University of Warsaw

Heavy Ion Laboratory

Annual Report

2015

Warszawa, May 2016

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Annual Report of the
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The photo on the title page was taken
in front of the HIL building on 7 April 2016
by Michalina Komorowska

The editors thank Michalina Komorowska, Tomasz Marchlewski and Mateusz Sitarz
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Introduction

In 2015 our laboratory gained Transnational Access Facility status from the European Union for a period of four years beginning in 2016. This is a great success of the whole community of Polish nuclear physicists. Together with our consortium partner, the Cyclotron Centre Bronowice of IFJ PAN in Kraków, we form part of a network of the best European nuclear physics laboratories like GANIL, INFN, CERN-ISOLDE, the University of Jyväskylä, CNRS-ALTO, GSI, KVI and IFIN-HH. Transnational access means that we will be able to support our visitors by covering their research costs from the ENSAR2 project budget. ENSAR2 (European Nuclear Science and Application Research 2) is a common project of thirty European institutions within the HORIZON 2020 framework of the European Union. Here I would like to thank all our colleagues, and in particular the Management of the project with its coordinator, professor Mushin Harakeh, for the huge amount of dedicated work that has led to this success.

The number of scientific papers published in 2015 reached its highest value in the twenty-year history of our laboratory. This increasing trend is a very good sign for the coming (in 2018) ranking of Polish scientific institutions by the Ministry of Science and Higher Education of Poland (MNiSW). We believe that more papers and increasing international recognition will lead to the upgrade of our laboratory to group A, opening additional possibilities to acquire local, Polish funds. It something of a curiosity that our laboratory, with (at present) MNiSW grade B, stands among the best European nuclear physics facilities.

The number of papers published is related to the number of scientists employed so we are trying to enlarge our small group of physicists and radio-chemists. A new opportunity was created in 2015 by the Narodowe Centrum Nauki (the National Science Centre, an agency of MNiSW) with the POLONEZ programme, a funding programme addressed to incoming researchers who may apply for 12–24 month fellowships at host institutions in Poland. We received four applications from different countries and are crossing our fingers for their success. The results will be announced in mid-2016 and the fellowships will start from the 1$^{\text{st}}$ of September 2016.

After a successful edition in 2013, our laboratory was again the main organiser of the Mazurian Lakes Conference on Physics. This is one of the most prestigious nuclear physics conferences, organised in Poland every second year, with a tradition dating back to 1968. The conference gathered about 130 physicists from 19 countries, among them many young post-docs and PhD students.

According to the work-plan, in July 2015 our heavy ion cyclotron was shut down for external users for a period of about ten months. This time is devoted to the installation and commissioning of new RF amplifiers — a project funded by MNiSW. Because of the short experimental period, the number of beam-hours delivered to users in 2015 was relatively small. Nevertheless, several experiments were successfully performed, among them a series of experiments in June devoted to a study of the properties of nuclei using the method of Coulomb excitation.

Summarising, the Heavy Ion Laboratory from a small university centre twenty years ago is constantly evolving into an internationally recognised “user” laboratory, upgrading its experimental facilities and attracting scientists and ideas from all over the world.

Prof. Krzysztof Rusek, Director of HIL

Part A

Laboratory overview

A.1 General information

J. Choiński, P. Napiorkowski and K. Rusek

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 two cyclotrons: a K=160 U-200P heavy-ion cyclotron and a GE PETtrace K=16.5 commercial cyclotron delivering high intensity proton and deuteron beams.

The first beam was extracted in 1994 and since that time HIL has been an effective "user facility", serving up to the present time several hundred 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. The only criteria are the scientific merit of the project and its technical feasibility. The research programme is mostly focused on nuclear physics and its medical applications including a production of radio-isotopes.

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

Since 2012 an important part of HIL has been the Radiopharmaceuticals Production and Research Centre focused on the production of and research into Positron Emission Tomography radiopharmaceuticals. The production of the longer-lived radioisotopes for life-sciences applications is also foreseen.

A.2 Cyclotron operation in 2015 and tasks carried out in order to improve the cyclotron infrastructure and efficiency

J. Choiński, P. Gmaj, A. Bednarek, T. Bracha, A. Górecki, A. Jakubowski, P. Jasiński, W. Kalisiewicz, M. Kopka, W. Kozaczka, P. Krysiak, K. Łabęda, K. Makowski, I. Mazur, J. Miszczak, Z. Morozowicz, B. Paprzycki, K. Pietrzak, B. Radomyski, O. Saeed Mohamed Nassar, K. Sosnowski, Ł. Standyło, K. Sudlitz, J. Sura

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Operation

Availability of the U-200P cyclotron for experiments in 2015 was significantly reduced due to preparations for the replacement of the RF amplifiers (see Fig. 1). In connection with this fact, the cyclotron was only available in the first half of 2015 and the total annual number of experimental hours was left at the level of the year 2014 when the major upgrade of the central region was conducted. The series of upgrades mean that this lowered cyclotron availability will continue also in 2016, when the new RF amplifiers will be installed and commissioned.

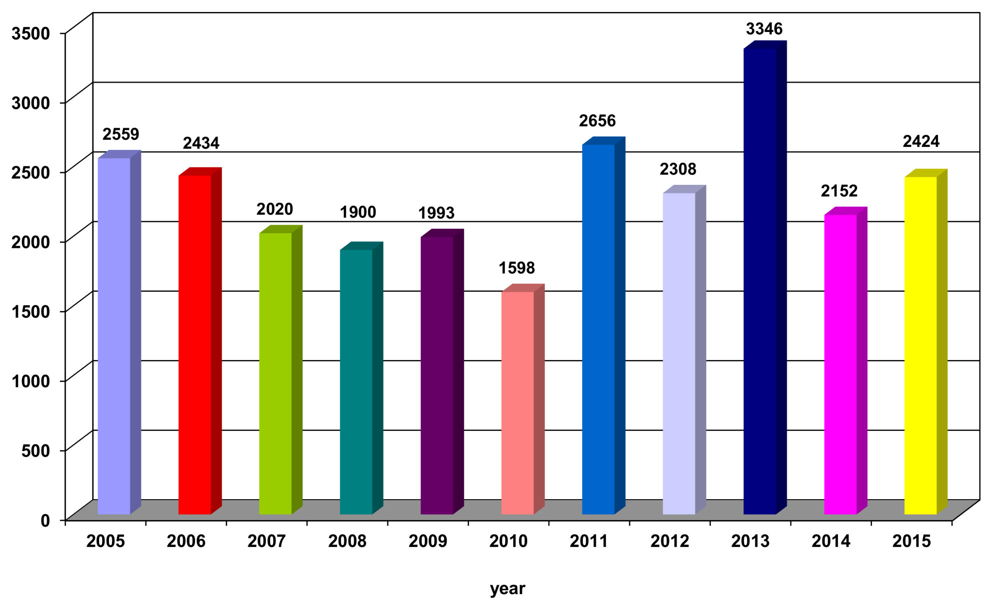

Figure 1: Total cyclotron beam time in the years 2005–2015.

The monthly distribution of beam time in 2015 is presented in Fig. 2. From August to November the cyclotron was shut down. In December beam time was dedicated to maintenance work only.

As in the previous few years, the main topics of the experiments were related to nuclear physics research, biological and medical research, wherein the beam time intended for medical-biological experiments and is growing from year to year. This also includes medical radioisotope production, for example ^{211}At, ^{43}Sc, ^{44}Sc, ^{72}Se or ^{72}As, in collaboration with the Institute of Nuclear Chemistry and Technology and the Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences. As the production of

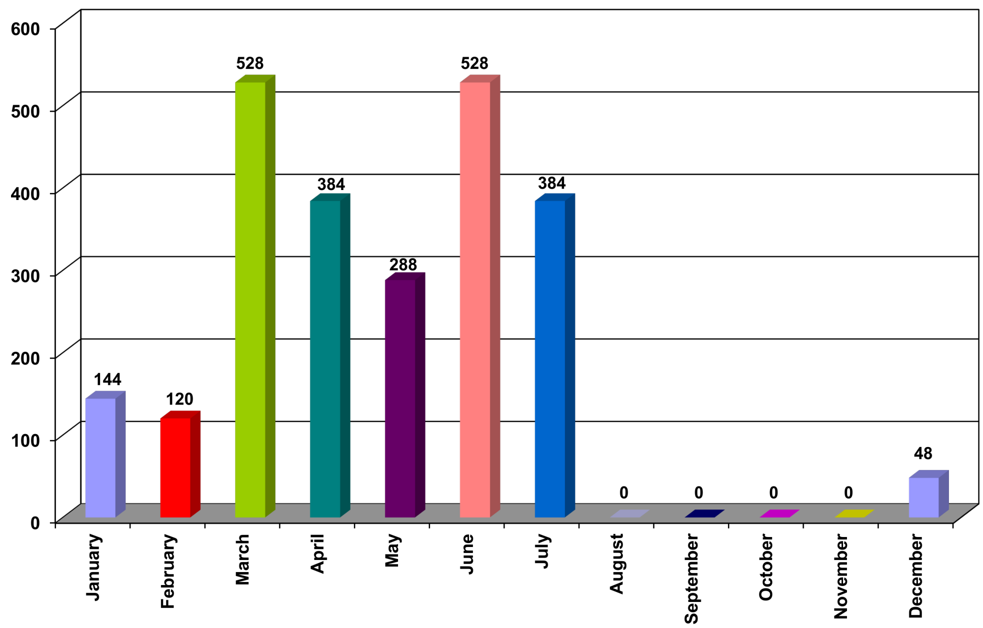

Figure 2: Beam time distribution (hours) in 2015 per month.

medical isotopes requires higher than currently available beam intensities, in 2015 work began on adjusting the cyclotron magnetic field. For the same reason, a large part of the beam time was devoted to work on the development of the structure of the cyclotron and beam tests. Due to the significantly smaller availability of the cyclotron in 2015, student projects at the annual workshop were conducted without beam. The diversity of the experiments performed during 2015 is illustrated in Fig. 3.

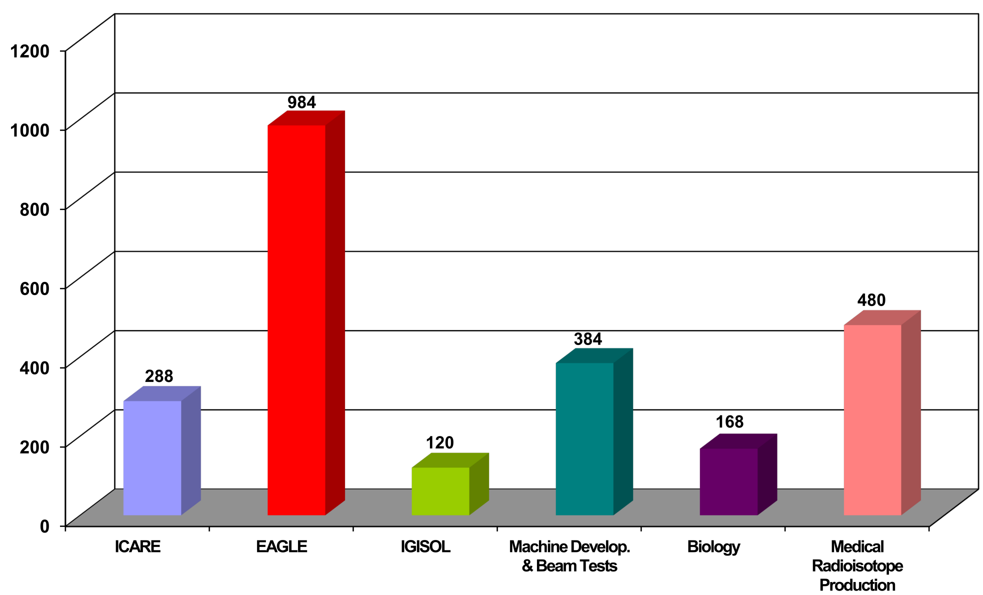

Figure 3: Distribution of beam-time (in hours) among different experimental setups.

Figure 4 illustrates the number of scientists using specific experimental frameworks. Detailed descriptions of the experimental setups available at HIL can be found on the laboratory web page: www.slcj.uw.edu.pl.

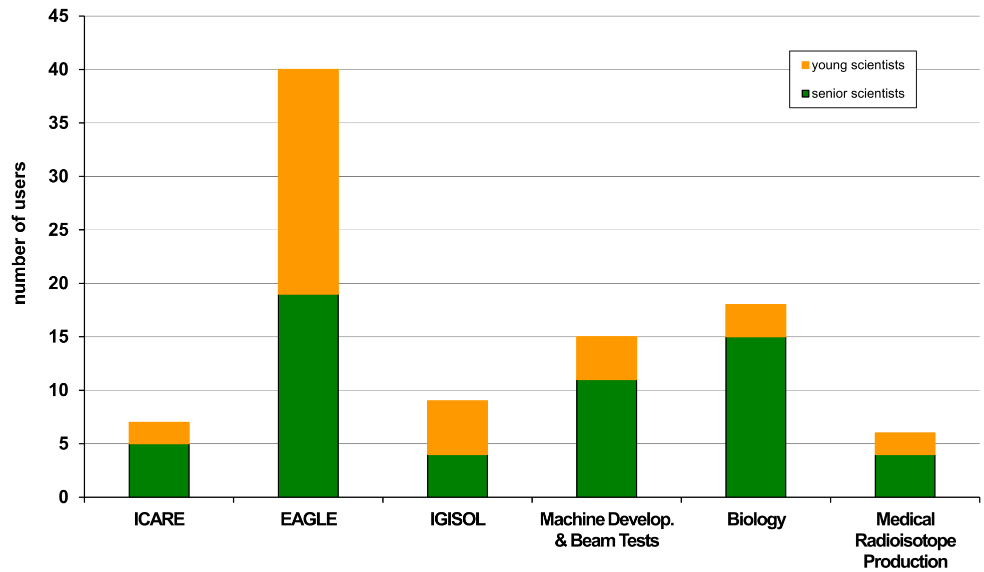

Figure 4: Number of users of the Warsaw cyclotron beams in 2015.

A list of the experiments performed in 2014 is presented in Appendix D.1 of this Annual Report.

Maintenance and development

ECR Source

Due to demand from users, the cyclotron team worked on expanding the list of available beams, in particular on the preparation of beams of metallic ions, such as Mg, Ni and Ca. These types of ions are obtained in an ECR ion source using special methods and devices, like a vapourising oven, sputtering system or the MIVOC method, all of them usually combined with a thin liner in the plasma chamber. In 2015 we made many attempts to achieve this type of beam in our Supernanogan-ECR using an oven and the plasma chamber screened with a tantalum liner. Tests were successful for a Mg beam. Other metallic beams had too small intensity. Therefore, it is important to study processes occurring in the plasma chamber to increase the efficiency of the ion source. For this purpose, in 2015, a special ECR test bench was designed and installed at HIL. It is specially dedicated to research on the ECR source efficiency. This bench was partially financed by NCBiR within the scope of the EMILI-EURISOL project, grant no. ERA-NET-NUPNET/02/12, and its purpose is to achieve the higher ion currents and longer uninterrupted operation of the source which are necessary for experiments.

RF system

The currently used RF amplifiers have come to the end of their days as they are already more than 30 years old. In particular, spare parts are no longer available. This concerns mainly such important components as GK-11A power tubes, T-16 thyristors. Therefore, in 2014 and 2015 the winners of three tenders for three stages of the new RF system were selected. The first stage (Comtech — RDE) was delivered on time, but realisation of the second and the third stage is delayed. The second stage amplifiers (System Engineering Solutions S.r.l.) were delivered, tested and returned to the manufacturer for repairing and adjusting to the tender requirements. The delivery of the third, power stage amplifiers (Popek Elektronik) is delayed and will possibly be completed in May 2016.

Due to the manufacturers' delays, the commissioning of the new RF system is currently planned for autumn 2016. In September 2015 the modernisation of the RF room and a new ventilation system was commissioned to be ready for the accommodation of the new RF amplifiers.

Power infrastructure

In addition to the normal maintenance resulting from wear and tear, some new energy nodes and power line modernisation were accomplished in 2015. Several new electrical installations were made. Some of them were strictly dedicated to the project of replacement of the RF amplifiers. The main modernisations are the following:

- Lighting replacement in the Cyclotron hall and RF amplifiers room with energy-efficient LEDs.
- Construction of new electric switchgear and power installation for the new RF amplifiers.
- Installation of the power switchboard for switching power between the old and new RF amplifiers.
- Modernisation of the power supply for the new ventilation system in the RF amplifiers room and the cyclotron hall.
- Power and lighting installations for the Isotope Laboratory in HIL.

Future projects

Focusing spiral inflector

In the next year we plan to replace the cyclotron inflector with a focusing one. Since the inflector affects the total beam transmission, we expect some improvements of the beam intensity at the level of 15%.

ECR and EMILIE project

At the end of 2015, the European ERANET NUPNET EMILIE project was completed with the commissioning of the ECR test bench. This bench was built with the purpose of increasing our knowledge and practices concerning ion sources of the ECR type. It solves the problem related to the competition between the time spent on research experiments (the role of the service) and the time needed for experiments bound up with the development of the cyclotron. This test stand will also model phenomena occurring when a +1 ion is injected into the charge breeder and then passes the plasma. It will also be used for studying experimentally some aspects of the charge breeder design.

New power supplies (beam line active elements)

The strategy of changing all the control system interfaces to one platform (LabView) was continued in 2015 by writing new control drivers for amplifiers in use. The aim is to make a homogeneous control environment. This strategy will continue in the next years by adopting the LabView platform where possible. This approach is improving significantly and will further improve the reliability of the cyclotron operation.

RF system

Up to the end of 2016 it is planned to replace the outdated amplifiers supplying the accelerating structure of the U-200P cycloatron with new ones. The new RF system will be commissioned in the middle of 2016 due to the above mentioned manufacturers' delay, which is six months later then previously predicted.

Power infrastructure

The power infrastructure will continue to be developed to adapt it to the new requirements resulting from the renewal of the power supply and control system, development of the ECR research bench and replacement of the RF amplifiers.

Magnetic structure of the U-200P cyclotron

The old, malfunctioning system for lifting the upper part of the cyclotron was replaced with a new one which is intended to allow for much faster operations. This change was needed before we could proceed to the measurement of the magnetic field, which in turn is necessary to improve the transmission of the accelerated ion beams. In 2014 a large program of collaboration with JINR FLNR was prepared and approved which will lead to a general reconstruction of the magnetic field. The project began in 2015 with designing the magnetic measurement system.

Vacuum system

The vacuum system has been gradually renewed since 2013 but it still needs some investment to replace the old vacuum pumps on the cyclotron and the beam lines. Three main cryogenic pumps of the cyclotron vacuum chamber are to be replaced in 2016.

A.3 Status of the Radiopharmaceuticals Production and Research Centre

J. Choiński, K. Kilian, J. Jastrzębski, M. Kopka, I. Mazur, M. Pęgier, R. Tańczyk

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The Radiopharmaceuticals Production and Research Centre (RPRC) is an integral part of the Heavy Ion Laboratory of the University of Warsaw. The Centre operates a 16.5 MeV proton and 8.4 MeV deuteron GE PETtrace cyclotron, six hot cells, six automatic synthesis and two dispensing units and quality control equipment. These devices are intended to produce commercial radiopharmaceuticals based on ^{18}F (Fluorodeoxyglucose, FDG) and research radiopharmaceuticals based on ^{18}F but also on ^{11}C and ^{15}O radioisotopes.

A dedicated line for FDG production, situated in Laboratory no. 1, operates under GMP conditions and is used on a daily basis. Currently, this part of the RPRC for commercial activity is leased to an external operator. The remaining equipment is located in Laboratory no. 2 and also operates under GMP conditions. This laboratory plays the role of our R&D lab. In 2015 we used it, for example, for ^{11}C-methionine pilot production. We currently have two operative grants: ALTECH, agreement no. PBS1/A9/2/2012, and PET-SKAND, agreement no. PBS3/A9/28/2015. Both of them are based on the cyclotron with its external, well cooled, target holder. During the reported period we have carried out many irradiations of target materials. In order to extend our research potential adaptation of existing rooms has been done. As a result, currently, we have gained a new class II laboratory. It will be used for installation of QC equipment soon.

In cooperation with the Collegium Medicum of the Jagiellonian University, studies of synthesis and applications of ^{18}F-MISO were conducted. The produced radiopharmaceuticals were applied in hypoxia studies in Lewis Lung Carcinoma animal models.

In 2015 4 BSc and 1 MSc thesis were supervised by RPRC staff and the experimental parts were realised in the Centre.

A.4 The Beam Chopper

M. Sobolewski, J. Miszczak, Z. Kruszyński

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The 80 Watt High Voltage power supply, planned for 2015 [1], was successfully built and tested. Also RF switches were redesigned in 2015. One is intended for more or less symmetric beam-on/beam-off waveform i.e. 5 RF periods of beam-on time and 6 RF periods of beam-off time. Both on and off times can be independently adjusted for ± 1 RF period. The second RF switch is capable of working with beam-on time from 1 to 4 RF periods, but its shortest beam-off time is 7 RF periods (and up to 20 RF periods).

After a few unsuccessful attempts the chopper was successfully operated with $^{20}Ne^{+3}$ beam: during the off time the beam was suppressed to barely measurable levels, while during the on time the beam was not attenuated, and the on/off transitions were clean (no partially suppressed beam pulses).

The cyclotron was shut down for maintenance and upgrades in mid July, so no further testing was possible in 2015.

Bibliography

[1] M. Sobolewski, J. Miszczak, Z. Kruszyński, HIL Annual Report 2014, page 19

A.5 Maintenance of the HPGe detectors used in experiments with EAGLE

T. Abraham[1], M. Kisieliński[1,2], J. Srebrny[1], M. Kowalczyk[1,3], A. Pietrzak[1], A. Jakubowski[1], M. Antczak[1]

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High Purity Germanium (HPGe) detectors are the most important ingredients of the central European Array for Gamma Levels Evaluations (EAGLE) set-up [1,2]. The Heavy Ion Laboratory (HIL) owns 19 HPGe detectors and 16 Anti Compton Shields (ACS). One of these detectors remains at the Institute of Nuclear Physics of the Polish Academy of Science in Krakow as part of a colaboration. The 18 detectors are used together with ACSs which reduces the number of the detectors which may be used at the same time in experiments to 16. The remaining detectors are a reserve.

In 2015, 18 detectors were used in experiments with beams of the U200-P cyclotron. Many of the detectors suffered neutron damage during these experiments and their properties needed to be restored by a process of regeneration. This process was applied 18 times: 10 detectors were processed once and 4 detectors were regenerated twice in 2015.

Table 1 shows the difference between the Full Width at Half Maximum (FWHM) measured for the 1333 keV γ-ray of a ^{60}Co source in the "test room" in 2014 and the same value measured in 2015. The FWHM is a measure of the energy resolution of the detector and it is desirable to obtain as small value as possible. One may note that the differences are very small and the overall performance of the detectors remained unchanged between 2014 and 2015.

The detectors owned by HIL are not the only detectors used in the EAGLE project. In previous years detectors from GAMMAPOOL were used [3]. GAMMAPOOL lent 20 detectors with 15 ACS for a campaign of experiments from 2011 to 2013. During the campaign several successful experiments were carried out. The outcome of this series of experiments encouraged us to apply again to GAMMAPOOL for the detectors to be used in 2017.

In 2015 the GAMMAPOOL Committee was concerned about the state of the detectors in the pool as reports suggested that only one third of them were operational. These concerns inspired the EAGLE team to act towards restoring the full capacity of the detectors. In November our expert visited the R&D detector laboratory at IPN-Orsay as part of a collaboration with GAMMAPOOL. The purpose of this visit was to assess the state of the GAMMAPOOL germanium detectors before using them in experiments at HIL in 2017. After inspection, it was discovered that out of the 8 detectors considered as damaged or malfunctioning only 1 was seriously impaired. Thus HIL will obtain 15 working germanium detectors at the beginning of 2017, not 7 detectors, as was stated before this assessment.

Table 1: Comparison of FWHM in keV at an energy of 1333 keV for a ^{60}Co source obtained in the test room in 2014 and 2015.

No	Detector number	FWHM 2014	FWHM 2015
1	1	2.2	2.4
2	2	2.3	2.3
3	3	2.2	2.1
4	4	2.3	2.2
5	5	2.1	2.3
6	6	2.5	2.6
7	8	2.6	2.6
8	21	2.4	2.5
9	22	2.8	2.6
10	23	1.9	2.1
11	31	2.4	2.4
12	42	2.2	2.2
13	43	2.2	2.3
14	44	2.5	2.7
15	45	2.6	2.5
16	51	2.1	2.2
17	52	2.5	2.1
18	54	2.1	2.3

Bibliography

[1] J. Mierzejewski *et al.*, Nucl. Inst. and Meth. **A659** (2011) 84

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

[3] T. Abraham *et al.*, HIL Annual Report 2013, page 20

A.6 XXXIV Mazurian Lakes Conference on Physics Frontiers in Nuclear Physics

C. Mazzocchi[1], *K. Rusek*[2], *K. Rykaczewski*[3], *M. Zielińska*[4]

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4) IRFU/SPhN, CEA Saclay, Gif-sur-Yvette, France

The conference was held in Piaski, Poland, from 6th till 13th September 2015. The programme covered a broad range of topics: fission and neutron rich nuclei, superheavy elements, nuclear reactions from keV to GeV, nuclear structure and nucleosynthesis, facilities and experimental techniques, applications of nuclear science. It was organised and sponsored by the University of Warsaw, the National Centre for Nuclear Research and the Pro-Physica Foundation. As two years ago, the conference was chaired by Krzysztof Rusek (HIL Warsaw) and Krzysztof Rykaczewski (ORNL Oak Ridge).

The continued interest in the Mazurian meetings organised regularly every second year resulted in about 130 physicists from 19 countries, including many PhD students and young post-docs, travelling to Piaski. They presented and listened to nearly 90 talks and participated in a lively poster session with over 30 posters on display.

There were two international scientific awards presented at the conference. The Zdzislaw Szymanski prize was awarded to Alexandra Gade of MSU (Lansing, USA) "in recognition of her leadership in the exploration of the structure of exotic nuclei at the extremes of neutron to proton ratio and, in particular for her seminal studies of spectroscopic factors in nuclei far from the valley of nuclear stability". The Tomek Czosnyka award was presented to Nigel Warr of the University of Koeln (Germany) who shared with the conference participants his view on "The resurgence of Coulomb excitation".

The social activities of the conference were aided by very good weather and by a large amount of young participants. The scientific discussions could be continued during outdoor activities like kayaking, canoeing, cycling and of course sailing on the Beldany lake. The traditional Regatta was won by Michał Warda and his team from the UMCS Lublin (Poland).

The next Mazurian Lakes Conference on Physics will be held at the beginning of September 2017, of course in the Mazurian Lakes District!

A.7 Polish Workshop on the Acceleration and Applications of Heavy Ions

P.J. Napiorkowski[1], *A. Trzcińska*[1], *T. Abraham*[1], *P. Gmaj*[1], *M. Komorowska*[1,2], *M. Kowalczyk*[1,2], *U. Kaźmierczak*[1], *K. Kilian*[1], *T. Marchlewski*[1,2] *M. Palacz*[1], *K. Rusek*[1], *O. Saeed Mohamed Nassar*[1], *M. Sitarz*[1] *A. Stolarz*[1], *Z. Szefliński*[1], *R. Tańczyk*[1], *M. Wolińska-Cichocka*[1]

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The Workshop on the Acceleration and Applications of Heavy Ions has been organised annually at HIL since 2005. It is intended for students of first cycle studies interested in nuclear physics, and offers them a unique opportunity to gain experience in methods of data acquisition and analysis, in operating the cyclotron including beam diagnostics measurements, and in charged particle and γ-ray detection techniques. Medical applications of nuclear physics have also been included in the programme of the Workshop.

In 2015 the cyclotron was not operational during the Workshop and experiments for students had to be performed without beam. The number of students attending the lectures and the practical training was limited to 15. The largest group of 6 persons came from the Poznań University of Technology. There were also 4 students from the University of Warsaw, 3 from the Warsaw University of Technology, as well as one from the University of Łódź and one from the Gdańsk University of Technology.

The programme of lectures was as follows:

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

Students took part in the following experimental tasks:

- Beam focusing in heavy ion acceleration;
- Identification of excited bands in gamma-gamma coincidences — gamma spectroscopy with the EAGLE setup;
- Target production and measurement of their thickness;
- Measurement of ^{137}Cs activity in environmental samples;
- Gamma camera image reconstruction.

As usual, the Workshop was completed by the session of student presentations.

