the incoming neutron energy is confirmed only for very small detector units (volumes of about 0.5 litres). For larger detector sizes, such as those that will be used for NEDA (volume of about 3 litres), this effect is smeared out. We have therefore concluded that there is no advantage in using the deuterated scintillator compared to the standard one, and a decision was taken to use BC501A for the NEDA detectors.

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C.3 The reaction of quercetin with copper ions

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Epidemiological studies show the possible role in preventing cancer and cardiovascular diseases of polyphenolic compounds [1,2]. The consumption of food rich in flavonoids can even reverse age-dependent deteriorations in memory and cognition [3]. Flavonoids play a role as antioxidants by a variety of ways such as direct trapping of reactive oxygen species, inhibition of enzymes responsible for superoxide anion production, chelation of transition metals involved in processes forming radicals and prevention of the peroxidation process by reducing alkoxyl and peroxyl radicals. Quercetin which is one of the most common polyphenols, was investigated in the presence of cupric ions in methanolic solution. Many of the beneficial effects of quercetin are connected to its ability to act as a free radical acceptor. However, the metal-complexing properties of this molecule may affect its total antioxidant activity. Metal ions which possess redox activity as cofactors for various enzymes generate reactive oxygen species (ROS). Flavonoids prevent metal-catalyzed free radical generation and their subsequent reactions also by chelating metal ions. They can protect very important biologically active molecules from oxidative stress [4].

The aim of this project was to find the mechanism of interaction between the quercetin (flavonol) and Cu^{2+}. To obtain an explanation of the mechanism of reaction UV-Vis spectrophtometry was used as an accurate method for detection of different forms of quercetin.

The UV-Vis spectrum of quercetin shows two bands: the first (λ_{max} = 258 nm) is related to the benzoyl moiety and the second - to the cinnamoyl moiety of quercetin (Fig. 1).

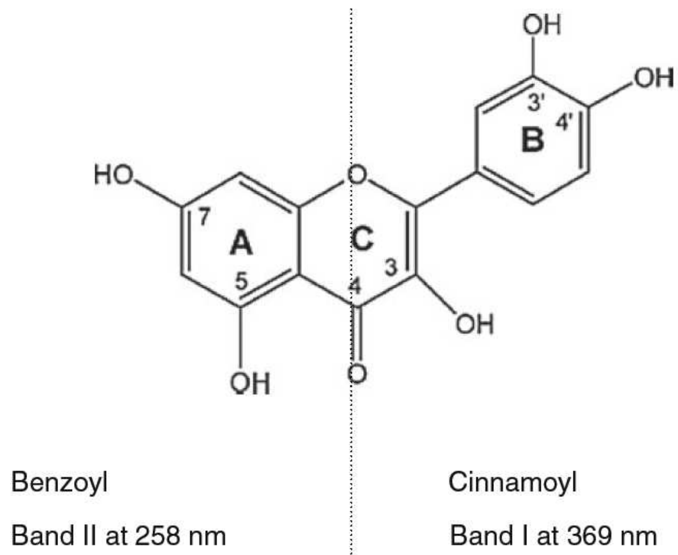

Figure 1: The structure of quercetin.

The study was related to various Q:Cu molar ratios and prolonged time. After addition of copper (II) ions we observed a change in the spectra of quercetin. The spectra of free quercetin (Q) and different Cu(II)-quercetin systems (Q:Me = 1:2, 1:1 and 2:1) in methanolic solutions recorded with two different times after mixing the reagents are presented in Fig. 2. The addition of Cu(II) to quercetin solution ($8.9 \cdot 10^{-5}$ M) leads to a large hypochromic shift in band I, particularly significant when the Cu:Q ratio was 2:1 (Fig. 2a). Band II of the quercetin spectrum demonstrated hyperchromic shift to 293 nm in the presence of copper ions. The decrease of the absorption band was connected with the simultaneous increase of a new characteristic band at $\lambda_{max} = 436$ nm, which corresponds to the complex formation reaction as neither the ligand nor the metal absorb at this wavelength. The excess of metal ions promoted the interaction of quercetin with Cu(II) as the absorbance at 436 nm is higher and less free ligand is present in solution in comparison to the other Q:Cu ratios (Fig. 2a). Over time after mixing the reagent solutions, the intensity of the observed bands changed, particularly in the presence of an excess of Cu(II) (Fig. 2b)). The peak at 298 nm was also observed for quercetin after the reaction with KMnO4 solution which is a strongly oxidative agent (Fig. 3). The results show that the reaction between quercetin and Cu(II) resulted first in the formation of a 1:1 metal-ligand complex through the carbonyl oxygen and 3-OH group in the C ring and then oxidation of quercetin to benzoquinone type products.

