University of Warsaw

Heavy Ion Laboratory

# Annual Report

# 2014

Warszawa, August 2015

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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 14 May 2015 by Joanna Strojek

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# Contents

# Introduction

Our first twenty years of active service as a national nuclear physics laboratory have been successfully completed. In March 1994 a $^{14}$N beam from the U200P cyclotron was delivered to the experimental area, beginning a new chapter in the history of Polish nuclear physics. The idea of Professors Andrzej Sołtan and Stefan Pieńkowski, expressed in the memorandum *"Remarks on the necessity of building a cyclotron in Poland"* from the thirties of the last century, was realised by their students as the Heavy Ion Laboratory (HIL) at the University of Warsaw. With the passing years more and more beams have been produced at HIL, experimental equipment has been modernised, the number of users has grown, not to mention published papers and diploma studies, to reach the status that is presented in this Report.

One of the most important achievements of our technical staff in 2014 was the modification of the centre of the cyclotron and the installation of a spiral ion beam inflector. This allowed full coupling of the new Supernanogan ECR ion source with the cyclotron which, in turn, led to a significant increase in the number of elements that could be accelerated and delivered to the experimental hall. Thus, at present the U200P heavy ion cyclotron is equipped with two fully operational ECR sources. Every stick has two ends, as we say in Poland — due to the work on the technical improvements to the cyclotron the number of beam-hours used for experiments was significantly lower than in the previous year; nevertheless, all the experiments approved by the PAC (21 in total) were run without any delay.

What may be noted in the present Annual Report is the significant growth in the number of contributions devoted to medical and biological applications, from 9 in 2013 to 14 in 2014. In particular, the group of scientists led by professor Jerzy Jastrzębski investigated the possibilities of producing the $^{99m}$Tc isotope, which has many medical applications, by irradiation of a Mo target with a proton beam from the C30 cyclotron at the National Centre for Nuclear Research (NCBJ). In parallel, they were working on the construction of an external beam line for the PETtrace cyclotron at our laboratory and on the manufacture of Mo targets so that these studies could be continued at HIL. Radio-chemists led by dr Krzysztof Kilian worked on the synthesis of new complexes for PET radiopharmaceutical applications. Studies of carbon ion tracks in matter are very important from the point of view of carbon hadrontherapy. Interesting results were obtained at HIL using nano-dosimeters developed at the Physikalisch-Technische Bundesanstalt and NCBJ. Studies of biological samples irradiated by heavy ions, to some extent, supplemented this research.

Concerning nuclear physics, studies of the properties of nuclear states (life times, spins) were performed using the EAGLE gamma-array. Alpha-cluster structure of nuclei was investigated using a standard elastic scattering method as well as — novel for us — the Thick Target Inverse Kinematics method. The latter was used for the first time at HIL and we are hoping that after this successful experiment others will follow soon.

Finally, I would like to mention that the collaboration between HIL and the Faculty of Physics was noticeably intensified in 2014. We have more students from the Faculty performing their diploma work (Bachelor, Master, PhD) and practical training in our laboratory. Is this simply the result of our close neighbourhood — the Faculty moved last year from the city centre to the Ochota Science Campus? In my opinion, our constant efforts to enrich the possibilities on offer for students (last year we opened the Laboratory of Medical Imaging, for example) play an important role in this process.

*Prof. Krzysztof Rusek, Director of HIL*

# Part A

# Laboratory overview

# A.1 General information

*J. Choiński, P. J. 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 unique 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 recommendations 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 low energy nuclear physics and its medical applications, including 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 $\gamma$-ray spectrometer, which can be easily coupled to ancillary detectors like an internal conversion electron spectrometer, a charged particle 4 $\pi$ multiplicity filter (Si-ball), a scattering chamber equipped with up to 110 PIN-diode detectors, a 60-element $BaF_2$ gamma-ray multiplicity filter, a sectored HPGe polarimeter and a plunger.

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

# A.2 Cyclotron operation in 2014 and tasks carried out in order to improve the cyclotron infrastructure and efficiency

*J. Choiński, P. Gmaj, A. Bednarek, T. Bracha, A. Jakubowski, W. Kalisiewicz, M. Kopka, I. Mazur, J. Miszczak, B. Paprzycki, K. Sosnowski, Ł. Standyło, O. Steczkiewicz, J. Sura*

*Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland*

## Operation

At the beginning of year 2014 the modernised central region of the U-200P cyclotron and a new spiral inflector were installed. These changes were made in order to take full advantage of the ECR ion source developed by Pantechnik: Supernanogan. This in turn will help to expand the available types of accelerated beams of non-volatile compounds.

However, two months of unavailability of the cyclotron due to the reconstruction significantly reduced the total annual number of experimental hours (see Fig. 1). Still, all projects accepted by the PAC for 2014 were successfully performed.

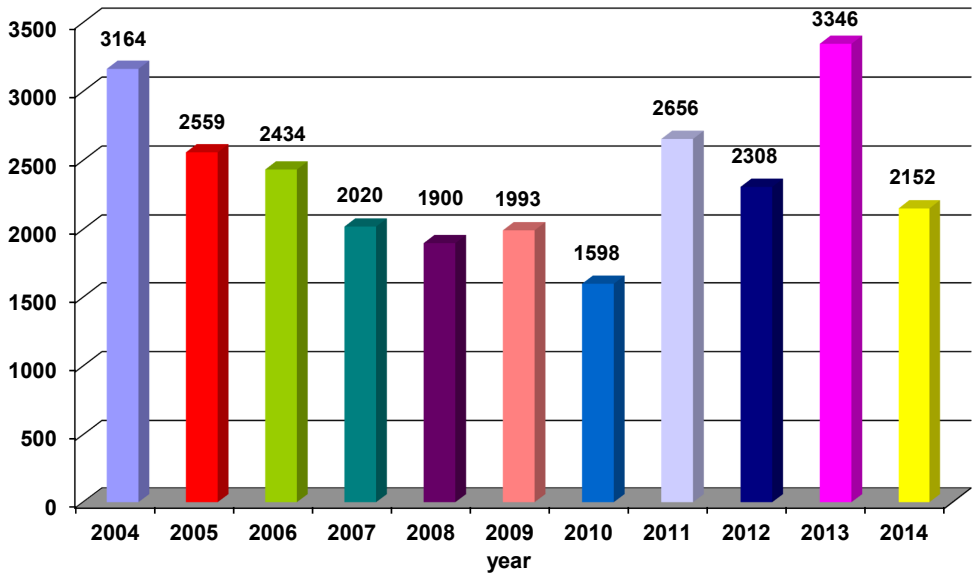


**Figure 1:** Total cyclotron beam time in the years 2005–2014.

The monthly distribution of beam time in 2014 is presented in Fig. 2. Starting from the end of January until the beginning of March the cyclotron was shut down for the above mentioned upgrade, whereas during half of July, August and September the cyclotron was closed for the summer vacation.

As for the last few years, the main topics of experiments were related to nuclear physics research, biological and medical research. A significant part of the beam time was dedicated to medical radioisotope production (astatine 211 chemical specimen production in collaboration with the Institute of Nuclear Chemistry and Technology and the Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences). For the above reasons, a large part of the beam time was devoted to work on the development

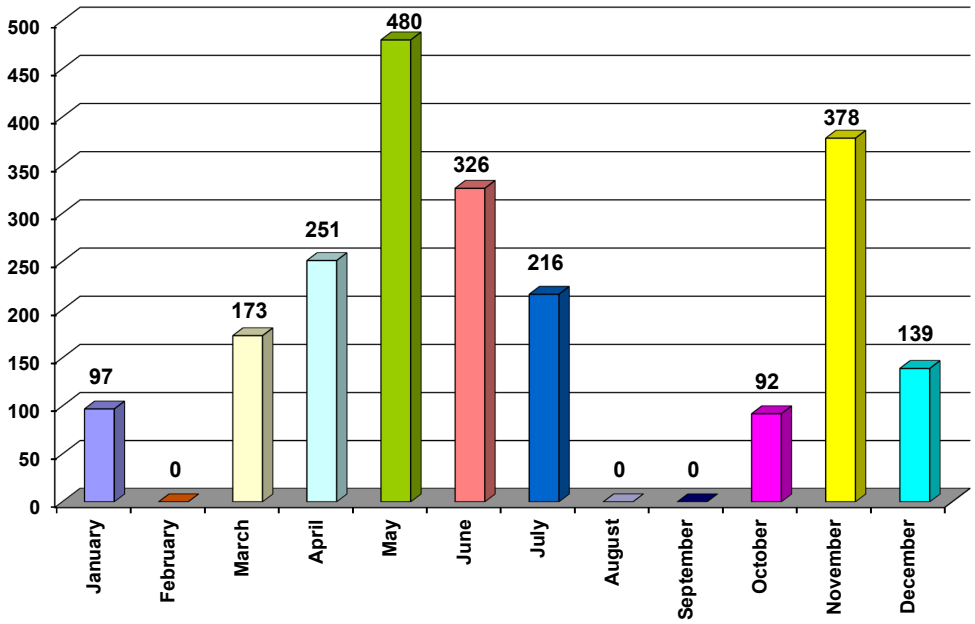


**Figure 2:** Beam time distribution (hours) in 2014 per month.

of the structure of the cyclotron and beam tests. Beam time was also allocated to the national and international student workshops, as in the last few years. The diversity of the experiments performed during 2014 is illustrated in Fig. 3

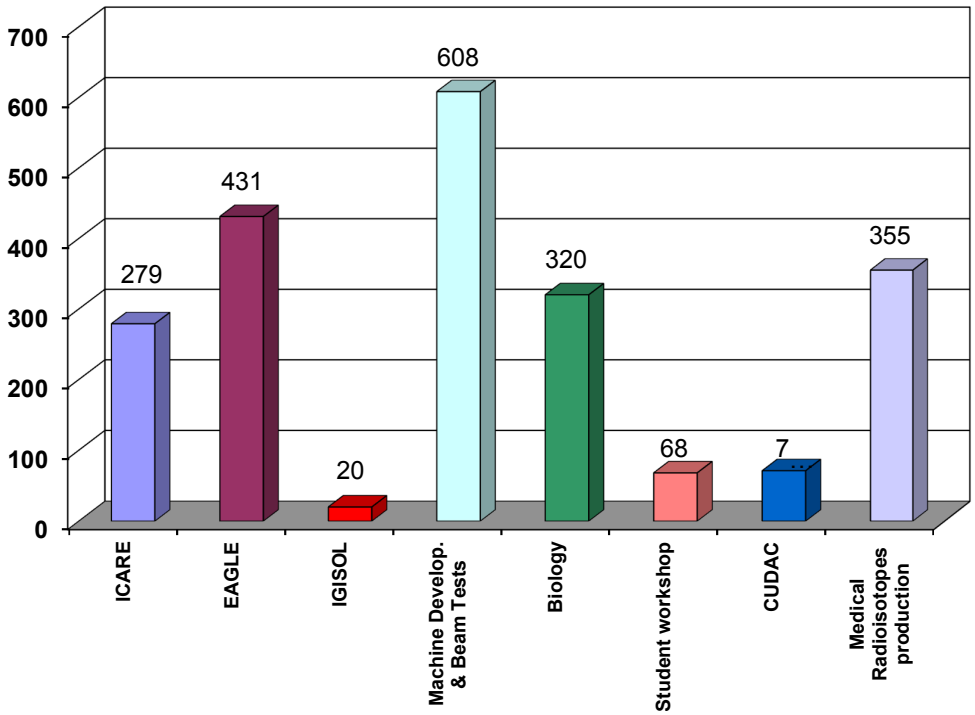


**Figure 3:** Distribution of beam-time (in hours) among different experimental setups.

In all the experiments the involvement of young researchers, graduate and undergraduate students, is traditionally large, illustrated in Fig. 4 which shows the number of sci-

entists using specific experimental equipment. Detailed descriptions of the experimental setups available at HIL can be found on the laboratory web page: `www.slcj.uw.edu.pl`.

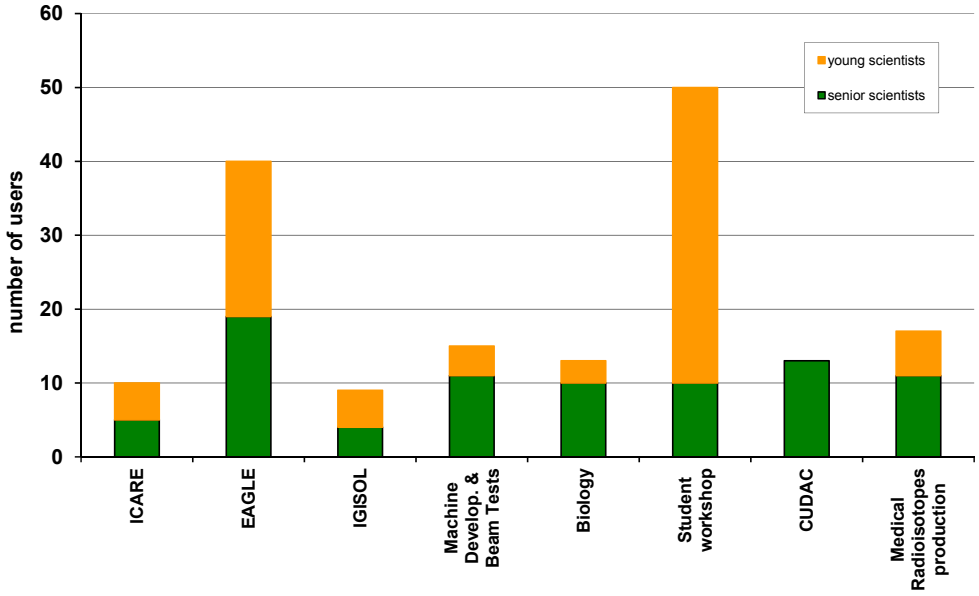


**Figure 4:** Number of users of the Warsaw cyclotron beams in 2014 (total 154).

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

## Maintenance

### ECR Source

The Supernanogan ECR ion source was used to provide all beams planned for 2014 instead of the old one. These experiments were planned and accepted in 2013 and thus, their scope included only ions produced previously by the old source. Production of the ions which have not previously been accelerated in the U-200P cyclotron, that is, above all, elements not having gaseous compounds under normal conditions (Mg, Ca, Fe etc.), requires some modifications to the source. The purpose of these modifications is to achieve the ion currents necessary for experiments and longer uninterrupted operation of the source. The related project is described below.

Beyond the normal wear and tear of the source (replacement of insulators, power supply failures), the Supernanogan computer control system was partially rewritten to provide more reliable operation.

### RF system

The RF amplifiers have come to the end of their days as they already have more than 30 years of service. The spare parts are no longer available; this concerns mainly such important components as GK-11A power tubes, T-160 thyristors etc. However, the number of failures in 2014 did not exceed the normal annual level recorded in recent years. The old Chrysolite amplifiers will be replaced by new ones. In 2014 two of three planned tenders were concluded. One for power final stages (Popek Elektronik) and the second for RF signal generation and stabilisation systems (Comtech-RDE). The third tender for

purchase of preamplifiers will be launched in 2015 and the system is to be commissioned at the beginning of 2016.

### Power infrastructure

Apart from normal maintenance resulting from wear and tear, some new energy nodes were established in the Laboratory in 2014. In addition several new electrical installations were made. Namely:

- Construction of the power distribution and electrical installations for experimental hall A.
- New special electrical installation for powering the experimental setup EAGLE.
- Electrical switch-gear RDK to replace the old set of quadrupole power supplies with a new one.
- Cabling between the control room and the PET cyclotron bunker for powering and control of the new external irradiation station.
- Installation of four new power supplies for quadrupole doublets on the ion beam lines.
- Quadrupole doublet modernisation.

## Development and projects

### Central Part, Spiral inflector

As mentioned at the outset, a number of important changes were carried out in 2014. Most important were modifications to the central part of the cyclotron, installation of the spiral inflector and setting up of the Supernanogan ion source for production.