Part B

Research for medical and biological applications

B.1 Production of and research on medical radioisotopes at the Heavy Ion Laboratory, University of Warsaw.

J. Jastrzębski[1], *J.Choiński*[1], *A. Jakubowski*[1], *M. Sitarz*[1,2], *A. Stolarz*[1], *K. Szkliniarz*[3], *A. Trzcińska*[1], *W. Zipper*[3]

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Two charged particle accelerators are currently in operation at the Heavy Ion Laboratory, University of Warsaw (HIL UW): a $K = 160$ isochronous cyclotron accelerating gaseous ions from He to Ar to energies from 2 to 10 MeV/nucleon and a high current medical p/d cyclotron, accelerating protons to an energy of 16 MeV and deuterons to an energy of 8 MeV. The alpha particle beam from the isochronous cyclotron and protons and deuterons from the medical cyclotron are currently used to produce research quantities of therapeutic and diagnostic radioisotopes. Occasionally, the C30 proton cyclotron at the National Centre for Nuclear Research, Świerk, is also employed.

The present research programme includes the production of the Targeted Alpha Therapy isotope ^{211}At, the prospective PET radioisotopes ^{43}Sc, ^{44}Sc and ^{44m}Sc and the positron generator ^{72}Se/^{72}As. An important research branch is also devoted to the accelerator production method of the most popular nuclear medicine radioisotope, ^{99m}Tc (an alternative way to the classical reactor route via the ^{99}Mo generator). The research on accelerator produced medical radioisotopes based on the HIL cyclotrons is conducted within a large collaboration, involving the Heavy Ion Laboratory, the University of Silesia, the Institute of Nuclear Chemistry and Technology (INCT), POLATOM at the National Centre for Nuclear Research, the Centre of Biological and Chemical Research of the University of Warsaw and the Institute of Nuclear Physics in Kraków. After target preparation and irradiation the properties of the produced radioisotopes are first investigated at HIL via gamma-ray spectroscopy techniques and subsequently transported to INCT or POLATOM for further chemical investigations. Some of the results obtained are shown in Table 1. Part of them are presented in more detail in the following contributions to this Annual Report.

This research was supported by the Polish Funding Agency NCBiR grants ALTECH and PET-SCAND. Discussion with and suggestions from Aleksander Bilewicz are greatly appreciated. Our thanks are also due to Jola Wojtkowska and Maciek Kisieliński for their help in the proton irradiations at Świerk.

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[1] K. Szkliniarz *et al.*, Acta Phys. Pol. **A127** (2015) 1471

[2] K. Szkliniarz *et al.*, *submitted to Applied Radiation and Isotopes*

[3] *From HIL unpublished data.*

Table 1: Investigated radioisotopes

Isotope	Target	Beam particle and energy (MeV)	TTY* (MBq/μAh)	Comments
^{211}At	^{209}Bi	α 29	37(6)	[1]
^{72}Se ^{72}As	$^{nat}GeO_2$	α 30	0.19(3) 2.7(1)	[1]
^{43}Sc	$^{nat}CaCO_3$	α 20	84(4)	[2]
^{44g}Sc ^{44m}Sc	$^{nat}CaCO_3$ (95.9%)	α 29	44(7) 4.7(8)	[2]
^{99m}Tc	^{100}Mo (99.815%)	p 16 p 25	382(25) 820(31)	[3]
^{98}Mo		p 16 p 25	2.3(6) 25(3)	[3]
^{43}Sc	$^{42}CaCO_3$ (68%)	d 7.6	26(5)	[3]
^{44g}Sc ^{44m}Sc	$^{nat}CaCO_3$	p 15.8	18.3(8) 0.094(5)	[3]

* Thick Target Yield

B.2 Accelerator Production of ^{99m}Tc

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Research on the possibilities of the accelerator production of the most popular medical diagnostic radioisotope ^{99m}Tc is presently conducted in a number of laboratories all around the world. In Warsaw two research proposals related to this subject were concluded in 2015: the ALTECH proposal ("Alternative Methods of ^{99m}Tc Production", NCBiR grant), and the IAEA Coordinated Research Project ("Accelerator-based Alternatives to Non-HEU Production of ^{99}Mo/^{99m}Tc"). HIL participated in these two projects, lead by the principal investigator POLATOM at the National Centre for Nuclear Research in Świerk. In this contribution we present the final results of our Laboratory research related to the investigation of the production efficiency and isotopic purity of the proton induced formation of the ^{99m}Tc radionuclide via the ^{100}Mo(p,2n)^{99m}Tc reaction.

The experiments were performed using two cyclotrons: the PETtrace machine operating at HIL [1] and equipped with an external irradiation beam line [2] and the home–made C-30 cyclotron operating in Świerk. The maximum PETtrace proton energy is 16.5 MeV whereas the C-30 machine can reach energies up to about 27 MeV. Tables 1–4 and Figures 1 and 2 summarise the experimental conditions and results.

Table 1: Isotopic composition of the targets employed.

	^{100}Mo(%)	^{98}Mo(%)	^{97}Mo(%)	^{96}Mo(%)	^{95}Mo(%)	^{94}Mo(%)	^{92}Mo(%)
^{nat}Mo	9.63	24.13	9.55	16.68	15.92	9.25	14.84
^{100}Mo	99.05	0.54	0.07	0.11	0.1	0.05	0.08
^{100}Mo	99.815	0.17	0.003	0.003	0.003	0.003	0.003

Table 2: Experimental values of the Thick Target Yield (TTY) and Saturation Yield (SY) of the ^{99m}Tc and ^{100}Mo produced in the ^{100}Mo target with the highest available enrichment.

Radio-isotope	Target chemical form	Proton energy range (MeV)	Direct TTY (MBq/μAh) (a)	Direct and indirect TTY (MBq/μAh)	Direct SY (MBq/μA)
^{99m}Tc	^{100}Mo (99.815 %)	16-8	381(20)	382(25)	3300(180)
		25-8	817(32)	820(31)	7080(280)
		26-8	865(30)	874(33)	7500(260)
^{99}Mo	^{100}Mo (99.815 %)	16-8	2.3(6)	-	210(50)
		25-8	25(3)	-	2380(290)
		26-8	31(4)	-	2950(380)

(a) The ^{99}Mo contribution to the measured ^{99m}Tc activity during and after irradiation was subtracted.

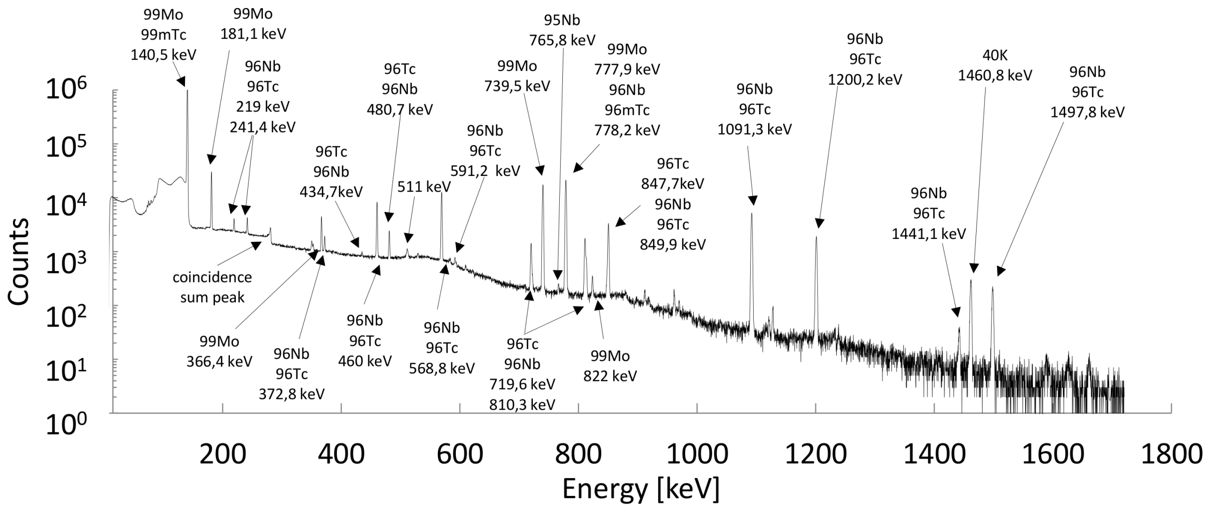

Figure 1: Gamma-ray spectrum of the highly enriched ^{100}Mo sample, irradiated during 6 h with a 25.8 MeV proton beam and collected during 1.3 h, 18 h after EOB (End Of Bombardment).

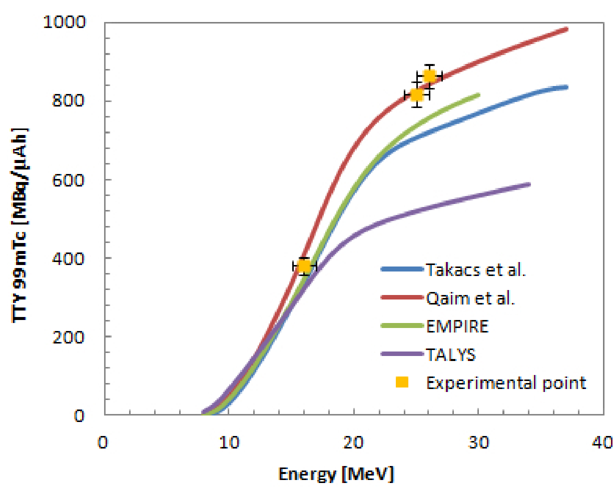

Figure 2: Comparison of the experimental data from Table 1 with the TTY values calculated using the cross-sections obtained from the EMPIRE [3] and TALYS [4] evaporation codes and the recommended cross section values from Ref. [5, 6].

Conclusions

The efficiency of the ^{99m}Tc radioisotope production should depend on the ratio of ^{99m}Tc nuclei produced in a given irradiation to the number of other Tc nuclei produced. For the highest energy employed in this investigation the number of ^{99m}Tc nuclei produced seems to be only 15% (EMPIRE code) or even 13 % (TALYS code) in comparison to all other Tc nuclei produced. This is 35% (or 43%) lower than for bombarding energy of 16 MeV. However, at 26 MeV bombarding energy the production yield of ^{99m}Tc is about 2.2 times larger than at 16 MeV, which can largely compensate this decrease. The experimental verification of these conclusions would need the availability of a proton beam of about 30 MeV energy and a beam intensity of at least a few µA.

Table 3: Measured and calculated relative number of atoms of Tc isotopes during the proton bombardment of highly enriched ^{100}Mo target. The calculated values (in italics) are obtained from the evaporation code EMPIRE [3] and, for ^{99g}Tc, from Ref. [7].

Isotope	Half-life $T_{1/2}$	EOB 99.815% 16–8 MeV	EOB 99.815% 26–8 MeV	6h 99.815% 16–8 MeV	6h 99.815% 26–8 MeV
^{99m}Tc	6.01 h	100	100	100	100
^{101}Tc	14.02 min	$4.2 \cdot 10^{-2}$	$5.5 \cdot 10^{-2}$	$1.6 \cdot 10^{-9}$	$2.0 \cdot 10^{-9}$
^{99g}Tc	$2.11 \cdot 10^{5}$ y	431	477	953	1010
^{98}Tc	$4.2 \cdot 10^{6}$ y	*0.4*	*208*	*0.8*	*400*
^{97}Tc	$2.6 \cdot 10^{6}$ y	*0.5*	*1.0*	*1.0*	*1.8*
^{97m}Tc	90 d	0.2	0.2	0.4	0.4
^{96}Tc	4.28 d	$1.4 \cdot 10^{-2}$	$9.0 \cdot 10^{-2}$	$2.8 \cdot 10^{-2}$	0.2
^{96m}Tc	51.5 min	$\mathit{7.0 \cdot 10^{-4}}$	$\mathit{4.9 \cdot 10^{-3}}$	$\mathit{1.1 \cdot 10^{-5}}$	$\mathit{7.4 \cdot 10^{-5}}$
^{95}Tc	20 h	$\mathit{1.2 \cdot 10^{-2}}$	$\mathit{1.7 \cdot 10^{-2}}$	$\mathit{2.0 \cdot 10^{-2}}$	$\mathit{2.7 \cdot 10^{-2}}$
^{95m}Tc	61 d	$2.7 \cdot 10^{-3}$	$\mathit{5.0 \cdot 10^{-3}}$	$5.4 \cdot 10^{-3}$	$\mathit{9.6 \cdot 10^{-3}}$
^{94}Tc	293 min	$\mathit{8.8 \cdot 10^{-3}}$	$\mathit{1.1 \cdot 10^{-2}}$	$\mathit{7.4 \cdot 10^{-3}}$	$\mathit{9.1 \cdot 10^{-3}}$
^{94m}Tc	52 min	$\mathit{7.8 \cdot 10^{-4}}$	$\mathit{6.9 \cdot 10^{-4}}$	$\mathit{1.3 \cdot 10^{-5}}$	$\mathit{1.1 \cdot 10^{-5}}$
^{93}Tc	2.75 h	$\mathit{6.8 \cdot 10^{-4}}$	$\mathit{5.1 \cdot 10^{-3}}$	$\mathit{3.1 \cdot 10^{-4}}$	$\mathit{2.3 \cdot 10^{-3}}$
^{93m}Tc	43.5 min	$\mathit{3.3 \cdot 10^{-5}}$	$\mathit{2.4 \cdot 10^{-4}}$	$\mathit{2.1 \cdot 10^{-7}}$	$\mathit{1.5 \cdot 10^{-6}}$

Table 4: The relative number of ^{99m}Tc nuclei compared to all Tc nuclei produced during a 6h irradiation of a highly enriched ^{100}Mo target. The quoted results are, for the ^{99m}Tc from the present experimental data, for the ^{99g}Tc from Ref. [7] and for other Tc isotopes from a calculation using the EMPIRE [3] and TALYS [4] evaporation codes.

Code	16–8 MeV	26–8 MeV	16–8 MeV	26–8 MeV
EMPIRE	0.23	0.15	0.105	0.071
TALYS	0.23	0.13	0.105	0.065

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B.3 Alpha-particle and deuteron production of the diagnostic positron emitter ^{43}Sc

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Recently there has been steadily growing interest in the medical applications of Sc radioisotopes. The longer half-life of the scandium β^+ emitters, ^{44g}Sc and ^{43}Sc ($T_{1/2}$ = 3.97 h and $T_{1/2}$ = 3.89 h, respectively), compared to that of other PET radioisotopes like ^{18}F ($T_{1/2}$ = 109.8 min), ^{68}Ga ($T_{1/2}$ = 67.7 min), ^{60}Cu ($T_{1/2}$ = 23.7 min), ^{11}C ($T_{1/2}$ = 20.3 min), ^{13}N ($T_{1/2}$ = 10.0 min), ^{15}O ($T_{1/2}$ = 122.2 s), potentially permits their regional distribution following production at a single central cyclotron facility.

The ^{nat}Ca element contains 96.9% of the ^{40}Ca isotope. Therefore, it may constitute a convenient production method for the ^{43}Sc radioisotope via the (α,p) and (α,n) reactions, the latter leading to the very short lived ^{43}Ti ($T_{1/2}$ = 0.5 s), forming almost immediately ^{43}Sc. The possibility of the formation of ^{43}Sc using the natural element is, evidently, a very attractive choice for ^{43}Sc production due to the low cost of the irradiated material.

The deuteron route needs the enriched ^{42}Ca isotope on which the (d,n) reaction leads to ^{43}Sc. In this communication we give some details related to ^{43}Sc production using alpha particle and deuteron beams from two accelerators operating at the Heavy Ion Laboratory. Table 1 below summarises the data obtained till now for these two projectiles, also illustrated in Figures 1 and 2. Figure 3 shows the deduced evolution in time of the relative activities of Sc radioisotopes.

Table 1: Thick Target Yield (TTY), Target Yield (TY) and Saturation Yield (SY) of ^{43}Sc radioisotopes produced by alpha particle and deuteron beams.

Projectile	Target chemical form	Energy range (MeV)	TTY or TY (MBq/μAh)	SY (MBq/μA)
α	$^{nat}CaCO_3$	29–0	110(20)	620(110)
		27–0	92(10)	530(60)
		24–0	95(7)	540(40)
		20.4–0	78(8)	450(50)
		20–0	84(4)	470(20)
	^{met}Ca	29–0	240(20)	1350(100)
		20–0	190(30)	1100(170)
	$^{40}CaCO_3$	20–0	88(13)	490(70)
	^{nat}KCl	29–19	4.2(6)	24(3)
d	$^{42}CaCO_3$ (68%)	6.8- 0	26(5)	144(30)

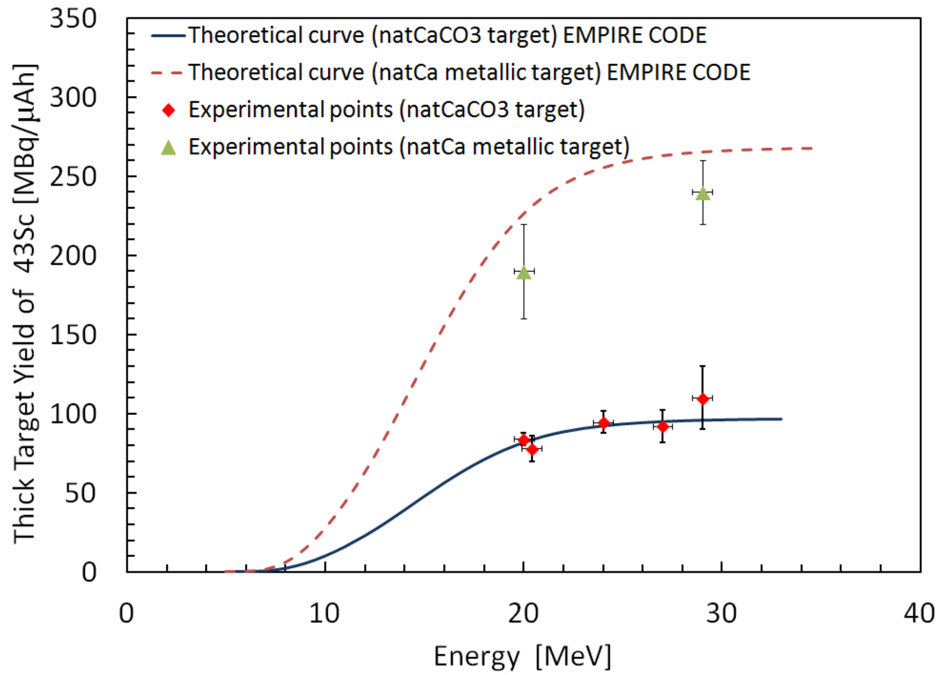

Figure 1: Comparison of the experimental and theoretical Thick Target Yield (TTY) for the production of the ^{43}Sc radioisotope by an alpha particle beam incident on $^{nat}CaCO_3$ and metallic ^{nat}Ca targets. The cross sections are calculated with the EMPIRE code [1] and the stopping powers using the SRIM code [2].

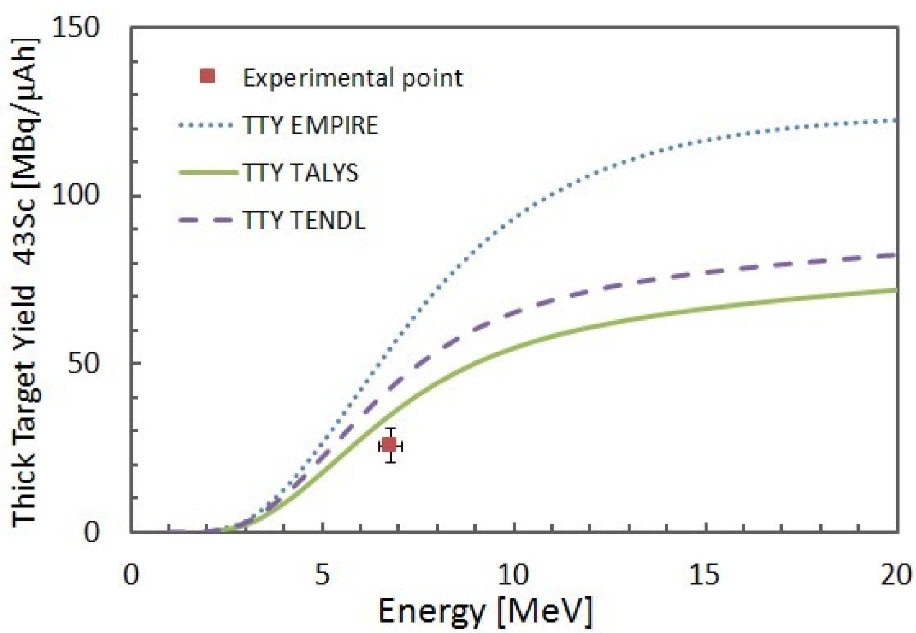

Figure 2: Comparison of the experimental and theoretical Thick Target Yield (TTY) for the production of the ^{43}Sc radioisotope by a deuteron beam incident on $^{42}CaCO_3$ target. The cross sections used for the Thick Target Yield calculations are from the EMPIRE code, TALYS code [3] and TENDL data [4].

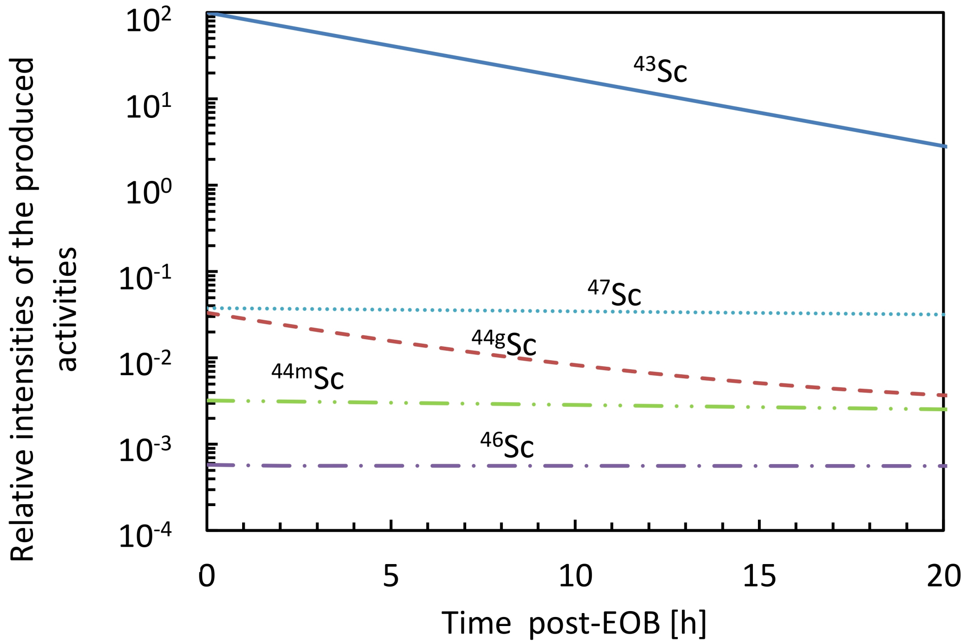

Figure 3: Evolution in time of the relative intensities of Sc radioisotopes produced during a 4 h irradiation of a $^{nat}CaCO_3$ target with a 20 MeV α-particle beam. A similar plot (not shown) for a $^{40}CaCO_3$ (99.99%) target shows only the ^{43}Sc activity, with impurities below 1.5×10^{-5} % at 20 h after EOB.

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B.4 Alpha–particle and proton production of the diagnostic positron emitter isomeric pair ^{44g}Sc and ^{44m}Sc

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Production of the two isomers of the ^{44}Sc radioisotope was investigated using 68% enriched $^{42}CaCO_3$ and ^{nat}KCl target material (alpha particles) and a $^{nat}CaCO_3$ target (protons). Figure 1 shows the corresponding level scheme of this pair.

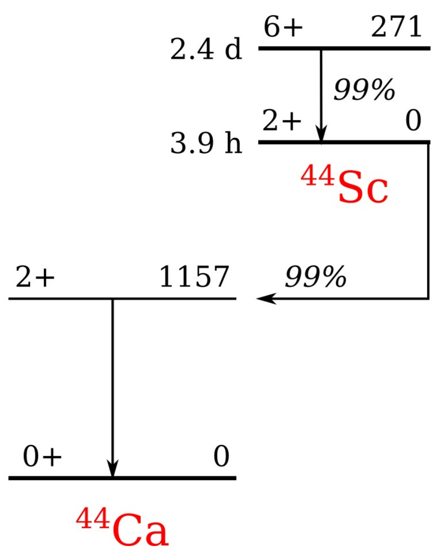

Figure 1: Decay scheme of ^{44}Sc.

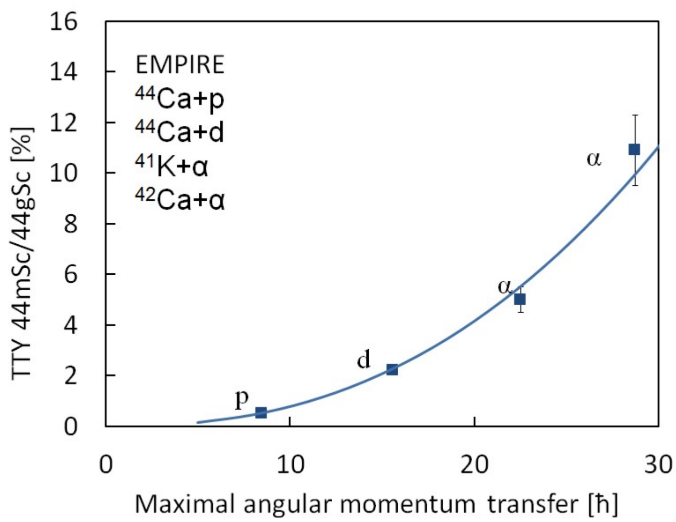

Figure 2: The Thick Target Yield ratio of high spin isomer to the low spin ground state of ^{44}Sc as a function of the calculated [10] maximum angular momentum transfer in reactions induced by protons, deuterons and alpha particles on highly enriched Ca and K targets. The line is to guide the eye.

The positron decay of the ground state is followed by the emission of a high energy gamma ray. This characteristic of the ^{44g}Sc decay was used in the proposal of the three photon PET principle [1,2], in which the spatial resolution of the obtained images should be substantially improved due to the elimination of the influence of the positron range before the annihilation.

The long lived 6+ isomeric state (Fig. 1) was previously formed by proton [3, 4] and deuteron induced reactions [5–8]. In the works with deuterons the production of the in vivo ^{44m}Sc/^{44g}Sc generator was proposed. In this contribution we present our data obtained with protons as well as with alpha particles on highly enriched $CaCO_3$ and natural KCl targets. The latter projectile, thanks to its larger mass as well as higher bombarding energy should favour excitation of the high spin isomer in comparison with the ground state. This is illustrated in Figure 2 and was, indeed, observed and is shown in Table 1.

Table 1: Thick Target Yield of ^{44g}Sc, ^{44m}Sc ($CaCO_3$) and the ratio of TTY for ^{44m}Sc/^{44g}Sc for p, d and α projectiles estimated from Ref. [7] (deuterons) and the present work (protons and alpha particles).

Projectile	p	d	α	α
Projectile energy (MeV)	15.8	14.9	20	29
Target	^{44}Ca	^{44}Ca	^{41}K	^{42}Ca
Target enrichment (%)	98	96.9	95.4	95.9
TTY^{44g}Sc (MBq/μAh)	854(37)	220	60(9)	44(5)
TTY^{44m}Sc (MBq/μAh)	4.4(2)	4.9	3.0(3)	4.8(6)
TTY ^{44m}Sc/^{44g}Sc (%) (exp) $^{(a)}$	0.52(3)	2.21	5.0(5)	10.9(1.4)
TTY ^{44m}Sc/^{44g}Sc (%) (exp EXFOR) $^{(b)}$	0.55	-	3.8	10.6
TTY ^{44m}Sc/^{44g}Sc (%) (th) $^{(c)}$	0.5	2.34	5.3	15.2
A(EOB) ^{44m}Sc after 12 h of 1 μA bombardment (MBq)$^{(d)}$	49	55	34	52

$^{(a)}$ From the thick target data.
$^{(b)}$ From the experimental cross-sections and SRIM stopping powers.
$^{(c)}$ Calculated using EMPIRE cross sections and SRIM stopping powers.
$^{(d)}$ From the experimental data.