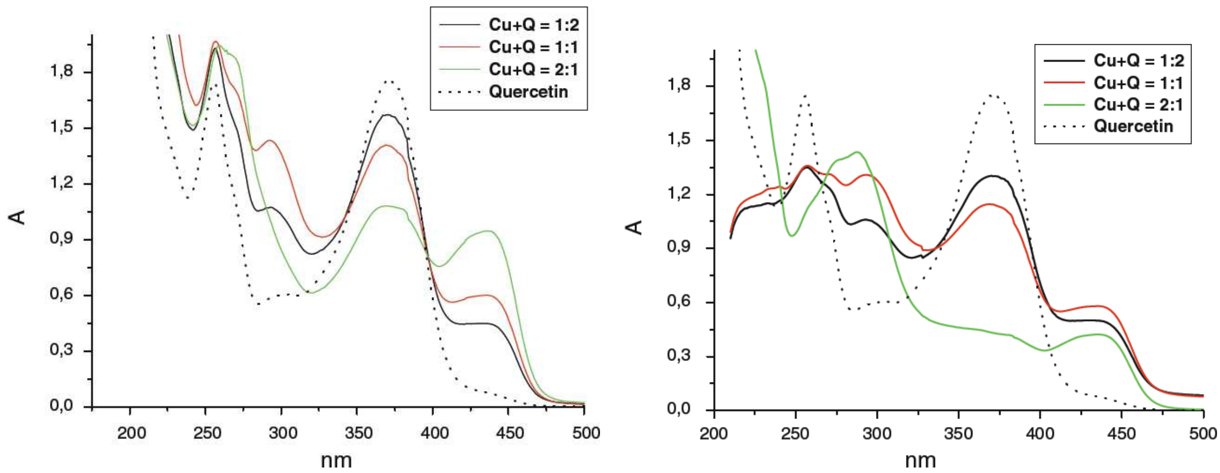

Figure 2: Absorption spectra of quercetin and Cu-quercetin complexes. A) Recorded immediately after mixing solutions; B) after 120 min $[Q] = 8.9 \cdot 10^{-5}$ M [5]

.

The addition of EDTA destroyed the complex (results not shown) but did not regenerate the whole original spectrum of free quercetin. The presence of EDTA prevents the formation of a copper — quercetin complex and quercetin oxidation.

Bibliography

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[5] A. Pękal, M. Biesaga, K. Pyrzynska Biometals **24** (2011) 41

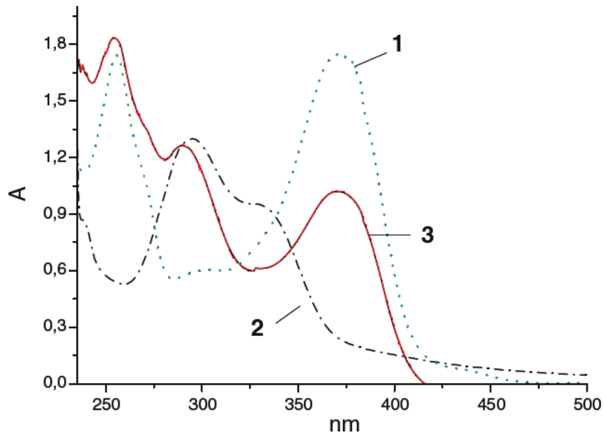

Figure 3: Absorption spectra of: (1) quercetin; (2) quercetin oxidized by KMnO4 and (3) Cu : Q = 2:1 solution after addition of EDTA $[Q] = 8.9 \cdot 10^{-5}$ M [5].

Part D

Appendices

D.1 Degrees and theses completed in 2011 or in progress

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

Katarzyna Wrzosek-Lipska
Badanie struktury elektromagnetycznej niskospinowych stanów wzbudzonych jądra ^{100}Mo metodą wzbudzeń kulombowskich
Electromagnetic structure of low-spin excited states in ^{100}Mo studied using the Coulomb excitation method
Supervisor: dr hab. L. Pieńkowski. Thesis defended with honours on 7 March 2011.

Jan Mierzejewski
Mechanizm niekompletnej fuzji badany z wykorzystaniem EAGLE i SiBall
Mechanism of incomplete fusion studied with EAGLE and SiBall
Supervisor: prof. dr hab. T. Matulewicz. Expected completion time: 2012.

Grzegorz Jaworski, Faculty of Physics, Warsaw University of Technology
Modelowanie wieloelementowych układów detekcyjnych w badaniach struktury egzotycznych jąder atomowych
Modelling of multidetector arrays in studies of the structure of exotic nuclei
Supervisor: prof. dr hab. J. Kownacki. Expected completion time: 2012.

Katarzyna Hadyńska-Klęk
Badanie struktury kolektywnej w izotopach wapnia metodą wzbudzeń kulombowskich
Studies of collective structure in calcium isotopes using the Coulomb excitation method
Supervisor: prof. dr hab. M. Kicińska-Habior. Expected completion time: 2012.

Daniel Piętak, Institute of Radioelectronics, Warsaw University of Technology
Metoda oceny jakości wyników z eksperymentów wzbudzeń kulombowskich z wykorzystaniem algorytmu genetycznego
Evaluation method based on a genetic algorithm for results of Coulomb excitation experiments
Supervisor: prof. dr hab. J. Wojciechowski. Expected completion time: 2012.

Izabela Strojek, The Andrzej Sołtan Institute for Nuclear Studies, Świerk
Wpływ struktury jądra ^{20}Ne na reakcje z jego udziałem
Influence of the structure of ^{20}Ne on reactions with this nucleus
Supervisor: prof. dr hab. K. Rusek. Expected completion time: 2012.

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

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

Joanna Czub, Faculty of Physics, Świętokrzyska Academy
Biologiczne działanie promieniowania o wysokim LET
Biological effects of radiation with high LET value
Supervisor: prof. dr hab. J. Braziewicz. Thesis defended on 16 September 2011.

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

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.

D.1.3 MSc theses supervised by HIL staff members

Grzegorz Mentrak, Faculty of Physics, Warsaw University of Technology
Opracowanie układu cyfrowo-analogowego sterowania zasilaczami prądu stałego do magnesów odchylających w Warszawskim Cyklotronie
A digital/analog control system for DC power supplies for bending magnets of the Warsaw Cyclotron
Supervisor: dr J. Choiński. Thesis completed in October 2011.