### ECR and EMILIE project

HIL has joined the European ERANET NUPNET EMILIE project which aims to improve charge breeder efficiency. The initial purpose of participating in this project is not only to increase knowledge and practices concerning ion sources of the ECR type. However, due to the problem related to the competition between the time spent on research experiments (the service role) and the time needed for experiments connected with the development of the cyclotron, it was decided to build an independent research stand. This work is funded by the EMILIE project which with the consent of the consortium and the sponsoring institution (NCBiR) was suitably modified in 2014. The new research stand is under construction and is to be commissioned in 2015. Up to the end of 2015 several experiments will be conducted to extend the production of metallic ions by choosing the proper material and shape of the internal layer of the plasma chamber.

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 charge breeder design.

### New power supplies (beam line active elements)

As mentioned above, several power supplies were replaced in 2014. In parallel the strategy of changing all the control systems interfaces one platform (LabView) is being accomplished by writing new control drivers for the new amplifiers in this homogeneous environment.

This strategy will continue in 2015 by adapting the LabView platform to the older power supplies and monitoring system. This approach is improving significantly and will further improve the reliability of the cyclotron operation.

### RF system

Up to the end of 2015 it is planned to replace the outdated amplifiers supplying the accelerating structure of the U-200P cyclotron with new ones. The new RF system should be commissioned at the beginning of 2016.

### 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 system for lifting the upper part of the cyclotron was replaced with a new one which is intended to allow for much faster operation. This change is needed before we can proceed to the measurement of the magnetic field, which in turn is necessary to improve the transmission of the accelerated ion beams.

In 2014 a large program of collaboration with JINR FLNR was developed and approved which will lead to a general reconstruction of the magnetic field. The project will begin in 2015 with design of the magnetic measurement system.

### Vacuum system

The vacuum system is being gradually renewed since 2013 but it still needs some investment to replace the old vacuum pumps on the beam lines.

## A.3 Maintenance of 19 HPGe detectors used in experiments with EAGLE

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

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In order to perform gamma spectroscopy on the central European Array for Gamma Levels Evaluations (EAGLE) set-up [1, 2] High Purity Germanium (HPGe) detectors are needed. In 2014 it was possible to use up to 16 HPGe detectors. The number of detectors used for experiments was limited by the number of Anti Compton Shields (ACS) available. Twenty three detectors were at disposal of HIL at the beginning of 2014. Out of the total number of 23 detectors, 4 ware broken beyond repair and one remained at the Institute of Nuclear Physics of Polish Academy of Science in Krakow.

Eighteen working detectors were used in in-beam experiments at the U200-P cyclotron. Many of the detectors suffered neutron damage during these experiments and needed to be restored by the process of regeneration [3]. This process was applied 20 times: 10 detectors were processed once, two detectors were processed twice and two detectors were regenerated three times during 2014.

Tables 1 and 2 below show the difference between the Full Width at Half Maximum (FWHM) measured for all detectors at an energy of 1333 keV of $^{60}$Co in the test room and the same value measured on EAGLE. The FWHM is a measure of the energy resolution of the detector and it is desirable to obtain as small a value as possible.

The detectors originate from the NORDBALL collaboration, the OSIRIS collaboration and the Department of Physics, of the University of Warsaw. We are grateful for such valuable gifts.

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

| No | Detector number | FWHM at 1333 keV measured in the test room | FWHM at 1333 keV measured on EAGLE |
|---|---|---|---|
| 1 | 1 | 2.2 | 2.6 |
| 2 | 2 | 2.3 | 2.4 |
| 3 | 3 | 2.2 | 2.3 |
| 4 | 4 | 2.3 | 3.0 |
| 5 | 5 | 2.1 | 2.4 |
| 6 | 6 | 2.5 | 2.6 |
| 7 | 8 | 2.6 | - |
| 8 | 21 | 2.4 | 2.8 |
| 9 | 22 | 2.8 | 3.2 |

**Table 2:** Comparison of FWHM at an energy of 1333 keV for a $^{60}$Co source obtained in the test room and in EAGLE in 2014 — part 2.

| No | Detector number | FWHM at 1333 keV measured in test room | FWHM at 1333 keV measured on EAGLE |
|---|---|---|---|
| 10 | 23 | 1.9 | 2.9 |
| 11 | 31 | 2.4 | 2.6 |
| 12 | 42 | 2.2 | 2.5 |
| 13 | 43 | 2.2 | 2.4 |
| 14 | 44 | 2.5 | 2.5 |
| 15 | 45 | 2.6 | 2.6 |
| 16 | 51 | 2.1 | - |
| 17 | 52 | 2.5 | 2.6 |
| 18 | 54 | 2.1 | 2.5 |

## 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.4 Development of the EAGLE gamma spectrometer data acquisition system

*M. Kowalczyk[1,2], M. Kisieliński[1,3], P. Matuszczak[1,3], W. Okliński[2]*

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*2) Faculty of Physics, University of Warsaw, Warszawa, Poland*
*3) National Centre for Nuclear Research, Otwock, Świerk, Poland*

Last year we continued testing and modifying our prototype digital ADC board [1]. Modifications of the analogue input tracks eliminated cross-talk between adjacent channels. The modifications made to the power supply of the analogue mezzanine unit improved the energy resolution. As a result we have obtained an energy resolution 5-10% better than in the old analogue system.

A new "front end logic" board CEFE (CAMAC EAGLE Front End) for the CAMAC part of the data acquisition system has been designed. A prototype module has been built (Figure 1). The board was designed as a standard CAMAC module and can be set up using the CAMAC crate controller. All the logic functions of the board are programmable in the Xilinx's Spartan-6 FPGA, which allows more complex trigger logic then in the previous solution. All the LeCroy logic modules, NIM logic, NIM gate and delay generators will be replaced by the CEFE module. The CEFE will be used in the trigger decision and will generate bit patterns. The new solution will reduce significantly the number of external LEMO and ECL cables. Additionally, the board will replace several CAMAC modules used in the data acquisition system, such as the scalers, the LAM generator and the reset module.

The 48 ECL input connector of the CEFE module can be used as a 16 Ge + ACS + PUR for the germanium part or as 48 independent particle detector input logic channels. The 5 ECL output channels can be used for the gate generator, the TDC start/stop signal and the fast clear. Another 6 input and 6 output channels were designed in the NIM logic standard and are dedicated to communication with the external NIM logic modules to exchange the trigger signal. The NIM signals will also be used for event synchronisation with other CEFE modules, placed in different CAMAC crates. The additional SMA input and output clock connectors together with the 5 LVDS inputs and outputs are dedicated to synchronising the CEFE with our digitizer boards. The analogue part which processes the signals from the germanium detectors will be replaced with a digital system.

To take advantage of the new CEFE module we decided to build a new CAMAC crate controller. This controller was designed as an interface between the Memec prototype board, equipped with the same Virtex-4 mezzanine board that we use in the digitizer, and the CAMAC dataway (Figure 2). The CAMAC dataway cycle control was programed inside the Virtex-4 FPGA fabric. The CEFE and the new controller are equipped with an 8-wire LVCMOS interface which allows for communication independent of the CAMAC dataway. The same software as in the digitizer board is used to communicate over gigabit Ethernet with the acquisition control program. The program, running on the Linux system, is backward compatible with the program running on the DOS system-(the previous platform). The new controller is still under test but the new version of the software has been used successfully in experiments for on-line data tracing and visualisation. The new software is not limited by the DOS memory size. It is about 100 times faster in off-line list

mode data processing. Additional features of the new software allow automated energy calibration and easy comparison of spectra from different runs.

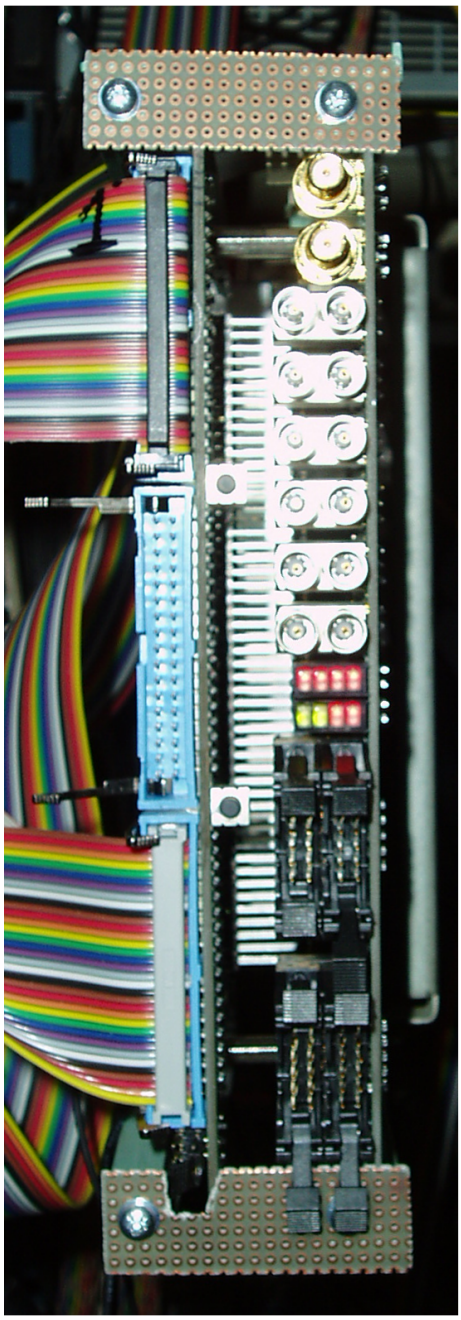

**Figure 1:** The CEFE module.

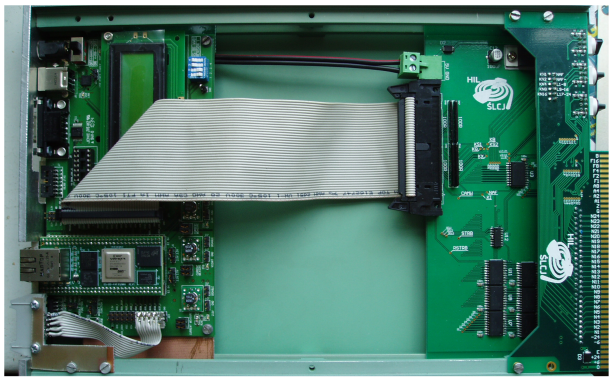

**Figure 2:** The new CAMAC Crate Controller.

## Bibliography

[1] J. Mierzejewski, J. Srebrny, HIL Annual Report 2013, page 17

## A.5 Beam Chopper

*M. Sobolewski, J. Miszczak, Z. Kruszyński*

*Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland*

First tests of the beam chopper were carried out in 2009, using the RF buncher working at 1/2 the cyclotron's frequency as a modulating element [1]. Although the results were promising, it soon became apparent that the buncher would not work as a chopper. The beam users expected attenuation of more than 40 dB (1/100) of unwanted beam pulses and beam-off time of at least 250–300 ns, but the attenuation was 24 dB and the off time not more than 120–160 ns (two RF periods).

In 2012 it was decided to use one set of electrostatic lenses (out of 4) in the beam injection line [2] as a modulating electrodes. The chopper hardware consists of the following modules: a regulated power supply with complementary outputs (up to +/- 300 V), fast HV switches ( $t_f = 10$ ns, $t_r = 120$ ns), and a phase shifter with RF synchroniser. The power supply used in the first test turned out to be too small (30 W), so a more powerful one (80 W) is under construction. The work will be continued in 2015.

### Bibliography

[1] M. Sobolewski, J. Miszczak, HIL Annual Report 2010, page 20

[2] M. Sobolewski, J. Miszczak, HIL Annual Report 2012, page 20

## A.6 Linux computers at HIL

*Ł. Świątek*

*Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland*

According to the plan mentioned earlier [1], in 2014 the operating system of the HIL Linux computers was upgraded. Most of the workstations that worked with the Linux 10.04 LTS system since 2011 did not meet the hardware requirements of the latest LTS (long-term-support) release. The computers were thus modernised, so it was possible to install the Ubuntu Linux 14.04 LTS system. The same operating system was also installed on the main HIL server.

In order to improve the security of the network, sshguard, a small program which cooperates with the iptables firewall, was installed on the HIL servers. Sshguard detects IP addresses from which attempts are made to log-in via the ssh service using the so called brute-force method. For such addresses a prohibiting entry is added to the main firewall on the firewall-gateway server.

A new script was implemented at the mail server to watch the number of connections to the mail server accounts. A warning is issued in case one of the e-mail accounts starts to send too many mails. This usually indicates that the account security has been compromised, and it is being used for sending spam.

In 2015 the hardware of the remaining computers will be upgraded so that the new operating system can be installed on all the machines. It is also planned to increase disk space on the main HIL server and to create a disk array server to ensure data security.

### Bibliography

[1] Ł. Świątek, HIL Annual Report 2013, page 22

## A.7 "The first 20 years at HIL" — a symposium to celebrate the 20th anniversary of the first extracted beam from the Warsaw Cyclotron

*P.J. Napiorkowski*

*Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland*

On 11th of April 1994 the first beam was extracted from the Warsaw Heavy Ion Cyclotron and directed onto a particle detector. To celebrate this anniversary a symposium was organised to summarise not only the achievements during the past twenty years, but especially to discuss the role in the European nuclear physics landscape of laboratories of similar size and resources to HIL. The event was held under the Honorary Patronage of the Rector of the University of Warsaw.

The two day conference gathered 17 speakers from Europe and USA. The audience of about one hundred friends and collaborators attended the inaugural session chaired by the President of the Laboratory Council and the Director of the Laboratory. In the official part of the meeting over twenty distinguished HIL employees were awarded the Medal of Merit of the University of Warsaw. Also, for the very first time the new "Tomasz Czosnyka Honorary Award 2014" was given to Emmanuel Clement from GANIL. The scientific programme of the symposium was opened by Jerzy Jastrzębski — a former director of HIL — with a presentation of the Laboratory's history.

The two scientific sessions of the conference covered topics of current research activity conducted recently at the Heavy Ion Laboratory and the new challenges which now face the nuclear physics and its new facilities.

The full programme of "The first 20 years at HIL" symposium was as follows:

- Opening and welcome addresses: Katarzyna Chalasińska-Macukow and Krzysztof Rusek.
- Jerzy Jastrzębski: History of HIL.
- Tomasz Czosnyka Honorary Award 2014 for Emmanuel Clement.

Session I:

- Ernest Grodner: Chirality studied with gamma spectroscopy.
- Magda Zielińska: Coulex @ HIL.
- Jarosław Perkowski: Electron spectrometer for nuclear structure.
- Agnieszka Trzcińska: Reaction studies @ HIL.
- Joanna Czub: Radiobiology with heavy ion beams.
- Jarosław Choiński : Radioisotopes for medicine in the Radiopharmaceuticals Production and Research Centre.
- Olga Steczkiewicz: The new ECR ion source and spiral inflector for the Warsaw Cyclotron.

- Jacek Dobaczewski: Theoretical challenges.

Session II

- Andreas Goergen: Lifetime measurements with EAGLE.
- Wiktor Kurcewicz: The Warsaw IGISOL system.
- John Wood: Where are the low-energy quadruple vibrations in nuclei ?
- Jerzy Jastrzębski: Medical applications — the new face of nuclear physics.
- Adam Maj: Cyclotron Centre Bronowice in the National Laboratory of Cyclotrons in Poland.
- Dimiter Balabanski: ELI — New concept of a Nuclear Physics facility
- Ismael Martel: LINCE — A new stable beam facility for Europe.
- Kirby Kemper: University Laboratories — research and education.
- Round table discussion: Future for regional facilities.

The opening lecture was printed as a monograph, being an important document concerning the most recent history of science in Poland. The publication was distributed among the Symposium participants.

**Figure 1:** Dr Anna Stolarz receives the Medal of Merit of the University of Warsaw from Prof. Marta Kicińska-Habior, Prorector of UW and Prof. Krzysztof Rusek, Director of HIL.

## A.8 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], L. Pieńkowski[3], K. Rusek[1], O. Steczkiewicz[1], A. Stolarz[1], Z. Szefliński[1], R. Tańczyk[1] M. Wolińska-Cichocka[1]*

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The Polish Workshop on the Acceleration and Applications of Heavy Ions has been organised at HIL for the past 10 years. It is intended for students of first cycle studies interested in nuclear physics, and offers them a unique opportunity to gain experience in methods of data acquisition and analysis, in operating the cyclotron including beam diagnostics measurements, and in charged particle and gamma-ray detection techniques. Medical applications of nuclear physics have also been included in the programme of the Workshop.