The experimental thick target yield and cross section [9] data leading to the formation of both isomers of ^{44}Sc are compared in Table 1 for the three projectiles considered here. As expected, due to the much larger stopping power for alpha particles the production efficiency of ^{44g}Sc for this projectile, even with 95.9% enriched target material, is much smaller than for proton or deuteron induced reactions. However, for 29 MeV alpha particles the TTY "isomeric ratio" is 5 times larger than for deuterons and 20 times larger than for protons. An increase of the alpha particle energy up to 50 MeV would lead to a TTY ratio of about 12, as expected from the measured cross section values. The TTY data calculated from the cross sections obtained using the EMPIRE evaporation code [10] overestimate the isomeric ratio for the highest alpha particle energies, whereas they are in reasonable agreement for proton and deuteron induced reactions. This result indicates that for the formation of the in vivo ^{44m}Sc/^{44g}Sc generator, proposed in [7], bombardment of a ^{42}Ca target with alpha particles may be one of the preferred routes if a reasonable alpha particle beam intensity is available. Indeed, for a 25 pμA beam and 12 h irradiation time of a highly enriched $^{42}CaCO_3$ target a 1GBq ^{44m}Sc/^{44g}Sc generator in radioactive equilibrium would be obtained 24 h after EOB, providing a target holder sustaining almost one kW of power on calcium carbonate is available.

However, as can be seen from this table the much lower ^{44m}Sc production cross section for protons is almost compensated for by the substantially larger projectile range in a thicker target (smaller stopping power for this projectile). As a result the Thick Target Yield and the EOB activity of ^{44m}Sc is of the same order of magnitude for protons and alpha particles. Therefore, a ^{44m}Sc/^{44gd}Sc generator of a similar equilibrium activity (1.4 GBq) may also be obtained by bombarding a $^{44}CaCO_3$ target with a proton beam of about 15 MeV energy with 50 μA beam current for 12 h, but in this case a 48 h cooling time is necessary. To the best of our knowledge this simple approach to in vivo ^{44m}Sc/^{44g}Sc generator formation using popular medical proton accelerators has not been discussed in the literature to date. The above comment on a high power target holder also applies.

Finally, in Figure 3 we compare the expected intensities of the ^{44m}Sc isomer produced with protons, deuterons and alpha particles using beam intensities as available from the commercial C30XP cyclotron. Again, the question of a high power target for $CaCO_3$ material should be solved.

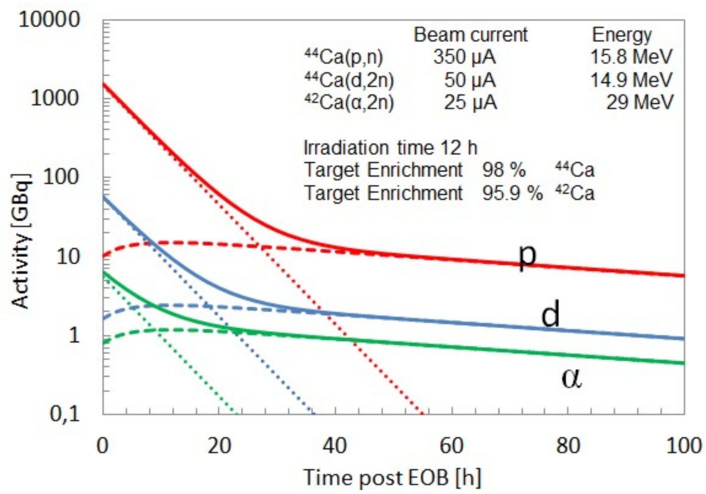

Figure 3: ^{44g,m}Sc activity (EOB) after 12 h irradiation of a highly enriched $CaCO_3$ target with p ,d and α beam with intensities available with the commercial C30XP IBA cyclotron.

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B.5 Cyclotron internal α-beam energy determination using the $^{210}At/^{211}At$ activities ratio

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The internal beam of singly charged He particles from the Warsaw U-200P cyclotron is used for the target irradiations presented in previous communications. The maximum available orbit for these irradiations is 82 cm and for this orbit the He+ energy, calculated from the machine design is 32.9 MeV. Due to the orbit precession this value can change slightly when the maximum beam intensity is tuned and is, therefore, not easily controllable. Its exact value is determined during each α-particle irradiation session using the saturation activity ratio of two At isotopes produced by the α-particle beam on ^{nat}Bi targets. Fig. 1 shows the $^{210}At/^{211}At$ saturation activity ratio as a function of the α-particle beam energy, as obtained from the cross section values recommended by the IAEA compilation (`https://www-nds.iaea.org/radionuclides/bi9a1at0.html.m`). The target was placed at the 82 cm cyclotron orbit. Before hitting the Bi sample the α-particle beam traversed a 10 μm Cu beam intensity monitor and 20μm Al envelope. The obtained saturation activity ratio of 0.0014 ± 0.0007 determined the beam energy on the Bi target as $29.95 + 0.15 - 0.40 MeV$ (Fig. 1). We adopt this error to be symmetric and equal to 0.4 MeV for the maximum α-particle energy of 32 MeV available for internal irradiations. To this value an error of ±0.25 MeV is added in squares to account for the assumed uncertainty of the At production cross sections as a function of the bombarding energy. This is illustrated in Figures 2–5, which present the IAEA values and their error estimates. In total the highest α-particle bombarding energy error amounts to ±0.5 MeV.

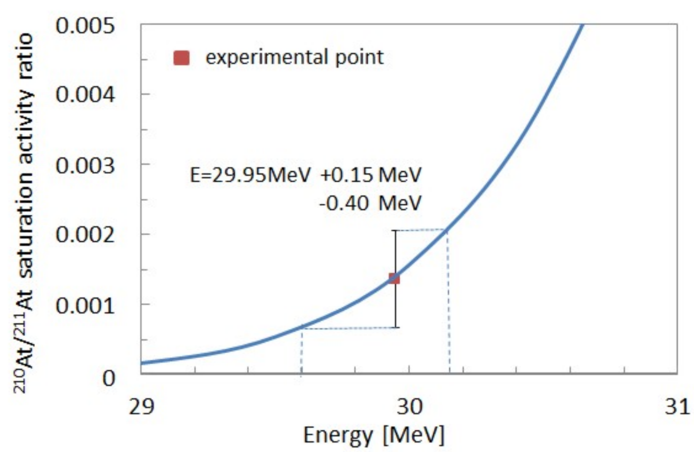

Figure 1: Example of beam energy error estimation from the astatine isotopes saturation activity ratio.

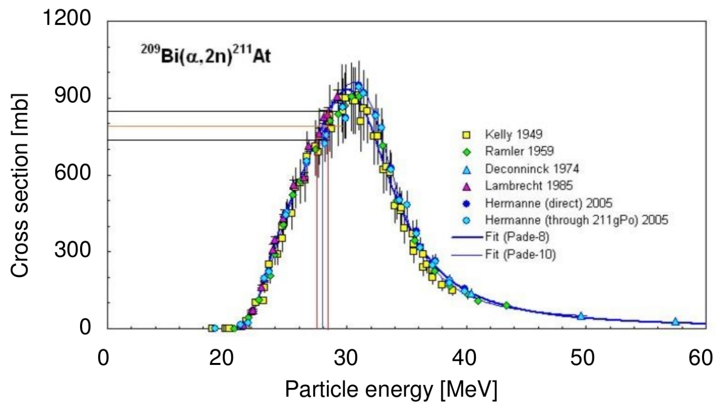

Figure 2: All IAEA data for ^{211}At. As an example, the correspondence between the beam energy and cross section uncertainty is marked at 28 MeV. The cross section error bar corresponds to a beam energy error of 0.5 MeV, as indicated by the horizontal and vertical lines. A few other energies checked are consistent with this result.

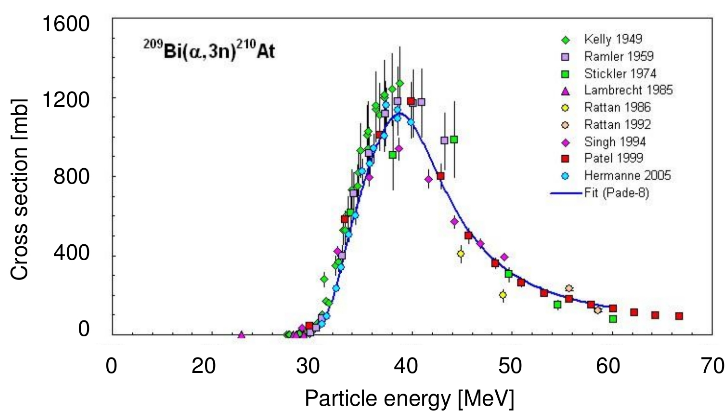

Figure 3: IAEA data for ^{210}At. An energy error of ±0.25 MeV is also assumed for α-particle energies below 34 MeV.

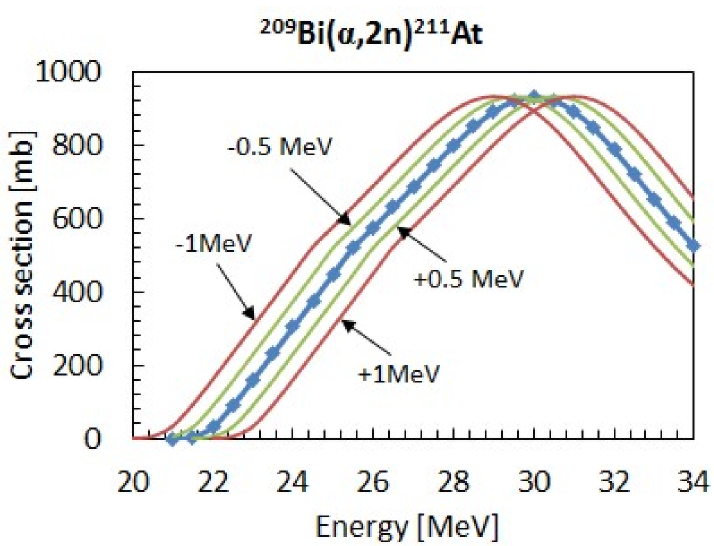

Figure 4: IEAE adopted cross section values for the production of ^{211}At.

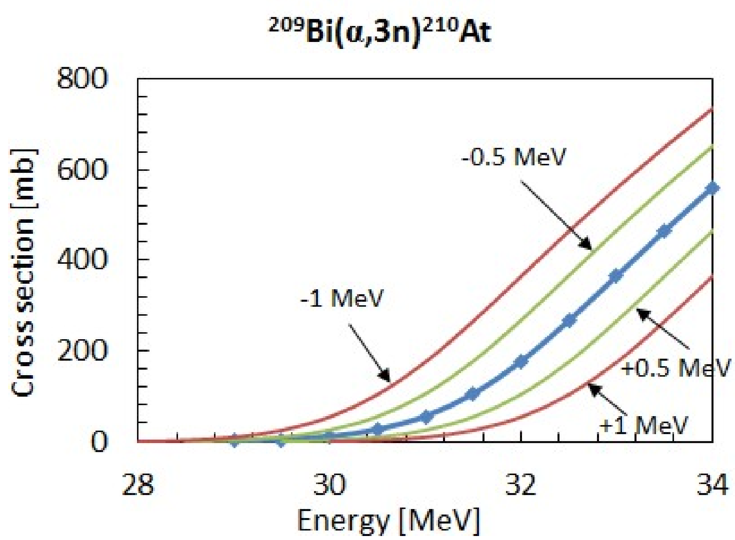

Figure 5: IAEA adopted cross section values for the production of ^{211}At.

B.6 Accelerator production of ^{99m}Tc — an external, well cooled, target holder for the PETtrace cyclotron

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In 2015 the execution of objective no. 3 of the grant "ALTECH", agreement no. PBS1/A9/2/2012 awarded to a consortium and financed by the National Centre for Research and Development, was continued and terminated. This was last year of execution of this grant. In 2014 a standalone external target system successfully passed the test procedure on a temporary test stand. Therefore, it has been transferred to its final location in the PETtrace cyclotron vault and connected to the cyclotron, see Fig. 1. It consists of:

1. a 100 cm long drift tube with its two correction permanent magnets (steering magnets);
2. a vacuum chamber equipped with a diagnostic system consisting of a graphite collimator and a Faraday cup, complete with an autonomous vacuum system; the graphite collimator consists of two independent electrodes;
3. a target chamber of the target station;
4. an autonomous control system;
5. a helium cooling system for the vacuum window;
6. a water cooling system for the Faraday cup;
7. a water cooling system for the target chamber;
8. a compressed air system;
9. an autonomous control system.

In 2015 the station was regularly used to provide irradiated targets of ^{100}Mo and $^{nat.}$Mo for further investigations according to the objectives of the "ALTECH" grant.

A patent application for the station for the PETtrace cyclotron, no. P.414054, was submitted on Sept. 17, 2015.

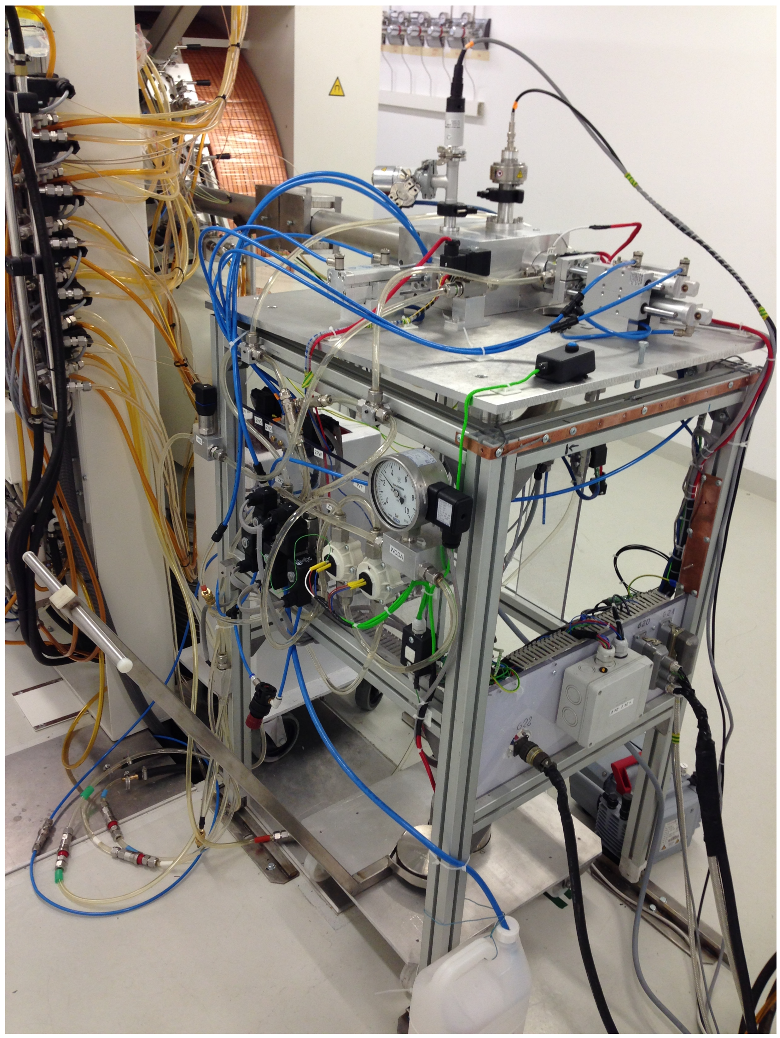

Figure 1: External target holder for the PETtrace cyclotron.

B.7 The adaption of an external, well cooled, target holder for the PETtrace cyclotron suitable for irradiation of powder targets

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In 2015 the execution of objective no. 3 of the grant "PET-SKAND", agreement no. PBS3/A9/28/2015 awarded to a consortium of three institutions and financed by the National Centre for Research and Development was begun. The PETtrace cyclotron is equipped with a standalone external target system originally designed to irradiate metallic targets, particularly molybdenum. The realisation of this project has given us an opportunity to upgrade some parts of the station, including safety conditions for the operational staff and to adapt it to the specific requirements of calcium powder targets.

The proton/deuteron cyclotron is used for commercial, daily production of fluorine F-18. This means that the targets for F-18 are highly radioactive everyday, which dramatically restricts "free-entry" to the cyclotron cave by staff in order to maintain the standalone external target system. Currently, the station is situated very close to the cyclotron. Thus it was agreed to modify the drift tube of the target holder as the first upgrade by replacing it with a beam line of about 3 m in length. The proposed modification consists of: a drift tube, two sets of steering magnets, one quadrupole doublet. The new beam line allows an additional shielding to be built, a concrete wall between the cyclotron and the diagnostic box of the target holder system. This shielding will reduce the radiation exposure of staff coming from the cyclotron F-18 targets during station maintenance. The designed beam line will also give us the opportunity to tune a proton or deuteron beam to the surface of the adapted targets. Thereby the beam transport efficiency to the target will be significantly improved. By adding the beam line we have redesigned the diagnostic box. Also, the existing vacuum pumps will be replaced with a new much more efficient ones. Currently, the new pump tender is under preparation. Completion is expected at the beginning of 2016. Figure 1 shows the scheme of the modified target holder. In the given period we have collected and assembled the quadrupole doublet for the beam line. It was checked on a temporary stand and passed all tests. We have also bought two power supplies to drive its coils. The design for the beam steering elements is finished. In our case they are made of permanent magnets.

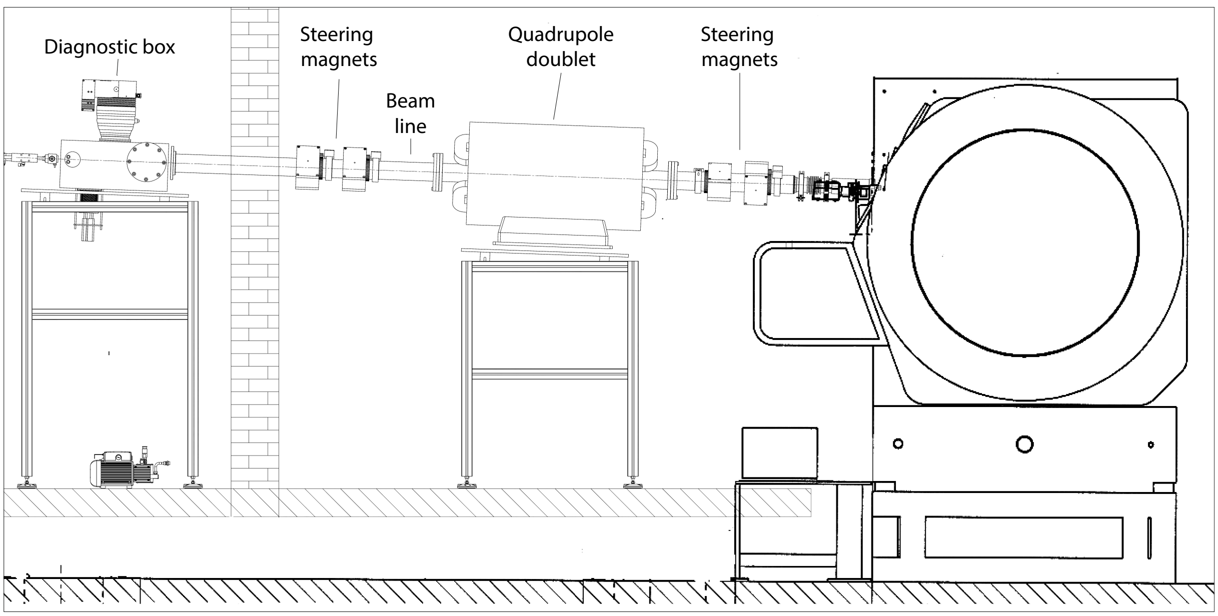

Figure 1: Scheme of the modified external, well cooled, target holder.

B.8 Imaging of hypoxia in small animals with ^{18}Fluoromisonidasole

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Hypoxia defines a pathological condition where oxygen is delivered to the tissue in insufficient quantities, which is the result of an impaired oxygen transport mechanism. Hypoxic conditions may have the features of a pathological process, e.g. during development of uncontrolled proliferative lesions.

The scope of this study was to synthesise [^{18}F]FMISO in a number of consecutive runs using fluorine from target flushing after the commercial manufacturing of [^{18}F]FDG and to prove the quality of the manufactured radiopharmaceuticals, as a proof of concept in studies on hypoxia in Lewis Lung Carcinoma (LLC) in mouse models.

A method of automated synthesis of [^{18}F]FMISO for applications in preclinical studies on small animals was presented. A remote controlled synthesizer, Synthra RN_{plus}, was used for nucleophilic substitution of NITTP (1-(2'-Nitro-1'-imidazolyl)-2-O-tetrahydropyranyl-3-O-toluenesulfonyl-propanediol) with ^{18}F anion. Labelling of 5 mg of precursor was performed in anhydrous acetonitrile at 100°C for 10 min and hydrolysis with HCl at 100°C for 5 min. Final purification was done with HPLC and the radiochemical purity of the radiotracer was higher than 99%. The identity of the manufactured [^{18}F]FMISO was confirmed by comparison of retention time to the certified reference standard (CRS) of the main compound (ABX, Radeberg, Germany).

Lewis Lung Carcinoma (LLC) cells were grown at 37°C in a humidified atmosphere of 5% CO_2/95% air in RPMI 1640 containing 10% heat-inactivated fetal bovine serum plus penicillin-streptomycin under sterile tissue culture conditions. C57BL/6JOlaHsd, $N = 10$ female mice aged of 8–10 weeks and about 20 g each were originally obtained from the animal breeding facility at the Faculty of Biochemistry, Biophysics and Biotechnology of the Jagiellonian University (Kraków, Poland). For each mouse $0.5 \cdot 10^6$ LLC cells, suspended in 100 μl of PBS, was injected intradermally into the right hind limb. The tumours became visible 4–6 days after implantation. When their size (greatest diameter) was about 5 mm the mice were transported in cages specially prepared for this purpose to the Biological and Chemical Research Centre of University of Warsaw. PET/CT measurements were performed on an Albira PET/SPECT/CT Preclinical Imaging System (Bruker, Germany). Prepared mice were placed in the supine position in the imager with the use of the animal bed and 10–15 MBq [^{18}F]FMISO was administered i.v. through a tail vein cannula.

The results show a difference in the distribution of [^{18}F]FDG and [^{18}F]FMISO in the body (Fig. 1). The physiological uptake of glucose is located in the heart and bladder, in the case of [^{18}F]FMISO, the tracer is accumulated in the intestine and bladder. Stomach and intestine high absorption was observed 30 minutes after the injection, whereas the kidney uptake increased up to 30 min after injection and remained in the bladder at a high level up to 120 min. A visible difference in the structure of the imaged cancer with [^{18}F]FDG and [^{18}F]FMISO is observed — for the first tracer the tumour area is

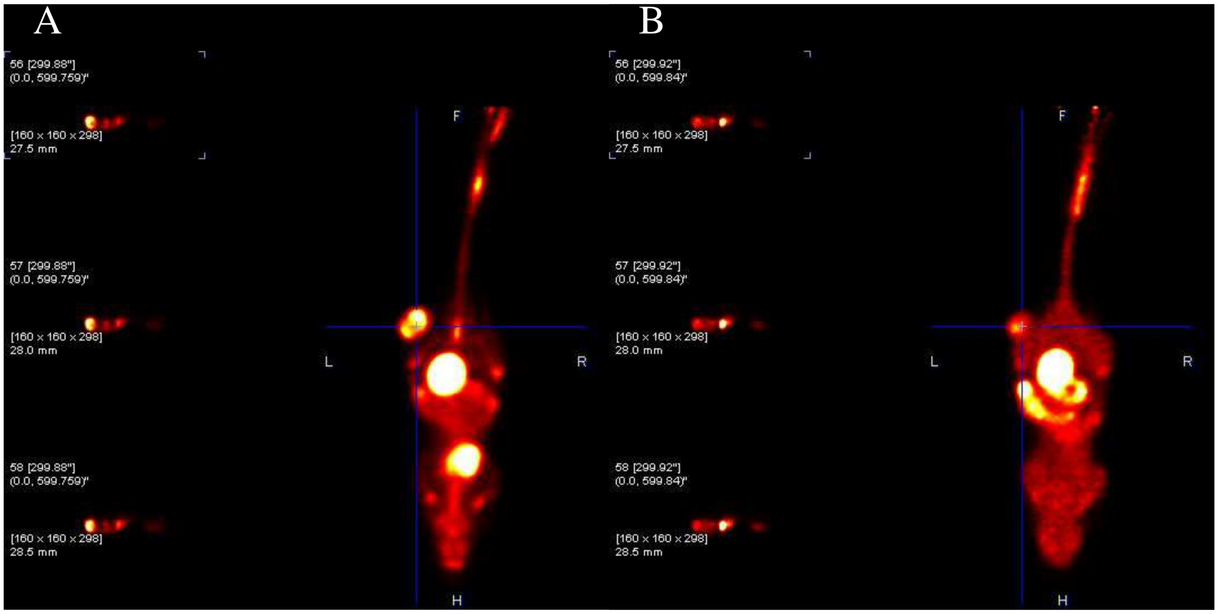

Figure 1: In vivo imaging of a mouse carrying an LLC tumour with [^{18}F]FDG (A) and [^{18}F]FMISO (B).

spherical and [^{18}F]FMISO is accumulated in two separate sites. Whereas [^{18}F]FMISO accumulated in relatively hypoxic areas of the tumour, [^{18}F]FDG was preferentially taken up by metabolically active tumour regions. The reason for the differences in structure of the imaged tumour depends on the uptake mechanism of the marker[18], where the uptake of [^{18}F]FDG in the tumour is caused by increased glucose metabolism, and [^{18}F]FMISO is a result of the presence of hypoxic areas of the tumour tissue.

B.9 Optimisation of Cu(II)-porphyrin complex synthesis for PET radiopharmaceutical applications

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Porphyrin based photosensitizers are useful agents for photodynamic therapy and fluorescence imaging of cancer. Additionally, porphyrins are excellent metal chelators, forming stable metalo-complexes and the ^{64}Cu isotope can serve as a positron emitter ($t_{1/2} = 12.7$ h). The other advantage of ^{64}Cu is its decay characteristics that facilitate the use of the ^{64}Cu-porphyrin complex as a therapeutic agent. Thus, ^{64}Cu chelation with porphyrin photosensitizer may become a simple and versatile labelling strategy for clinical positron emission tomography. The present study reports a convenient method for the synthesis of Cu complex with tetrakis(4-carboxyphenyl)porphyrin (TCPP). The experimental conditions for labelling, such as the metal-to-ligand molar ratio, pH and time of reaction were optimised to achieve a high complexation efficiency in a period of time as short as possible. In order to accelerate the metallation, the use of substitution reactions of cadmium or lead porphyrin and the presence of a reducing agent, such as ascorbic acid (Fig. 1), hydroxylamine and flavonoid-morin, were evaluated (Fig. 2).

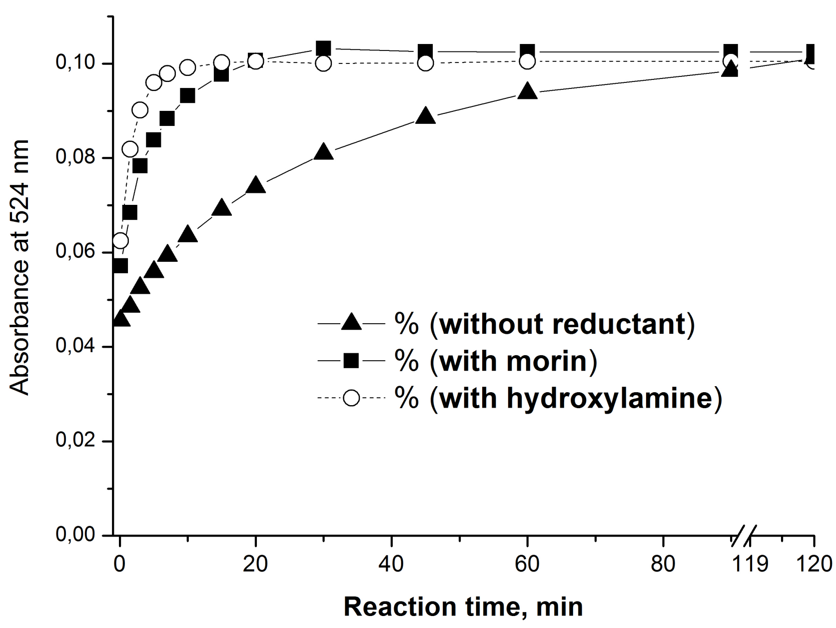

Figure 1: The changes in absorbance at λ_{max} over time for the reaction of Cu(II) and TCPP in the presence of ascorbic acid (AA) at different concentrations. $[Cu^{2+}] = [TCCP] = 10^{-5}$ M.