Michalina Komorowska, Faculty of Physics, University of Warsaw
Supervisors: prof. M. Kicińska-Habior, dr J. Srebrny. Expected completion time: 2012

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

Aleksandra Rubin, Wojciech Piątek, Faculty of Mathematics and Natural Sciences, Cardinal Stefan Wyszyński University in Warsaw
Równoległe wyznaczanie wartości funkcji celu z wykorzystaniem architektury rozproszonej
Parallel determination of the objective function value based on a distributed application structure
Supervisors: prof. dr hab. J. Górecki, prof. dr hab. L. Socha. BSc thesis defended in 2011

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

Małgorzata Łoniewska, Faculty of Physics, University of Warsaw
Supervisor: dr hab. Z. Szefliński. BSc thesis defended in 2011

Michał Czerwiński, Faculty of Physics, University of Warsaw
Survival of cell lines under influence of local dose

Supervisor: dr hab. Z. Szefliński. MSc thesis, expected completion time: 2012

Elżbieta Gajewska-Dendek, Faculty of Physics, University of Warsaw
Monte Carlo simulations of the therapeutic dose in NVIDIA CUDA technology
Supervisor: dr hab. Z. Szefliński. MSc thesis, expected completion time: 2012

Justyna Chudyka, Faculty of Mathematics, Physics and Chemistry, University of Silesia
Superisor: prof. dr hab. W. Zipper. MSc thesis, expected completion time: 2012

Katarzyna Tworek, Faculty of Mathematics, Physics and Chemistry, University of Silesia
Superisor: prof. dr hab. W. Zipper. MSc thesis, expected completion time: 2012

D.2 Seminars

D.2.1 Seminars co-organised by HIL

Nuclear Physics Seminars

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

M. Lewitowicz — GANIL, France 13 January 2011
Physics opportunities and status of the SPIRAL 2 Project

W Satuła — Inst. of Theoretical Physics, Univ. of Warsaw 20 January 2011
Isospin mixing and isospin-symmetry-breaking corrections to the superallowed beta decay

P. Decowski — NIKHEF, Amsterdam, Netherlands 17 February 2011
Measuring neutrino properties and geoneutrinos with KamLAND

S. Wycech — NCNR, Świerk, Poland 24 February 2011
Barionium a fizyka FAIR
Barionium and physics of FAIR

S.G. Rohoziński — Inst. of Theoretical Physics, Univ. of Warsaw 3 March 2011
Symptomy chiralności w układach rdzeń-cząstka-dziura
Signatures of chirality in the core-particle-hole systems

P. Olbratowski — Inst. of Theoretical Physics, Univ. of Warsaw 10 March 2011
Szkolenie polskich edukatorów energetyki jądrowej we Francji
Training of Polish nuclear power tutors in France

D. Tarpanov — Bulgarian Acad. of Sc. and Univ. of Warsaw 17 March 2011
Nuclear structure calculations in large domain of energy excitations

M. Palacz, HIL 24 March 2011
Neutron-proton interaction in ^{92}***Pd***

A. Pastore — Institut de Physique Nucléaire de Lyon 31 March 2011
Nuclear response for the Skyrme functional with zero-range tensor terms

J. Dobaczewski — Inst. of Theoretical Physics, Univ. of Warsaw 7 April 2011
Stany jąder ciężkich jako laboratorium badania procesów fundamentalnych
Heavy atomic nuclei as a laboratory for fundamental processes

N. Keeley — NCNR, Świerk, Poland 14 April 2011
Nuclear structure influences on near-barrier elastic scattering

K. Siwek-Wilczyńska — Inst. of Experimental Physics, Univ. of Warsaw 21 April 2011
Modelowanie syntezy jąder superciężkich
Modelling of the synthesis of super-heavy nuclei

Ł. Wieteska — Medical University in Łódź 28 April 2011
Znaczenie promieniowania tła dla reakcji komórki na uszkodzenia DNA
Influence of the background radiation on cell response to DNA damage

I. Mukha — GSI, Darmstadt 5 May 2011
Proton and two-proton decays in-flight studied by tracking technique

K. Piasecki — Inst. of Experimental Physics, Univ. of Warsaw 12 May 2011
Global dynamics and strangeness production in heavy-ion collisions at 1-2 A·GeV with FOPI

M. Pomorski — Inst. of Experimental Physics, Univ. of Warsaw 19 May 2011
Spektroskopia ^{48}Ni — pierwsze wrażenia z eksperymentu w NSCL
Spectroscopy of ^{48}Ni —- first impressions from an experiment at NSCL

M. Jentschel — ILL Grenoble 26 May 2011
Gamma Ray Spectroscopy with Laue Diffraction Spectrometers

M. Konecki — Inst. of Experimental Physics, Univ. of Warsaw 6 October 2011
Fizyka zderzeń proton-proton przy wielkich energiach — ostatnie wyniki eksperymentów ATLAS i CMS
Physics of high energy proton-proton collisions — recent results of the ATLAS and CMS experiments

C. Mazzocchi — Inst. of Experimental Physics, Univ. of Warsaw 13 October 2011
Alpha-decay in the neighbourhood of ^{100}Sn, an overview on recent results

K. Grzelak — Inst. of Experimental Physics, Univ. of Warsaw 20 October 2011
Pomiary prędkości neutrin
The neutrino velocity measurements