Since 2012 the Workshop has been organised as a general university course. This status attracts students both from the University of Warsaw and from other Polish universities. In 2014 twenty one students attended the lectures and the practical training. Seven persons came from the University of Warsaw, 4 — from the University of Łódź, 4 — from the Maria Skĺodowska-Curie University in Lublin, 4 — from the Adam Mickiewicz University in Poznań, 1 — from the Poznań University of Technology and 1 student from the University of Wrocław.

In 2014, the programme of the lectures was as follows:

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

Students took part in the following experimental tasks:

- Beam focusing in heavy ion acceleration;
- Beam energy measurements based on Rutherford scattering;

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

The Workshop concluded with the student presentation session. To celebrate the 10th anniversary of the workshop all participants received commemorative gifts.

# Part B

# Research for medical and biological applications

# B.1 Production of the $^{211}$At radioisotope using the Warsaw Heavy Ion Cyclotron

*K. Szkliniarz[1], J. Jastrzębski[1], A. Bilewicz[3], J. Choiński[1], A. Jakubowski[1], Ł. Janiszewska[3], E. Leszczuk[3], M. Łyczko[3], M. Sitarz[1,4], A. Stolarz[1], A. Trzcińska[1], B. Wąs[4], W. Zipper[2]*

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*2) Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland*
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Research quantities of $^{211}$At, one of the most promising TAT radioisotopes, have been produced using the Warsaw Heavy Ion Cyclotron since 2010 [1]. The internal alpha particle beam of up to 1 μA intensity and maximum energy of 32 MeV, strikes perpendicularly a 100 μm, high purity (5N) Bi target, produced by direct melting of Bi metal onto a target cavity in an aluminium backing. The backing, together with the Bi grains, is heated on a hot plate and the molten Bi is distributed over the area of the cavity. Due to the use of an internal beam the target has a special shape, i.e. one edge is frameless. The Bismuth target, wrapped in thin aluminium foil and covered with 10 μm natural copper foil for beam intensity monitoring, is fixed to a water cooled copper holder. Using gamma-ray spectroscopy methods the irradiated sample activity is determined about one hour after the EOB. The $^{211}$At and $^{210}$At Thick Target Yield (TTY) and Saturation Yield (SY) are determined in the energy range from 23 up to 32 MeV. For each bombardment series the highest available energy is used at first and the beam energy verified using the $^{210}$At/$^{211}$At activity ratio. For lower bombarding energies Al beam energy degraders are used when required. The obtained TTY and SY are in excellent agreement with values calculated using the adopted (IAEA) reaction cross-sections and alpha particle ranges (SRIM) over the whole investigated energy range (see Fig. 1). The values of TTY and SY determined by other teams and presented in a number of publications compared with our results are shown in Fig. 2. In spite of the fact that the TTY determination is a rather simple experiment, the published results often differ from the calculated values and have significant scatter. As an example, for a bombarding energy of 28 MeV the published TTY values differ by a factor of 6.

Although the currently available alpha particle intensity is too low for the production of clinically significant quantities of $^{211}$At, after one night of irradiation the EOB intensity attains 300-500 MBq, sufficient for research on radiopharmaceutical synthesis. This research is conducted in the Institute of Nuclear Chemistry and Technology. There the $^{211}$At is isolated from the target by thermochromatographic methods. Our studies with $^{211}$At have been directed to obtaining a radiopharmaceutical for the treatment of the residue of glioma cancer cells after brain tumour resection. For the binding of $^{211}$At to substance P (a vector with high affinity to the NK1 receptor on glioma cells) the following approaches were studied: attaching $^{211}$At to $Rh^{3+}$ tetrathioether complexes such as Rh[16aneS4-diol]$^{211}$At, the adsorption of $^{211}$At on silver impregnated $TiO_2$ nanoparticles, and recently adsorption on gold nanoclusters and nanoparticles. The radiobioconjugates obtained exhibited good stability in various biological liquids including human serum and

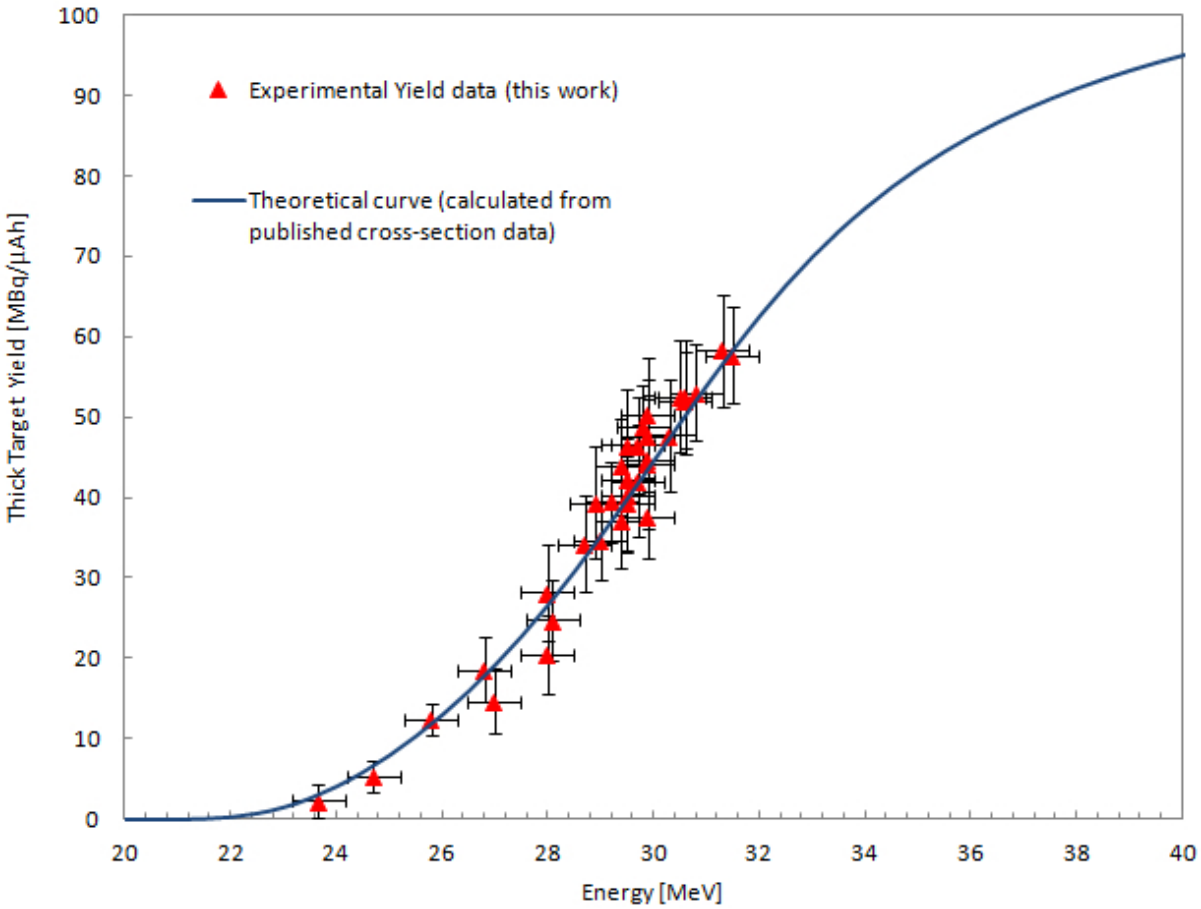


**Figure 1:** Experimental thick target yield [2] for the production of $^{211}$At by the (α,2n) reaction on a Bi target. The theoretical curve was calculated using the cross-section data of Ref. [3].

cerebral spinal fluid. In the short term studies on cell affinity and radiotoxicity of the obtained radiobioconjugates will be performed.

Research on $^{211}$At production as well as other medical radioisotopes is part of the scientific programme of the Heavy Ion Laboratory. Generally the Laboratory Programme Advisory Committee recommends about 5–6 working weeks yearly for this research. The $^{211}$At samples are produced during the night whereas during the day beam time is used for research on other medical radioisotopes. A cyclotron upgrade aimed at increasing the alpha particle beam intensity is planned shortly. The results obtained in $^{211}$At radiopharmaceutical research will also be of great value for a new alpha particle beam facility based on a commercial 30 MeV high intensity cyclotron, recently accepted as part of the Polish Roadmap of Research Infrastructures, to be installed by the National Centre for Nuclear Research in Świerk.

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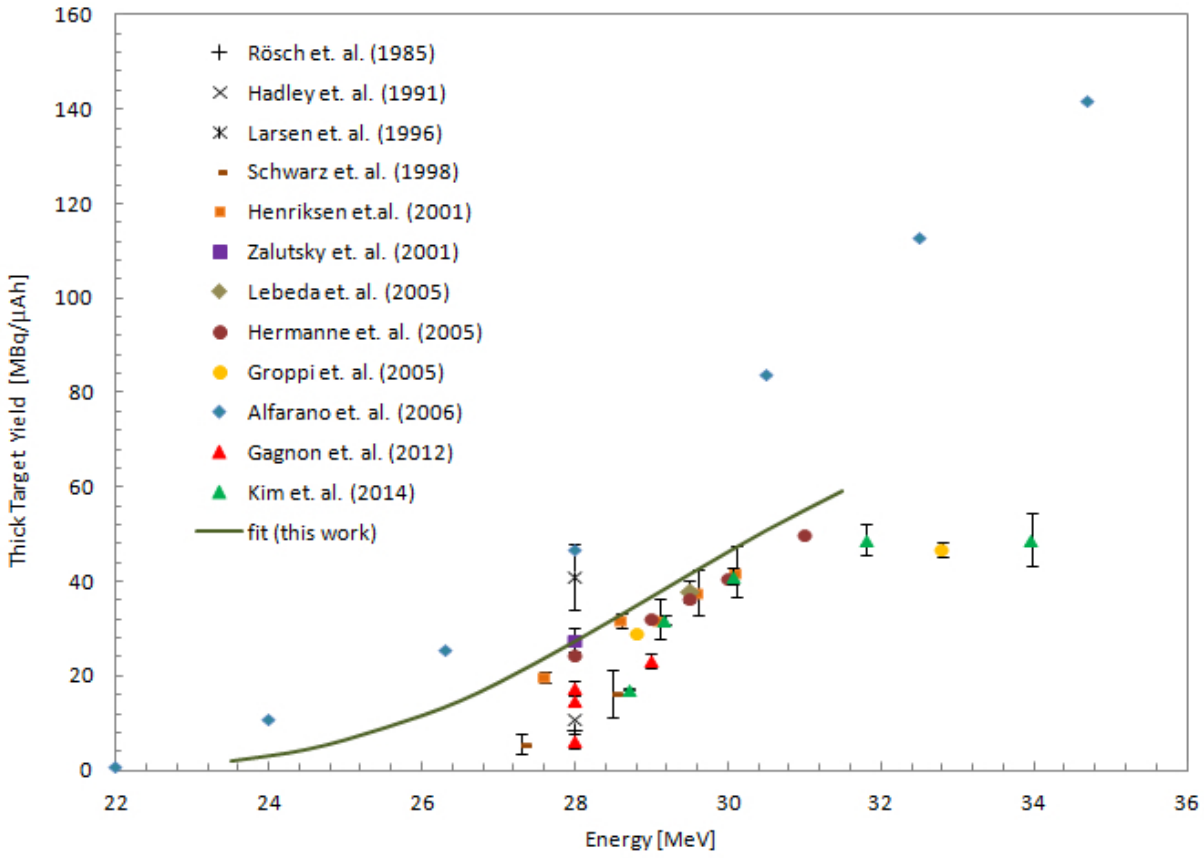


**Figure 2:** Comparison of previously published thick target yields for $^{211}$At production by the (α,2n) reaction with the fit to the present experimental points, as presented in Fig 1.

## B.2 Accelerator production of $^{99m}$Tc

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

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*3) Institute of Physics, University of Silesia, Katowice, Poland*

The rationale for the experimental research in our Laboratory on the most popular medical radioisotope, $^{99m}$Tc, was presented in last year's Annual Report [1]. During 2014 the first irradiation of a natural Mo sample was performed using the proton beam from the C30 cyclotron in Swierk. Fig. 1 presents the scheme of the irradiated sample with the proton beam energies indicated. Fig. 2 displays a typical gamma ray spectrum and Fig. 3 the relative intensities of the produced radioactivities. Finally, the observed intensity of the produced $^{99m}$Tc radioisotope is compared to the theoretical expectation using the experimentally determined $^{100}$Mo(p,2n) cross-sections in Fig. 3.

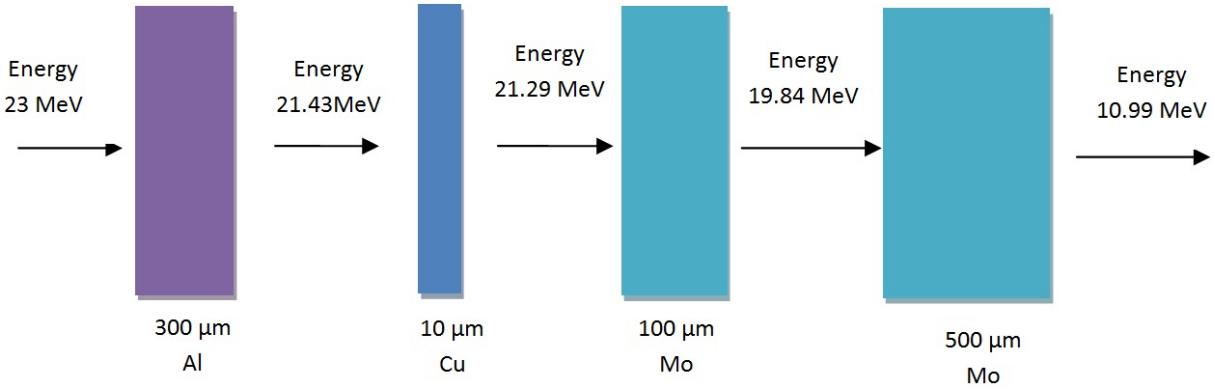


**Figure 1:** Scheme of the irradiated sample with the proton beam energies indicated.

## Bibliography

[1] A. Stolarz et al., HIL Annual Report 2013, page 44

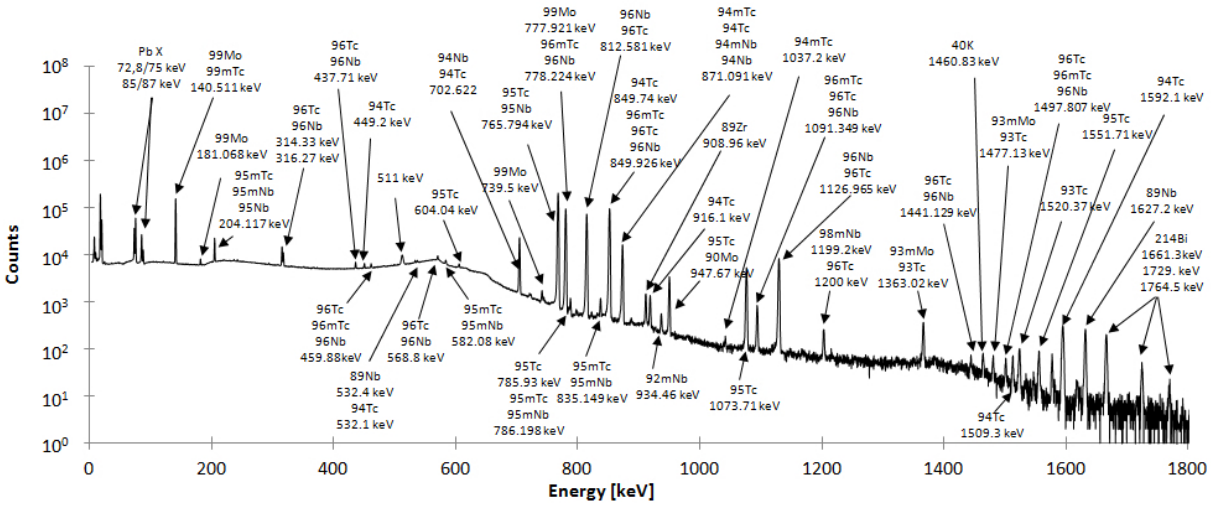


**Figure 2:** Gamma-ray spectrum obtained with a HPGe detector placed at 5.5 cm from the $^{nat}$Mo target of thickness 500 μm irradiated for 13 minutes by protons of 19.84 MeV energy and intensity of 7.16 nA. The measurement was started 26.5 h after EOB. The measurement time was 2.13 h.