The optimum conditions for the synthesis of the copper complex were a borate buffer at pH = 9 with the addition of 10-fold molar excess, with respect to Cu^{2+} ions and TCPP

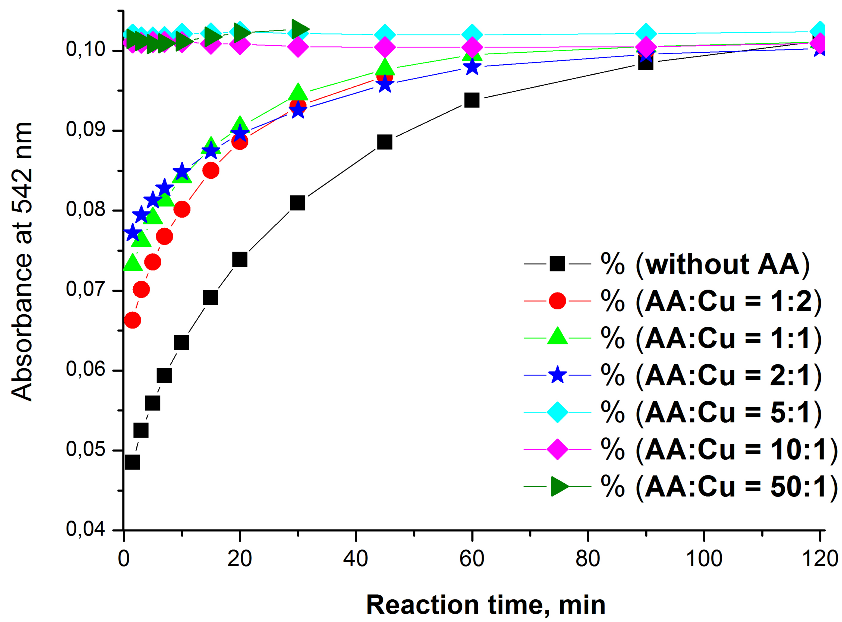

Figure 2: The changes in absorbance at 542 nm over time for the reaction of Cu(II) and TCPP in the presence of hydroxylamine and morin. $[Cu^{2+}] = [TCCP] = [morin] = [hydroxylamine] = 10^{-5}$ M.

and ascorbic acid which resulted in reduction of the reaction time from 30 min to below 1 min.

B.10 Sorption of Sc(III) ions on solid sorbents

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The aim of these studies was to check the sorption parameters of Sc(III) ions on commercially available cation exchangers (Dowex HCR-S, Amberlite IR-120, Amberlyst 15, AG MP 50, Cellex P), anion exchangers (Dowex 1-4, Amberlite IRA-401) and chelating resin (Chelex 100). Cation exchangers retain scandium in acidic pH, which proves it exists in cationic form. As far as anion exchangers are concerned scandium is quantitatively retained in basic conditions, which confirms that scandium hydroxide $Sc(OH)_3$ is amphoteric. The next step was to modify commercially available sorbents with xylenol orange, which is an efficient complexation agent for Sc(III) ions. The best results of xylenol orange sorption were obtained using an anion exchanger in high pH. Although the percent of sorption is 100%, the modification is not stable in acidic pH. Based on the sorption experiments a new method of separation of scandium from $CaCO_3$ has been developed. It can be utilized in the extraction of $^{43/44}$Sc obtained from the target during irradiation in a cyclotron. The first step was to test the method available in the literature, in which the target is dissolved in 1M HCl and scandium is separated and preconcentrated on Chelex 100 resin. The results obtained were the same. In the next step the extraction of scandium from a $CaCO_3$ target using 1M NaOH combined with separation from calcium on a Dowex 1-4 anion exchanger was performed, but failed. Another approach was to use EtOH as extractant for scandium separation. The developed method can be used for processing of $^{43/44}$Sc solution on Chelex 100 resin after isolation from a solid target. Further purification of scandium is necessary, because it suffers from relatively high concentration of calcium. It would also allow the final concentration of HCl to be lowered.

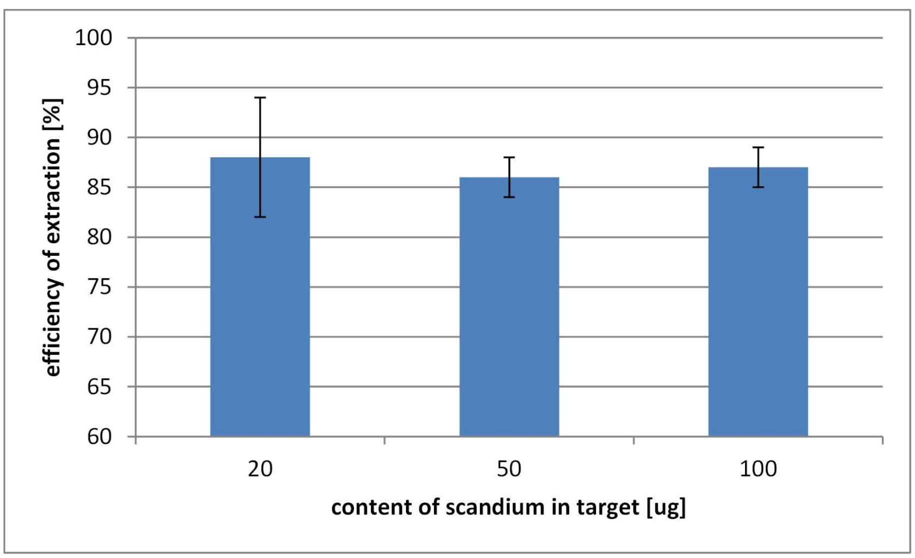

Figure 1: Extraction of scandium from solid target.

B.11 Biophenols in extracts from wild and cultivated heather (Calluna vulgaris L. Hull)

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The high content of polyphenols and the biological activity of these compounds serve as the basis for the beneficial effect of heather as a medicinal plant. Calluna vulgaris is the dominant species of forest shrub in Poland. It grows on acidic soils in open sunny situations and in moderate shade. It is known as an antiseptic, woundhealing, antirheumatic and choleretic remedy. The aerial parts of the heather exhibit an anti-inflammatory and antioxidant capacity.

The content of some polyphenols was investigated in extracts of wild heather collected from natural environmental localities in central Poland and in extracts from cultivated plants.

Water, ethanol and a mixture of both as well as ethyl acetate were used for extraction. Chromatographic analysis was performed using a Shimadzu high performance liquid chromatography system equipment with a binary pump, degasser and autosampler, connected to an 8030 Triple Q Mass spectrometer. A MS system was equipped with an electrospray ionisation source (ESI) operated in negative-ion mode and a quadrupole mass analyser in scan mode from 50 to 1500 m/z. Nitrogen was used as curtain and auxiliary gas at 0.3 MPa.

Gradient elution was used: 8 mM formic acid (pH 2.8) and acetonitrile. Compounds were identified by comparing retention time and m/z values obtained by MS and MS^2 with the mass spectra from standards tested under the same conditions. Quantification of compounds was done from the calibration curves obtained in Multiple Reaction Mode (MRM).

Lots of polyphenolic acids and flavonoids were identified in the extracts from heather flowers. Some compounds could not be determined, e.g. vanilic acid, because they were below the limit of detection.

Chlorogenic acid was isolated as the major constituent in the extracts from heather flowers. The highest concentration of this acid, more than 4000 µg/g flowers, was found in 60% ethanol fraction. Caffeic acid was present in the extracts from heather flowers as glycoside because the highest concentration of this acid was found in ethanol with hydrochloric acid fraction.

Catechin was isolated as the major flavonoid in the extracts from heather flowers. The highest concentration of this compound, more than 1000 µg/g flowers, was found in 60% ethanol fraction (Fig. 1).

Rutin and quercetrin in the ethanol with hydrochloric acid fraction are absent, because of hydrolysis of glycosidic bonds. In this condition the highest amount of quercetin can be observed (Fig. 1).

A literature survey found that the major flavonoid in heather is kaempferol as glycoside. It is kaempferol-3-O-glycoside and kaempferol-3-O-galactoside.

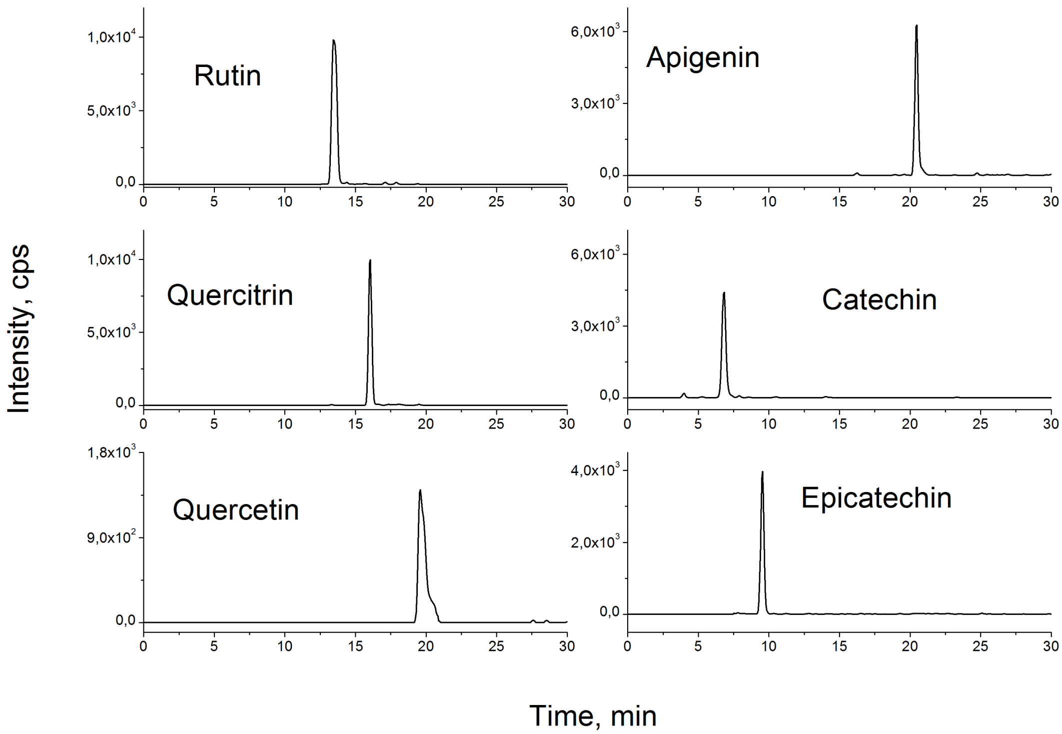

Figure 1: Total ion chromarogram (TIC) in SIM mode of heater extract (60% ethanol fraction).

The content of polyphenols in heather flower extracts strongly depends on the extractant. The lowest concentration of phenolic acids and flavonoids was found in ethyl acetate fraction.

Part C

Nuclear physics

C.1 ^{128}Cs chiral bandhead decay study

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The decay of the $\pi h_{11/2} \otimes \nu^{-1} h_{11/2}$ yrast state, the bandhead of chiral partner bands was studied with the help of datasets collected in two complementary experiments. The first experiment [1] aimed to perform DSA lifetime measurements and was performed at HIL with the help of the OSIRIS II array, a predecessor of the EAGLE spectrometer. The second experiment was performed at IPN ORSAY for g-factor measurements [2] using two LEPS detectors and a ^{10}B pulsed beam. The pulsed beam provided by the Tandem accelerator enabled investigation of the γ-γ coincidences collected between beam pulses. The γ-γ coincidences were registered around 15 ns after the beam pulse within 100 ns. The coincidence window for two gamma quanta to be registered was set to 20 ns. In this way, the coincidence matrix was free of prompt radiation and contained sequences of fast transitions below the isomeric chiral bandhead. Several transitions known from Refs. [3,4] were identified. These are 114 keV, 151 keV, 159 keV, 169 keV, 188 keV, 266 keV. Five other transitions, 64 keV, 73 keV, 167 keV, 230 keV, 495 keV were observed for the first time. In general, around 13 gamma transitions were identified that form two independent branches of the isomeric state decay.

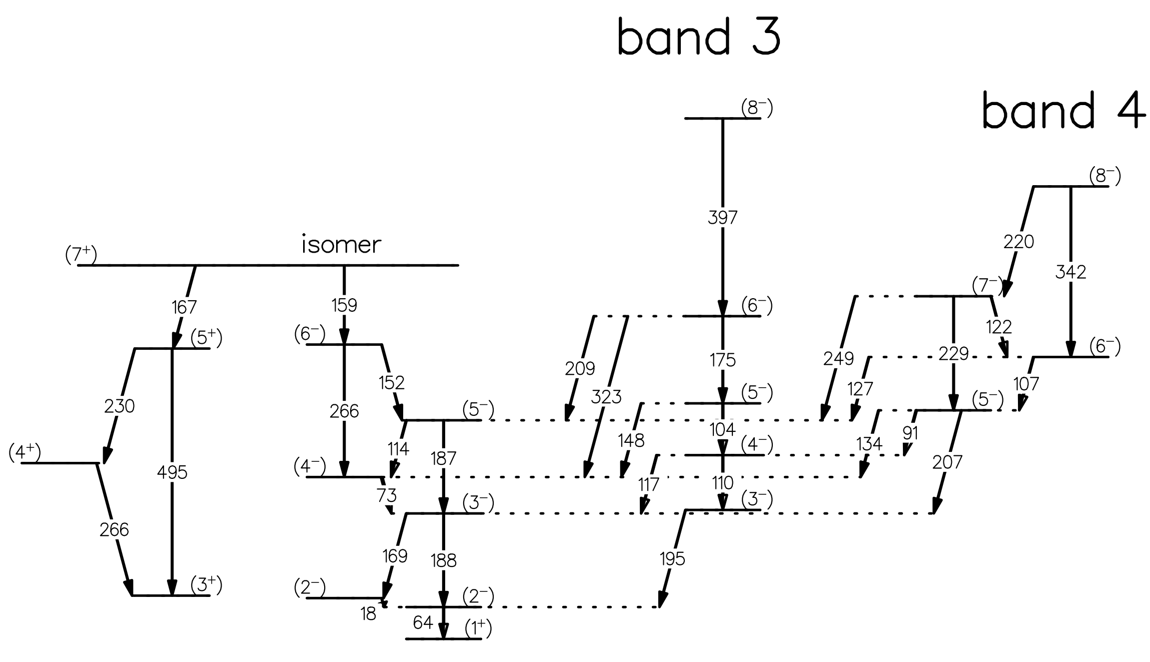

Figure 1: Lower part of the level scheme of ^{128}Cs reconstructed from gamma coincidence data collected at HIL (Poland) and at IPN Orsay (France) [1].

The coincidence techniques, applied to the pulsed beam data collected at IPN Orsay, allowed the isomeric state decay to be reconstructed with limited precision. Due to unexpected noise in the LEPS detectors, their efficiency (threshold levels) was changed during the preparation of the experiment causing their efficiency measurement to be invalid. Therefore, the level scheme could not be verified by gamma intensity analysis. Even if the gamma transitions from the chiral bandhead decay were identified, their proper sequence still had to be verified by other independent methods. Here, data taken at the Heavy Ion Laboratory with the help of the U-200P cyclotron and the OSIRIS II array with the same reaction and beam energy were used for verification of the isomeric decay sequence. While the IPN setup used for the g-factor measurement required best timing resolution at a limited efficiency, the OSIRIS II multidetector array consisting of 10 Compton-suppressed HPGe detectors allowed γ-γ coincidences to be registered with much higher efficiency at a limited timing. Around 10^9 γ-γ coincidences collected for the ^{122}Sn(^{10}B,4n)^{128}Cs reaction with a coincidence window of 200 ns were used to investigate transitions from negative parity bands to levels below the isomeric chiral bandhead. These coincidences avoid the feeding of the isomer and allow the major part of the low energy level scheme of ^{128}Cs to be reconstructed. Figure 1 presents the level scheme below the chiral bandhead reconstructed from the combined data collected with help of the IPN setup and the OSIRIS II array. The two negative parity bands 3 and 4 were reported in Ref. [3] and attributed to $\pi h_{11/2} \otimes \mu g_{7/2}$ and $\pi g_{7/2} \otimes \mu h_{11/2}$ configurations, respectively. The decay scheme of these bands to levels below the chiral bandhead was changed significantly since several new coincidence transitions were found. The 91 keV, 104 keV and 110 keV transitions linking the negative parity bands with the isomeric state decay levels were observed for the first time. The 104 keV gamma line is in coincidence with all known transitions of band 3. There are also strong coincidences with the 175 keV, 110 keV and 195 keV transitions indicating that these transitions belong to the decay path of band 3 too. The newly found 91 keV transition belongs to the decay path of the negative parity band 4. Indeed, 91 keV line is in coincidence with all transitions of band 4 reported in Ref. [3]. The gamma energy spectrum gated on the 91 keV transition shows the absence of the 104 keV line, confirming that both transitions — the 91 keV and the 104 keV — go parallel to each other. Moreover, the presence of the 107 keV line of band 4 and the 110 keV line of band 3 — seen also in the 104 keV gate — suggests that both the 91 keV and the 104 keV transitions feed the same level decaying via 110 keV gamma decay.

Thus, two decay paths of the two negative parity bands to levels below the chiral bandhead could be identified. These paths are linked by the 91 keV transition shown in Fig. 1. With the indentification of the decay paths of the negative parity bands, it was possible to verify the sequence of transitions below the isomeric state by setting gates on transitions linking the bands with the decay path of the isomer.

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C.2 Study of low-spin levels in the ^{140}Sm nucleus using the angular correlation method.

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The ^{140}Sm nucleus belongs to a transitional region where the nuclear shape changes rapidly with neutron number, from a spherical (for $N = 82$) to a deformed shape ($N < 82$). Theoretical calculations [1] predict a small oblate deformation for ^{140}Sm.

Nuclear shapes can be measured using, among others, the Coulomb excitation method. In the case of ^{140}Sm, studied with this technique, information about spins was indispensable. Recently, in ^{140}Sm, the spins of the 990 and 1599 keV levels (Fig. 1) have been measured using the γ-γ angular correlation method [2]. This work was performed at the Heavy Ion Laboratory, University of Warsaw. The main aim of our new experiment is the determination of the spins (which are not firmly established) of the excited states in ^{140}Sm (Fig. 1).

To obtain a unique information concerning the spin values of the excited states of ^{140}Sm (Fig. 1) γ-γ angular correlations [3] were measured. These states were populated in the ^{140}Eu → ^{140}Sm and the ^{140}Gd → ^{140}Eu → ^{140}Sm decays. The ^{140}Gd and ^{140}Eu nuclei were produced in the ^{104}Pd+^{40}Ar reaction at a beam energy of 210 MeV. The beam was provided by the U-200P cyclotron [4] of the Heavy Ion Laboratory, University of Warsaw. A ^{104}Pd self-supporting target of 10 mg/cm^2 thickness with a Au degrader of 5 mg/cm^2 thickness was used. The optimum energy of the ^{40}Ar beam was calculated using the COMPA code [5]. This code allows the calculation of cross sections as a function of ion energy in the case when the target and degrader thicknesses are known. At a beam energy of 210 MeV the ^{140}Gd and ^{140}Sm nuclei are produced with relatively high yield, as presented in Figure 2.

The γ-γ coincidences were registered using twelve Compton-suppressed HPGe detectors from the EAGLE array [6]. The relative angles between the Ge detectors were as follows: 38°, 42°, 70°, 79°, 109°, 138°, 142° and 180° and the number of detector pairs at each angle were 4, 9, 18, 5, 18, 7, 2 and 3, respectively. The γ-γ coincidence spectra as well as the singles spectra of gamma quanta accompanying the ^{140}Eu and ^{140}Gd decays were registered during off-beam periods. The singles spectra allow the efficiency of the Ge detectors to be determined. Preliminary analysis of the data revealed five times higher statistics than in the previous experiment [2]. We plan to determine the spins of the 1628.65, 2284.14, 2482.34 and 2595.9 keV levels (marked with green lines in Fig. 1) and the multipolarities of the 608.6, 1097.7, 1752.8, 1491.3 and 2064.9 keV transitions (marked with green arrows in Fig. 1). It is worth adding that in the new experiment all γ transitions marked with green arrows in Fig. 1 were observed with sufficient statistics.

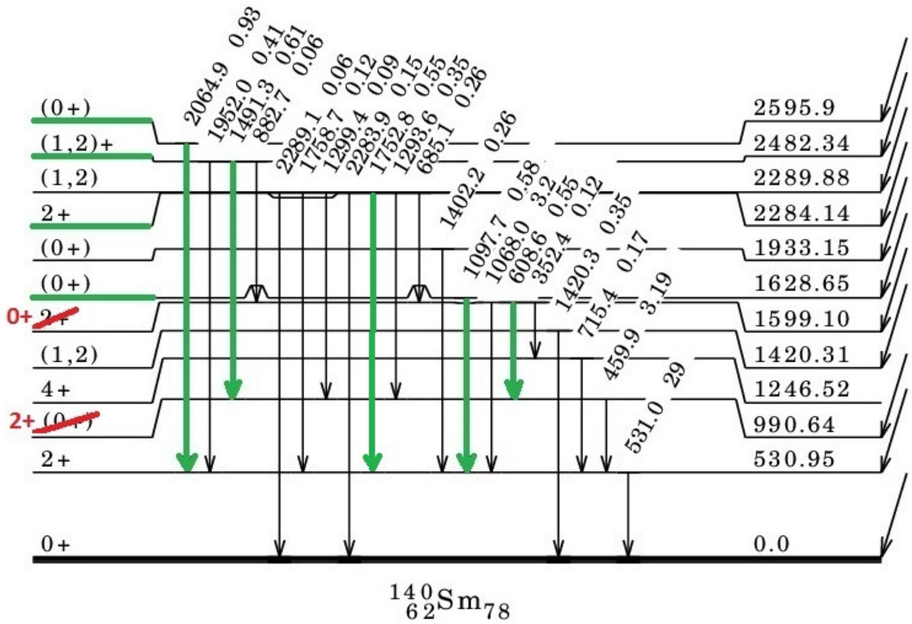

Figure 1: Partial level scheme of ^{140}Sm relevant to our work, taken from Ref. [7]. Spin values of the 990.64 and 1599.10 keV levels (marked in red) are shown according to the results of the previous experiment [2]. Green arrows and green lines indicate transitions and levels in ^{140}Sm studied in our work.

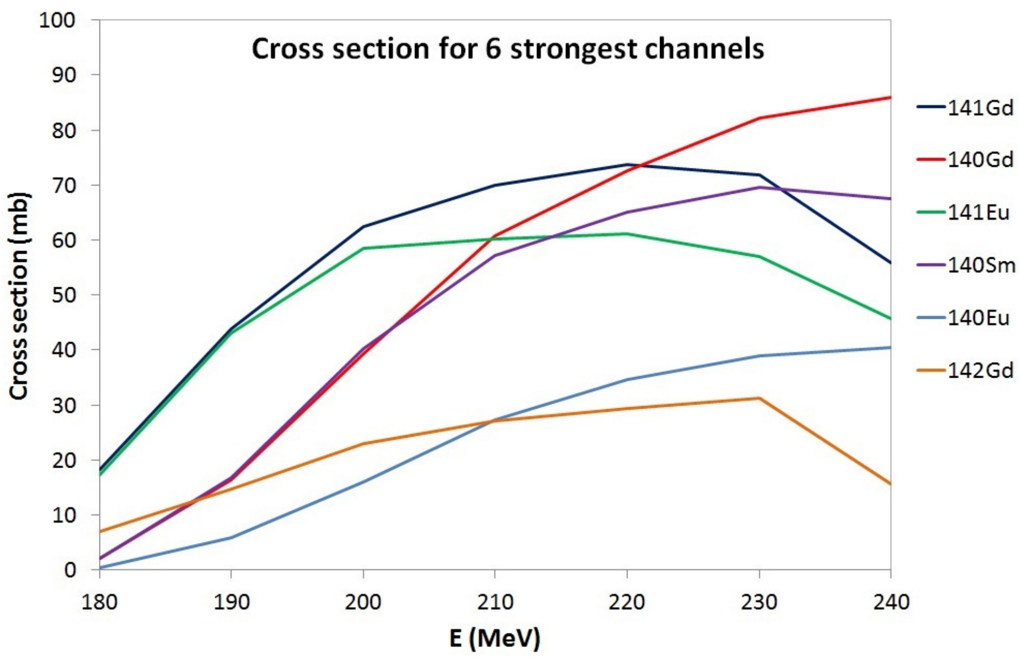

Figure 2: Cross sections (integrated over the target thickness) for the ^{104}Pd+^{40}Ar reaction.

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C.3 Measurements of the elastic and inelastic scattering cross sections of ^{13}C ions on ^{12}C nuclei at a near Coulomb barrier energy

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The neutron transfer mechanism is responsible for the cross section increase in the backward hemisphere in the elastic scattering ^{12}C(^{13}C,^{12}C)^{13}C. In this context, a study of the cross sections in this area is of great interest for astrophysics since it allows us to estimate the cross sections of the possible radiative capture reaction ^{12}C(n, γ)^{13}C and its role in the evolution of the Universe immediately after the Big Bang. Due to the Coulomb repulsion, for reactions near the Coulomb barrier the process of neutron transfer is peripheral.

Previously, the ^{12}C + ^{13}C elastic scattering at an energy close to our was investigated in a limited range of angles up to 60° [1]. In the present work the angular range was extended substantially (up 120° in the center of mass system). Differential cross sections for elastic and inelastic scattering of ^{13}C ions on ^{12}C were measured using a beam extracted from the $K = 160$ Cyclotron of HIL (University of Warsaw) at an energy of 2.5 MeV/nucleon, see Figure 1.

The experimental data on elastic and inelastic scattering were analysed within the framework of the optical model (OM) and the Coupled Reaction Channels (CRC) method with the code FRESCO [2], taking into account the neutron transfer mechanism. As seen from Figure 1, the OM does not provide a cross section enhancement in the backward direction. Only taking into account the neutron transfer mechanism gives rise to cross sections at large angles. So, it is important to extend the measurement to angles greater than 120°. A value for the deformation parameter of $\delta = 1.1$ fm was obtained from the analysis of the experimental data of inelastic scattering. The set of optimal parameters is given in Table 1.

Table 1: Potential parameters.

E (MeV)	V_0 (MeV)	r_V (fm)	a_V (fm)	W_0 (MeV)	r_W (fm)	a_W (fm)
32.5	73.1	1.03	0.699	35.22	1.19	0.211

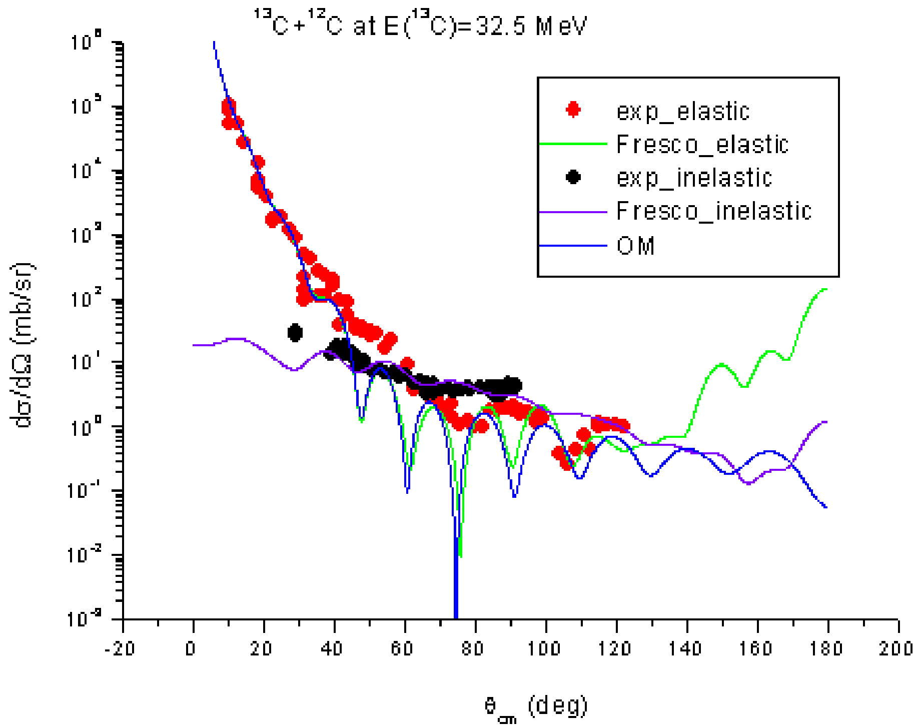

Figure 1: Angular distribution of the elastic scattering of ^{13}C on ^{12}C at 32.5 MeV. The red circles are the experimental elastic scattering data while the black circles are inelastic scattering data. Curves: the blue line is the optical model prediction; the green represents the coupled reaction channels calculation of the elastic scattering by the code FRESCO, violet represents the FRESCO analysis of the inelastic scattering.