M. Karny — Inst. of Experimental Physics, Univ. of Warsaw 27 October 2011
Rozpad beta ^{100}Sn
Beta decay of ^{100}Sn

K. Rusek — HIL 3 November 2011
Fizyka jądrowa i jej medyczne zastosowania w ŚLCJ UW
Nuclear physics and its applications at HIL

Z. Patyk — NCNR, Świerk, Poland 10 November 2011
Jądrowy wychwyt elektronu w jonach wodoro-, helo- i lito-podobnych
Orbital electron capture of hydrogen- helium- and lithium-like ions

O. Hartmann — Austrian Academy of Sciences, Vienna 17 November 2011
Strangeness Physics with FOPI at GSI-SIS

J. Kurpeta — Inst. of Experimental Physics, Univ. of Warsaw 24 November 2011
Stany izomeryczne w neutrono-nadmiarowych fragmentach rozszczepienia o masach w pobliżu A=110
Isomeric states in neutron-rich fission fragments with masses close to A=110

A. Korgul — Inst. of Experimental Physics, Univ. of Warsaw 1 December 2011
Nowe informacje spektroskopowe o rozpadach β oraz βn nuklidów z okolicy podwójnie magicznego jądra ^{78}Ni
New spectroscopic information in the vicinity of the doubly-magic nucleus ^{78}Ni

S. Kistryn — Jagiellonian University, Kraków 28 November 2011
Centrum Cyklotronowe Bronowice — nowe laboratorium fizyki jądrowej
Bronowice Cyclotron Centre - a new laboratory of nuclear physics

M. Kirejczyk — Inst. of Experimental Physics, Univ. of Warsaw 25 November 2011
Statystyczne i niestatystyczne aspekty zderzeń jądro-jądro w wynikach detektora FOPI
Statistical and non-statistical aspects of the FOPI detector results

W. Nazarewicz — Univ. of Tennessee, and ORNL, USA 19 December 2011
Zawartość informacyjna nowej obserwabli
Information content of a new observable

D.2.2 External seminars given by the HIL staff

P.J. Napiorkowski, D.A. Piętak 17 January 2011
Obliczanie kształtów jąder atomowych z wykorzystaniem algorytmów heurystycznych i przetwarzania rozproszonego
Calculation of nuclear shapes using heuristic algorithms and distributed processing
Seminar in the Cardinal Stefan Wyszyński University, Warszawa, Poland

J. Sura 19 January 2011
Thomson type spectrometer
Seminar of the Faculty of Physics, University of Messina, Italy

A.Trzcińska 2 May 2011
Barrier height distributions — the influence of weak channels
FUSION 2011 Conference, St. Malo, France

M. Zielińska 6 May 2011
Coulomb excitation studies
Physics Group Meeting, CSNSM, Orsay

J. Jastrzębski 12 May 2011
Produkcja izotopów medycznych w ŚLCJ
Production of medical isotopes at HIL
Scientific Session “2011 - year of Maria Skłodowska-Curie”, University of Silesia, Katowice, Poland

J.Jastrzębski 19 May 2011
Radioizotopy stosowane w medycynie
Radioisotopes used in medicine
University of Maria Skłodowska-Curie, Lublin, Poland

J.Mierzejewski 27 June 2011
Dynamics of Incomplete fusion reaction — first experiment on EAGLE array
EGAN 2011 workshop, Padova, Italy

J.Jastrzębski 18 June 2011
^{211}At production on the Warsaw Cyclotron
7th Symposium on Targeted Alpha Therapy, Berlin, Germany

E. Piasecki 7 August 2011
Coulomb barrier distributions
Summer School ”Modern Problems of Nuclear Physics and Astrophysics”,
Astana, Kazakhstan

D.A. Piętak, J.Wojciechowski, P.J.Napiorkowski 29 August 2011
A Front Line Algorithm for Error Estimation in Data Sets with Nonuniform Sampling Distribution
European Conference on Circuit Theory and Design, Linkoping, Sweden

K. Rusek 5 September 2011
Fizyka jądrowa i jej medyczne zastosowania w ŚLCJ UW
Nuclear Physics and its medical applications at HIL
XLI Meeting of Polish Physicists, Lublin, Poland

M. Zielińska 8 September 2011
Warsztaty Akceleracji i Zastosowań Ciężkich Jonów w ŚLCJ UW
Workshops on Acceleration and Applications of Heavy Ions at HIL
XLI Meeting of Polish Physicists, Lublin, Poland

J. Mierzejewski 8 September 2011
COMPA — a fusion-evaporation event generator code that handles stopping of the reaction products in the target material
11th Agata Week, Darmstadt, Germany

K. Rusek 12 September 2011
Role of one-neutron transfer in ^{11}Be + ^{120}Sn scattering
XXXII Mazurian Lakes Conference on Physics, Piaski, Poland

J. Mierzejewski 13 September 2011
Dynamics of the Incomplete fusion reaction-first measurements with EAGLE array
XXXII Mazurian Lakes Conference on Physics, Piaski, Poland

J. Kownacki 14 September 2011
Beginning of Nuclear Spectroscopy in neighbourhood of Warsaw
XXXII Mazurian Lakes Conference on Physics, Piaski, Poland

J.Jastrzębski 17 September 2011
Radioactive Nuclei for Medical Applications
XXXII Mazurian Lakes Conference on Physics, Piaski, Poland

J.Jastrzębski 22 September 2011
Radiopharmaceuticals Production and Research Centre at the University of Warsaw
Int. Conf. "Physics and Engineering for Health and Wellness of Society", Poznań, Poland