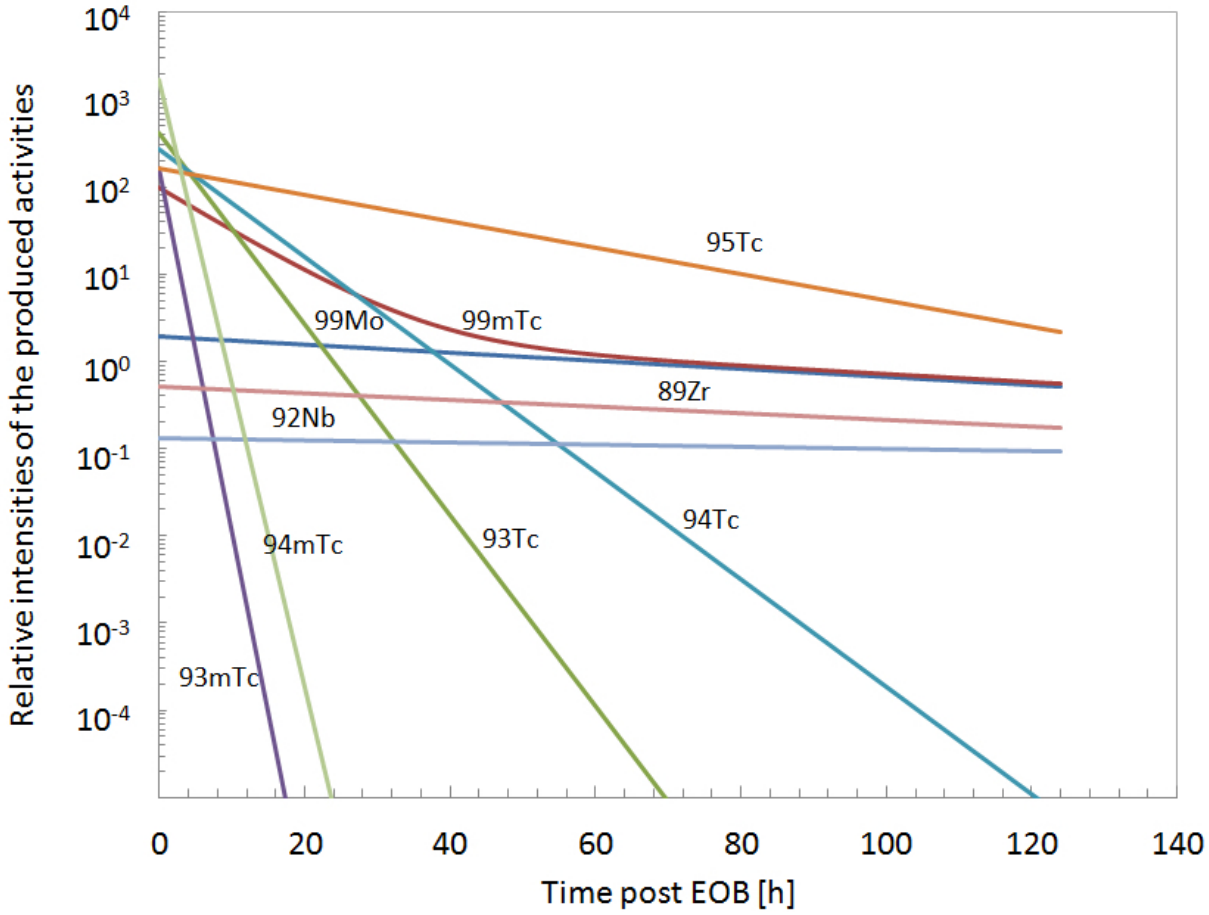


**Figure 3:** Activity balance of technetium radioisotopes as a function of time after a 0.22 h irradiation of a thick target at 19.84–10.99 MeV

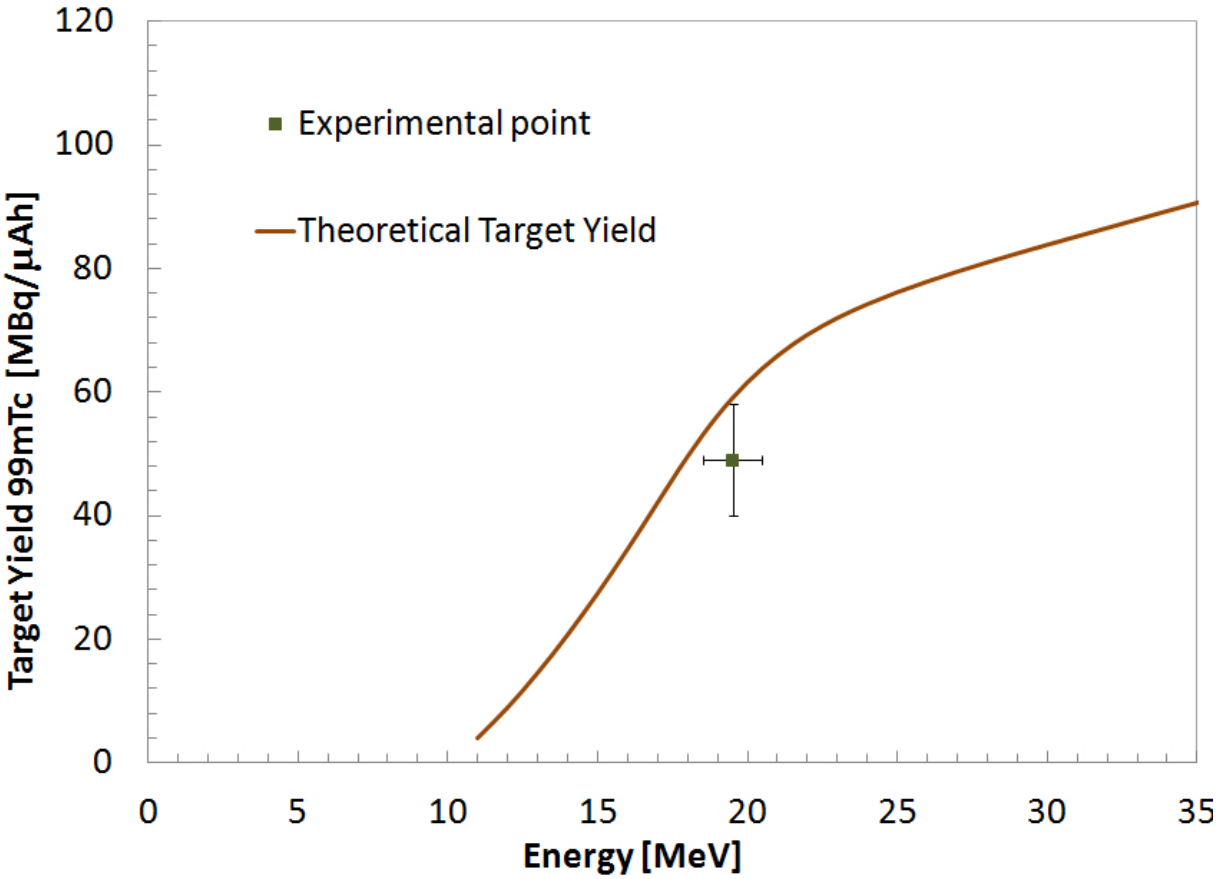


**Figure 4:** Comparison of the experimental and theoretical Target Yield for the production of $^{99m}$Tc from a $^{nat}$Mo target with a thickness of 500 µm at a bombarding energy of 19.8–11.0 MeV.

## B.3 Accelerator production of $^{99m}$Tc — construction of an external, well cooled, target holder for the PETtrace cyclotron

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*Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland*

In 2014 the execution of objective no. 3 of the grant "ALTECH", agreement PBS1/A9/2/2012 awarded to a consortium and financed by the National Centre for Research and Development, was continued. As a result a molybdenum target station was designed, manufactured and assembled as a standalone external target system. It consists of:

1. a 100 cm long drift tube and two permanent correction 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.

All the mechanical subsystems mentioned above were tested on a temporary test stand. The autonomous control system of the molybdenum target station consists of two subsystems. Subsystem I is based on a programmable logic controller (PLC). This is the main control unit. Its objective is to control all processes of the target station on an autonomous basis. It also communicates with subsystem II. Subsystem II is based on a PC computer equipped with the Windows 7 operating system. A Graphical User Interface displays on a monitor all important information for the operator about the current status of the target station before, during and after irradiation. It allows the operator to control the target station remotely.

# B.4 Molybdenum targets produced by mechanical reshaping

*A. Stolarz[1], J.A. Kowalska[1], P. Jasiński[1], T. Janiak[2], J. Samorajczyk[3], J. Jastrzębski[1], J. Choiński[1]*

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Targets for determination of the parameters of the $^{100}$Mo(p,xn)$^{99m}$Tc reaction, the subject of studies within the ALTECH project (for more details see J. Choiński et al., this Report, page 33) and estimation of the $^{99m}$Tc production yield were prepared starting with powder material as isotopically enriched molybdenum is available in powder form only. The production of foils for the above mentioned studies requires powder consolidation by melting and conversion of the bead obtained into a foil by mechanical reshaping.

The powdered material in the amount corresponding to the target thickness and its size (up to about 1300 mg) was pelletized with the use of a hydraulic press and die allowing air removal during pellet formation (Fig. 1).

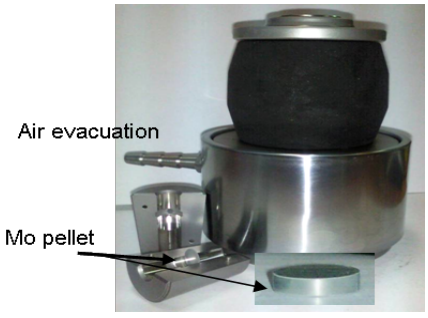


**Figure 1:** The pellet die with air evacuation option.

The obtained pellet was melted into a droplet in a vacuum of about $10^{-6}$ mbar with electrons provided by an e-beam gun. Before reaching the melting temperature, the pellet was carefully heated with the e-beam, both for outgassing i.e. removing the residual air and evaporating the molybdenum oxide ($t_{evap} \approx 1155$°C). The total material loss during the melting process was about 15–18%.

The droplet produced by melting the powder was placed between stainless steel sheets (rolling pack) to pass through the rolling mill. To remove stresses from the rolled foils they were, every once in a while, annealed in vacuum for about 10 to 15 minutes at a temperature of about 1200 °C. The described procedure allows production of thin (10 μm) foils. The production of a sufficient area of these foils (to prepare a stacked foil target composed of 10 Mo pieces) took about a week of whole day work.

Annealing useful in the preparation of thin foils (below 100 μm) was not significantly helpful in the production of thick ones (400–600 μm). The number of cracks was lower but when the did appear they propagated through the foil/disc area preventing production of a foil of the required size (Fig. 2).

Expecting improvement in the purity of the melted material, and thus its malleability, the Mo powder was heated in a reducing atmosphere (1 h at 1600 °C at $H_2$ atmosphere) for removing the oxide residues before pellet forming. In another approach the pellet was

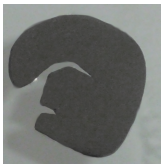

**Figure 2:** Example of a crack passing through the disc about 1 mm thick.

sintered under the same conditions but in both cases no improvement in the molybdenum malleability was observed.

## Hot reshaping of the droplet and subsequent cold rolling

To produce thick foils relatively large droplets (6–7 mm diameter) were flattened at high temperature before rolling. Molybdenum, an oxygen resistant metal at ambient temperature, oxidises easily at temperatures above 600 °C. To protect molybdenum from oxidation at the elevated temperature the droplet was packed into the stainless steel packet (envelope) under an argon atmosphere (Fig. 3a and 3b).

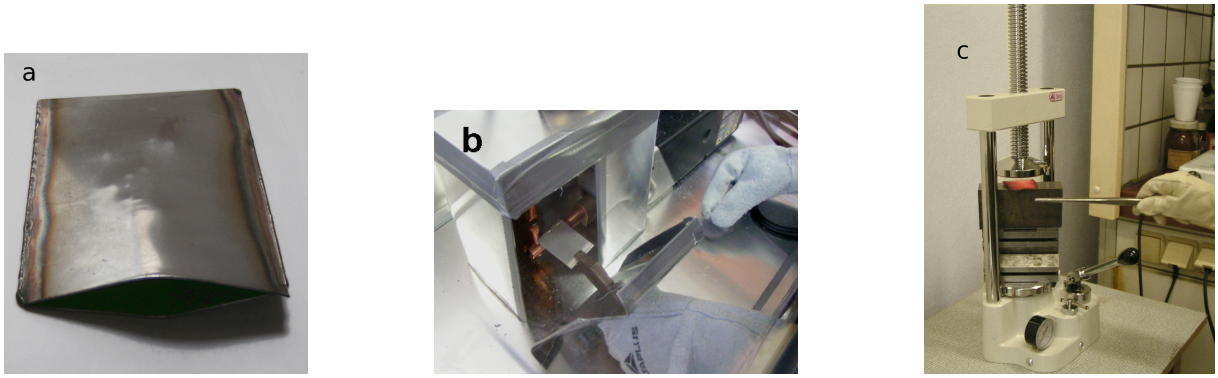


**Figure 3:** To flatten the Mo droplet at temperature, a droplet prepared by powder melting was packed into a stainless steel envelope (a) sintered tightly under an argon atmosphere (b). The packet was heated to 1100 °C and when hot, pressed under the hydraulic press (c).

The packed droplets of about 6–7 mm in diameter were heated at a temperature of 1100 °C for 3–5 minutes and when hot were flattened with a hydraulic press as quickly as possible to preserve the high temperature (see Fig. 3c). When cold, the disc was removed from the envelope and rolled down to the required thickness of a few hundred μm.

The thinnest foil produced in this work was about 250 nm thick (thickness measured by the alpha particle energy loss method). Below this thickness the material starts sticking to the rolling pack and attempts to reduce further the foil thickness were not undertaken.

More details can be found in a paper published in J. Radioanal. Nucl. Chem., DOI 10.1007/s10967-015-3956-1.

## Acknowledgement

Work supported by the grant ALTECH PBS1/A9/2/2012 awarded by the National Centre for Research and Development within the IAEA Coordinated Research Project (CRP) "Accelerator-based alternatives to non-HEU production of $^{99}$Mo/$^{99m}$Tc".

## B.5 Positron emitting $^{43,44}$Sc radioisotopes

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The two radioisotopes of a similar half-life (4 h), $^{43,44}$Sc are expected to replace in some cases the shorter lived $^{18}$F or to be a substitute for $^{68}$Ga for some special tumours, insensitive to fluorine compounds. $^{44}$Sc is an ideal radioisotope for three photon techniques [1], where a rather high energy gamma transition is used to substantially increase the resolution of the PET image, smeared out due to the positron range.

There is a number of nuclear reactions which lead to the formation of these radionuclides using medical p/d cyclotrons and isotopically separated targets. In the present study an alternative way was investigated by irradiating a natural CaO target (97% $^{40}$Ca) with an alpha particle beam. This investigation was only initiated and will be continued during the following months. The (α,p) reaction on a $^{40}$Ca target has a threshold at 5 MeV, a maximum cross-section of about 840 mb at 14 MeV and decreases to 340 mb above 20 MeV. (The maximum calculated cross-section of the (α,n) reaction is only 40 mb and occurs at roughly the same bombarding energy). Therefore, a rather pure $^{43}$Sc activity would be produced using an alpha particle energy below 20 MeV. However, a bombarding energy of 30 MeV was instead used for the first irradiations, in order to estimate the $^{44}$Sc production rate on a $^{42}$Ca target (0.6% in natural Ca) using the (α,pn) reaction. The determined thick target yields and saturation yields for the $^{43}$Sc and $^{44}$Sc radioisotopes are shown in Table 1. Figure 1 shows the radionuclidic purity of $^{43}$Sc as a function of time after the EOB.