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C.4 Do transfer channels influence the barrier height distribution? — back-scattering of ^{20}Ne on ^{58,60,61}Ni at a near-barrier energy — experiment

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Studies of the Coulomb barrier height distribution (BD) were continued. The shapes of the distribution for ^{20}Ne + ^{58}Ni and ^{20}Ne + ^{60}Ni [1] are in a fair agreement with those predicted by CC calculations. The barrier distribution for ^{20}Ne + ^{61}Ni (^{61}Ni is the isotope with high level density) is very different from the theoretical prediction, namely, it has no structure. These results support our hypothesis that the weak but numerous couplings to non-collective levels give rise to smoothing of the barrier height distribution structure [2,3].

Comparison of the differential transfer cross sections at a near barrier energy for these systems was the subject of the next experiment [4]. The aim of the measurement was to check whether transfer channels in these systems could also influence the barrier height distributions. We performed the experiment reported in the present work: a comparison of differential transfer cross sections for ^{20}Ne + ^{58,60,61}Ni back-scattering at a near-barrier energy.d

A ^{20}Ne beam of 51 MeV energy with a resolution of 0.9 MeV (FWHM) and ~ 60 enA intensity was delivered by the Warsaw U200-P Cyclotron. The energy was chosen to correspond to the BD minimum predicted by CC calculations [1]. Isotopically enriched self-supporting targets of ^{58,60,61}Ni (enrichment: 99.92 %, 99.79 % and 92.92 %, respectively) of ~ 100 μg/cm^2 thickness were used [5, 6].

The experimental set-up was presented in Ref. [4]. The time-of-flight (TOF) technique was applied to identify the mass of the detected ions. For charge identification of scattered ions a ΔE–E telescope was employed. The full product identification, i.e. mass and charge assignment, was done combining the data from these two detector systems and information on the Q-values. According to the Rehm systematics [7], there is a positive correlation between the transfer probability and the effective the Q value, Q_{eff} [8].

The contributions of 1 and 2 neutron pick-up as well as α and 2p + 1n stripping to all registered back-scattering events, σ_{tr}/σ_{QE}, were determined. The results are presented in Fig. 1(a). The resulting transfer product cross sections are given in Table 1 and presented in Fig. 1(b).

The total (summed over all transfer channels) differential transfer cross sections obtained are similar for all three systems. Moreover, they are about 3 times smaller than the total transfer cross section for the ^{20}Ne + ^{90}Zr system, for which the QE barrier height distribution has a clearly visible structure (2 maxima) [2]. These results support

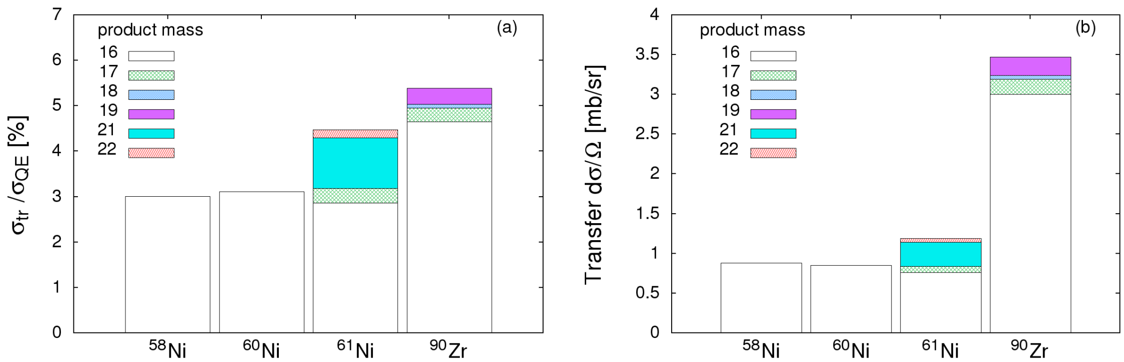

Figure 1: Contributions of different transfer channels to the quasi-elastic scattering at 142° in the lab system (panel (a)) and the corresponding differential cross sections (panel (b)) for ^{20}Ne + ^{58,60,61}Ni. Data for ^{20}Ne + ^{90}Zr at $E_{cms} \simeq 51$ MeV [2] are also shown.

Table 1: Transfer cross sections in the ^{20}Ne + ^{A}Ni system at $\Theta = 142°$ for the near-barrier energy 51 MeV.

Target	Transfer product cross sections [mb/sr]			
	$A = 16$	$A = 17$	$A = 21$	$A = 22$
^{58}Ni	0.89 ± 0.01	< 0.01	< 0.04	< 0.03
^{60}Ni	0.90 ± 0.01	< 0.06	< 0.09	< 0.03
^{61}Ni	0.76 ± 0.08	0.08 ± 0.02	0.30 ± 0.04	0.05 ± 0.01

the hypothesis that transfer channels are not responsible for smoothing out the shape of the BD in the ^{61}Ni case.

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C.5 Do transfer channels influence the barrier height distribution? — ^{20}Ne + ^{61}Ni at near-barrier energy — CRC calculations

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The experimental results for transfer cross section for the ^{20}Ne + ^{58,60,61}Ni systems at a near-barrier energy suggest that transfers do not influence the shape of the barrier height distribution for these systems [1]. Detailed theoretical checking of this conclusion is not possible at present. Accurate modelling of the effect of transfers of more than one nucleon, in particular alpha particle transfers, is hampered by the lack of reliable absolute spectroscopic amplitudes for these processes.

The fact that the α particle transfer cross sections for all 3 targets are almost the same strongly suggests that the smoothing is not caused by α transfer. Moreover, as one can see from Fig. 1 in the previous article [1], the main difference between the transfers for these three targets consists in the 1n pick-up observed in the case of the ^{61}Ni target. Is this transfer responsible for smoothing? This possibility we could check by calculations.

A series of coupled reaction channels (CRC) calculations was carried out with the code FRESCO [2] to investigate the influence of coupling of the single-neutron pick-up reaction to back-scattering. Inelastic excitation of the ^{20}Ne 2_1^+ and 4_1^+ states, assumed to be members of a rotational band built on the 0^+ ground state, was also included in the calculations since these couplings are mainly responsible for the split in the calculated barrier distribution. The entrance channel optical potential was of Woods-Saxon form, with parameters $V = 57.23$ MeV, $R_0 = 1.15 \times ({\mathrm{A_p}}^{1/3} + {\mathrm{A_t}}^{1/3})$ fm, $a_0 = 0.642$ fm, $W = 20$ MeV, $R_W = 1.0 \times ({\mathrm{A_p}}^{1/3} + {\mathrm{A_t}}^{1/3})$ fm, $a_W = 0.4$ fm (where $\mathrm{A_p}$ and $\mathrm{A_t}$ are projectile and target mass numbers, respectively). The parameter values for the real part of the potential were taken from the Akyüz-Winther paper [3] with R_0 sightly adjusted in order to reproduce the mean barrier height [4]. The "interior" imaginary potential (also used in our previous work) simulates the ingoing-wave boundary condition.

The ^{20}Ne $B(E2)$ and $B(E4)$ values were 135.6 e^{2}fm^4 and 5265 e^{2}fm^8, respectively, taken from Ref. [5]. The corresponding nuclear deformation lengths were $\delta_2 = 1.436$ fm and $\delta_4 = 0.843$ fm.

To simplify the calculations the ^{61}Ni nucleus was assumed inert. This is justified by the fact that collective excitation effects are dominated by ^{20}Ne due to the strong projectile deformation.

Spectroscopic factors for the ^{20}Ne $\to$ ^{21}Ne transitions were taken from Fortier *et al.* [6]. Pick-up to the 0.35 MeV $5/2^+$ and 2.80 MeV $1/2^+$ states of ^{21}Ne was included, as these are the strongest individual single-neutron states. Transitions to the states in ^{60}Ni listed in Table 1 were included, with spectroscopic factors taken from Table IV of Ref. [7].

The n + ^{20}Ne and n + ^{60}Ni binding potentials were both of Woods-Saxon form with parameters $R_0 = 1.25 \times {\mathrm{A_c}}^{1/3}$ fm, $a_0 = 0.65$ fm, where $\mathrm{A_c}$ denotes the mass number of the corresponding "core" nucleus, the depths being adjusted to give the correct binding energies. The exit channel ^{21}Ne + ^{60}Ni optical potential used the same parameters as the entrance channel potential. The full complex remnant term and non-orthogonality correction were included.

Table 1: States in ^{60}Ni coupled to in the CRC calculations.

E_x (MeV)	I^π	C^2S
0.00	0^+	0.32
1.33	2^+	0.43
2.51	4^+	0.39
2.63	3^+	0.60

The calculated barrier distributions are shown in the Figure 1. It is seen that the influence of 1n pick-up is negligible. In particular it does not smooth the BD for this system.

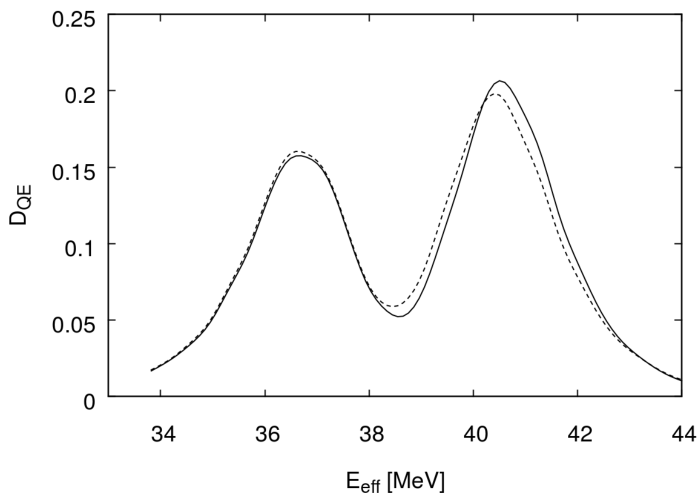

Figure 1: Barrier height distribution calculated with the FRESCO code: solid line — only collective channels taken into account, dashed line — 1n transfer also included.

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C.6 Coulomb excitation of ^{146}Nd and ^{148}Sm to study octupole collectivity

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For certain combinations of protons and neutrons in atomic nuclei the onset of a reflection asymmetry is expected. Experimental $E3$ strengths, which as a function of the neutron number peak at around $N \approx 88$ and $N \approx 134$, indicate enhanced octupole correlations as predicted by theory [1]. Low-energy Coulomb excitation is a highly successful method for establishing the evolution of nuclear shapes. Measured excitation cross sections of the populated states can be directly related to the static and dynamic moments of the charge distribution of the nucleus. A Coulomb excitation experiment was performed at the ALTO facility, Orsay to study the octupole correlations and collective properties of ^{146}Nd and ^{148}Sm [2]. The experiments aimed in particular to determine the magnitude of the $\langle 3^- \| E3 \| 0^+ \rangle$ and $\langle 1^- \| E3 \| 4^+ \rangle$ matrix elements that could provide a distinction between octupole vibration and rigid deformation.

The experiment was conducted using the MINORCA spectrometer (MINiball and ORgam Campaign at ALTO). The γ-ray detection setup was composed of two arrays: eight MINIBALL triple cluster detectors [3] and fifteen Compton-suppressed EUROGAM Phase-I HPGe detectors. The photopeak efficiency of the MINORCA setup was 7.3% at 1332 keV. A new annular Double-Sided Silicon Strip Detector (DSSSD) was used for particle detection [4]. It was placed within the reaction chamber at backward angles with respect to the beam direction, covering an angular range from 120 to 160 degrees in the laboratory frame. In order to exploit the dependence of the Coulomb excitation probability on the proton number Z, two different ion beams were used: 182 MeV ^{58}Ni ($Z = 28$) and 104 MeV ^{32}S ($Z = 16$). Both beam energies were chosen such that the "safe energy" condition is satisfied [5]. This ensures a purely electromagnetic interaction between the collision partners for all scattering angles. A 1.6 mg/cm^2 ^{146}Nd target isotopically enriched to 97.4% and 1.5 mg/cm^2 ^{148}Sm target enriched to 96.4% were used.

The 6^+, second 4^+ and 1^- states in ^{146}Nd were populated for the first time via Coulomb excitation. In Figure 1 Doppler-corrected γ-ray energy spectra of excited ^{146}Nd and ^{148}Sm are shown with the corresponding partial level schemes. Both beams are marked with different colours — ^{32}S with black and ^{58}Ni with red. Further analysis aims to determine the electromagnetic properties of the studied nuclei. Measured γ-ray intensities combined with existing spectroscopic data, such as lifetimes of low-lying states and branching ratios, will allow for the extraction of a set of matrix elements between all populated states in ^{146}Nd and ^{148}Sm. For this purpose the least square fitting code GOSIA will be used [6].

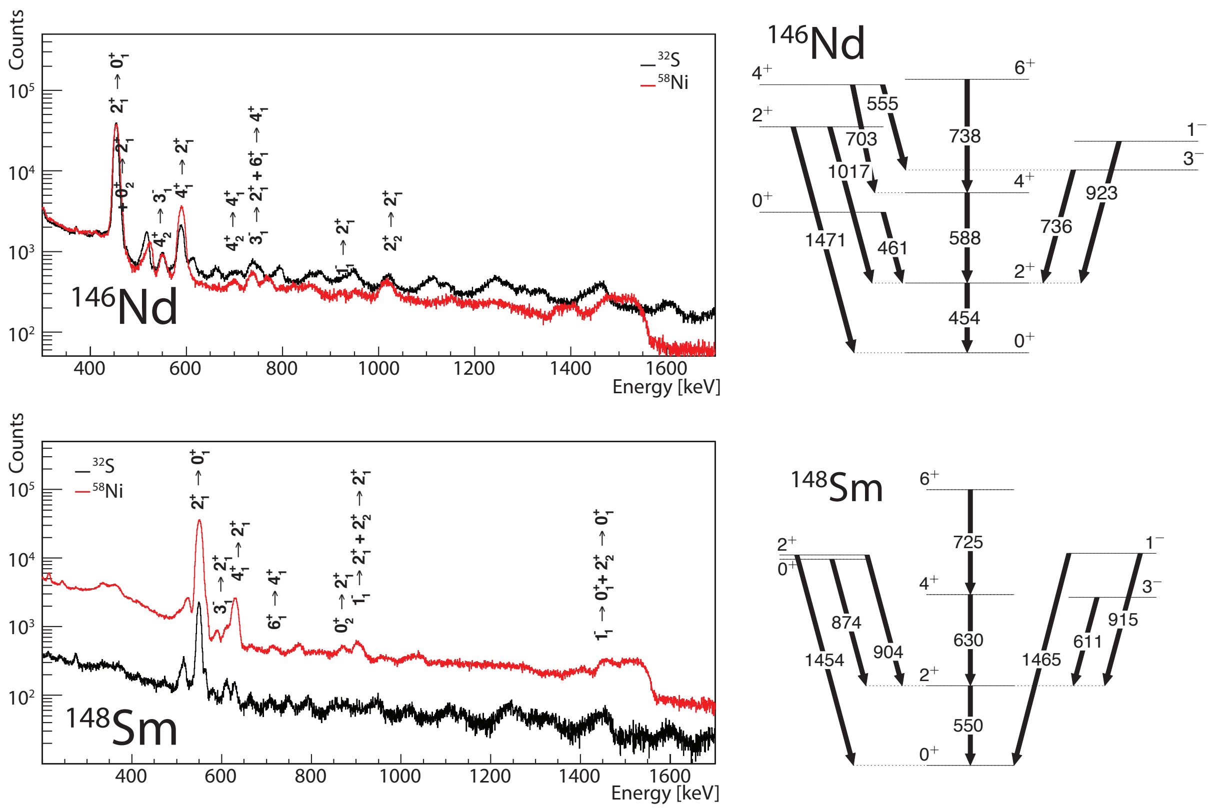

Figure 1: Left: Doppler-corrected γ-ray energy spectra showing Coulomb excitation of ^{146}Nd and ^{148}Sm obtained in experiments with ^{32}S and ^{58}Ni beams, marked with black and red, respectively. Right: Partial level schemes of ^{146}Nd and ^{148}Sm showing levels and transitions observed in these experiments.

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C.7 New setup for Coulomb excitation experiments

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The mechanical development and tests of a new annular Double-Sided Silicon Strip Detector (DSSSD) have been performed at HIL. The detector was used for the first time in the Coulomb excitation experiments performed at the ALTO facility, IPN Orsay during the MINORCA campaign [1].

The detector was manufactured by RADCON Ltd., Zelenograd, Russia and assembled at Lund University, Sweden. It is owned by CEA Saclay IRFU/SPhN. The shape of the device physically resembles a compact disc with an inner diameter of 10 mm and outer of 85 mm (see photo in Fig. 1). It is small enough to fit inside a large solid angle γ-detector array and enables Doppler shift corrections at energies in the vicinity of the Coulomb barrier. The front side of the DSSSD detector is composed of 64 annular junction strips with 16-fold electronic segmentation. On the rear side it has 32 ohmic radial strips, alternately paired (i.e. even-odd) resulting in a 16-fold electronic segmentation. The detector geometry follows the scattering symmetry that can be encountered in many experiments and it allows for both Θ and Φ angles to be determined unambiguously. The Si wafer of 0.52 mm thickness is mounted on a custom-made printed circuit board. Six straight high-density connectors guide the total of 96 signals to the MINIBALL CD preamplifiers [2].

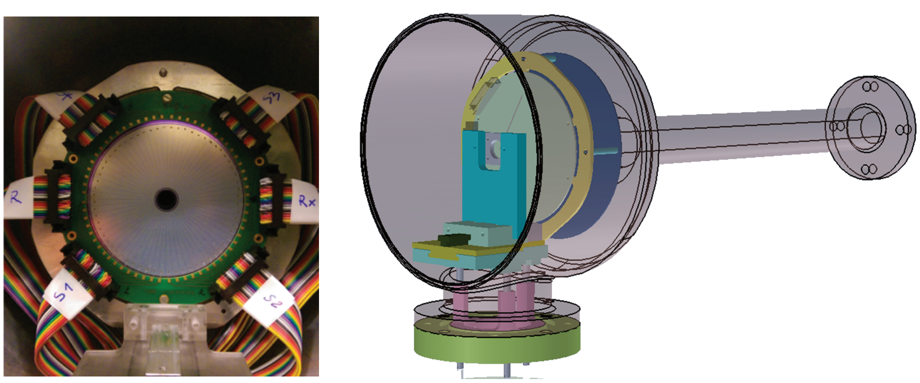

Figure 1: Right: the final design of the detector and target holder mechanics. Left: photo of the DSSSD placed within the Minorca Array target chamber.

The cabling, connectors and vacuum feedthroughs for mounting the detector within the target chamber were made at HIL. Fig. 1 shows the mechanical design of the detector and target holder placed within the target chamber. A chamber, which is regularly used for target thickness measurements, was adapted for testing the detector with an ^{241}Am alpha source. In Fig. 2 signals from one segment and one ring are shown in the left and right panel, respectively.

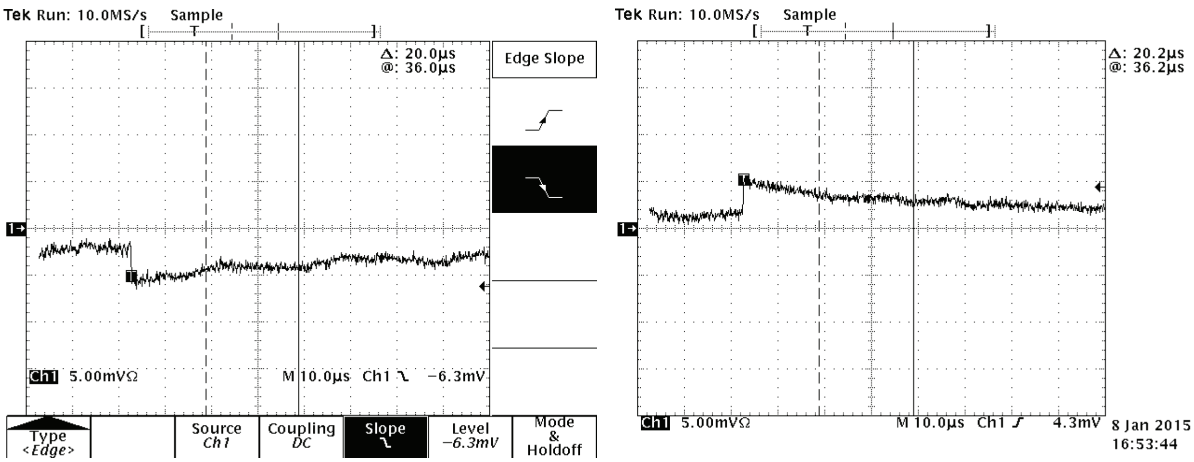

Figure 2: A signal from the ^{241}Am alpha source observed on an oscilloscope. Left: signal from one segment, right: signal from one ring.

The detector was coupled with the MINORCA array at IPN Orsay and successfully used in the Coulomb excitation experiments in which ^{74}Se, ^{146}Nd and ^{148}Sm nuclei were studied. In Figure 3 scattered beam energy spectra from one run with the 182 MeV ^{58}Ni beam bombarding a 1.5 mg/cm^2 ^{146}Nd target are presented. The detector hit pattern is shown in the inset.

The DSSSD detector will be used again during the PARIS@ALTO campaign. It will be combined with the PARIS array consisting of LaBr$_3$-NaI phoswich detectors [3], to measure Coulomb excitation of ^{14}C and ^{40}Ca beam scattered on a ^{208}Pb target.

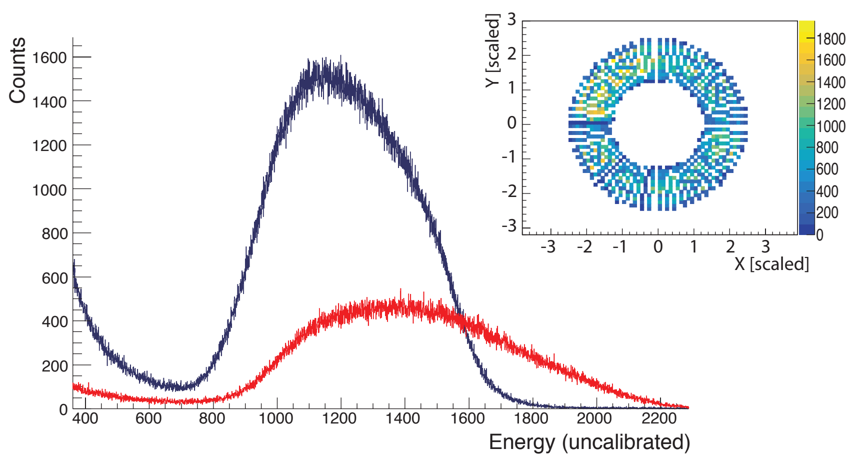

Figure 3: The in-beam particle energy spectra from the DSSSD detector measured in the Orsay experiment. The ^{58}Ni beam ions were scattered from a ^{146}Nd target. One segment and one ring are shown in blue and red, respectively. Inset: Detector hit-pattern.

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C.8 Coulomb excitation of ^{110}Cd

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Coulomb excitation of ^{110}Cd was measured in June 2015 using a 91 MeV ^{32}S beam delivered by the Warsaw Cyclotron. The main goal of the experiment was to determine the spectroscopic quadrupole moments of the low-lying 2^+ states and the reduced transition probabilities, $B(E2)$ values, for transitions deexciting the 0^+_2 and, if possible, the 0^+_3 states. These data are crucial for understanding the low-energy structure of ^{110}Cd, which traditionally has been considered as one of the best textbook examples of a quadrupole vibrator [1, 2]. However, recent spectroscopic data seem to refute this widely accepted view and indicate a rather complicated structure [3–10].

The Coulomb excitation measurement was performed using the EAGLE gamma–ray spectrometer [11] coupled to a compact scattering chamber, which was equipped with 48 PIN diodes [12]. The EAGLE array consists of 15 Compton-suppressed HPGe detectors of 25%–30% efficiency. The particle detectors, PIN diodes, were placed at backward angles of 110 to 152 degrees in the laboratory frame, with respect to the beam direction. An enriched (97.36%) ^{110}Cd target of 1.3 mg/cm^2 thickness was used. Gamma rays depopulating Coulomb excited states of ^{110}Cd and measured in coincidence with backscattered particles were Doppler broadened and shifted in energy.

Fig. 1 presents the low-energy part of the level scheme of ^{110}Cd together with the γ rays observed in the experiment.

A total Doppler-corrected and background subtracted γ-ray spectrum of ^{110}Cd is shown in Fig. 2. The spectrum is summed over all HPGe and charged-particle detectors.

Several states of ^{110}Cd were populated in the present experiment, predominantly through the one-step and two-step Coulomb excitation processes. In addition to the ground-state band, non-yrast levels were also populated. The 0^+_2, 2^+_1, 4^+_1 states of similar energies, interpreted as a two-phonon triplet within the vibrational model, are clearly visible. A weak γ ray at 938 keV is observed and was attributed to the deexcitation of

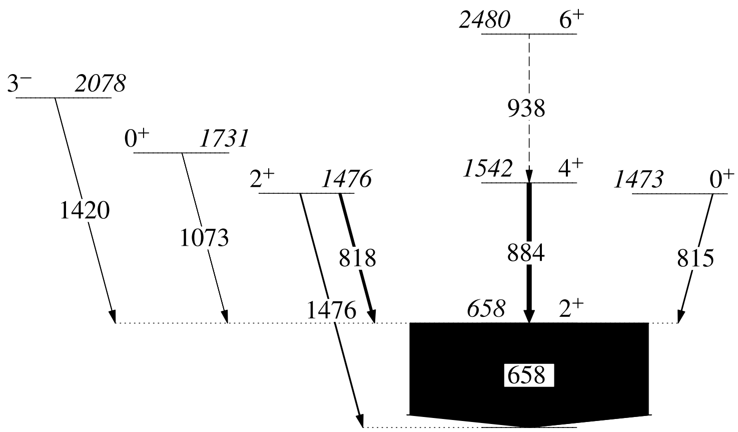

Figure 1: Low-energy states of ^{110}Cd populated in the present experiment. Widths of the arrows are proportional to the γ-ray intensities. A weak $6^+_1 \rightarrow 4^+_1$ γ ray is shown with a dashed arrow.

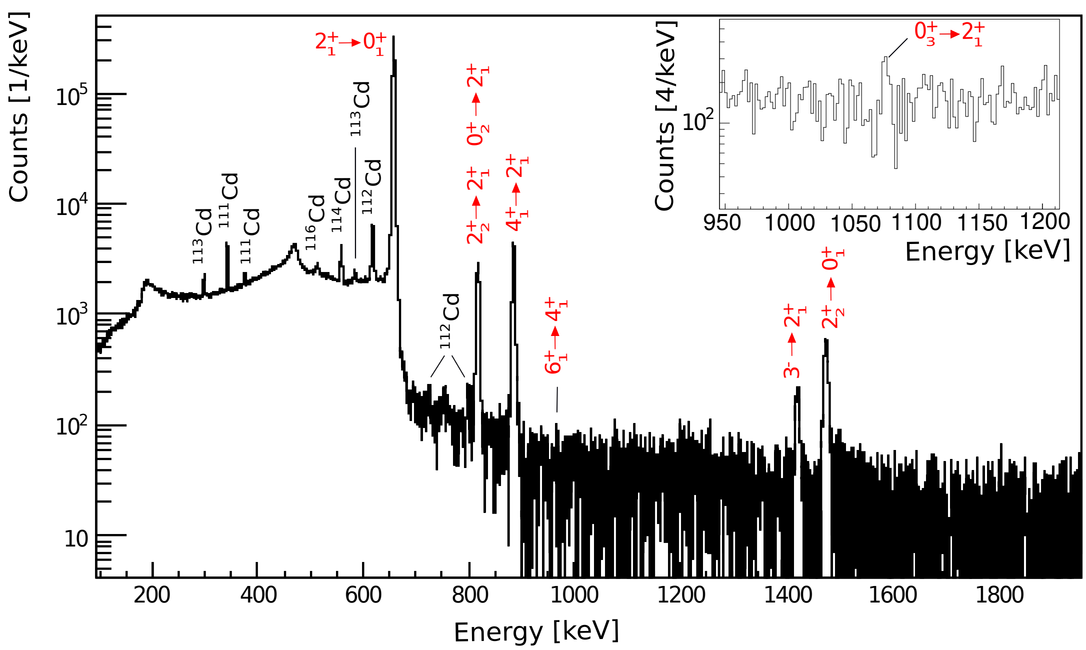

Figure 2: Total Doppler-corrected and background subtracted γ-ray spectrum of ^{110}Cd. Gamma rays observed for ^{110}Cd are marked in red. Both $2^+_2 \rightarrow 2^+_1$ and $0^+_2 \rightarrow 2^+_1$ transitions are observed as a doublet at 818 keV, which can be disentangled using known γ-ray branchings for transitions deexciting the 2^+_2 state [3]. γ-ray lines from Coulomb excitation of target contaminants, $^{111-114}$Cd and ^{116}Cd, are also visible. Enlarged: a weak $0^+_3 \rightarrow 2^+_1$ γ ray in ^{110}Cd is observed.

the 6^+_1 state to the 4^+_1 state. Its intensity, however, requires further analysis and verification. Furthermore, population of the 0^+_3 state is observed as well through a weak $0^+_3 \rightarrow 2^+_1$ γ ray. It is worth pointing out that low-lying 0^+ states were not populated in earlier Coulomb excitation measurements performed with lighter beams of protons, alpha particles or ^{16}O ions [13–18].