J.Mierzejewski 22 September 2011
Incomplete fusion reaction modelling
Compound Nuclear Reactions and Related Topics, Prague, Czech Republic

K.Rusek 26 October 2011
Crisis creates opportunities: perspective from a small European laboratory
Asia-Europe Physics Summit 2011, Wrocław, Poland

J. Choiński 4 November 2011
Ośrodek produkcji i badań radiofarmaceutyków
Radiopharmaceuticals production and research laboratory
4th CePT Conference, Warszawa, Poland

D.2.3 Poster presentations

K. Rusek
New results on fusion of ^{8}He halo nucleus with ^{206}Pb at the energies below the Coulomb barrier
A.M.Sanchez-Benitez et al., ARIS 2011, Katholieke Universiteit Leuven,
29 May–3 June 2011

K. Rusek, A.Trzcińska
Probing the ^{17}F+p potential by means of elastic scattering measurements at near barrier energies
N. Patronis et al., ARIS 2011, Katholieke Universiteit Leuven, 29 May – 3 June 2011

J. Mierzejewski
Incomplete fusion reaction modelling
Nordic Conference on Nuclear Physics 2011, 13-17 June 2011, Stockholm, Sweden

P. Napiorkowski, K. Rusek, M. Zielińska
Workshops on Acceleration and Applications of Heavy Ions at the Heavy Ion Laboratory
XXXII Mazurian Lakes Conference on Physics, 11–18 September 2011, Piaski, Poland

A. Kordyasz
Silicon vertex detector for superheavy elements identification
XVIIth Colloque GANIL 25–30 September 2011, Belgodere, Corsica, France

P. Napiorkowski, K. Rusek, M. Zielińska
Workshops on Acceleration and Applications of Heavy Ions at the Heavy Ion Laboratory
Asia-Europe Physics Summit, 26–29 November 2011, Wrocław, Poland

A. Kordyasz, M. Kowalczyk, M. Kisieliński, A. Bednarek, K. Hadyńska-Klęk, (14 names)
Silicon vertex detector for superheavy elements identification
International Workshop on Multifragmentation and Related Topics 2011,
2–5 November 2011, GANIL, France

J. Choiński, K. Kilian, A. Pękal, D. Szczepaniak
Pracownia ^{11}C i ^{15}O
^{11}C and ^{15}O Laboratory
IV CePT Conference, 4 November 2011, Warszawa, Poland

W. Szkutnik, K. Kilian, A. Pękal, K. Pyrzyńska
Wykorzystanie metody headspace GC do oznaczania pozostałości rozpuszczalników organicznych w radiofarmaceutykach
Use of the GC headspace method for the determination of residual organic solvents in radiopharmaceuticals
Ogólnopolska Konferencja Radiofarmaceutyczna 12–13 May 2011, Łódź, Poland

D.2.4 Lectures for students

K. Wrzosek-Lipska, M. Zielińska — 17–20 May 2011
Course "GOSIA for beginners"
TU Darmstadt, Germany (15 hours of lectures and training sessions)

O. Steczkiewicz — 2 February 2011
Akceleracja ciężkich jonów i elementy optyki jonowej
Acceleration of heavy ions and ion optics elements
Maria Skłodowska-Curie University, Lublin, Poland

K. Rusek — 2 February 2011
100 lat fizyki jądrowej
100 years of Nuclear Physics
Maria Skłodowska-Curie University, Lublin, Poland

M. Zielińska 2 February 2011
Prezentacja Środowiskowego Laboratorium Ciężkich Jonów
Presentation of the Heavy Ion Laboratory
Maria Skłodowska-Curie University, Lublin, Poland

K. Kilian 2 February 2011
Radiofarmaceutyki do pozytonowej tomografii emisyjnej (PET)
Radiopharmaceuticals for positron-electron emission tomography (PET)
Maria Skłodowska-Curie University, Lublin, Poland

L. Pieńkowski 2 February 2011
Synergia węglowo-jądrowa
Nuclear-coal synergy
Maria Skłodowska-Curie University, Lublin, Poland

M. Zielińska 27 June 2011
Prezentacja Środowiskowego Laboratorium Ciężkich Jonów
Presentation of the Heavy Ion Laboratory
Lecture for post-graduate students of Physics and Astronomy, HIL

L. Pieńkowski 27 June 2011
Synergia węglowo-jądrowa
Nuclear-coal synergy
Lecture for post-graduate students of Physics and Astronomy, HIL

D.2.5 Science popularisation lectures

L. Pieńkowski 24 September 2011
Energetyka jądrowa - szanse i zagrożenia
Nuclear energy — opportunities and hazards
XV Festival of Science, Warszawa, Poland

P.J. Napiorkowski 24 September 2011
Fizyka jądrowa w walce z fałszerzami win
Nuclear physics against wine forgers
XV Festival of Science, Warszawa, Poland

K. Kilian 24 September 2011
Tomografia emisji pozytonu (PET). Nowe możliwości dla nauki, ochrony zdrowia i przemysłu
Positron emission tomography (PET). New opportunities for science, health care and industry
XV Festival of Science, Warszawa, Poland

K. Kilian 22 September 2011
Zastosowanie fizyki jądrowej w diagnostyce medycznej
Applications of nuclear physics in medicine
XV Festival of Science, Warszawa, Poland

P.J. Napiorkowski 23 September 2011
Fizyka dla bramkarzy
Physics for goalkeepers
XV Festival of Science, Warszawa, Poland