**Table 1:** Thick target yield (TTY) and saturation yield (SY) of radioisotopes produced by the alpha particle beam.

| Isotope | Target chemical form | Target thickness [mg/cm$^2$] | Energy α-particle [MeV] | TTY [MBq/μAh] | SY [MBq/μA] |
|---|---|---|---|---|---|
| $^{43}$Sc | natCaO | 98 | 31 | 98(10) | 547(55) |
| $^{44}$Sc | | | | 0.66(3) | 3.7(5) |
| $^{44m}$Sc | | | | 0.042(4) | 3.6(3) |

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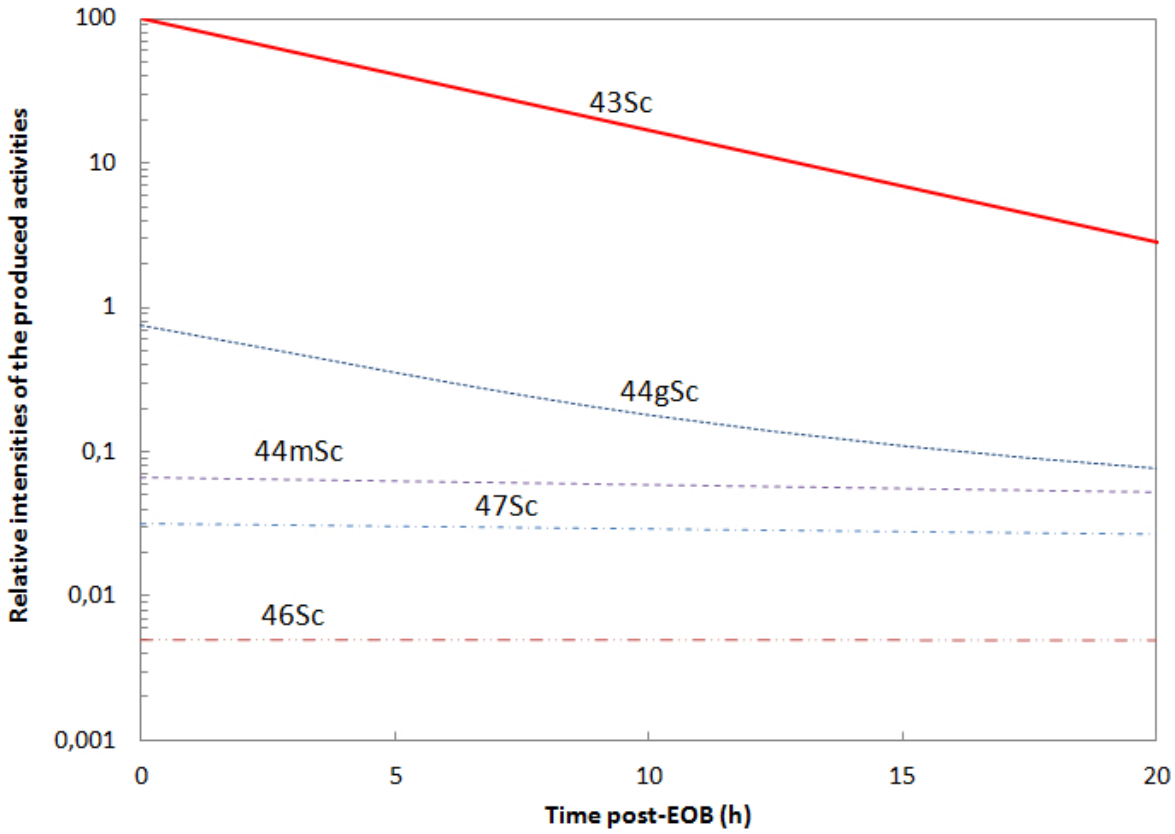


**Figure 1:** Evolution in time of the relative intensities of Sc isotopes produced during a 4 h irradiation of a natCaO target with a 31 MeV $\alpha$ particle beam.

# B.6 Synthesis of copper (II)-porphyrin complexes for PET radiopharmaceutical applications

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

The aim of this study was to investigate the reaction between copper (II) ions and tetrakis-4-carpoxyphenyl-porhyrin (TCPP) and optimise it for application in $^{64}$Cu PET radiopharmaceutical synthesis. Moreover, because of its unique decay properties ($T_{1/2}$ = 12.70 h, 17.9% $\beta^+$, 39.0% $\beta^-$, 43.1% EC, 0.5% $\gamma$) the designed radiopharmaceutical can be utilised as a therapeutic agent. For diagnostic purposes the other positron emitting copper radioisotopes can also be used ($^{60,61,62}$Cu). The water soluble TCPP served as ligand. Porphyrins are a group of compounds that occur naturally in organisms (e.g. heme, vitamin B12), as well as synthetically. In their structure a characteristic tetrapyrrole ring occurs, that can chelate metal ions. Porphyrins also have affinity to malignant tumour tissues, so they can be used in diagnostic and therapeutic oncology. The main problem in the complexation reactions between metal ions and porphyrins is the low reaction rate, due to distortion of the highly symmetric porphyrin ring that has to occur during the reaction. One solution is to use the sitting-atop mechanism (SAT). The first step of a SAT reaction is the complexation of an ion with high ionic radius (for example Hg (II), Pb(II), Cd (II)) by the porphyrin ring. Because the dimensions of the ion are too large, it doesn't fit into the ring and the formed complex is distorted. When an ion with a lower radius (e.g. Cu (II)) appears near such a SAT complex, the final chelation is much faster. The other strategy utilises copper (I) ions that are obtained by reduction of existing Cu (II) ions. Copper (I) ions, with higher ionic radius than Cu (II), can serve as a SAT complex formation substrate and thus can improve the reaction kinetics.

The reaction was studied using a Perkin Elmer Lambda 25 UV-VIS spectrophotometer (Perkin Elmer, Waltham, USA), because formation of metalloporphyrins causes certain changes in the UV-VIS spectrum. The characteristic changes in the spectrum of the sample during the formation of the CuTCPP ($C_{TCPP} = C_{Cu} = 10^{-5}$ mol·dm$^{-3}$, borate buffer) complex are presented in Fig. 1. The reaction was carried out in three different buffer solutions to optimize the environment. In the acetate buffer (pH = 4.5) the reaction didn't occur. The phosphate buffer (pH = 7) was a better environment, since the synthesis was completed, but in took quite a long time (210 min). The best was the borate buffer (pH = 9), where it took 120 min to complete the reaction. As far as the reagent ratio between Cu and TCPP is concerned the best for possible radiopharmaceutical synthesis is 1:1 (or a slight excess of porphyrin because of the variable activity of the produced isotope). The results for this ratio showed a compromise between reaction time and the copper used for the process. The next step was to apply $Pb^{2+}$ ions as a complexation accelerator. The results for the Cu:Pb:TCPP ratio 1:1, 5:1 show that the SAT mechanism effectively improves reaction kinetics (reaction time 30 min). The reaction kinetics with Pb acceleration are presented in Fig. 2.

Another procedure that has to be established after the "cold" synthesis and optimisation but before using radioactive $^{64}$Cu, is the purification strategy and quality control and this is the subject of further research.

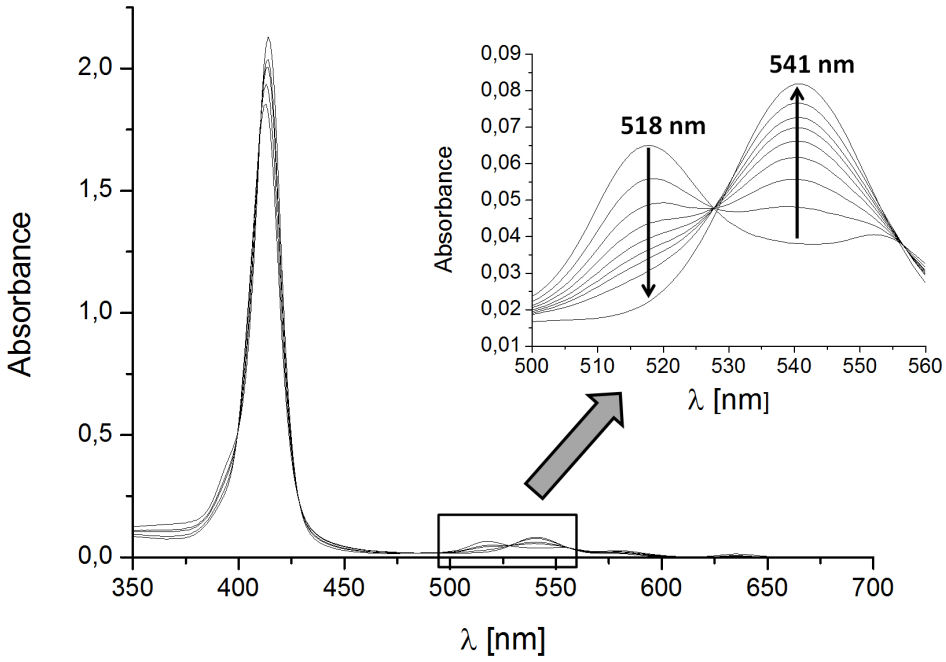


**Figure 1:** The formation of a CuTCPP complex with characteristic changes in the UV-VIS spectrum.

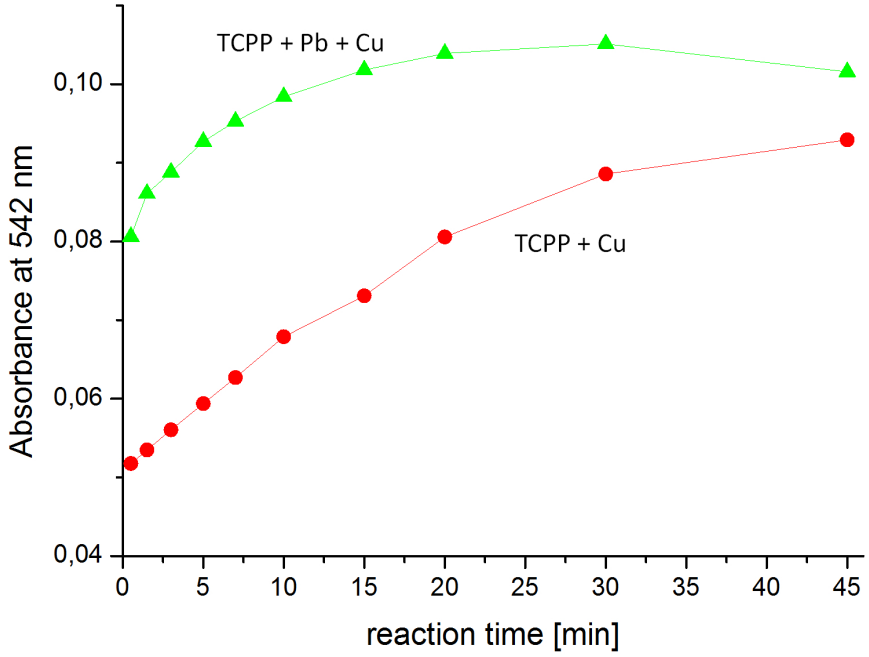


**Figure 2:** The kinetics of CuTCPP complex synthesis using different accelerators.

# B.7 Distribution and separation of metallic impurities in the production of $^{18}$F-fluorodeoxyglucose

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*2) Faculty of Chemistry, University of Warsaw, Warszawa, Poland*

In this study identification, determination and distribution of metallic contaminants in the synthesis of $^{18}$F-fluorodeoxyglucose is presented. $^{18}$F-FDG was synthesised in six independent runs using the standard method from mannose triflate with alkaline hydrolysis. Ten complete sets of the following samples were collected: ion exchange column Accel Plus QMA Sep-PakTM, used for preconcentration and separation of $^{18}$F from target, reverse phase separation columns Sep-PakTM C-18 RP used in basic hydrolysis and the purification process of $^{18}$F-FDG and alumina column Sep-PakTM N Plus for ionic contaminant removal. The list of samples was complemented by liquid samples of final product, saline, waste after synthesis and recovery water.

A ICP-QMS (NEXIon 350, Perkin-Elmer Sciex, USA) quadrupole spectrometer was used for determination of the following elements: Ag, Al, B, Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, Ti, V and Zn.

For ICP-MS measurements the metallic impurities from purification columns were eluted with 1 ml of 1M $HNO_3$, whereas liquid samples were measured directly. Cobalt was found mainly in the recovery water ($95.9 \pm 2.36$ μg/L) and only approx. 10% was collected in QMA column. This concentration ratio confirms the results obtained from γ-spectrometry. Chromium is deposited mainly in the post-production wastes ($771 \pm 15.3$ μg/L) and is not strongly retained on any of the other steps of the synthesis. The source of Cr in the whole system may be Havar and stainless steel elements on the way from the cyclotron to the $^{18}$F synthesizer. Copper is present in the final stages ($Al_2O_3$: $50.8 \pm 0.74$ μg/L, wastes: $21.0 \pm 0.50$ μg/L) of synthesis and in the formulated product ($51.7 \pm 2.32$ μg/L). The highest level in the final product can be explained by saline addition in the final formulation, as in saline significant Cu content ($262.4 \pm 0.5$ μg/L) was found. The highest concentration of lead was observed in $^{18}$F-FDG $13.5 \pm 0.11$ μg/L). As Pb is frequently used as a shield against radiation, the contamination may be present at all stages. Nickel was detected mainly in $^{18}$F-FDG $187 \pm 6.64$ μg/L). The distribution of Ni in other stages indicates that the dominant contamination occurs during dispensing. The source is the sterile stainless steel needle used for injection of the final product to into individual vials. Titanium dominated in the QMA column ($209 \pm 3.31$ μg/L). Molybdenum is partially trapped by the QMA column $7.12 \pm 0.23$ μg/L) and partially gets to enriched water ($4.44 \pm 0.19$ μg/L) and does not contaminate the $^{18}$F-FDG. Zinc is a common impurity and the concentration gradually drops along the synthesis path. An increase is observed in the final product due to the saline addition $212.6 \pm 1.7$ μg/L) as for copper. An extra source of Zn is the new QMA column, where a significant blank was observed (μg/L). The highest concentration of boron was observed in the QMA column ($373 \pm 4.80$ μg/L). Boron is a ubiquitous element in nuclear science and technology so the sources could be varied. Further distribution in the synthesis system suggests external sources i.e. glass parts of equipment containing B in their composition. Other sources of metallic impurities could be the purification columns. The QMA column contains a significant amount of Ti ($161 \pm 4$ ppb). Zn and Cu are common metals and they are

present in all columns. The most metal impurities are in the alumina column, containing relatively high concentrations of Cr (47.2±0.8 μg/L), Cu (56±3 μg/L), V (93.6±1.0 μg/L) and Ni (31.3 ± 0.3 μg/L) and these could increase the contaminant content in waste. The results clearly indicate that metallic impurities are not a threat to the quality of the produced $^{18}$F-FDG and are significantly lower than the levels set by the regulatory office. Most of the metallic impurities are concentrated in the ion exchange column or migrate with enriched water to recovery and do not influence significantly the synthesis process.

To conclude, the main source of metallic impurities is Havar, which contacts directly with the target material. Metal contaminants (and boron) can also enter the process during formulation, dispensing and with new purification columns. Their distribution along the synthesis process varies depending on the investigated element.