Electromagnetic matrix elements connecting states populated in ^{110}Cd will be determined by further analysis. Moreover, the data collected will enable us to determine, for the first time, the reduced transition probability, $B(E2;\ 0^+_2 \rightarrow 2^+_1)$ and at least to establish a lower limit for $B(E2;\ 0^+_3 \rightarrow 2^+_1)$. A rich set of precise complementary spectroscopic data [3–5, 19] will help to constrain the multi-dimensional fit in the Coulomb excitation data analysis which will increase the sensitivity to the quadrupole moments and the relative signs of the matrix elements. The latter are crucial in extracting the asymmetry deformation parameter (triaxiality) for the 0^+_{gs} state. Moreover, it will be possible to determine the overall deformation for both the ground and first excited 0^+ states.

In summary, the collected experimental data will provide essential information to establish the underlying structure of the low-lying states in ^{110}Cd, in particular to understand the character of the low-lying 0^+ states and to reveal whether or not ^{110}Cd possesses a two-phonon 0^+ excited state. Furthermore, verification of mixing of spherical and deformed configurations that coexist in ^{110}Cd should also be possible.

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C.9 Coulomb excitation measurement of ^{104}Pd

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Experimental data on the electromagnetic structure of ^{104}Pd are scarce compared to the experimental information available for the other even-even Pd-isotopes. Earlier, the level structures of even-even stable Pd isotopes were considered as being examples of quadrupole vibrational spectra [1]. However, Coulomb excitation investigations of $^{106-110}$Pd have demonstrated that these nuclei show rather complicated structures [2, 3], which may be explained as a result of the interplay of collective and single particle effects. In particular, the relatively low-lying 0^+ states in this isotopic chain may arise from collective excitations, but it has been suggested that some of them are built on the single-particle intruder states [3].

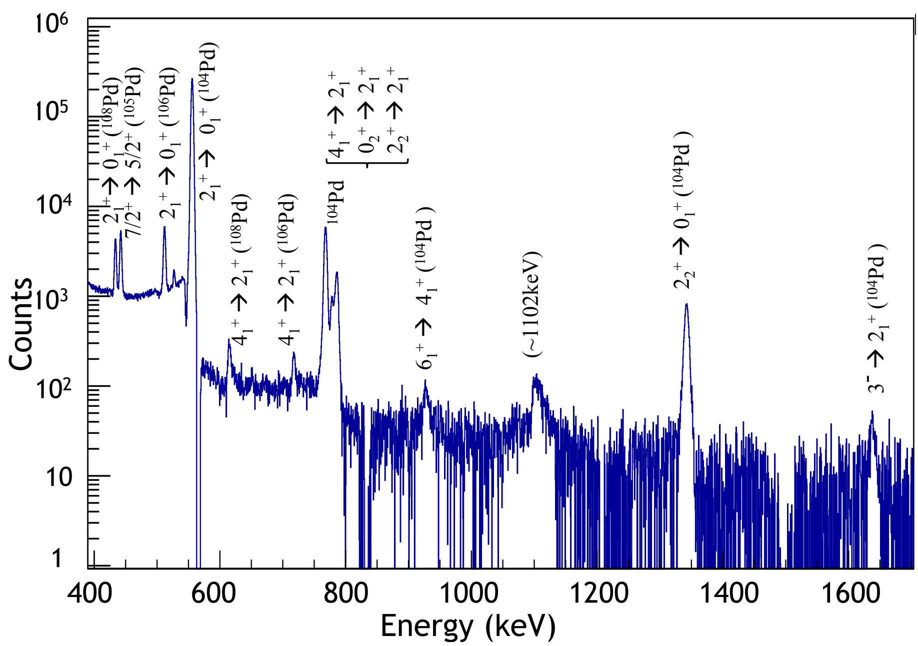

Figure 1: Energy-calibrated, Doppler corrected and random subtracted gamma-ray spectrum resulting from the Coulomb excitation of a highly enriched ^{104}Pd target with a 91 MeV ^{32}S beam.

A Coulomb excitation experiment of ^{104}Pd was carried out at the Heavy Ion Laboratory, Warsaw using a 91 MeV ^{32}S beam. A ^{104}Pd target of 2 mg/cm^2 thickness was used in this experiment. The γ rays depopulating Coulomb excited states were detected using the EAGLE gamma-ray spectrometer [4] in coincidence with scattered projectiles. A total of 48 PIN-diodes of 0.5 x 0.5 cm^2 active area, covering backward angles from 120° to 170° in the Munich chamber [5] were used to detect the back scattered projectiles. Data were collected in particle-gamma coincidence mode for 5 days.

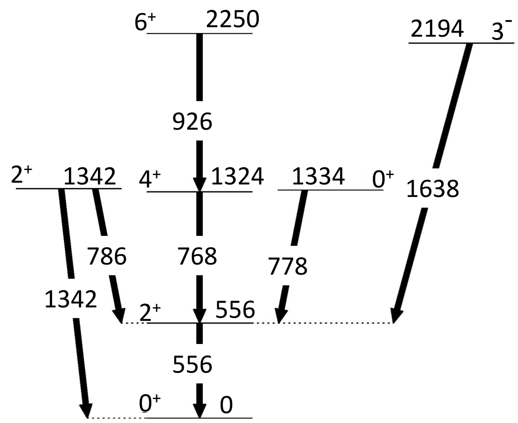

Figure 2: Low energy part of the level scheme of ^{104}Pd populated in the Coulomb excitation experiment with ^{32}S beam. All the energies of levels and gammas are in keV.

Gamma rays depopulating Coulomb excited states of ^{104}Pd were Doppler broadened, therefore correction for this effect was required. Timing gates for prompt and random events were applied to each individual PIN-diode and HPGe detector combination. Random events were subtracted from the prompt events to normalise the 511 keV γ-annihilation peak. The prompt gated and random subtracted gamma-ray spectra for individual PIN-diode-HPGe detectors were summed over all the PIN-diodes and HPGe detectors to get the total statistics, as shown in Fig. 1.

In the present experiment states up to 6^+ in the ground state band along with the low lying non-yrast bands were also populated. Gamma-rays for other stable Palladium isotopes, ^{105,106,108,110}Pd, were also observed as an isotopic contamination in the target and are tagged in the spectrum presented here. The experimentally observed level scheme of ^{104}Pd, together with the observed electromagnetic transitions, is shown in Fig. 2. Further analysis of the data is in progress to determine the matrix elements of different levels using the least square fitting code GOSIA [6].

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C.10 Multi-step Coulomb excitation of ^{132}Ba

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For the understanding of nuclear shell structure, nuclei in the vicinity of doubly magic ^{100,132}Sn are of key importance. In the mass region $A \approx 130$, the xenon and barium nuclei develop a transitional path from spherical shapes to strong deformations. The isotones with $N = 82$, which are semi-magic nuclei, show the features of a spherical vibrator with small collective strength. However, with increasing neutron number the $B(E2;\ 2^+_1 \rightarrow 0^+_{gs})$ value for Ba isotopes decreases and hence the collectivity increases. The same trend is also visible for nuclei with decreasing neutron number. From the additional knowledge of the 4^+ state the nuclear structure can be extracted. For the structure of heavy isotopes one finds an axially symmetric rotor, while nuclei with $N < 82$ show features of triaxial deformation. In the case of ^{132}Ba measurements for the 2^+_1 state were performed in 1958 and 1985 [1,2], but no data for the 4^+ state is available .

A Coulomb excitation experiment of ^{132}Ba was performed in June 2015 at the Heavy Ion Laboratory, Warsaw. A ^{32}S beam of 91 MeV was provided by the U-200P cyclotron. The projectile energy was well below the Cline "safe energy" limit [3]. The gamma rays emitted from Coulomb excited ^{132}Ba nuclei were detected by the EAGLE gamma-ray spectrometer [4]. A compact Coulex chamber, also known as the Munich chamber [5], equipped with 48 PIN-diodes of 0.5 x 0.5 cm^2 active area covering 110°–170° backward angles, was used for the detection of backscattered ^{32}S projectiles to select particle-gamma coincidences in order to perform event by event Doppler shift corrections. Energy calibration of the HPGe-detectors was done using a standard ^{152}Eu source. A ^{132}Ba target (40% enrichment) of ≈ 0.5 mg/cm^2 thickness was prepared in the target laboratory of HIL, Warsaw. Several attempts were made to prepare these targets.

A precise Doppler correction was performed as the gamma-rays detected by the HPGe detectors were Doppler broadened. The timing spectrum was calibrated for 0.1 ns/channel. Timing gates for prompt and random events were applied to each individual combination of PIN-diode and HPGe detector. Random events were subtracted from the prompt events to normalise the 511 keV γ-annihilation peak. The prompt gated and random subtracted gamma-ray spectra for individual PIN-diode-HPGe detector pairs

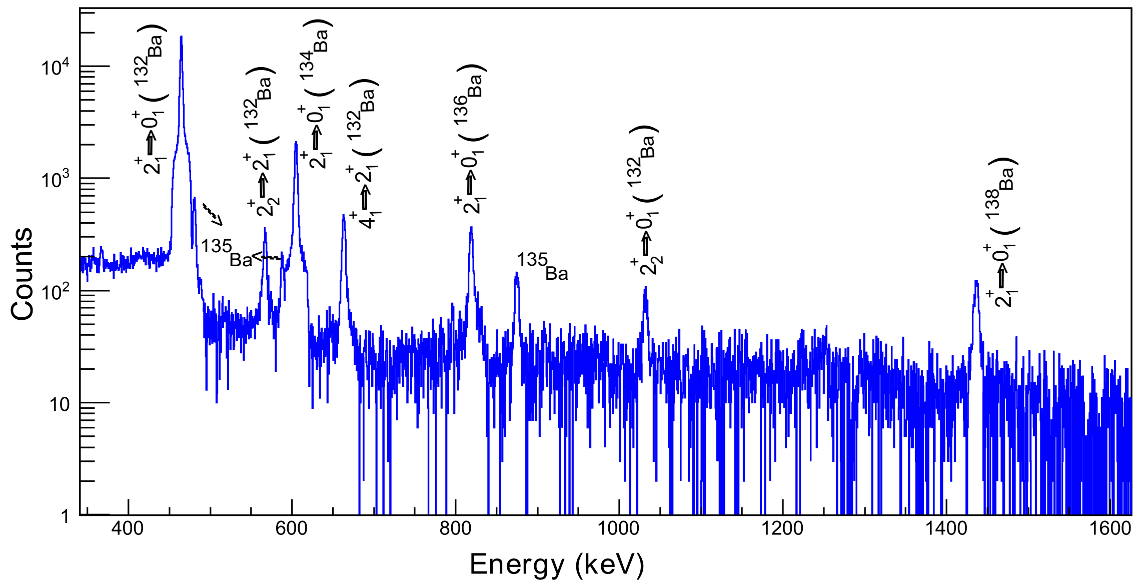

Figure 1: Energy-calibrated, Doppler corrected and random subtracted gamma-ray spectrum resulting from the Coulomb excitation of a highly enriched ^{132}Ba target with 91 MeV ^{32}S beam.

were summed over all the PIN-diodes and HPGe detectors to get the total statistics, and the resulting spectrum is presented in Fig. 1. The data collected are encouraging. The 2^+_1, 4^+_1, 2^+_2 states in ^{132}Ba were observed via de-excitation gamma-rays of 464.5 keV, 663.1 keV and 1031.7 keV & 567.2 keV, respectively. The first 2^+ states in ^{134,136,138}Ba were also observed along with low-lying excited states in ^{135}Ba as an isotopic contamination in the target.

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C.11 Static quadrupole moments in ^{120}Te nuclei

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In recent years the region in the vicinity of the tin isotopes has been intensively investigated both from experimental and theoretical perspectives. In tellurium nuclei with two protons outside the major shell, the partial level schemes are dominated by the $1g_{7/2}$ orbit leading to 6^+ isomers in the vicinity of the $N = 82$ shell closure. At low spin, the Te nuclei are considered to be one of the best examples of quadrupole vibrators. The collective model of nuclear vibrations based on a harmonic oscillator predicts:

(i) a nearly degenerate two-phonon triplet of 0^+, 2^+ and 4^+ states,

(ii) a $B(E2;\ 4_1^+ \to 2_1^+)/B(E2;\ 2_1^+ \to 0_{g.s.}^+)$ ratio equal to 2,

(iii) enhanced quadrupole transitions between states differing by one phonon (e.g. $B(E2;\ 2_1^+ \to 0_{g.s.}^+)$) and strong hindrance of $E2$ transition between states differing by more than one phonon (e.g. $B(E2;\ 2_2^+ \to 0_{g.s.}^+)$),

(iv) vanishing spectroscopic quadrupole moments.

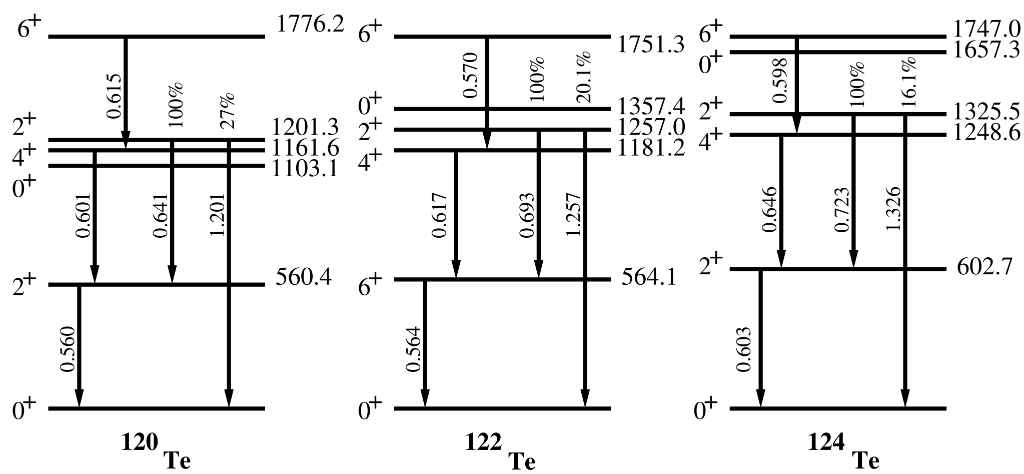

Figure 1: Partial level schemes of ^{120,122,124}Te [3]. The numbers on the arrows are the energies of γ-rays in MeV.

For the mid-shell ^{120,122,124}Te nuclei the partial low-energy level schemes are presented in Fig. 1. The vibrational-like structure with an almost equal energy spacing between the phonon states is visible. This is in contrast to the measured quadrupole moments (Q_{2^+}) in ^{122,124}Te isotopes [1, 2], which reach almost 60% of the values calculated with the rotational model.

In our recent Coulomb excitation experiment [4] at IUAC, New Delhi the $B(E2;\ 0^+_{g.s.} \rightarrow 2^+_1)$ value in ^{120}Te was re-measured with high precision. In addition, the nuclear structure of ^{120,122,124}Te was also investigated by determining the $B(E2\uparrow)$ values to higher lying states. We could clearly see that the experimental $B(E2;\ 4^+_1 \rightarrow 2^+_1)/B(E2;\ 2^+_1 \rightarrow 0^+_{g.s.})$ ratios never reach the vibrational limit. Based on the all experimental findings, level schemes and reduced transition probabilities, for ^{120,122,124}Te one obtains the best agreement with an asymmetric rotor behavior. The aim of the present experiment was to measure the quadrupole moments ($Q_{2^+_1}$) of the first excited states of the stable ^{120}Te using the reorientation effect.

The present experiment was carried out using a 91 MeV ^{32}S beam from the U-200P cyclotron at the Heavy Ion Laboratory, University of Warsaw, Poland. An enriched ^{120}Te target of $\sim 160\ \mu$g/cm^2 thickness with a 10–20 μg/cm^2 carbon backing was used for the measurement. The target enrichment for ^{120}Te was 57.6% with the largest impurity coming from ^{122}Te ($\sim 42\%$). The gamma rays emitted by the ^{120}Te recoils after Coulomb excitation were detected by the EAGLE array consisting of 15 HPGe detectors equipped with BGO anti-Compton shields. A compact Coulex chamber (the so-called Munich Chamber), equipped with 48 PIN-diodes of 0.5 x 0.5 cm^2 active area, was used for the detection of backscattered ^{32}S ions to select particle-gamma coincidences. The PIN-diodes were placed at angles from 110 to 152 degrees to enhance the probability of multi-step Coulomb excitation. For the same reason, the beam energy was chosen to be as high as possible while still ensuring a purely electromagnetic interaction between the collision

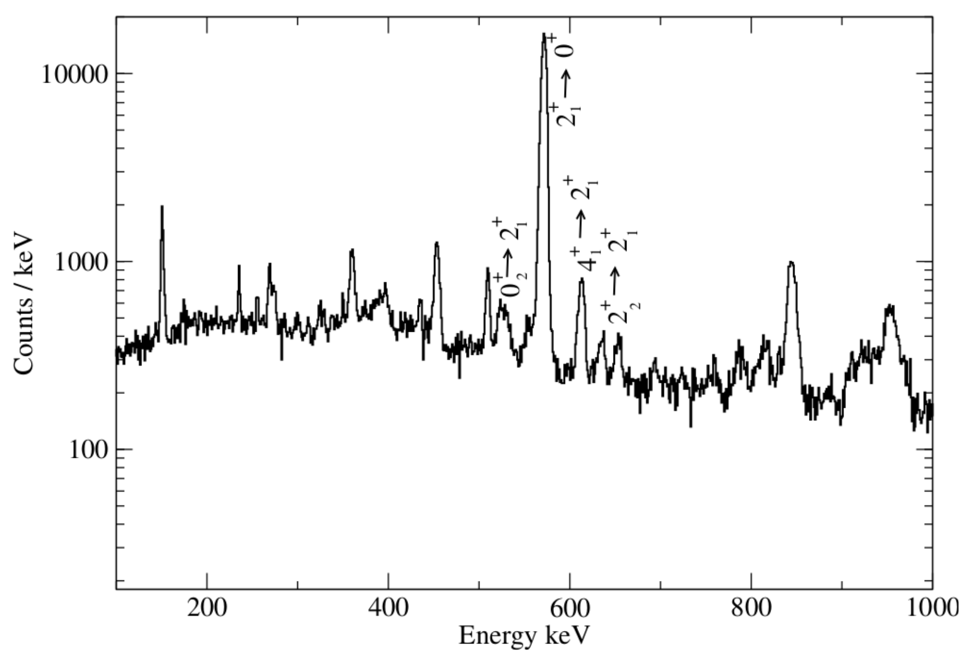

Figure 2: Example of and energy calibrated particle-γ coincidence spectrum of Coulomb excited ^{120}Te for a single HPGe detector.

partners, defined by Cline's criterion [5]. To limit the Doppler broadening of the observed gamma lines, a thin ^{120}Te target was used.

The present data analysis was performed using a dedicated code written using the GO4 software package. Fig. 2 shows an example of an energy calibrated spectrum for one of the Ge detectors. Further analysis of the data, including a precise Doppler correction of the measured γ rays, is in progress. Determination of a set of matrix elements will be performed using the least square fitting code GOSIA [6].

The authors would like to thank the staff of the Heavy Ion Laboratory, University of Warsaw, for providing a stable ^{32}S beam throughout the experiment.

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C.12 Study of beta-delayed charged particle emission from ^{27}S

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Experimental studies of the structure of β-delayed particle emission from ^{27}S and ^{26}P were performed at the ACCULINNA separator at the Flerov Laboratory of Nuclear Reactions (FLNR). The main goal of the experiment was the search for new, so-far unobserved, decay channels of the proton drip-line nucleus ^{27}S. The Optical Time Projection Chamber (OTPC) was employed [1] as the main detection instrument. A diagram showing the principle of operation of the OTPC is presented in Fig. 1.

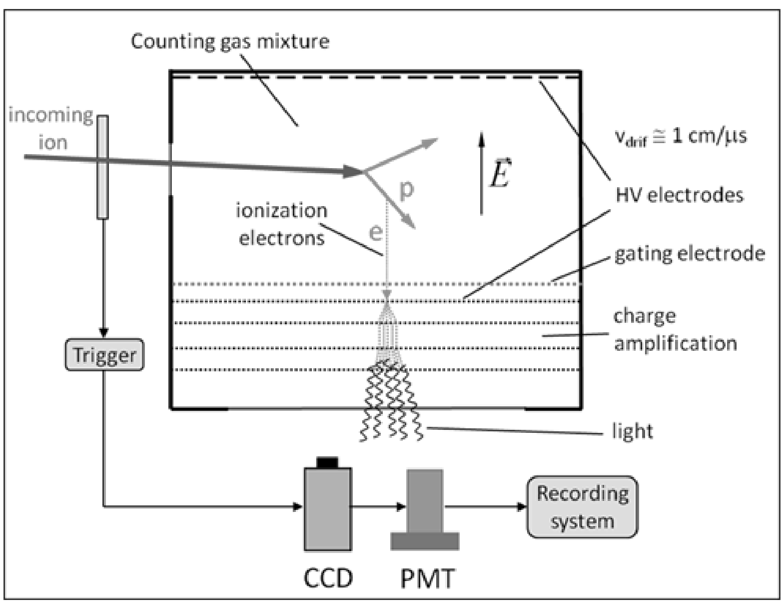

Figure 1: Scheme of operation of the Optical Time Projection Chamber.

The ions of interest were produced by fragmentation of a ^{32}S beam (50 MeV/u) on a ^{9}Be target, followed by in-flight separation at ACCULINNA. Time-of-flight (TOF) and energy-loss measurements were applied for the identification of the ions. The OTPC detector was mounted at the final focal plane of ACCULINNA. It served to record ionisation tracks of charged particles emitted in the decay of ions implanted into the active volume of the detector, which was filled with a gaseous mixture composed of 49.5% Ar + 49.5% He + 1% CO_2.

The ACCULINNA separator was tuned for the optimal transmission of ^{27}S. The production rate of ^{27}S was about 1 ion per 2 minutes. In addition to ^{27}S ions of ^{26}P were also implanted into the OTPC and their decays were recorded. As a result, we observed many events with one and two protons emitted in the decays of ^{27}S and ^{26}P. In Fig. 2 examples of β-delayed proton emission are shown as recorded by the CCD camera of the OTPC. Such information, especially concerning low-energy protons, was not available in previous experiments using different detection technique based on silicon detectors [2]. The results of our experiment may provide new information on the decay schemes of ^{27}S and ^{26}P. Moreover, the angular correlation between the the emitted protons in β2p decay can be obtained. Analysis of the collected data is currently proceeding.

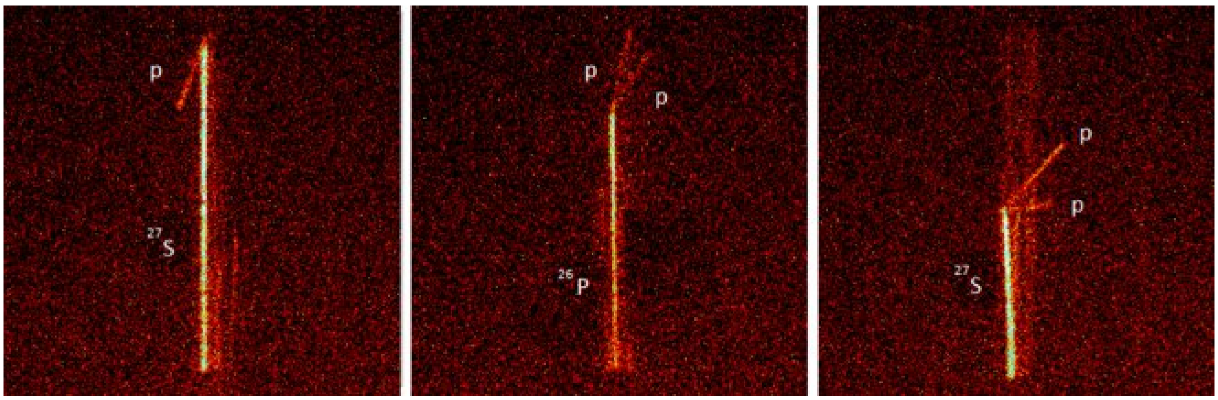

Figure 2: Images recorded by the CCD camera of the OPTC of β-delayed proton events: (a) from ^{27}S, and β 2p emission from (b) ^{26}P, and (c) from ^{27}S.

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C.13 Enhancement factor for the two-neutron transfer reaction induced in ^{6}He + ^{206}Pb scattering below the Coulomb barrier

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Two-nucleon transfer reactions have been used to extract information about pairing correlations in stable nuclei [1, 2]. The problem of pairing is especially interesting in the case of light, neutron rich isotopes like ^{6}He and ^{11}Li. Therefore, in this short contribution we extract the so-called "enhancement factor" (often used as a measure of pairing correlation) for the two-neutron transfer reaction, ^{206}Pb(^{6}He,α)^{208}Pb, from the experimental data taken with a ^{6}He beam at $E_{lab} = 18$ MeV and from their DWBA analysis [3].

In the experiment the angular distribution of the total alpha-yield coming from ^{6}He breakup as well as from the one-neutron and two-neutron transfers was measured. The analysis of the data showed that the alphas coming from breakup are located at forward angles (θ_{lab}), the alphas coming from one-neutron transfer peak at around 100° while the alphas corresponding to the two-neutron transfer are mostly emitted at backward angles. Since the spectroscopic factors for ^{6}He = ^{5}He + n and for the single particle states populated in the ^{207}Pb final nucleus are known, the DWBA calculations published in [3] provided absolute values of the differential cross sections for the one-neutron transfer process, $\sigma_{1n}(\theta_{lab})$. By subtracting these values from the total alpha yield (measured at angles larger than 100° where the contribution from breakup is negligible) one obtains the values of the differential cross section for the two-neutron transfer, $\sigma_{2n}(\theta_{lab})$, in the experimental angular range $\theta_{lab} = 107$–155°.

These data could be presented as the transfer probabilities, P_i, defined as:

$$P_i(\theta_{lab}) = \frac{\sigma_i}{\sigma_{Ruth}}(\theta_{lab}), \tag{1}$$

where σ_{Ruth} is the Rutherford cross section and i stands for one-neutron and two-neutron transfer. The transfer probabilities, in turn, can be presented as a function of the classical distance of closest approach (the experiment was performed below the Coulomb barrier),

$$D = \frac{Z_a Z_A e^2}{2E_{cm}}\left(1 + \frac{1}{sin(\theta_{cm}/2)}\right), \tag{2}$$

where Z_a and Z_A are the charge numbers of the projectile and the target, respectively. The points plotted in Fig. 1 represent the values of the two-neutron transfer probabilities obtained from $\sigma_{2n}(\theta_{lab})$ using the above equations.

It is usually assumed that in the case of uncorrelated neutrons (lack of pairing) in a nucleus the probability of two-neutron transfer is related to the probability of one-neutron transfer in the following way [4],

$$P_{2n} = P_{1n}^2. \tag{3}$$

Recently Hagino and Scamps [5] have shown that the relation

$$P_{2n} = \frac{P_{1n}^2}{4} \tag{4}$$

is more consistent with the result of their coupled-channel calculations for the system ^{40}Ca + ^{96}Zr. Therefore, in Fig. 1, two curves obtained from the DWBA values of σ_{1n} [3] are plotted as dashed and dotted curves, depending on the assumption (eqs. 3 and 4, respectively). Both of them underestimate the points — by a factor of about 12.3 (solid curve) in the first case (eq. 3) and about 50 in the second case (eq. 4). This "enhancement factor" reflects the pairing correlations of the two-neutrons in ^{6}He. It would be very interesting to compare this result with such factors extracted from similar experiments with other neutron-rich nuclei (like ^{11}Li and ^{8}He).