L. Pieńkowski 17 September 2011
Przyszłość energetyki jądrowej po Fukushimie
Nuclear energy after Fukushima
XV Festival of Science, Warszawa, Poland

D.3 Publications

D.3.1 ISI listed publications

Publications resulting from work performed with HIL facilities

A.T. Rudchik, Yu.M. Stepanenko, K.W. Kemper, A.A. Rudchik, O.A. Ponkratenko, E.I. Koshchy, S. Kliczewski, K. Rusek, A. Budzanowski, S.Yu. Mezhevych, I. Skwirczynska, R. Siudak, B. Czech, A. Szczurek, J. Choinski, L. Glowacka
Comparison of the ^{7}Li(^{18}O, ^{17}N)^{8}Be and ^{18}O(d,^{3}He)^{17}N reactions
Phys. Rev. **C83** (2011) 024606

J. Kownacki, Ch. Droste, T. Morek, E. Ruchowska, R.M. Lieder, M. Kisielinski, M. Kowalczyk, J. Andrzejewski, J. Perkowski, P.J. Napiorkowski, K. Wrzosek-Lipska, M. Zielinska, A. Kordyasz, A. Korman, K. Hadynska-Klęk, E. Grodner, J. Mierzejewski, J. Srebrny
Decay properties of long-lived isomers in the odd-odd N=81 nucleus ^{146}Tb compared to the ^{148}Ho and ^{150}Tm nuclei
Phys. Rev. **C83** (2011) 027301

J. Mierzejewski, J. Srebrny, H. Mierzejewski, J. Andrzejewski, W. Czarnacki, Ch. Droste, E. Grodner, A. Jakubowski, M. Kisieliński, M. Komorowska, A. Kordyasz, M. Kowalczyk, J. Kownacki, A.A. Pasternak, J. Perkowski, A. Stolarz, M. Zielińska, R. Anczkiewicz
EAGLE — the central European Array for Gamma Levels Evaluation at the Heavy Ion Laboratory of the University of Warsaw
Nucl. Inst. and Meth. **A659** (2011) 84

A.T. Rudchik, Yu.O. Shyrma, K.W. Kemper, K. Rusek, E.I.Koshchy, S. Kliczewski, B.G. Novatsky, O.A. Ponkratenko, E. Piasecki, G.P. Romanyshyna, Yu.M. Stepanenko, I. Strojek, S.B. Sakuta, A. Budzanowski, L. Glowacka, I. Skwirczynska, R. Siudak, J. Choiński, A. Szczurek
Elastic and inelastic scattering of ^{13}C + ^{18}O versus ^{12}C + ^{18}O and ^{13}C + ^{16}O
Nucl. Phys. **A852** (2011) 1

A.T. Rudchik, Yu.O. Shyrma, K.W. Kemper, K. Rusek, E.I. Koshchy, S. Kliczewski, B.G. Novatsky, O.A. Ponkratenko, E. Piasecki, G.P. Romanyshyna, Yu.M. Stepanenko, I. Strojek, S.B. Sakuta, A. Budzanowski, L. Glowacka, I. Skwirczynska, R. Siudak, J. Choiński, A. Szczurek
Elastic and inelastic scattering of ^{14}C + ^{18}O versus ^{12,13}C + ^{18}O and ^{14}C + ^{16}O
Eur. Phys. J. **A47** (2011) 50

J. Srebrny, D. Cline
Model independent determination of quadrupole deformation parameters from Coulomb excitation measurements
Int. J. Mod. Phys. **E20** (2011) 422

E. Grodner, I. Sankowska, T. Morek, S.G. Rohozinski, Ch. Droste, J. Srebrny, A.A. Pasternak, M. Kisielinski, M. Kowalczyk, J. Kownacki, J. Mierzejewski, A. Krol, K. Wrzosek
Partner bands of ^{126}Cs — first observation of chiral electromagnetic selection rules
Phys. Lett. **B703** (2011) 46

K. Wrzosek-Lipska, M. Zielinska, K. Hadynska-Klek, J. Iwanicki, M. Kisielinski, M. Kowalczyk, P.J. Napiorkowski, D. Pietak, J. Srebrny
Quadrupole Moment of the 2_1^+ State in ^{100}Mo
Acta Phys. Pol. **B42** (2011) 803

K. Wrzosek-Lipska, M. Zielinska, K. Hadyńska-Klęk, Y. Hatsukawa, J. Iwanicki, J. Katakura, M. Kisielinski, M. Koizumi, M. Kowalczyk, H. Kusakari, M. Matsuda, T. Morikawa, P.J. Napiorkowski, A. Osa, M. Oshima, D. Pietak, L. Prochniak, T. Shizuma, J. Srebrny, M. Sugawara, Y. Toh
Shape evolution in heaviest stable even-even molybdenum isotopes studied via Coulomb excitation
Int. J. Mod. Phys. **E20** (2011) 443