**Table 1:** Metal content at different stages of $^{18}$F-FDG synthesis and in the final product. LOQ — limit of quantification; N/A — not available.

| | LOQ $\mu gL^{-1}$ | Recovery water | QMA column | C18 column | $Al_2O_3$ column | $^{18}$F-FDG product | Wastes | Saline | EMEA limits $\mu gL^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| Ag | 0.13 | 39.1 ± 1.07 | 4.84 ± 0.19 | 0.51 ± 0.02 | 0.35 ± 0.01 | 0.35 ± 0.01 | 0.48 ± 0.02 | 0.039 ± 0.01 | N/A |
| B | 5.94 | 132 ± 2.92 | 373 ± 4.80 | 4.99 ± 0.78 | 53.5 ± 0.85 | 56.2 ± 2.27 | 196 ± 3.06 | < LOQ | |
| Cd | 0.75 | 0.89 ± 0.02 | 0.84 ± 0.01 | 1.11 ± 0.02 | 1.02 ± 0.01 | 0.58 ± 0.01 | 0.51 ± 0.01 | 0.011 ± 0.003 | 250 |
| Co | 0.08 | 95.9 ± 2.36 | 7.17± 0.13 | 0.24 ± 0.01 | 0.71 ± 0.01 | 0.38 ± 0.01 | 1.33 ± 0.03 | 0.115 ± 0.003 | 10000 |
| Cr | 8.18 | 80.6 ± 5.68 | 61.2 ± 2.52 | 22.0 ± 0.33 | 91.3 ± 0.94 | 53.8 ± 6.79 | 771 ± 15.3 | 2.36 ± 0.11 | 1500 |
| Cu | 3.14 | 2.54 ± 0.07 | 10.9 ± 0.50 | 10.6 ± 0.49 | 50.8 ± 0.74 | 51.7 ± 2.32 | 21.0 ± 0.50 | 262.4 ± 0.5 | 5000 |
| Mn | 0.90 | 2.17 ± 0.06 | 1.93 ± 0.03 | 1.64 ± 0.02 | 21.1 ± 0.19 | 2.21 ± 0.08 | 1.76 ± 0.03 | 0.93 ± 0.02 | 70000 |
| Mo | 1.07 | 4.44 ± 0.19 | 7.12 ± 0.23 | 0.66 ± 0.02 | 0.47 ± 0.01 | 1.15 ± 0.05 | 1.59 ± 0.03 | < LOQ | |
| Ni | 6.42 | 50.5 ± 1.09 | 9.38 ± 0.21 | 10.7 ± 0.16 | 34.7 ± 0.34 | 187 ± 6.64 | 28.0 ± 0.41 | < LOQ | |
| Pb | 0.32 | 0.77 ± 0.01 | 4.25 ± 0.03 | 1.21 ± 0.01 | 5.16 ± 0.03 | 13.5 ± 0.11 | 1.53 ± 0.03 | < LOQ | 100 |
| Ti | 0.95 | 3.82 ± 0.17 | 209 ± 3.31 | 57.9 ± 1.28 | 32.2 ± 0.42 | 11.3 ± 0.76 | 7.57 ± 0.22 | 3.27 ± 0.09 | |
| V | 0.05 | 0.28 ± 0.02 | 0.92 ± 0.17 | 1.01 ± 0.02 | 41.5 ± 0.42 | 17.7 ± 0.35 | 4.57 ± 0.12 | 55.5 ± 0.6 | |
| Zn | 12.6 | 105 ± 3.18 | 95.0 ±1.38 | 69.7 ± 0.98 | 56.5 ± 0.58 | 121 ± 5.54 | 86.5 ± 2.08 | 212.6 ± 1.7 | 150000 |

## B.8 Quality control of $^{11}$C-methionine

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$^{11}$C-methionine increased its clinical significance when methionine uptake was identified as one of the critical factors in tumour growth and began to be a standard method for visualisation of gliomas in neurooncology. $^{11}$C-methionine was synthesised via $^{11}$C methylation from L-cysteine thiolactone (ABX, Radeberg, Germany) in solution using the bubbling method.

Chemical purity was determined in all produced $^{11}$C-methionine samples. L-homocysteine thiolactone hydrochloride (impurity A), $^{11}$C-methionine and homocysteine (impurity B) were identified by a qualitative comparison with the reference solution, containing the maximum available concentration of the respective CRS as described in Eur. Pharm. The retention times were 2.51 min. for impurity B, 3.05 min. for methionine and 3.72 min. for impurity A, which corresponded to resolution factors 1.02 and 1.28 vs. methionine. In all $^{11}$C-methionine samples the area of the corresponding peaks was smaller than obtained with the reference solution and the signal from precursor (L-homocysteine thiolactone hydrochloride) was negligible or not even observed (Fig. 1).

Radiochemical purity was determined by HPLC with radiometric detection, where the peak of $^{11}$C-methionine was observed at 3.07 min, with no other signals recorded (Fig.2). The average content of $^{11}$C-methionine was higher than 99%. Six consecutive runs were analysed, each in triplicate. Enantiomeric purity was assessed by chiral HPLC. L- and D- isomers were identified by HPLC with UV and radiometric detectors (Fig. 3). The percentage of L-$^{11}$C-methionine was $91.6 \pm 0.4\%$.

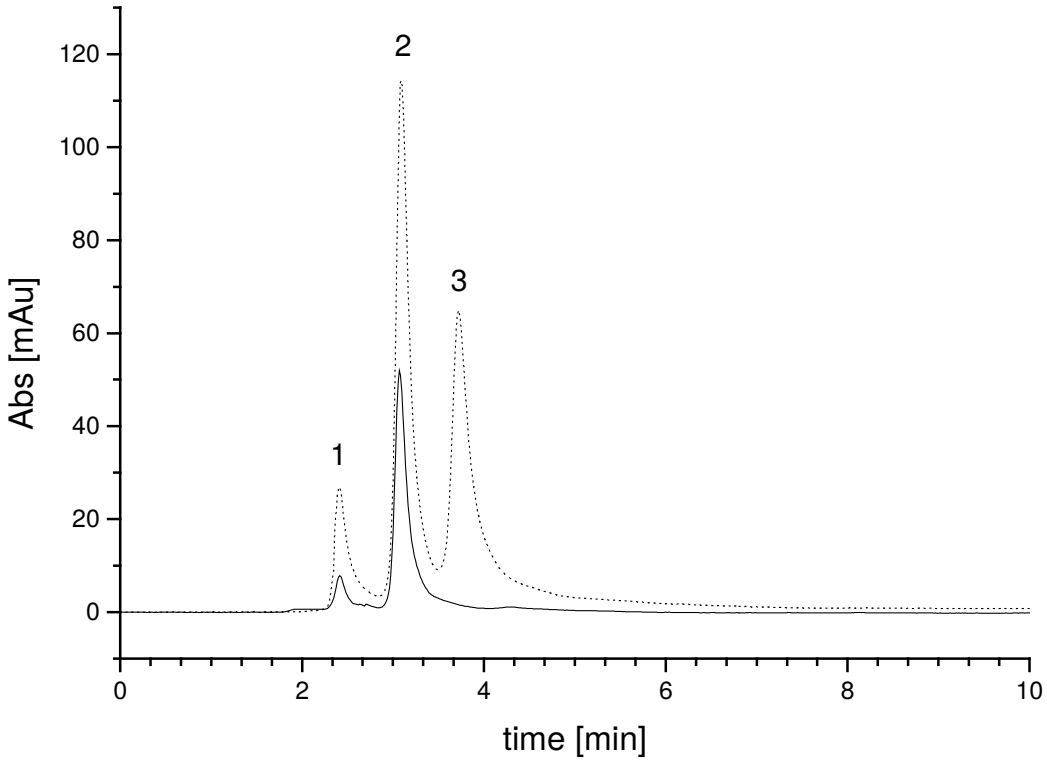


**Figure 1:** UV-Chromatogram of reference standards (dotted line) and $^{11}$C-metnionine sample (solid). 1-L-homocysteine (tr=2.51 min), 2-methionine (tr=3.05 min.), 3-L-homocysteine thiolactone hydrochloride (tr=3.72 min.)

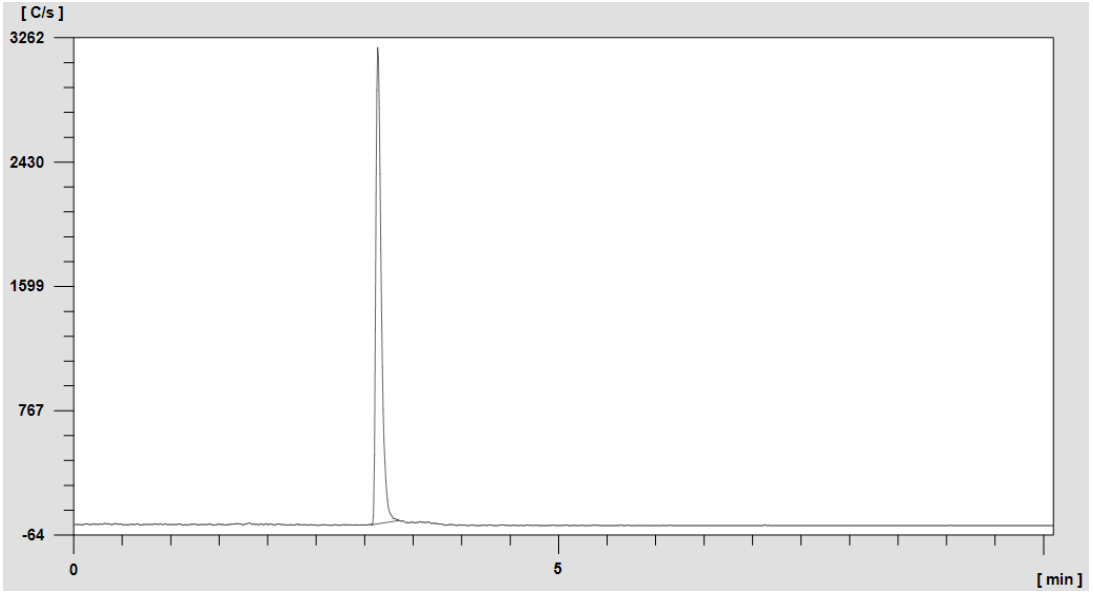


**Figure 2:** Radiochromatogram of $^{11}$C-methionine (tr=3.07 min)

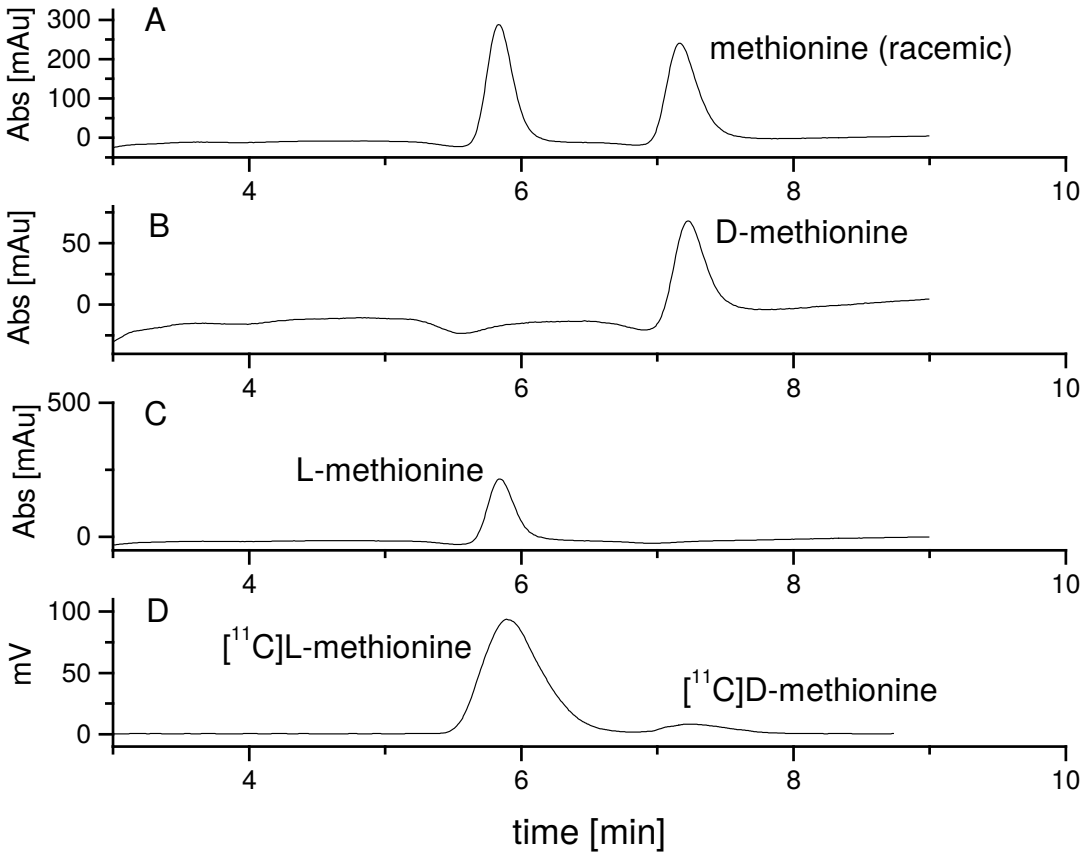


**Figure 3:** Standard and sample chromatograms for enantiomeric purity evaluation. (A) UV spectra of racemic methionine CRS, (B) UV spectra of D-methionine CRS, (C) UV spectra of L-methionine CRS, (D) Radiochromatogram of $^{11}$C-methionine sample.

# B.9 Spectrophotometric determination of scandium with xylenol orange

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A spectrophotometric procedure for the determination of scandium has been developed using xylenol orange as the colorimetric indicator. The conditions for complex formation, stability of the complex, influence of foreign ions and validation process were investigated. This spectrophotometric method was later used to study sorption of scandium on ion exchange resins and purification of the element after production in the cyclotron.

The following procedure for the determination of scandium was applied: to a 10 ml volumetric flask containing scandium were added sequentially: 1 ml chloride buffer pH=2, 1 ml 0.05% xylenol orange solution and water to the mark. The absorbance of the solution was measured at 555 nm against a reagent blank as a reference. The maximum absorption of xylenol orange is at 432 nm, while the absorption of Sc-xylenol orange complex is at 555 nm.

Optimum conditions for complex formation were established in pH between 1.5–2 where the complex gives the highest absorbance. In the pH range 3–5 absorbance is significantly reduced. In pH lower than 1 the colour reaction does not occur. Finally, pH in the range 1.5–2 was chosen for further investigations.

Stability and formation kinetics of the complex were satisfactory — the complex was stable over time and formed immediately after mixing the solutions so measurements could be made immediately after mixing (Fig. 1).

The calibration graph for quantitative measurement was linear over the range 0.05–3 ppm of scandium, the equation of the straight line is $A = 0.78169C - 0.07162$, where $A$ is the absorbance and $C$ the concentration of Sc in mg/L. The linear correlation coefficient $R^2 = 99877$ (Fig. 1).

The method was characterised by good reproducibility and precision. The relative standard deviation of the spectrophotometer, at 6 replicates analysis, was 0.02–0.12% for the concentration of scandium in the range 0.5–1.5 ppm. RSD of the analyst determined in the same way was 0.7–1.7%. The detection limit of the presented method was found to be 15 ng/g.

Other ions do not interfere significantly with the determination of scandium, i.e. $Na^+$, $K^+$, $Mg^{2+}$, $SO_4{}^{2-}$ $Cl^-$. Most ions interfere little, e.g. 100-fold amounts of $Ca^{2+}Pb^{2+}$, $Cd^{2+}$, $Mn^{2+}$, $NO_3{}^-$ interfere in higher concentrations, where up to 100-fold amounts are tolerable, only $Fe^{3+}$, $Ga^{3+}$, $Al^{3+}$ interfere seriously.