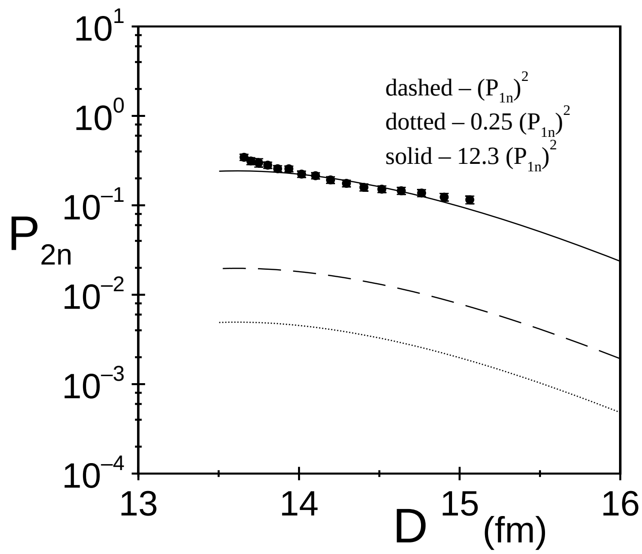

Figure 1: Transfer probabilities for the ^{206}Pb(^{6}He,α)^{210}Pb reaction at a bombarding energy of 18 MeV, as a function of the distance of closest approach. Solid points — values extracted from experimental data [3]. The curves correspond to the predictions according to eqs. 3 and 4. See text for details.

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C.14 Numerical codes for models of nuclear collective excitations

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Collective excitations connected with changes of nuclear deformation constitute a large part of the low-energy spectra of medium and heavy-mass nuclei. Such excitations are most easily visible in even-even nuclei while in odd and odd-odd nuclei they are coupled with single-particle degrees of freedom. The deformation of a nucleus is typically described through a series expansion, most often in a series of spherical multipoles with the quadrupole ($L = 2$) playing the most important role.

Since 1952 (the date of the first paper by A. Bohr on this topic) there have appeared plenty of theoretical papers treating various aspects of quadrupole collectivity using different approaches; we cite here only two recent reviews [1, 2]. Below we focus on the model based on the so-called General Bohr Hamiltonian. For the quadrupole deformation it is possible to define an intrinsic (also called a principal axes) system in which deformation is described by five real variables: β, γ and the Euler angles Ω. In such a way one can simultaneously treat vibrational and rotational degrees of freedom and possible couplings between them.

The collective excitations are described by the Bohr Hamiltonian:

$$H_{\mathrm{coll}} = T_{\mathrm{vib}}(\beta, \gamma; B_{\beta\beta}, B_{\beta\gamma}, B_{\gamma\gamma}) + T_{\mathrm{rot}}(\beta, \gamma, \Omega) + V_{\mathrm{coll}}(\beta, \gamma) \tag{1}$$

where

$$T_{\mathrm{rot}} = \frac{1}{2} \sum_k \frac{J_k^2}{4\beta^2 B_k \sin^2(\gamma + 2k\pi/3)} \tag{2}$$

where the J_k are the components of the angular momentum operator. Six inertial functions $B_{\beta\beta}, B_{\beta\gamma}, B_{\gamma\gamma}, B_k$ which enter the kinetic energy can depend on the deformation but often they are approximated by a constant parameter B (except for $B_{\beta\gamma} = 0$). There are two main approaches to find these functions: the first, more difficult, tries to calculate them from deeper microscopic theory, while the second simply guesses a reasonable form for the functions. Of course it must be an educated guess taking into consideration several requirements coming from e.g. symmetry conditions and physical properties. In this second approach the kinetic energy usually takes the simpler form mentioned previously. There are a few cases where analytical solutions of the eigenvalue problem of the operator (1) are known but in most cases one must resort to numerical calculations.

For several years we have developed numerical codes for calculating the eigenvalues and eigenfunctions of the Bohr Hamiltonian. Recently we added a web interface to access these codes through the HTTP protocol. More precisely, the codes are run on one of the HIL servers while the parameters of the chosen model are set by a user through a web browser and the results of the calculations are also obtained through a browser.

At present it is possible to perform calculations of two types:

1. The full Bohr Hamiltonian (1) with one of the potentials given below:

$$V_1(\beta, \gamma) = Vc\beta^2/2 + G(\exp(-\beta^2/a^2) - 1) \tag{3}$$

$$V_2(\beta,\gamma) = (C/8)(\beta^2/2 + \beta_0^4/\beta^2 - 2\beta_0^2) - D \tag{4}$$

$$V_3(\beta,\gamma) = C_2\beta^2/2 + f\beta^3\cos(3\gamma) + C_8\beta^8 + G(\exp(-\beta^2/a^2) - 1) \tag{5}$$

$$\begin{aligned} V_4(\beta,\gamma) = {} & C\beta^2/2 - f\beta^3\cos(3\gamma) + \\ & + \exp(-\beta^2/a^2)(G_0 + G_1(\beta/a)^3\cos(3\gamma) + G_2(\beta/a)^6\cos(3\gamma)^2) \end{aligned} \tag{6}$$

We preserve the notation used in the papers where these potentials were proposed [3–5].

2. The triaxial rigid rotor (Davydov-Filippov model [6]) where

$$H_{\text{coll}} = T_{\text{rot}} \tag{7}$$

This model can also be regarded as a limiting case of the Bohr Hamiltonian when the deformations β and γ are fixed.

Input data to be given by the user consists of the parameters entering the formulae (3-6), an effective charge used for the calculation of the E2 transitions as well as some additional information e.g. the range of angular momenta, number of calculated eigenstates etc. Output data are: eigenenergies of the Hamiltonian and matrix elements of the E2 electromagnetic transition operator. The Bohr Hamiltonian code also gives probabilities of the K number components in the expansion of a given eigenfunction. The rigid rotor code also produces an input to a code calculating the spectra of odd nuclei within the Core-Particle-Coupling model (not yet available through the web interface).

The codes are accessible through the webpage `http://buka.slcj.uw.edu.pl/www`. Typical run-time does not exceed some minutes for type 1 calculations and some seconds for type 2.

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C.15 New development of large area thin and super-thin epitaxial silicon detectors

A.J. Kordyasz[1], W. Czarnacki[2], Ł. Kordyasz[3], M. Gerlach[3], A. Bednarek[1], M. Kowalczyk[1,4], J. Tarasiuk[4], M. Kisieliński[1], T. Kozik[5], E. Piasecki[1], P. Napiorkowski[1], J. Sarnecki[6], D. Lipiński[6], H. Wodzińska[6], M. Teodorczyk[6], M. Gajewski[6], A. Zagojski[6], K. Krzyżak[6]

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Thin epitaxial silicon detectors

The low-temperature techniques of thin silicon ion implanted epitaxial detectors [1] were elaborated and tested with heavy ions with charge resolution up to $Z = 25$. However, large leakage currents were detected since the edges of the detectors were not protected by a SiO_2 layer [1]. This technology is tested using $20\times20\text{mm}^2$, 21 μm thick epitaxial detectors. An efficient decrease of the leakage current of surface barrier silicon detectors has been achieved by pyrolytic oxide, 700 Å thick, deposited on the detector edge regions [2]. The creation of pyrolytic oxide is a low temperature process, therefore it can be applied to the low-temperature technique of thin silicon ion implanted epitaxial detectors [1]. Now the work with 20×20 mm^2, 20 μm thick epitaxial detectors is carried out using 1200 Å thick pyrolytic oxide.

Large-area, super-thin epitaxial silicon detectors

Super-thin, self-biased silicon strip epitaxial detectors have been described in the work of Ref. [3]. Using the anodic dissolution process a four inch epitaxial silicon membrane about 5 μm thick was produced for super-thin silicon detectors. Detector strips on this membrane were created by the low-temperature technique [1, 3]. The strip detector was operated using the internal built-in potential, without any external bias. The detector response ($\Delta E - E$ plots) for α particles and fission fragments from ^{252}Cf was measured. The main problem is the huge capacitance of super-thin self-biased strip detectors, which produces noise in the charge preamplifier. To overcome this problem the surface of the strips should be reduced. A measurement of the energy loss of 5 MeV protons in a 5 μm thick silicon detector is possible, if electronic noise is at the level of about 20 keV. The reduction of electronic noise is possible for a self-biased thin 5 μm thick silicon detector by decreasing the detector capacitance, which can be achieved by reducing the strip width to about 0.1 mm. Such a strip detector with strips 20 mm long and 0.1 mm wide will be able to measure protons, light charged particles and heavy ions. Super-thin strip detectors of this kind are in preparation and their applications are discussed in Ref. [3].

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C.16 Prospects for the construction of diamond detectors to detect charged particles, fission fragments and heavy ions

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A low power Microwave Chemical Vapour Deposition (MWCVD) reactor has been constructed at HIL [1]. In this reactor we controlled by a computer system the temperature of the Mo holder containing the diamond sample, the CH_4/H_2 ratio, and the pressure of the gas mixture. Diamond detectors were constructed using a diamond layer grown on a diamond HPHT substrate. The detector registered a high flux of X rays in current mode with good linearity versus X-ray dose [1]. Unfortunately, α particles, fission fragments from a ^{252}Cf source and heavy ions were not registered in the pulsed mode using a charge preamplifier. The most probable reason is contamination of the CH_4/H_2 plasma by nitrogen from the air, which stopped the electron and hole pair transport in the diamond crystal [2]. The nitrogen may be present in the reactor due to the plastic tubes which leak air [1].

For the production of detectors very pure diamond material should be used. For example, the Element Six company produced an electronic grade single cristal CVD with nitrogen concentration smaller then 1 ppb. In such material the lifetime of holes and electrons is greater than 1 microsecond, and the collection of charges is achieved in a thickness of about 1 mm.

A new version of the CVD reactor should be built using high vacuum technology for protection against nitrogen contamination. The production of hydrogen by electrolysis of water should be well separated from air to stop contamination by nitrogen. The amount of nitrogen in the CH_4/H_2 gas mixture should be controlled by high resolution plasma optical spectrometry.

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Part D

Appendices

D.1 List of experiments performed at HIL in 2015

A list of the experiments performed in 2015 is presented in the following pages. The following acronyms of institution names are used in the list:

- HIL — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland;
- Aligarh Univ. — Department of Physics, Aligarh Muslim University, Aligarh, India;
- Bratislava — Inst. of Physics, Slovak Academy of Sciences, Bratislava, Slovakia;
- CEA Saclay — IRFU/SPhN, CEA Saclay, Gif-sur-Yvette, France;
- GANIL —GANIL, Caen, France;
- GENU — L.N. Gumilyov Eurasian National University, Astana, Kazakhstan;
- HCCC Kielce — Holycross Cancer Center, Kielce, Poland;
- IEP UW —Institute of Experimental Physics, University of Warsaw, Warszawa, Poland;
- INFN Milano — I.N.F.N. Sezione di Milano, Milano, Italy;
- iThemba LABS — iThemba Lab. for Accelerator Based Sciences, Faure, South Africa;
- INP Kraków — The H. Niewodniczański Institute of Nuclear Physics, Kraków, Poland;
- INP Uzbekistan — Uzbekistan Academy of Sciences, Institute of Nuclear Physics, Tashkent, Uzbekistan;
- JINR — Joint Institute for Nuclear Research, Dubna, Russia;
- JYFL — Department of Physics, University of Jyväskylä, Finland;
- KNU Almaty — Al-Farabi Kazakh National University, Almaty, Kazakhstan;
- New Delhi Univ. — Department of Physics and Astrophysics, University of Delhi, New Delhi, India;
- New Delhi A.C. — Inter University Accelerator Centre, New Delhi, India;
- NCNR Świerk — National Centre for Nuclear Research, Świerk, Poland;
- NNC Almaty — Institute of Nuclear Physics of the National Nuclear Center, Almaty, Kazakhstan;
- NU Astana— Nazarbayev University Research and Innovation System, Astana, Kazakhstan;
- ORNL — Oak Ridge National Laboratory, Oak Ridge, TN, USA;
- PTB — PTB, Braunschweig, Germany;
- PW — Warsaw University of Technology, Warszawa, Poland;
- RC Russia — National Research Center "Kurchatov Institute", Moscow, Russia;
- SPSU — Saint-Petersburg State University, Saint-Petersburg, Russia;
- U. Guelph — University of Guelph, Ontario, Canada;
- U. Kentucky — Department of Physics and Astronomy, University of Kentucky, Lexington, KY, USA;
- UŁ — Faculty of Physics and Applied Computer Science, University of Lodz, Łódź, Poland;
- U. Oslo — Department of Physics, University of Oslo, Oslo, Norway;
- US Katowice — Institute of Physics, University of Silesia, Katowice, Poland;

For each experiment the following information is provided: ion, energy, setup/beam line information, date, proposal number, subject, spokespersons and institutions.

$^{12}C^{+3}$ – 90 MeV – beam line A 19.01 – 20.01
HIL051 – Characterization of the Optical Time Projection Chamber (C. Mazzocchi)
IEP UW

$^{12}C^{+3}$, $^{16}O^{+4}$ – 90 MeV/A, 118 MeV – Radiobiology 26.01 – 30.01
HIL042 – Survival of CHO-K1 cells after double-ions irradiation (J. Czub, Z. Szefliński)
HCCC Kielce, HIL, IEP UW

$^{16}O^{+3}$ – 80 MeV – ICARE 03.02 – 05.02
HIL047 – Identification of the fission fragments produced in the $^{16}O+^{208}Pb$ reaction using a E-ΔE telescope (A. Kordyasz)
HIL, NCNR Świerk, IEP UW

$^{4}He^{+1}$ – 30 MeV – Internal beam 11.02 – 13.02
HIL055 – Medical radioisotopes produced using alpha-particle beam from the Warsaw Heavy Ion Cyclotron (J. Jastrzębski)
HIL, US Katowice

$^{10}B^{+2}$ 24, 25, 26.02
HIL000 – Test of the cyclotron (P. Gmaj)
HIL

$^{32}S^{+5}$ – 90 MeV – EAGLE 02.03 – 08.03
HIL053 – Study of static quadrupole moments in ^{120}Te (M. Saxena, R. Kumar)
New Delhi, HIL, IEP UW

$^{32}S^{+5}$ – 90 MeV – EAGLE 09.03 – 13.03
HIL043 – Coulomb excitation of ^{104}Pd (K. Wrzosek-Lipska)
HIL, New Delhi A.C., Aligarh Univ., IEP UW, UŁ

$^{40}Ar^{+8}$ – 220 MeV – EAGLE 17.03 – 27.03
HIL046 – Level spins in ^{140}Sm measured using the angular correlation method (J. Samorajczyk, J. Srebrny)
UŁ, HIL, NCNR Świerk, IEP UW

$^{4}He^{+1}$ – 30 MeV – Internal beam 30.03 – 02.04
HIL055 – Medical radioisotopes produced using alpha-particle beam from the Warsaw Heavy Ion Cyclotron (J. Jastrzębski)
HIL, US Katowice

$^{10}B^{+2}$ 10, 14.04
HIL000 – Test of the cyclotron (P. Gmaj)
HIL

$^{16}O^{+4}$ – 95 MeV – ICARE 15.04 – 17.04
HIL047 – Identification of the fission fragments produced in the $^{16}O+^{208}Pb$ reaction using a E-ΔE telescope (A. Kordyasz)
HIL

$^{32}S^{+6}$ – 95 MeV – IGISOL 20.04 – 23.04
HIL048 – Search for beta-delayed proton emission in the beta decay of ^{80}Zr (K. Miernik, Z. Janas)
IEP UW

$^{24}Mg^{+4}$ 28.04
HIL000 – Test of the cyclotron (P. Gmaj)
HIL

$^{4}He^{+1}$ – 30 MeV – Internal beam 04.05 – 07.05
HIL055 – Medical radioisotopes produced using alpha-particle beam from the Warsaw Heavy Ion Cyclotron (J. Jastrzębski)
HIL, US Katowice

$^{14}N^{+2}$ – 34 MeV – ICARE 11.05 – 13.05, 21.05
HIL040 – Measurements of cross sections for elastic scattering and one-nucleon transfer reactions with ^{14}N ions on light nuclei at energies near the Coulomb barrier (S. Kliczewski, N. Burtebayev)
NNC Almaty, HIL, KNU Almaty, RC Russia, NU Astana, INP Uzbekistan

$^{40}Ar^{+7}$ 26, 28, 29.05
HIL000 – Test of the cyclotron (P. Gmaj)
HIL

$^{40}Ar^{+7}$ – 150 MeV – EAGLE 08.06 – 13.06
HIL045 – Coulomb excitation of the strongly deformed band in ^{40}Ar (K. Hadyńska-Klęk, P. Napiorkowski)
U.Oslo, HIL, INP Kraków, iThemba LABS, IEP UW, INFN Milano, CEA Saclay, New Delhi Univ., New Delhi A.C.

$^{32}S^{+5}$ – 90 MeV – EAGLE 15.06 – 21.06
HIL044 – Electromagnetic structure of low-lying sates in ^{116}Cd studied with multi-step Coulomb excitation (K. Wrzosek-Lipska)
HIL, U.Guelph, U.Kentucky, ORNL, New Delhi Univ., New Delhi A.C., Aligarh Univ., Bratislava, IEP UW, UŁ, PW, U.Oslo

$^{32}S^{+5}$ – 90 MeV – EAGLE 22.06 – 28.06
HIL052 – Multiple Coulomb excitation of ^{132}Ba (R.Kumar, S.Dutt)
New Delhi, U.Guelph, U.Kentucky, ORNL, Bratislava, UŁ, PW, HIL

$^{4}He^{+1}$ – 30 MeV – Internal beam 28.06 – 01.07
HIL055 – Medical radioisotopes produced using alpha-particle beam from the Warsaw Heavy Ion Cyclotron (J. Jastrzębski)
HIL, US Katowice

$^{14}N^{+3}$ 03.07
HIL000 – Test of the cyclotron (P. Gmaj)
HIL

$^{14}N^{+3}$ – 85 MeV – IGISOL 06.07 – 08.07
HIL048 – Search for beta-delayed proton emission in the beta decay of ^{80}Zr (K.Miernik, Z.Janas)
IEP UW

$^{4}He^{+1}$ – 30 MeV – Internal beam 13.07 – 16.07
HIL055 – Medical radioisotopes produced using alpha-particle beam from the Warsaw Heavy Ion Cyclotron (J. Jastrzębski)
HIL, US Katowice

$^{4}He^{+1}$ – 30 MeV – Internal beam 20.07 – 23.07
HIL055 – Medical radioisotopes produced using alpha-particle beam from the Warsaw Heavy Ion Cyclotron (J. Jastrzębski)
HIL, US Katowice

$^{14}N^{+3}$ 24.07
HIL000 – Test of the cyclotron (P. Gmaj)
HIL

$^{24}Mg^{+5}$ 02.12 – 03.12, 09.12 – 10.12
HIL000 – Test of the cyclotron (P. Gmaj)
HIL

D.2 Degrees and theses completed in 2015 or in progress

D.2.1 PhD theses of students affiliated to HIL, of HIL staff members, and supervised by HIL staff

Justyna Samorajczyk, University of Łódź
Gamma-ray angular correlation studies with the EAGLE setup
Supervisors: prof. dr hab. J. Andrzejewski, dr J. Perkowski. Defended in December 2015.

Urszula Kaźmierczak, Faculty of Physics, University of Warsaw
Dawka lokalna i jej rola w biologicznej odpowiedzi linii komórkowych ssaków in vitro
Local dose and its role in the biological response of mammalian cells in vitro
Supervisors: dr hab. Z. Szefliński, prof. dr hab. A. Lankoff. Defended in May 2016.

Olga Saeed Mohamed Nassar, Faculty of Physics, Warsaw University of Technology
Optyka jonowa w centrum cyklotronu U-200P
Ions trajectory in the central region of the U-200P cyclotron
Supervisors: dr hab. Marcin Palacz, dr Ivan Ivanenko. Expected completion time: 2017.

Łukasz Standyło, National Centre for Nuclear Research, Świerk
Badanie oddziaływania ^{6}He z jądrami ^{206}Pb przy energiach blisko bariery kulombowskiej
Study of the interaction of ^{6}He with ^{206}Pb nuclei at energies close to the Coulomb barrier
Supervisor: prof. dr hab. K. Rusek. Expected completion time: 2016.

Tomasz Marchlewski, Faculty of Physics, University of Warsaw
Supervisors: prof. dr hab. K. Rusek, dr E. Grodner. Expected completion time: 2017.

Michalina Komorowska, Faculty of Physics, University of Warsaw
Pear-shaped Nuclei in the $N \sim 88$ mass region
Supervisors: dr hab. L. Próchniak, dr P. Napiorkowski, dr W. Korten, dr M. Zielińska.
Expected completion time: 2018.

Mateusz Pęgier, Faculty of Chemistry, University of Warsaw
Synteza i kontrola jakości radiofarmaceutyków znakowanych izotopem ^{44}Sc
Synthesis and quality control of the radiopharmaceuticals labelled with ^{44}Sc
Supervisor: prof. dr hab. K. Pyrzyńska. Expected completion time: 2018.

Mateusz Sitarz, Faculty of Physics, University of Warsaw
Supervisors: prof. dr hab. T. Matulewicz, dr A. Trzcińska.
Expected completion time: 2019.

D.2.2 Other PhD theses based on experiments performed at HIL

Katarzyna Szkliniarz, Silesian University
Supervisor: prof. dr hab. W. Zipper. Expected completion time: 2016.

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

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

Sunil Dutt, Aligarh Muslim University, Aligarh, (U.P.) India
Supervisor: prof. A. Rizvi. Expected completion time: 2018.

D.2.3 MSc and BSc theses supervised by HIL staff members

Hubert Dąbrowski, Faculty of Chemistry, University of Warsaw
Sorpcja jonów Sc(III) na stałych sorbentach
Sorption of Sc(III) ions on solid sorbents
Supervisors: prof. dr hab. K. Pyrzyńska, dr K. Kilian.
MSc thesis completed in June 2015.

Mateusz Sitarz, Faculty of Physics, University of Warsaw
Produkcja radioizotopów ^{43}Sc i ^{44}Sc z użyciem wiązki cząstek a jako emiterów pozytronów do obrazowania medycznego — ocena wydajności procesu
Production of positron emitters: ^{43}Sc and ^{44}Sc using an alpha particle beam — process efficiency evaluation
Supervisors: dr R. Kuś, dr A. Trzcińska. MSc thesis completed in July 2015.

Roman Szenborn, Faculty of Physics, University of Warsaw
Analysis of random γ-γ coincidences in DSA experiments with the EAGLE array
Supervisors: dr E. Grodner, dr J. Srebrny. MSc thesis, expected completion time: 2016.

Mateusz Filipek, Faculty of Physics, University of Warsaw
Wpływ kolimatorów na parametry obrazu ze skanera SPECT
Influence of collimators on image parameters of the SPECT scanner
Supervisors: dr R. Kuś, U. Kaźmierczak. BSc thesis completed in September 2015.

Marina Gerszewska, Faculty of Physics, University of Warsaw
Synteza ^{18}F MISO do badań przedklinicznych na małych zwierzętach
Synthesis of ^{18}F MISO for preclinical studies on small animals
Supervisors: dr hab. P. Suffczyński, dr K. Kilian. BSc thesis completed in September 2015.

Piotr Kaźmierczak, Faculty of Physics, University of Warsaw
Ocena jakościowa i ilościowa zanieczyszczeń radionuklidowych w procesie syntezy fluorodeoksyglukozy
Qualitative and quantitative evaluation of radionuclide contamination in the synthesis of fluorodeoxyglucose
Supervisors: dr K. Kilian, dr hab. P. Suffczyński. BSc thesis completed in February 2015.

Natalia Ojrzyńska, Faculty of Physics, University of Warsaw
Zastosowanie radiofarmaceutyków krótkożyciowych w diagnostyce kardiologicznej. Stan obecny i perspektywy rozwoju.
Application of short-lived radiopharmaceuticals in cardiology. Current status and perspectives.
Supervisors: dr K. Kilian, dr hab. J. Żygierewicz. BSc thesis completed in December 2015.

Magdalena Rodak, Faculty of Physics, University of Warsaw
Wykorzystanie reakcji kompleksowania do wytwarzania radiofarmaceutyków znakowanych izotopami metalicznymi
The use of complexation reactions for synthesis of radiopharmaceuticals with metallic isotopes
Supervisors: dr K. Kilian, dr hab. P. Suffczyński. BSc thesis completed in June 2015.

Agnieszka Strzeżek, Faculty of Physics, University of Warsaw
Analiza wykrywalności guzów o podwyższonej aktywności na rzeczywistych i symulowanych obrazach w tomografii pojedynczych fotonów (SPECT).
Analysis of detection of tumors with increased activity in real and simulated images in single photon tomography (SPECT).
Supervisor: dr hab. Z. Szefliński. MSc thesis, expected completion time: 2016.

Zofia Biały, Faculty of Physics, University of Warsaw
Określenie granic wykrywania patologii w obrazowaniu medycznym z użyciem fantomu Jaszczaka.
Determination of pathology detection limits in medical imaging using a Jaszczak phantom.
Supervisor: dr hab. Z. Szefliński. BSc thesis, expected completion time: 2016.

Łukasz Celejewski, Faculty of Physics, University of Warsaw
Porównanie systemów dozymetrycznych stosowanych w Pracowni Obrazowania Medycznego ŚLCJ.
Comparison of dosimetry systems used in the Laboratory of Medical Imaging at HIL.
Supervisor: dr hab. Z. Szefliński. BSc thesis, expected completion time: 2016.

Norbert Suchojad, Faculty of Physics, University of Warsaw
Kalibracja Gamma Kamery i dozymetria przy przygotowaniu fantomów
Gamma Camera calibration and dosimetry in phantom preparation
Supervisor: dr hab. Z. Szefliński. BSc thesis, expected completion time: 2016.

Kamila Żujewska, Faculty of Physics, University of Warsaw
Badanie struktury trajektorii cząstki alfa oddziaływującej w rozrzedzonym molekularnym azocie.
Examination of the structure of the trajectory of alpha particles interacting in rarefied molecular nitrogen.
Supervisor: dr hab. Z. Szefliński. BSc thesis, expected completion time: 2016.

Błażej Mleczko, Silesian University
Opracowanie metody wyznaczania aktywności radioizotopu ^{211}At za pomocą radiometru
Preparation of a method of determining ^{211}At activity using a radiometer
Supervisors: dr hab. A Konefał, prof. dr hab. J. Jastrzębski.
MSc thesis, expected completion time: 2016.

D.3 Publications

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

A. Bantsar, G. Hilgers, S. Pszona, H. Rabus, and Z. Szefliński. *Experimental investigation of ionisation track structure of carbon ions at HIL Warsaw.* Radiation Protection Dosimetry **166**, 253 (2015).

C. Betsou, A. Pakou, F. Cappuzzello, L. Acosta, C. Agodi, X. Aslanoglou, D. Carbone, M. Cavallaro, A. D. Pietro, J. Fernandez-Garcia, P. Figuera, M. Fisichella, A. Foti, N. Keeley, G. Marquinez-Duran, I. Martel, M. Mazzocco, N. Nicolis, D. Pierroutsakou, K. Rusek, O. Sgouros, V. Soukeras, E. Stiliaris, E. Strano, and D. Torresi. *Study of the $^{6}Li\ p \rightarrow {}^{3}He\ {}^{4}He$ reaction in inverse kinematics.* Eur. Phys. J. A **51**, 86 (2015).

S. Bottoni, S. Leoni, B. Fornal, R. Raabe, K. Rusek, G. Benzoni, A. Bracco, F. C. L. Crespi, A. I. Morales, P. Bednarczyk, N. Cieplicka-Orynczak, W. Królas, A. Maj, B. Szpak, M. Callens, J. Bouma, J. Elseviers, H.D. Witte, F. Flavigny, R. Orlandi, P. Reiter, M. Seidlitz, N. Warr, B. Siebeck, S. Hellgartner, D. Mucher, J. Pakarinen, M. Vermeulen, C. Bauer, G. Georgiev, R. V. F. Janssens, D. Balabanski, M. Sferrazza, M. Kowalska, E. Rapisarda, D. Voulot, M. L. Benito, and F. Wenander. *Cluster-transfer reactions with radioactive beams: A spectroscopic tool for neutron-rich nuclei.* Phys. Rev. C **92**, 024322 (2015).