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A.T. Rudchik, Yu.M. Stepanenko, K.W. Kemper, A.A. Rudchik, O.A. Ponkratenko, E.I. Koshchy, S. Kliczewski, K. Rusek, A.Budzanowski, S.Yu. Mezhevych, Val.M. Pirnak, B. Czech, R. Siudak, I. Skwirczynska, A. Szczurek, J. Choiński, L. Glowacka
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M. Scheck, P.A. Butler, L.P. Gaffney, N. Bree, R.J. Carrol, D. Cox, T. Grahn, P.T. Greenlees, K. Hauschild, A.Herzan, M. Huyse, U. Jakobsson, P. Jones, D.T. Joss, R. Julin, S. Juutinen, S. Ketelhut, R.-D. Herzberg, M. Kowalczyk, A.C. Larsen, M. Leino, A. Lopez-Martens, P. Nieminen, R.D. Page, J. Pakarinen, P. Papadakis, P. Peura, P. Rahkila, S. Rinta-Antila, P. Ruotsalainen, M. Sandzelius, J. Saren, C. Scholey, J. Sorri, J. Srebrny, P. Van Duppen, H.V. Watkins, J. Uusitalo
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F. Naqvi, P. Boutachkov, M. Gorska, J. Gerl, F. Farinon, E.T. Gregor, K. Hadynska, A. Jhingan, R. Janik, I. Kojouharov, N.A. Kondratyev, M.A.G. Alvarez, I. Mukha, P. Napiorkowski, C. Nociforo, D. Pietak, W. Prokopowicz, S. Pietri, A. Prochazka, H. Schaffner, P. Strmen, H. Weick, H. J.Wollersheim
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Eur. Phys. J. **A47** (2011) 25

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A. Stolarz
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Nucl. Inst. and Meth. **A655** (2011) 34

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B. Bruyneel, T. Davinson, P. Delahaye, J. Diriken, J. Eberth, G. Georgiev, D. Fedorov, V.N. Fedosseev, E. Fiori, S. Franchoo, Ch. Fransen, K. Geibel, K. Gladnishki, K. Hadynska, H. Hess, K. Heyde, M. Huyse, O. Ivanov, J. Iwanicki, J. Jolie, M. Kalkuehler, Th. Kroll, R. Krucken, U. Koster, G. Lo Bianco, R. Lozeva, B.A. Marsh, S. Nardelli, F. Nowacki, N. Patronis, P. Reiter, M. Seidlitz, K. Sieja, N. Smirnova, J. Srebrny, J. Van de Walle, P. Van Duppen, N. Warr, F. Wenander, K. Wimmer, K. Wrzosek, S. Zemlyanoi, M. Zielinska
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Phys. Rev. **C84** (2011) 064323

D.3.2 Conference contributions and other publications in journals not included in the ISI list

J. Jastrzębski
Radioactive Nuclei for Medical Applications
Annales UMCS, Section AAA, Volume LXVI (2011) 49

D.A.Piętak, J. Wojciechowski, P. Napiorkowski
A front line algorithm for error estimation in data sets with nonuniform sampling distribution
IEEE Xplore Proceedings page 210

A. Trzcińska, W. Czarnacki, P. Decowski, M. Kisieliński, P. Koczoń, A. Kordyasz, M. Kowalczyk, E. Piasecki, K. Rusek, A. Stolarz
Barrier heigt distributions - the influence of weak channels
European Physical Journal Web of Conferences **17** (2011) 05006

V.V. Parkar, G. Marquinez, I. Martel, A.M. Sanchez-Benitez, L. Acosta, R. Berjillos, J. Duenas, J.L. Flores, J.P. Bolivar, A. Padilla, M.A.G. Alvarez, D. Beaumel, M.J.G. Borge, A. Chbihi, C. Cruz, M. Cubero, J.P. Fernandez-Garcia, B. Fernandez Martinez, J. Gomez-Camacho, N. Keeley, J.A. Labrador, M. Marquis, M. Mazzocco, A. Pakou, N. Patronis, V. Pesudo, D. Pierroutsakou, R. Raabe, K. Rusek, R. Silvestri, L. Standylo, I. Strojek, N. Soic, O. Tengblad, R. Wolski, A.H. Ziad
Fusion of ^{8}He with ^{206}Pb around Coulomb barrier energies
European Physical Journal Web of Conferences **17** (2011) 16009

I. Skwira-Chalot, J. Wilczyński, T. Cap, F. Amorini, A. Anzalone, L. Auditore, V. Baran, J. Brzychczyk, G. Cardella, S. Cavallaro, M.B. Chatterjee, M. Colonna, E. De Filippo, M. Di Toro, W. Gawlikowicz, E. Geraci, A. Grzeszczuk, P. Guazzoni, S. Kowalski, E. La Guidara, G. Lanzalone, J. Łukasik,C. Maiolino, Z. Majka, N.G. Nicolis, A. Pagano, M. Papa, E. Piasecki, S. Pirrone, R. Płaneta, G. Politi, F. Porto, F. Rizzo, P. Russotto, K. Schmidt, A. Sochocka, Ł. Świderski, A.Trifiro, M. Trimarchi, J.P. Wieleczko, L. Zetta, W. Zipper
Ternary and quaternary re-separation of heavy colliding systems
Proceeding of Science **59** (2011) 1

D.3.3 Internal reports

M. Kopka, W. Kozaczka, P. Krysiak, Z. Morozowicz, K. Pietrzak
Układ wentylacji budynku cyklotronu, obwody wentylatorów
Cyclotron building ventilation system, fans circuits

M. Kopka, W. Kozaczka, P. Krysiak, Z. Morozowicz, K. Pietrzak
Pomiary termowizyjne. Pomiar temperatut zasilacza ZM1
Thermal measurements. Temperature measurement of the main power supply ZM1

M. Kopka, W. Kozaczka, P. Krysiak, Z. Morozowicz, K. Pietrzak
Pomiary cewek pułapki magnetycznej źródła jonów ECR
Measurements of the magnetic trap coils for the ECR ion source

D.4 Awards

The Rector of the University of Warsaw awards

M. Palacz, J. Kownacki
For the work on structure of exotic nuclei published in Nature, vol. 469, page 68, *Evidence of a spin-aligned neutron-proton paired phase from the level structure of* ^{92}Pd.