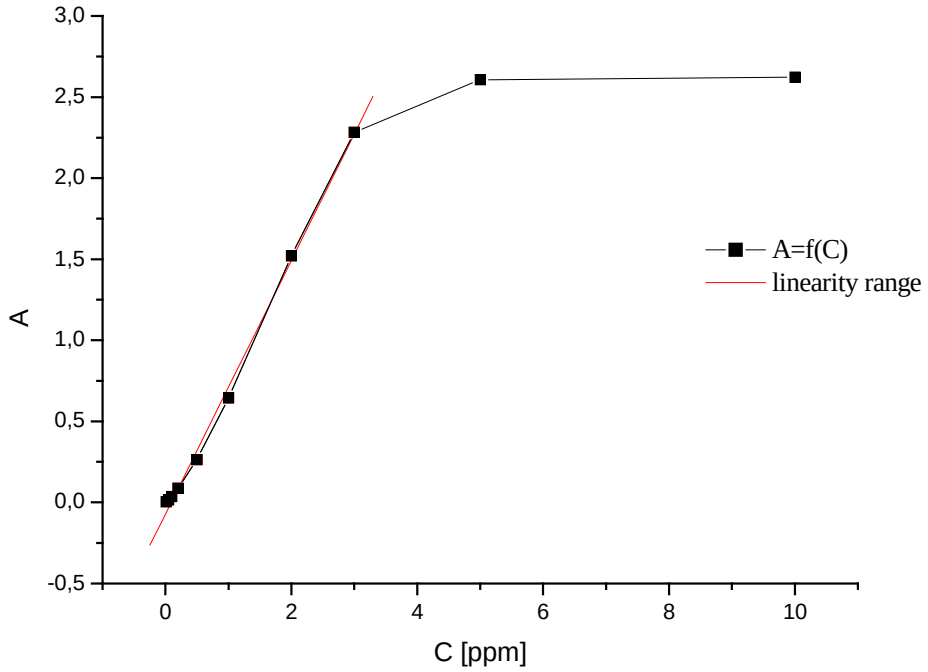


**Figure 1:** Calibration curve for Sc-xylenol orange complex.

# B.10 ILITS experiment: scaling of cluster size distributions

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## Introduction

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

ILITS (Investigation of Light-Ion Track Structure) is part of the European Joint Research Project "BioQuaRT" (Biologically weighted Quantities in Radiotherapy) [1], which aims to lay the foundations for a new concept of radiation quality based on measurable physical characteristics of ionising particle track structure. Two of the three nanodosimeters involved in BioQuaRT are also involved in ILITS, namely the NCBJ Jet Counter and the PTB Ion Counter. By conducting measurements with these nanodosimeters for the same particles and energies, ILITS aims to contribute to the more fundamental investigations of BioQuaRT, such as the correlation between track structure characteristics and different target sizes. Measurements have been performed exclusively with carbon ion beams of various energies. These measurements include ionisation cluster size distributions in 0.5 mbar $C_3H_8$ and in 0.75 mbar and 1.2 mbar $N_2$ produced by 45 MeV and 76 MeV $^{12}C^{6+}$ ions, which were obtained with the PTB Ion Counter at beam line A of the HIL cyclotron.

## PTB Ion Counter setup

The PTB Ion Counter [2] detects positive ions created by ionising primary particles passing through or nearby the sensitive volume. Basically, the setup of the PTB nanodosimeter for accelerator operation consists of two vacuum chambers (see Figure 1): the scattering chamber (provided by the HIL) and the nanodosimeter itself, which are separated by a vacuum tight window of 2.5 µm thick Mylar foil. In the scattering chamber, the primary particle rate is reduced for use in the nanodosimeter which occupies the second chamber. A small number of scattered primary ions enter the second low-pressure interaction chamber (i.e. nanodosimeter) and create ions along their tracks. An electrode system extracts the ions from the interaction chamber into an evacuated acceleration stage, which has an ion detector at its end to register the ions individually. The height of the sensitive volume is defined by the width of the drift time window, which is applied for the detection of ions. The diameter of the sensitive volume is defined by the 1 mm diameter of the extraction aperture and the efficiency map for ion collection [3].

For triggering the data acquisition, the PTB Ion Counter uses a position-sensitive detector to detect the arrival of the primary ions. This detector, which is 20 mm in width, records the position of the primary particles with respect to the centre of the

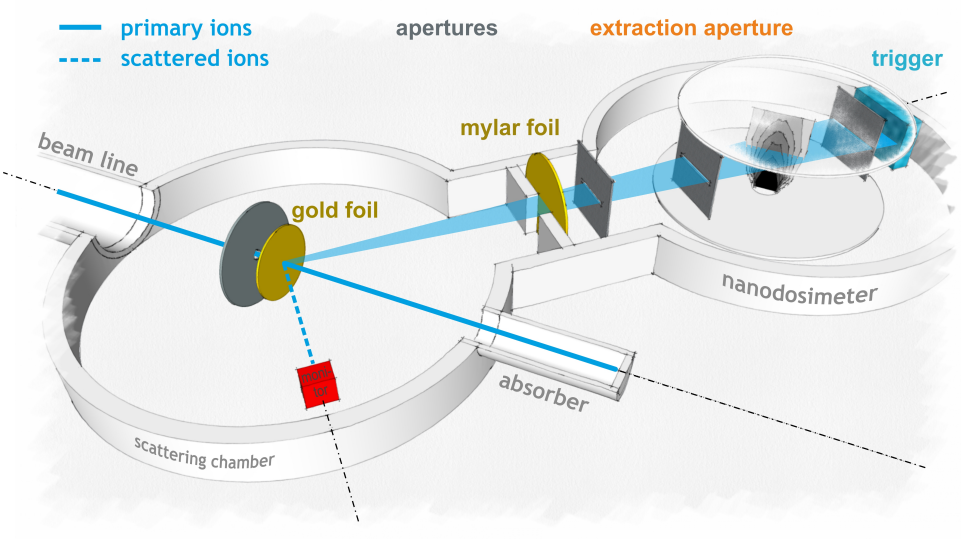


**Figure 1:** Schematic setup of the PTB nanodosimeter for measurements at an ion accelerator.

sensitive volume. The number of ions collected in the sensitive volume is correlated to the primary particle's position. In this way, it is possible to record ionisation cluster size distributions for different distances $d$ (impact parameter) of the primary particle tracks with respect to the centre of the sensitive volume without moving the ion counter. Repeated measurements for a large number of single primary particles of radiation quality $Q$ are used to calculate the relative frequency distribution of the ionisation cluster size of the detected ions.

## Scaling of cluster size distributions

Nanodosimetric quantities cannot be measured directly in a biological target. This is also true for water, which is commonly used as a "biological" reference material for defining nanodosimetric quantities related to radiation quality [4, 5]. Experimentally, ionisation cluster size distributions can be assessed using a nanodosimeter, which basically comprises a gas filled counter operating at low pressure. The issue of relating ionisation cluster size distributions of different materials has been addressed by Grosswendt [6], who proposed a simple scaling procedure to relate ionisation cluster size distributions measured in a macroscopic gas target with those calculated by Monte Carlo simulations for nanometric water targets. With this scaling procedure, the gas pressure in the nanodosimeter is chosen such that

$$(D\rho)^{(gas)} = (D\rho)^{(water)}(Q)\frac{(\lambda_{ion}\rho)^{(gas)}(Q)}{(\lambda_{ion}\rho)^{(water)}(Q)} \tag{1}$$

where $D\rho$ is the mass per unit area, ($\lambda_{ion}$ is the ionisation mean free path of radiation with quality $Q$, and $\rho$ is the material density. In order to have uniquely defined dosimetric quantities, Equation 1 should be valid irrespective of radiation quality and selected materials. Thus, an important step towards the direct measurement of cluster size distributions expected in a DNA segment is to test experimentally the scaling procedure defined by Equation 1. Equation 1 was derived for a primary particle beam crossing the sensitive volume centrally (i.e. $d = 0$), and for this irradiation geometry the scaling relation has already been validated [7]. For the purpose of extending the applicability of the scaling

procedure to primary particle beams passing the sensitive volume at a distance d, ionisation cluster size distributions were measured with the PTB Ion Counter for 45 MeV and 76 MeV $^{12}C^{6+}$ ions using $C_3H_8$ and $N_2$ as target gases. According to the aforementioned equation and the mean free path calculated from the cross sections used in PTra [8, 9], equivalent cluster size distributions for $^{12}C^{6+}$ ions in both media could be obtained for pressures of 0.5 mbar $C_3H_8$ and 1.2 mbar $N_2$. Figures 2 and 3 show the data measured with the PTB Ion Counter in 0.5 mbar $C_3H_8$ and 1.2 mbar $N_2$ for 76 MeV $^{12}C6+$ ions. Figure 2 shows the mean ionisation cluster size as a function of the impact parameter d. In figure 3, the impact parameter has been scaled in terms of $\rho d/\lambda_{el,ion}$ in order to take into account the different densities $\rho$ of the two target gases and the different ionisation mean free paths of secondary electrons $\lambda_{el,ion}$ in the two target gases for electrons of the mean kinetic energy. The mean cluster sizes for 1.2 mbar $N_2$ for impact parameters larger than the target volume ($\leq 0.2$ µg/cm$^3$) have been compensated with respect to the solid angle covered by the target volume as seen from the primary particle track. The newly-scaled mean cluster sizes for 1.2 mbar $N_2$ as a function of the rescaled impact parameter agree well with the mean cluster sizes for 0.5 mbar $C_3H_8$ for impact parameters larger than the target volume. Although these data are only preliminary, these results indicate that the scaling relation in Equation 1 can also be applied to primary particle beams that pass by the sensitive volume at a distance $d$.

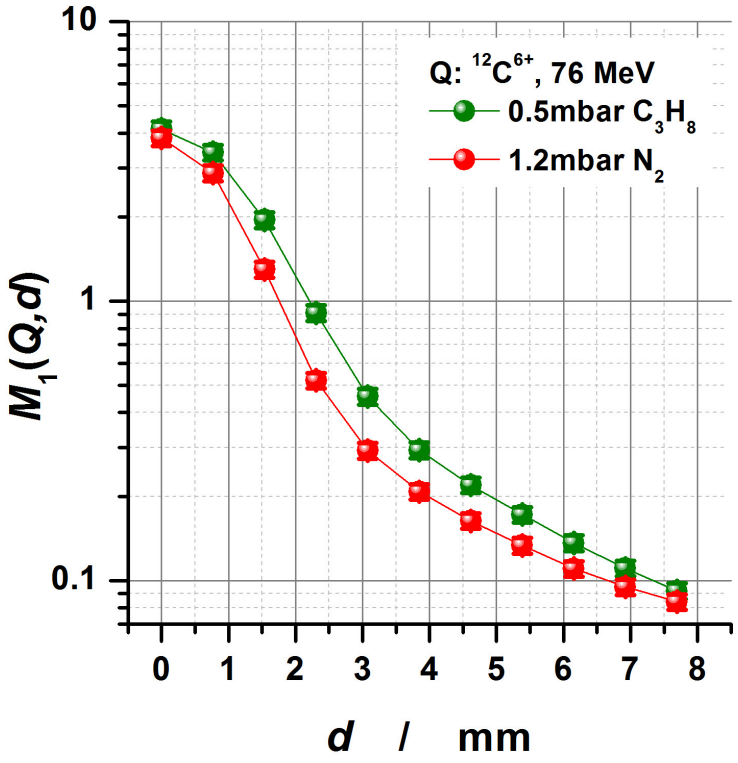


**Figure 2:** Mean ionisation cluster size distributions for 76 MeV $^{12}C^{6+}$ ions measured with the PTB Ion Counter in 0.5 mbar $C_3H_8$ and 1.2 mbar $N_2$ for different impact parameters $d$.

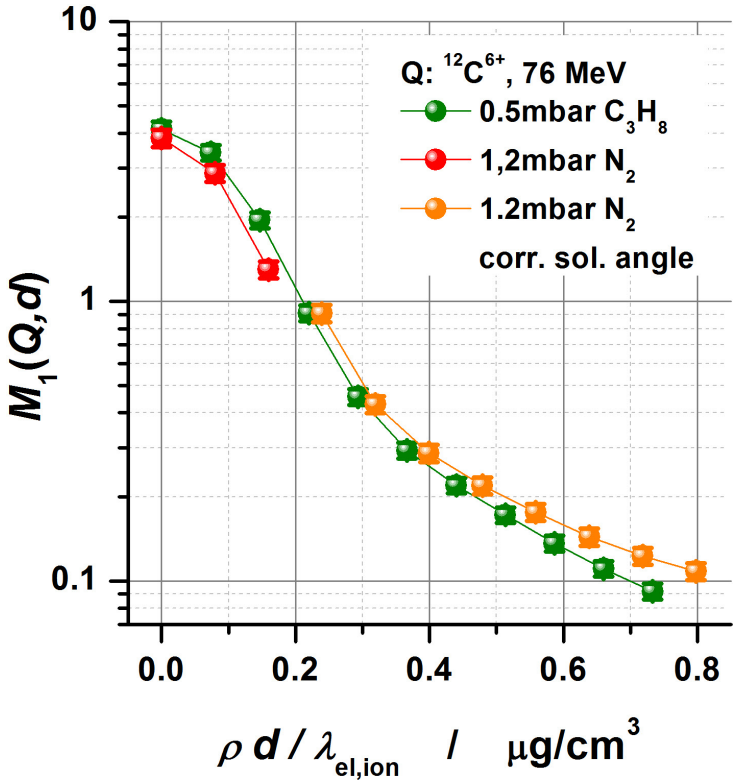


**Figure 3:** Mean ionisation cluster size distributions for 76 MeV $^{12}C^{6+}$ ions measured with the PTB Ion Counter in 0.5 mbar $C_3H_8$ and 1.2 mbar $N_2$ for different impact parameters in terms of $\rho d/\lambda_{el,ion}$. The mean cluster sizes for 1.2 mbar $N_2$ for impact parameters larger than the target volume ($\leq$ 0.2 µg/cm$^3$) have been compensated with respect to the solid angle covered by the target volume as seen from the primary particle track.

## Acknowledgement

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# B.11 γ-H2AX assay in studies of the biological response in irradiated cells

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Ionizing radiation induces a variety of DNA lesions, including single and double strand breaks (DSBs). Irradiation of biological material with heavy ions causes large energy deposition precisely localized along the ion track and can lead to complex types of DNA DSBs. These lesions are induced linearly with radiation dose. Apart from ionizing radiation only a few other environmentally relevant agents or processes are known to generate significant levels of DNA damage [1]. In response to DSB formation histone H2AX phosphorylation is induced and the concentration of DNA repair proteins at the damaged chromatin starts. The γ-H2AX assay allows for microscopical visualization of formed foci. The aim of this study was to investigate the biological response in cells irradiated with $^{12}$C ions and for this purpose γ-H2AX assay was used.

At the set-up with a horizontal beam line an independent Si-detector system was used for beam diagnosis and monitoring. The beam dosimetry was based on single-particle counting. The measured flux of the ions registered by the 0° detector in the air, outside the exit window, was proportional to the count rate of the 20° detector registering scattered ions in the chamber [2]. The measured relation of the number of ions reaching the detector at an angle of 20° to the number of ions registered at 0°, taking into account the type of ions and their energy, was used to calculate the total fluence of carbon ions as well as the dose deposited in the biological material.

Chinese Hamster Ovary cells (CHO-K1) were irradiated with doses: 0.1 Gy, 1 Gy and 4 Gy of $^{12}$C ions and processed for the γ-H2AX assay. Next, the cells were mounted with Vectashield mounting medium for fluorescence with DAPI. The number of ion tracks registered in individual cells was counted under a NIKON TI Eclipse A1 confocal microscope. Representative images of cells processed for the γ-H2AX assay are shown in Figure 1. Part (a) of the Figure presents a non-irradiated cell with a spontaneous focus. It is a single focus located in the centre of the nucleus. In contrast with the control cell, in Figure 1 (b) a cell irradiated with 70 MeV $^{12}$C ions is shown. The single focus, visible in the top view of this cell (left part of the Figure) in fact consists of several foci, shown in the cross-section of the nucleus. Foci patterns extending across the entire nucleus, along the tracks of carbon ions, are evident. The arrangement of the foci pattern maps the traces of three carbon ions that passed through the cell nucleus.