N. Bree, K. Wrzosek-Lipska, P. A. Butler, L. P. Gaffney, T. Grahn, M. Huyse, N. Kesteloot, J. Pakarinen, A. Petts, P. Van Duppen, and N. Warr. *X-ray production with heavy post-accelerated radioactive-ion beams in the lead region of interest for Coulomb-excitation measurements.* Nucl. Instrum. Methods Phys. Res. B **360**, 97 (2015).

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EJNMMI Physics **2**, 1 (2015).

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J. Phys.: Conf. Ser. **620**, 012006 (2015).

D.4 Seminars

D.4.1 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

K. Piasecki — Institute of Experimental Physics, University of Warsaw, Warszawa, Poland — 15 January 2015
Near-threshold production of light strange mesons in heavy-ion collisions

A. Maj — The H. Niewodniczański Institute of Nuclear Physics, Kraków, Poland — 22 January 2015
Experimental investigations of Pygmy Dipole Resonances

K. Wrzosek-Lipska — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 26 February
Koegzystencja kształtów w neutrono-deficytowych izotopach Po i Hg
Shape coexistence in the neutron deficient Po and Hg isotopes

M. Scholz — The H. Niewodniczański Institute of Nuclear Physics, Kraków, Poland — 5 March 2015
Rola projektu IFMIF w programie syntezy termojądrowej
Role of the IFMIF project in the thermonuclear synthesis programme

U. Kaźmierczak — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 12 March 2015
Dawka lokalna i jej rola w biologicznej odpowiedzi linii komorkowej CHO-K1
Local dose and its role in the biological response of CHO-K1 cell line

S. Wronka — National Centre for Nuclear Research, Świerk, Poland — 19 March 2015
Akceleratory stosowane w radioterapii
Accelerators used for radiotherapy

M. Palacz — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 26 March 2015
Stany wzbudzone jąder z obszaru ^{100}Sn — badania prowadzone w reakcjach fuzji-ewaporacji, z wykorzystaniem detektorow promieniowania gamma, cząstek naładowanych i neutronów
Excited states of nuclei in the vicinity of ^{100}Sn — in-beam studies using fusion-evaporation reactions employing detectors of γ rays, charged particles and neutrons

S. Kistryn — M. Smoluchowski Institute of Physics, Jagiellonian Univ., Kraków, Poland — 9 April 2015
Obserwable polaryzacyjne dla reakcji kilkunukleonowych
Polarisation observables in a few nucleon reactions

N. Keeley — National Centre for Nuclear Research, Świerk, Poland — 16 April 2015

Dynamical non-locality in nuclear potentials; demonstration of a practical method

J. Srebrny — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 23 April 2015

Fascynujace eksperymentalnie i teoretycznie izotopy rutenu

Experimentally and theoretically fascinating ruthenium isotopes

P. Moskal — M. Smoluchowski Institute of Physics, Jagiellonian Univ., Kraków, Poland — 30 April 2015

Perspektywy badania symetrii dyskretnych i morfologii tkanek przy pomocy tomografu J-PET

Future of discrete symmetry and tissue morphology studies with J-PET tomography

M. Pietrzak — Institute of Experimental Physics, University of Warsaw, Warszawa, Poland — 7 May 2015

Nanodozymetria ciężkich cząstek naładowanych — modele doświadczalne i symulacje Monte Carlo

Heavy charged particle nanodosimetry — experiment and Monte Carlo simulations

T. Kajdrowicz — The H. Niewodniczański Institute of Nuclear Physics, Kraków, Poland — 14 May 2015

Teraźniejszość i przyszłość radioterapii protonowej w CCB IFJ PAN

Present and future of proton radiotherapy in CCB IFJ PAN

S. Puławski — Institute of Physics, University of Silesia, Katowice, Poland — 21 May 2015

Identyfikacja i analiza produkcji naładowanych hadronów w zderzeniach p+p z eksperymentu NA61/SHINE przy energiach CERN SPS

Identification and analysis of charged hadron production in p+p interactions from the NA61/SHINE experiment at CERN SPS energies

J. Jastrzębski — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 28 May 2015

Produkcja i badanie radioizotopów medycznych w ŚLCJ UW

Production of and research on medical radioisotopes at the Heavy Ion Laboratory

P. Magierski — Faculty of Physics, Warsaw University of Technology, Warszawa, Poland — 11 June 2015

Zależna od czasu metoda funkcjonału gęstości energii — teoria i praktyka opisu dynamiki układów nadciekłych

Time-dependent density-functional theory; concepts and practical applications for superfluid system dynamics

Y. Oganessian — Joint Institute for Nuclear Research, Dubna, Russia 7 October 2015
Nuclei at the End of the Nuclear Map

A. Gulielmentti — INFN, Laboratori Nationali di Legnaro, Legnaro, Italy 8 October 2015
The LUNA experiment at the Gran Sasso Laboratory: studying stars by going underground

M. Pfützner — Institute of Experimental Physics, University of Warsaw, Warszawa, Poland 22 October 2015
Wirtualne przejście β-γ w rozpadzie ^{59}Ni
Virtual β-γ transitions in ^{59}Ni decay

M. Matejska-Minda — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 29 October 2015
Badanie włanośći kolektywnych pasm wzbudzonych w neutronodeficytowych jądrach o masach $A \approx 70$ za pomocą pomiaru czasu życia stanów jądrowych
Study of rotational bands properties in neutron deficient nuclei with $A \approx 70$ by measuring lifetimes of excited states

W.H. Trzaska — Department of Physics, University of Jyväskylä, Finland 5 November 2015
The Hunt for mass hierarchy and CP violation

K. Czerski — Institute of Physics, University of Szczecin, Szczecin, Poland 12 November 2015
Zagadka ekranowania elektronowego w reakcjach fuzji deuteronów przy bardzo niskich energiach — nowe wynik
Recent experimental results on the electron screening in deuteron fusion reactions at very low energies

Z. Janas — Institute of Experimental Physics, University of Warsaw, Warszawa, Poland 19 November 2015
Badania rozpadu β jądra ^{8}He przy użyciu detektora OTPC
Beta-decay studies of ^{8}He with the OTPC detector

Ch.Aa. Diget — Department of Physics, University of York, York, UK 26 November 2015
Down-to-Earth astrophysics — studying stellar explosions with accelerators

S. Gales — Institut de Physique Nucléaire, Orsay, France 3 December 2015
ELI — nuclear physics mariage of laser and accelerator technology: project implementation and scientific program

E. Grodner — Institute of Experimental Physics, University of Warsaw, Warszawa, Poland — 10 December 2015
Pomiar momentu magnetycznego podstawy pasm partnerskich w ^{128}Cs — wgląd do wnętrza chiralności
Magnetic momentum measurements of chiral partner bands in ^{128}Cs — an insight into the chirality phenomena

D.4.2 Other seminars organised at HIL

Internal semi-formal HIL seminars

C. Spitaleri — Istituto Fisica dell'Universitá, Catania, Italy — 30 January 2015
The Treiman-Yang criterion and the Trojan Horse Method

Z. Szefliński — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 29 April 2015
Radiobiologia układów komórkowych — wiązki ciężkich jonów
Cell system radiobiology — heavy-ion beams

C. Bordeanu — Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucurest, Romania — 20 May 2015
Experimental needs in experimental nuclear astophysics (^{12}C+^{12}C, ^{19}F+α)

A. Kordyasz — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 20 May 2015
Pierwsze testy supercienkiego epitaksjalnego, implantowanego, krzemowego detektora paskowego wykonanego niskotemperaturową techniką
First tests of superthin, ion-implanted silicon strip detectors produced by the low-temperature technique

I. Strojek — Department of Physics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague, Czech Republic — 4 September 2015
AEgIS — współczesny eksperyment Galileusza dla antymaterii
AEgIS — modern Galileo experiment with antimatter

J. Choiński — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 18 November 2015
Sprawozdanie z konferencji HIAT-13, 7–11 Września 2015, Yokohama, Japonia
HIAT-13 Yokohama Conference report

D.4.3 External seminars given by HIL staff

K. Kilian 10 April 2015
Oznaczanie zanieczyszczeń metalicznych oraz radionuklidowych w radiofarmaceutykach do PET
Determination of metallic and radionuclidic impurities in PET radiopharmaceuticals
XXIV Poznańskie Konwersatorium Analityczne, Poznan, Poland

L. Próchniak 20–22 April 2015
Consequences of gamma-softness of the core for some properties of chiral nuclei
NORDITA Workshop — chiral bands in nuclei, Stockholm, Sweden

P.J. Napiorkowski 24 April 2015
Digital processing of phoswich signals
1st PARIS Weekend, University of Milan, Italy

K. Wrzosek-Lipska 1–6 May 2015
Probing nuclear structure with various experimental techniques at the Heavy Ion laboratory in Warsaw
ISTROS Conference, Casta Papiernicka, Slovenia

J. Choiński 19–21 May 2015
Production of the ^{211}At radioisotope using the Warsaw Heavy Ion Cyclotron
9th Symposium on targeted alpha therapy, Warsaw, Poland

A. Stolarz 28–29 May 2015
The Warsaw Heavy Ion Cyclotron — a complement to the p/d cyclotron for medical radioisotope production at the Heavy Ion Laboratory
III Międzynarodowa Konferencja Radiofarmaceutyczna, Łódz, Poland

K. Kilian 7–13 June 2015
From beam to the target advances in PET radiochemistry
Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, Kraków, Poland

K. Kilian 6–10 July 2015
Badanie i kontrola jakosci radiofarmaceutyków do tomografii pozytonowej
Quality control of PET radiopharmaceuticals
IX Polska Konferencja Chemii Analitycznej, Poznań, Poland

K. Rusek 14–18 July 2015
Testing reaction models in experiments with weakly bound projectiles
Int. Conf. on Nuclear Structure and Related Topics, Dubna, Russia

J. Jastrzębski 2–5 September 2015
Production and research on medical radioisotopes at the Heavy Ion Laboratory, University of Warsaw
Kongres 50 lat PTFM, Warsaw, Poland

U. Kaźmierczak 2–5 September 2015
Dosimetry in the radiobiological studies at HIL
Kongres 50 lat PTFM, Warsaw, Poland

K. Wrzosek-Lipska 6–13 September 2015
Investigating shape coexistence with Coulomb excitation above $Z = 82$ at REX-ISOLDE in CERN
XXXIV Mazurian Lakes Conference on Physics — Frontiers in Nuclear Physics, Piaski, Poland

U. Kaźmierczak 6–11 September 2015
Dozymetria promieniowanie jonizujacego w badaniach radiobiologicznych w ŚLCJ UW
Dosimetry in the radiobiological studies at HIL
XLIII Zjazd Fizyków Polskich, Kielce, Poland

J. Choiński 7–11 September 2015
The Heavy Ion laboratory, University of Warsaw — a unique research center in Poland
13th Int. Conference on Heavy Ion Accelerator Technology, RIKEN Nishina Center, Yokohama, Japan

Z. Szefliński 24 September 2015
Heavy ion beam for radiobiology — dosimetry and nanodosimetry at HIL
II Symposium on Positron Emission Tomography, Kraków, Poland

J. Srebrny 27 September – 1 October 2015
Gamma spectroscopy at the Warsaw cyclotron
NUSTAR Week 2015, Warsaw, Poland

A. Stolarz 10–14 October 2015
Cyclotron production of ^{43}Sc — a new radionuclide for the PET technique
28th Annual EANM Congress, Hamburg, Germany

A. Stolarz 10–14 October 2015
Gold nanoparticle-substance P(5-11) conjugate as a carrier for ^{211}At in α-particle therapy
28th Annual EANM Congress, Hamburg, Germany

A. Stolarz 23–25 November 2015
Production of medical radioisotopes with p/d medical and heavy ion cyclotrons
CHANDA Target Workshop, PSI Villingen, Switzerland

P.J. Napiorkowski 26 November 2015
Coulomb Excitation: not only at the Heavy Ion laboratory, University of Warsaw
Tata Institute for Fundamental Research,Mumbai, India

D.4.4 Poster presentations

K. Kilian 14–16 May 2015
^{18}F MISO synthesis for small animals PET imaging
Warsaw Medical Physics Meeting, Warszawa, Poland

K. Kilian 14–16 May 2015
Macrocyclic complexes as precursors for diagnostic radiopharmaceuticals
Warsaw Medical Physics Meeting, Warszawa, Poland

K. Kilian 14–16 May 2015
Metallic and radionuclidic impurities in ^{18}F-FDG production
Warsaw Medical Physics Meeting, Warszawa, Poland

K. Kilian 28–29 May 2015
Synthesis and quality control of ^{11}C-methionine
Synteza i kontrola jakosci ^{11}C-metioniny
III Miedzynarodowa Konferencja Radiofarmaceutyczna, Łódź, Poland

M. Komorowska 1 June 2015
Pear-shaped nuclei in $N \approx 88$ mass region
Forum franco-polonais de la recherche et de l'innovation, Warsaw, Poland

A. Stolarz 8–12 June 2015
New results on the medical radioisotope ^{211}At produced using the α-particle beam
3rd Int. Conference on radiation and dosimetry in various fields of research, Budva, Montenegro

K. Kilian 6–10 July 2015
Reactions of Cu(II) ions with with porphyrins using SAT complex formation
Reakcje jonów miedzi(II) z porfiryna z wykorzystaniem kompleksu SAT
IX Polska Konferencja Chemii Analitycznej, Poznań, Poland

M. Sitarz 3–5 September 2015
Production of ^{43}Sc and ^{44}Sc with α-particle beam as positrons emitters for medical imaging — evaluation of the process efficiency
Congress of the 50 years of Polish Society of Medical Physics, Warsaw, Poland

P.J. Napiorkowski 6–11 September 2015
Warszawski Konkurs Chemiczno-Fizyczny "Eureka"
Warsaw Chemistry and Physics Competition "Eureka"
XLIII Zjazd Fizyków Polskich, Kielce, Poland

S. Dutt 6–13 September 2015
Nuclear Structure Study of ^{104}Pd by Coulomb Excitation at the Warsaw Heavy Ion Laboratory
XXXIV Mazurian Lakes Conference on Physics — Frontiers in Nuclear Physics, Piaski, Poland

M. Komorowska 6–13 September 2015
Study of octupole collectivity in ^{146}Nd and ^{148}Sm using Coulomb excitation
XXXIV Mazurian Lakes Conference on Physics — Frontiers in Nuclear Physics, Piaski, Poland

A. Kordyasz 6–13 September 2015
First tests of superthin, ion implanted strip detectors produced by the low-temperature technique
XXXIV Mazurian Lakes Conference on Physics — Frontiers in Nuclear Physics, Piaski, Poland

M. Komorowska 22–27 Spetember 2015
Pear-shaped nuclei in $N \approx 88$ region. Study of octupole collectivity in ^{146}Nd and ^{148}Sm using Coulomb excitation.
XXII Nuclear Physics Workshop, Kazimierz Dolny, Poland

D.4.5 Lectures for students and student laboratories

K. Kilian winter semesters of the academic year 2015/2016, 90 hours
Pracownia Analizy Środowiska
Environmental Analysis Laboratory
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

K. Kilian winter semester of the academic year 2015 /2016 , 20 hours
Zarzadzanie Środowiskiem
Environmental Management
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

K. Kilian winter semester of the academic year 2015/2016, 30 hours
Metody izotopowe i chemia radiofarmaceutyków
Radiochemistry and radiopharmacy
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of the academic year 2014/2015, 60 hours
Pracownia radiofarmaceutyków
Laboratory of Radiopharmaceuticals
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of the academic year 2014/2015, 15 hours
Radiofarmaceutyki — synteza, wytwarzanie i zastosowania
Radiopharmaceuticals — synthesis, production and application
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

U. Kaźmierczak winter semester of the academic year 2015/2016, 45 hours
Pracownia fizyczna IIA
Physics IIA Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

U. Kaźmierczak summer semester of the academic year 2014/2015, 45 hours
Pracownia fizyczna IIB
Physics IIB Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

M. Palacz academic year 2014/2015 (72 hours), and 2015/2016 110 hours
Pracownia ochrony radiologicznej
Radioprotection Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

A. Trzcińska academic year 2014/2015 (72 hours), and 2015/2016 110 hours
Pracownia ochrony radiologicznej
Radioprotection Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński summer semester of the academic year 2014/2015, 30 hours
Energetyka Jądrowa
The nuclear power industry
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński summer semester of the academic year 2014/2015, 30 hours
Techniki jadrowe w diagnostyce i terapii medycznej
Nuclear techniques in Medical Diagnostics and Therapy
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński winter semester of the academic year 2015/2016, 30 hours
Energia w Środowisku — technika ograniczenia i koszty
Energy in the environment — technique limitations and costs
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński winter semester of the academic year 2015/2016, 45 hours
Fizyka I
Physics 1, mechanics, lecture
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński winter semester of the academic year 2015/2016, 15 hours
Fizyka I — ćwiczenia do wykładu
Physics 1, mechanics, class plenary
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński winter semester of the academic year 2015/2016, 45 hours
Pracownia fizyczna IIA
Physics IIA Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński summer semester of the academic year 2014/2015, 45 hours
Pracownia fizyczna IIB
Physics IIB Laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

D.4.6 Science popularisation lectures

P.J. Napiorkowski lectures for middle school pupils

Fizyka dla bramkarzy (2x60 min)
Physics for goalkeepers

O wpływie promieniowania na zdrowie inaczej — czyli rzecz o PET (3x60 min)
A different point of view on radiation health effects — the thing about PET

Z. Szefliński lectures for high school pupils and students

Promieniowanie jonizujące — radon w naszym otoczeniu (1x45 min)
Ionising radiation — radon in the environment

Fizyka jądrowa w doświadczeniach (2x60 min)
Nuclear physics in experiments

Fizyka w diagnostyce medycznej — Tomografia pozytonowa (2x45 min)
Nuclear physics in medical diagnostics — Positron Emission Tomography

Jądro atomowe — fakty i mity (2x60 min)
The Atomic Nucleus — facts and myths

D.5 Honours and Awards

State Awards

The following employees of the Heavy Ion Laboratory received Honours and Awards from the President of Poland:
Jarosław Choiński — Gold Cross of Merit,
Paweł Napiorkowski — Bronze Cross of Merit,
Krzysztof Rusek — Silver Cross of Merit,
Agnieszka Trzcińska — Silver Medal for Long Service.

The Rector of the University of Warsaw awards

In 2015 the following employees of the Heavy Ion Laboratory received the Rector of the University of Warsaw award:
Anna Błaszczyk-Duda, Tomasz Bracha, Jarosław Choiński, Piotr Jasiński, Agnieszka Maciejewska, Bogdan Radomyski, Łukasz Standyło, Lidia Strzelczyk, Łukasz Świątek, Katarzyna Wrzosek-Lipska

D.6 Laboratory staff

Director: Krzysztof Rusek
Deputy directors: Jarosław Choiński
Paweł Napiorkowski
Financial executive: Agnieszka Maciejewska

Senior scientists:

Jerzy Jastrzębski[a], Andrzej Kordyasz[a], Marcin Palacz, Ernest Piasecki[a], Leszek Próchniak, Krzysztof Rusek, Anna Stolarz, Józef Sura, Zygmunt Szefliński[a]

Scientific staff and engineers:

Tomasz Abraham, Andrzej Bednarek, Jarosław Choiński, Przemysław Gmaj, Andrzej Jakubowski, Krzysztof Kilian, Maciej Kisieliński[a], Marian Kopka, Michał Kowalczyk, Magdalena Matejska-Minda, Paweł Matuszczak[a], Ireneusz Mazur, Jan Miszczak, Paweł Napiorkowski, Wojciech Piątek, Bogdan Radomyski, Olga Saeed Mohamed Nassar, Justyna Samorajczyk[b], Mateusz Sobolewski[ac], Łukasz Standyło, Julian Srebrny[a], Łukasz Standyło, Roman Tańczyk, Agnieszka Trzcińska, Andrzej Tucholski, Marzena Wolińska-Cichocka, Katarzyna Wrzosek-Lipska, Bogumił Zalewski[cd]

Doctoral candidates:

Urszula Kaźmierczak[e], Michalina Komorowska[e], Tomasz Marchlewski[e], Mateusz Pęgier[f], Mateusz Sitarz[e]

Technicians:

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

Administration and support:

Anna Błaszczyk-Duda, Marek Budziszewski, Przemysław Czwarnok, Rafał Klęk[h], Barbara Kowalska[a], Joanna Kowalska, Agnieszka Maciejewska, Jolanta Matuszczak, Jolanta Ormaniec, Piotr Piegat[a], Joanna Strojek, Ewa Sobańska, Lidia Strzelczyk, Krystyna Szczepaniak, Wanda Wesoły, Andrzej Wiechowski, Katarzyna Włodarczyk[a], Magdalena Zawal[i], Irena Żejmo[a]

Voluntary scientists:

Jędrzej Iwanicki[j], Jan Kownacki, Andrzej Wojtasiewicz

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[a] part time
[b] since 1 February 2015
[c] since 1 September 2015
[d] on leave since 2 November 2015
[e] PhD student at the Faculty of Physics, University of Warsaw
[f] PhD student at the Faculty of Chemistry, University of Warsaw
[g] until 5 August 2015
[h] until 31 May 2015
[i] since 26 October 2015
[j] since 1 August 2015

D.7 Laboratory Council

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

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

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

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

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

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

7. Przemysław Gmaj
(representative of the HIL staff)
Heavy Ion Laboratory
University of Warsaw
02-093 Warszawa, ul. Pasteura 5A

8. Prof. dr hab. Andrzej Góźdź
Dep. of Theoretical Physics
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20-031 Lublin, ul. Radziszewskiego 10

9. Prof. dr hab. Zenon Janas
Inst. of Experimental Physics
University of Warsaw
02-093 Warszawa, ul. Pasteura 7

10. Prof. dr hab. Jerzy Jastrzębski
Heavy Ion Laboratory
University of Warsaw
02-093 Warszawa, ul. Pasteura 5A

11. Prof. dr hab. Marta Kicińska-Habior
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University of Warsaw
02-093 Warszawa, ul. Pasteura 5

12. Prof. dr hab. Stanisław Kistryn
Jagiellonian University
31-007 Kraków, ul. Gołębia 24

13. Prof. dr hab. Adam Maj
The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences
31-342 Kraków, ul. Radzikowskiego 152

14. Prof. dr hab. Wojciech Nawrocik
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Adam Mickiewicz University
61-614 Poznań, ul. Umultowska 85

15. Prof. dr hab. Sławomir Nazarewski
Medical University of Warsaw
02-091 Warszawa, ul. Żwirki i Wigury 61

16. Prof. dr hab. Paweł Olko
The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences
31-342 Kraków, ul. Radzikowskiego 152

17. Prof. dr hab. Ernest Piasecki
Heavy Ion Laboratory
University of Warsaw
02-093 Warszawa, ul. Pasteura 5A

18. Dr hab. Ludwik Pieńkowski
AGH University of Science and Technology
30-059 Kraków, ul. Mickiewicza 30

19. Prof. dr hab. Krzysztof Rusek
(Director of HIL)
Heavy Ion Laboratory
University of Warsaw
02-093 Warszawa, ul. Pasteura 5A

20. Prof. dr hab. Teresa Rząca-Urban
Faculty of Physics
University of Warsaw
02-093 Warszawa, ul. Pasteura 5

21. Prof. dr hab. Adam Sobiczewski
The National Centre for Nuclear Research
02-093 Warszawa, ul. Pasteura 5

22. Prof. dr hab. Ryszard Sosnowski
The National Centre for Nuclear Research
05-400 Świerk k/Warszawy

23. Prof. dr hab. Wiktor Zipper
Institute of Physics
University of Silesia
40-007 Katowice, ul. Uniwersytecka 4

D.8 Programme Advisory Committee

PAC members

- Dimiter Balabanski (Sofia University, Sofia, Bulgaria)
- Konrad Czerski (Institute of Physics, University of Szczecin, Szczecin, Poland; Physics Department, Technical University of Berlin, Germany)
- Piotr Bednarczyk (The H. Niewodniczański Institute of Nuclear Physics, Kraków, Poland)
- Gilles de France (GANIL, Caen, France)
- Zenon Janas (Faculty of Physics, University of Warsaw, Warszawa, Poland)
- Nicholas Keeley (National Centre for Nuclear Research, Świerk, Poland)
- Rainer Lieder (RFW, University of Bonn, Germany)
- Piotr Magierski (Faculty of Physics, Warsaw University of Technology, Warszawa, Poland)
- Leszek Próchniak (Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland)
- Brunon Sikora (Faculty of Physics, University of Warsaw, Warszawa, Poland)
- Władysław Trzaska (Department of Physics, University of Jyväskylä, Finland)

The international Programme Advisory Committee of the Heavy Ion Laboratory meets usually twice a year, in spring and 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 (the Heavy Ion Laboratory).

D.9 External participants in HIL experiments and HIL guests

D. Alimov	Institute of Nuclear Physics of the National Nuclear Center, Almaty, Kazakhstan
J.M. Allmond	Oak Ridge National Laboratory, Oak Ridge, TN, USA
I. Ami	University of Science and Technology Houari Boumediene, Bab Ezzouar, Algeria
J. Andrzejewski	Fac. of Phys. and Appl. Comp. Sci., U. of Lodz, Łódź, Poland
P. Bednarczyk	The H. Niewodniczański Institute of Nuclear Physics, Kraków, Poland
V. Bekhterev	Joint Institute for Nuclear Research, Dubna, Russia
F.L. Bello Garrote	Department of Physics, University of Oslo, Oslo, Norway
H. Bidaman	University of Guelph, Ontario, Canada
V. Bildstein	University of Guelph, Ontario, Canada
C. Bordeanu	H. Hulubei Nat. Inst. of Phys. and Nucl. Eng., Bucurest, Romania
I. Boztosun	Akdeniz University, Antalya, Turkey
J. Braziewicz	Institute of Physics, Jan Kochanowski University, Kielce, Poland
C. Burbadge	University of Guelph, Ontario, Canada
N. Burtebayev	Institute of Nuclear Physics of the National Nuclear Center, Almaty, Kazakhstan
J. Czub	Institute of Physics, Jan Kochanowski University, Kielce, Poland
A. Diaz Varela	University of Guelph, Ontario, Canada
W. Dominik	Faculty of Physics, University of Warsaw, Warszawa, Poland
D.T. Doherty	IRFU/SPhN, CEA Saclay, Gif-sur-Yvette, France
Ch. Droste	Faculty of Physics, University of Warsaw, Warszawa, Poland
G. Duran	University of Huelva, Huelva, Spain
S. Dutt	Inter University Accelerator Centre, New Delhi, India
P. Garrett	University of Guelph, Ontario, Canada
A. Gawlik	Fac. of Phys. and Appl. Comp. Sci., U. of Lodz, Łódź, Poland
A. Giaz	I.N.F.N. Sezione di Milano, Milano, Italy
K. Hadyńska–Klęk	Department of Physics, University of Oslo, Oslo, Norway
M. Hlebowicz	Faculty of Physics, Warsaw University of Technology, Warszawa, Poland
O. Hryhorenko	Kharkiv National University, Kharkiv, Ukraine
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G. Khatri	M. Smoluchowski Institute of Physics, Jagiellonian Univ., Kraków, Poland
K. Kmiecik	The H. Niewodniczański Institute of Nuclear Physics, Kraków, Poland

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Ł. Kordyasz	SonicTech, Łomianki, Poland
A. Korgul	Faculty of Physics, University of Warsaw, Warszawa, Poland
A. Korman	National Centre for Nuclear Research, Świerk, Poland
R. Kumar	Inter University Accelerator Centre, New Delhi, India
W. Kurcewicz	Faculty of Physics, University of Warsaw, Warszawa, Poland
S. Lewandowski	Faculty of Physics, University of Warsaw, Warszawa, Poland
A. Lis	Faculty of Physics, University of Warsaw, Warszawa, Poland
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K. Miernik	Faculty of Physics, University of Warsaw, Warszawa, Poland
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M. Stryjczyk	Faculty of Physics, University of Warsaw, Warszawa, Poland
R. Szenborn	Faculty of Physics, University of Warsaw, Warszawa, Poland
K. Szkliniarz	Institute of Physics, University of Silesia, Katowice, Poland
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S. Yates	Department of Chemistry, University of Kentucky, Lexington, KY, USA Department of Physics and Astronomy, University of Kentucky, Lexington, KY, USA
M. Ziębliński	The H. Niewodniczański Institute of Nuclear Physics, Kraków, Poland

W. Zipper	Institute of Physics, University of Silesia, Katowice, Poland
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M. Zielińska	IRFU/SPhN, CEA Saclay, Gif-sur-Yvette, France