J. Srebrny, J. Mierzejewski, M. Kisieliński, M. Kowalczyk, K. Wrzosek-Lipska
For the study of symmetry in nuclei published in Physics Letters B703, page 46, *Partner bands of* ^{126}Cs *— first observation of chiral electromagnetic selection rule.*

A. Bednarek, P. Gmaj
For the work within the project entitled *New high-frequency generators for the Warsaw Cyclotron.*

M. Kopka
For the work on the new power supplies for the high-frequency generators.

A. Jakubowski
For the maintenance of the experimental hall.

L. Strzelczyk
For the maintenance of the HIL building.

Other awards granted to HIL staff and PhD students

Kastarzyna Hadyńska-Klęk
Anna Pękal

Research scholarships for academic year 2011/2012 from the "Modern University" project, funded by the European Social Fund in the framework of the Human Capital programme. The scholarships were awarded to the best PhD students at the University of Warsaw.

Grzegorz Jaworski

Research and development scholarship for best PhD students granted by the Faculty of Physics, Warsaw University of Technology, for 4 months, from 1 October 2011.

Katarzyna Wrzosek-Lipska

International internship for a young post-doc at the Technische Universität Darmstadt from the "Modern University" project, funded by the European Social Fund in the framework of the Human Capital programme.

Mikołaj Tarchalski, Andrzej Kordyasz

MSc thesis of Mikołaj Tarchalski, prepared under supervision of Dr. Andrzej Kordyasz from HIL, was awarded the second prize in the contest of the Polish Nuclear Society for the best MSc theses on nuclear physics and energy, which were defended in 2010/2011. The thesis "Correction of resistivity of Si wafers using Selective Transmutation Doping" was defended at the Faculty of Physics, Warsaw University of Technology.

D.5 Laboratory staff

Director: Krzysztof Rusek
Deputy directors: Jarosław Choiński, Magdalena Zielińska[1]

Financial executive: Paweł Napiorkowski

Senior scientists:

Jerzy Jastrzębski[2], Jan Kownacki[2], Andrzej Kordyasz, Ernest Piasecki[2], Ludwik Pieńkowski, Krzysztof Rusek, Józef Sura

Scientific staff and engineers:

Tomasz Abraham, Andrzej Bednarek, Izabela Cydzik[3], Jarosław Choiński, Bohdan Filipiak[2], Przemysław Gmaj, Jędrzej Iwanicki[3], Andrzej Jakubowski, Krzysztof Kilian, Maciej Kisieliński[2], Marian Kopka, Michał Kowalczyk[2], Ireneusz Mazur, Jan Mierzejewski, Jan Miszczak, Paweł Napiorkowski, Marcin Palacz, Anna Pękal[2], Daniel Piętak[3], Mateusz Sobolewski, Olga Steczkiewicz, Anna Stolarz, Julian Srebrny[2], Dorota Szczepaniak, Roman Tańczyk, Radosław Tarnowski, Agnieszka Trzcińska, Marzena Wolińska-Cichocka[3], Magdalena Zielińska[1]

Doctoral candidates:

Katarzyna Hadyńska-Klęk[4], Grzegorz Jaworski[5],

Technicians:

Mariusz Antczak, Tomasz Bracha, Marek Figat, Andrzej Górecki, Piotr Jasiński, Wiesław Kalisiewicz, Wojciech Kozaczka, Zbigniew Kruszyński, Piotr Krysiak, Krzysztof Łabęda-Dyszy, Zygmunt Morozowicz, Bogusław Paprzycki, Wiesław Perkowski[2], Andrzej Pietrzak, Krzysztof Pietrzak, Ryszard Pozorek, Irena Skrzeczanowska[2], Krzysztof Sosnowski

Administration and support:

Anna Błaszczyk-Duda, Marek Budziszewski, Rafał Klęk, Agnieszka Maciejewska, Ewa Sobańska, Lidia Strzelczyk, Krystyna Szczepaniak, Sylwester Świecicki, Iwona Tomaszewska, Joanna Wasilewska, Wanda Wesoły, Andrzej Wiechowski, Katarzyna Włodarczyk[2]

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[1]till 30 September 2011
[2]part time
[3]on long term leave
[4]PhD student at the Institute of Experimental Physics, University of Warsaw
[5]PhD student at the Faculty of Physics, Warsaw University of Technology

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PAC members

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- Konrad Czerski (Institute of Physics, University of Szczecin; Physics Department, Technical University of Berlin)
- 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 (The A. Sołtan Institute for Nuclear Studies, Warszawa)
- Rainer Lieder (University of Bonn, Germany)
- Piotr Magierski (Faculty of Physics, Warsaw University of Technology)
- Leszek Próchniak (Maria Curie-Skłodowska University, Lublin)
- 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).

D.8 External participants of HIL experiments and HIL guests

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A.A. Amar	Kazakh National University, Almaty, Kazakhstan
J. Andrzejewski	University of Łódź, Poland
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D. Banaś	Holycross Cancer Centre, Kielce, Poland
D. Balabanski	Sofia University "St. Kliment Ohridski", Sofia, Bulgaria
A. Bezbach	Joint Institute for Nuclear Research, Dubna, Russia
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E. Herczyńska	Gdańsk University of Technology, Gdańsk, Poland
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