Results of the γ-H2AX assay were compared to the expected number of foci per cell and are presented in table 1. All data are expressed as the mean ± standard error [3]. Experimental data were obtained from the analysis of 100 scored cells per dose. The predictions were determined by the size of the apertures installed in the set-up and the

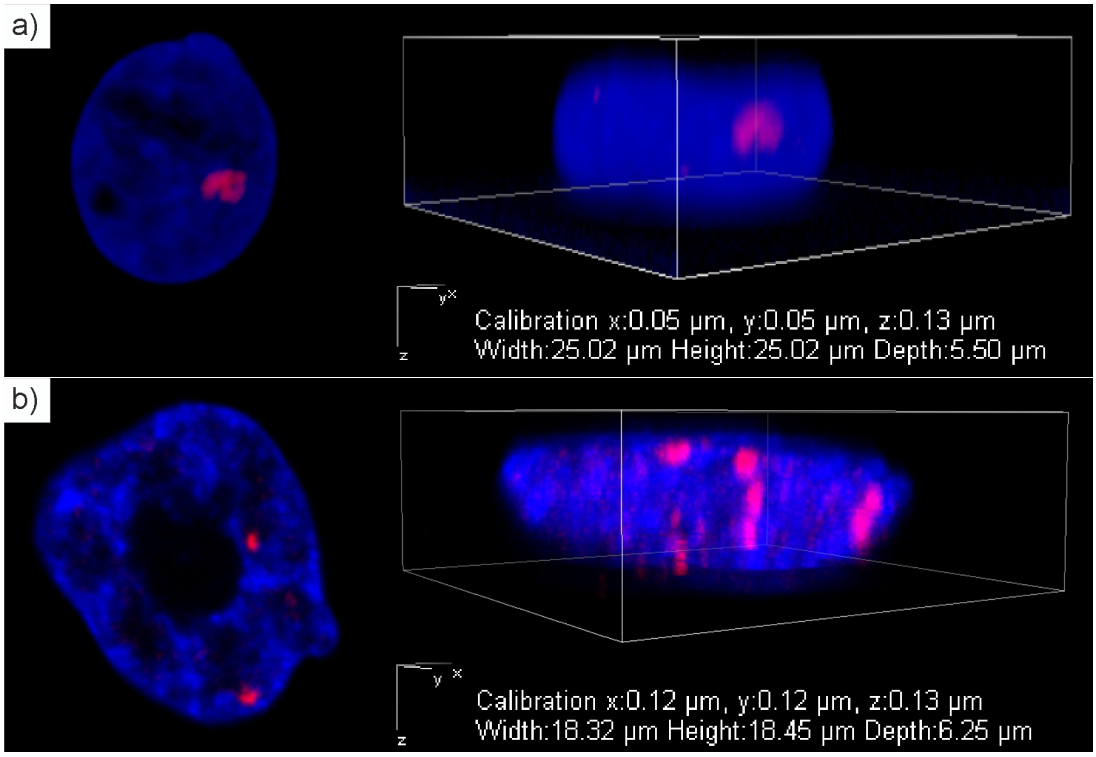


**Figure 1:** CHO-K1 cell nuclei processed for the γ-H2AX assay: (a) control cell and (b) irradiated cell. Both cells are viewed from the top and in cross-section.

expected number of ions reaching the 0° detector, with the assumption that the CHO-K1 nucleus area was (98 ± 5) µm$^2$ [4].

**Table 1:** Comparison of the observed number of γ-H2AX foci per cell with the expected number.

| Dose [Gy] | Number of foci per cell | Expected number of foci |
|---|---|---|
| 0 | $0.00 \pm 0.06$ | 0 |
| 0.1 | $0.10 \pm 0.07$ | $0.096 \pm 0.008$ |
| 1 | $0.89 \pm 0.11$ | $0.96 \pm 0.05$ |
| 4 | $4.30 \pm 0.22$ | $3.82 \pm 0.20$ |

Our results revealed that the number of ion traces detected in CHO-K1 cells by the γ-H2AX assay was correlated with the expected number of foci per cell, calculated on the basis of the detector system used in the set-up. The results were within 1 or 2 standard errors and confirmed that the single-particle counting system serves its dosimetric purpose.

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# B.12 Nanodosimetry of carbon ions at HIL — study of the wall effect in the Jet Counter

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To date, three types of nanodosimetesr have been developed that are capable of measuring track structure of ionizing particles in a gas target equivalent to a nanometric site in condensed matter. Two of these three nanodosimeters, namely the PTB Ion Counter [1] and the NCBJ Jet Counter [2], were involved in experimental investigations at HIL in the past [3, 4]. These devices differ with respect to their operating principle, the size of the simulated nanometric volume, the efficiency of ion collection and most significantly in the method of creating the gaseous target. The target volume in the Jet Counter is surrounded by a thin mylar (1 mg/cm$^2$) wall. The impact of the wall on the measured ionization cluster-size distributions (ICSD) is presented. The results are discussed.

## NCBJ Jet Counter (JC)

The NCBJ ion counting nanodosimeter Jet Counter described in detail elsewhere [5] consists of an interaction chamber where a sensitive volume equivalent to nanometre-size dimension is obtained by nitrogen expansion from a reservoir by a pulse operating a piezoelectric valve with a repetition rate of 1–4 pulses per second. The interaction chamber has a cylindrical shape (10 mm in diameter, 10 mm in height) with walls of 1 mg/cm$^2$ mylar. The size of the equivalent nanometric target is established from a combination of the pressure in the reservoir and the voltage applied to the piezoelectric valve and monitored by measuring the transmission of a 1 keV electron beam. Nitrogen molecules are ionized by single carbon ions crossing the sensitive volume forming ionization clusters of different size. The frequency of the created ionization clusters is determined by collecting the ionized gas molecules on an event-by-event basis. Due to the pulsed structure of the carbon beam, the gas injection to the JC is synchronized to the RF signal from the HIL cyclotron.

## Results and Discussion

The nanodosimetric experiments were carried out at HIL with carbon ions crossing the nitrogen gas cavity with various impact parameters. The mass-per-area of the nitrogen target was set to 0.32 μg/cm$^2$ for the zero impact parameter. The was irradiated with 50 MeV single carbon ions collimated with rectangular collimator 0.8 mm in width and 3 mm in height. Thus, the impact parameter of the single carbon ion varies from the beam impact parameter in the range ±0.4 mm. The results of the measured mean cluster size are presented in Fig. 1 together with theoretical curves. The theoretical model is based on the assumption that the mean cluster size is proportional to the path length of the primary particle and to the irradiated area of the mylar wall:

$$M_1(y; N_S, N_C) = N_S S(y) + N_C \overline{C}(y)$$

where $M_1$ is the predicted mean cluster size for a given beam impact parameter $y$, $\overline{C}$ is the mean chord (the mean path length of the primary particle), $S$ is the irradiated area of the wall, $N_S$ and $N_C$ are fitting parameters representing the mean number of ionizations

per unit area of the irradiated part of the wall and per unit path length of the primary particle, respectively.

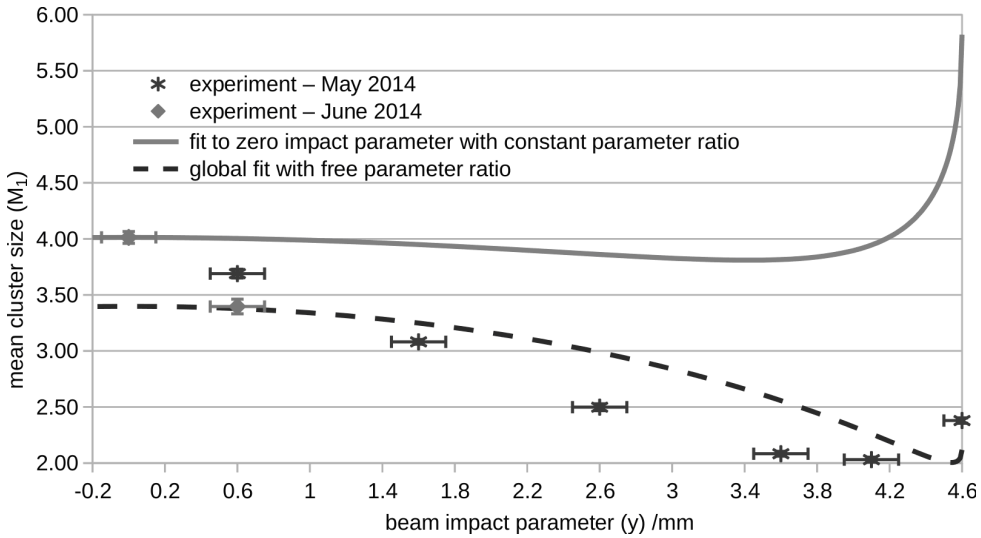


**Figure 1:** Data obtained in two experiments with the carbon ion beam at HIL. The curves represent two fits of the simple geometric model of the wall effect. The constant parameter ratio was obtained in the Monte Carlo simulation.

As can be seen in Fig. 1 the experimental data do not follow the the theoretical dependence, which indicates the presence of some additional phenomenon. The most probable candidates are the nonuniform ion collection efficiency and inhomogeneities in the target density. However, the most relevant parameter describing the nanometric volume in nanodosimetry is the effective mass-per-area $\nu l \rho$, where $\nu$ — ion counting efficiency, $l$ — length of particle track, $\rho$ — target density. Since one needs to know only the value of the product $\nu\rho$, to distinguish between inhomogeneous density and nonuniform efficiency is not necessary. Thus, it is possible to calculate the dependence of mass-per-area $\nu\rho$ normalized to its value at zero impact parameter, which is shown in Fig. 2. The conclusion is that the dependence of $(\nu\rho/)_y/(\nu\rho)_0$ may be considered as a density-efficiency map of the Jet Counter in the radial direction.

## Acknowledgement

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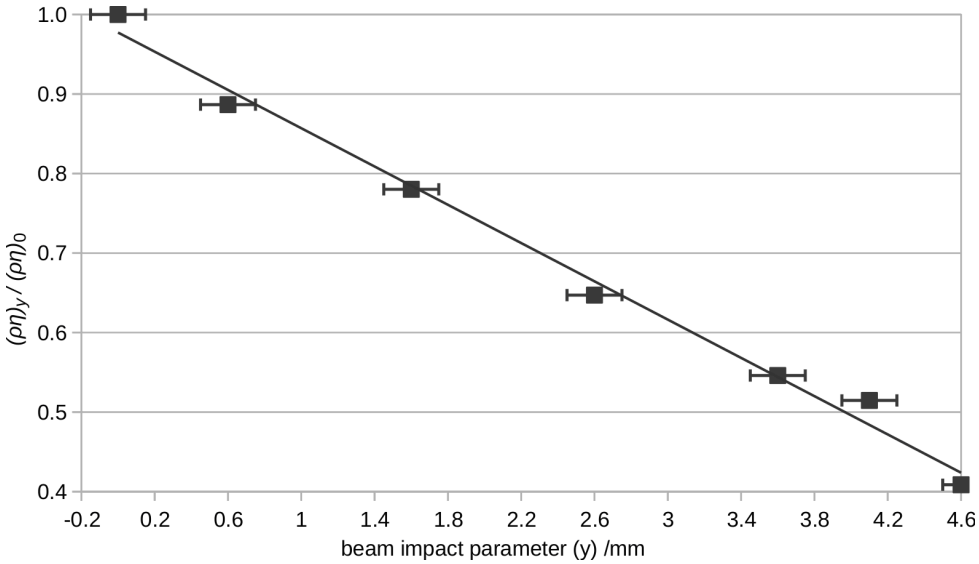


**Figure 2:** Efficiency-density dependence on the beam impact factor for the 0.32 μg/cm$^2$ nitrogen target in the Jet Counter.

## B.13 Hilic chromatography — a powerful technique in the analysis of polyphenols

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Hydrophilic Interaction Chromatography (HILIC) is a technique which combines polar, stationary phases used in normal phase chromatography with mobile phases, characterised by a high content of organic solvent, which are used in reversed phase chromatography. In another words it is a hybrid of these two separation techniques. It usually shows opposite retention in comparison to that obtained in RP-HPLC. HILIC seems to be a missing tool in the analysis of small polar compounds which were eluted in dead volume (when separated by RP-HPLC) or too strongly retained on stationary phases (when separated by NP-HPLC). Due to the high content of organic solvent in the mobile phase, HILIC is recommended in the HILIC-MS combination. This specific combination of mobile phases enhances the ionisation efficiency in the ion source of a mass spectrometer. It is possible that we can lower the limit of detection, when we use HILIC in our analysis. This fact could be important in the analysis of natural samples in which analytes are in very low concentration. It should be noticed that interest in HILIC applications is still increasing, which can easily be seen by the increasing number of publication about it. The aim of this study was to examine the potential of HILIC in the analysis of polyphenols. Three different stationary phases were used in our study: diol, silica and sulfobetaine. They belong to three different groups: neutral, charged and zwitterionic. After choosing the best stationary phase and optimisation of other separation parameters the technique was used for the natural samples. We analysed fruit juices as well as different kinds of herbal infusions. We compared the separation efficiency with that obtained with classical reserved phase chromatography in terms of the limit of detection, resolution of separation and so on. Data obtained from the analysis of herbal infusions were combined with the results from a spectrophotometric measurement. Two commonly used spectrophotometric methods were used: Folin-Ciocalteu and the CUPRAC method.

# B.14 Polyphenols in heather flowers (Calluna vulgaris L. Hull)

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**Objective:** Calluna vulgaris L. Hull can be found in most parts of Europe. Heather flowers of are a rich source of polyphenolic compounds such as flavonoids, phenolic acids, procyanidins, sterols and triterpenes. Extracts from plant material are part of traditional folk medicine for treating urinary tract disturbances and inflammatory related disorders. Moreover, heather flowers are components in herbal mixtures used in some cosmetic products.

**Methods:** The aim of this study was to investigate the content of some polyphenols and the antioxidant capacity found in extracts of the aerial parts of Calluna vulgaris (L.) Hull.

Samples were collected in the Wyszków Forest District in Poland in September 2014. Water, ethanol and its mixture as well as ethyl acetate were used for extraction. The influence of extraction temperature was also studied. The antioxidant capacity of the prepared extracts was screened by spectrophotometric methods: Folin-Ciocalteu (so-called total phenolic content), cupric ion reducing antioxidant capacity (CUPRAC), DPPH and the aluminium chloride method (so-called total flavonoids content). The content of some polyphenols was determined by high performance liquid chromatography-tandem mass spectrometry (HPLC-MS). Gradient elution was used: 8 mM formic acid (pH 28) and acetonitrile. Compounds were identified by retention time, MS and $MS^2$ spectrum for standard references.

**Results:** Flavonoids: quercetin, rutin, quercetrin, luteolin, apigenin, catechin, epicatechin and phenolic acids: ferulic, gallic and chlorogenic acid were determined in the extracts from heather flowers. The phytochemistry of heather extracts and their antioxidant capacity strongly depend on the extractant. The highest content of polyphenols was found in 60% ethanol, the lowest, especially for quercetin and rutin glycosides, was obtained when water was used as an extractant. Temperature can increase the efficiency of the extraction process.

# Part C

# Nuclear physics

# C.1 Stopping power measurements by the semi-thick target method

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The stopping power for velocities below 1% of the velocity of light in the slowing down material was investigated by the semi-thick target method at HIL. In the low and medium-velocity regions, experimental data are scanty, and it is conventional to use extrapolation estimates of stopping cross sections in calculating heavy-ion energy loss. The available Ziegler tables use extrapolated procedures from higher energy data or from light particles: protons and light ions. The method used is called the semi-thick target method due to the thicknes of the target which has to be not too thick and not too thin — it should be similar to the recoil range in the studied material.

Three nuclei have been studied in the reactions: $^{120}$Sn($^{14}$N,5n)$^{129}$La, $^{120}$Sn($^{11}$B,4n)$^{127}$Cs and $^{118}$Sn($^{11}$B,4n)$^{125}$Cs. The target quality and its thickness (1.2 mg/cm$^2$ ) were determined by the Rutherford backscattering spectrometry technique at the National Centre for Nuclear Research in Świerk, Poland. The electronic and nuclear stopping-power parameters were determined for Cs and La ions in Sn and compared with parameters measured with the same method for Pm, Sm and Nd ions in Cd and I ions in Ag. A comparison with the LSS theory [1] was made for the energy range below 0.2 MeV/nucleon, where the Bethe-Bloch formula [2] has no application.

The experimental stopping powers expressed in universal units are plotted in Fig. 1. The recalculation of the stopping power from universal units to MeV/mg/cm$^2$ is shown in Table 1 in the penultimate column. The solid line represents the LSS approximation, while the points with error bars denote the experimental results. The experimental points follow the predictions of the LSS theory.

The experimental results for stopping powers presented in Fig. 1 and Table 1 cover the initial velocity ($v_0$) range from about 1% to 2% of the speed of light. They were obtained using the semi-thick target method. It turns out that all the considered experimental points are closely located to the predictions of the LSS theory. More experiments are needed for various ions and stopping media to draw a definite conclusion about the usefulness of the LSS theory in the low energy region. Until it is definitely confirmed we recommend the use of the LSS formula for low energy ions. The experiment was concluded by an extensive publication in Nuclear Instrument and Methods [5].

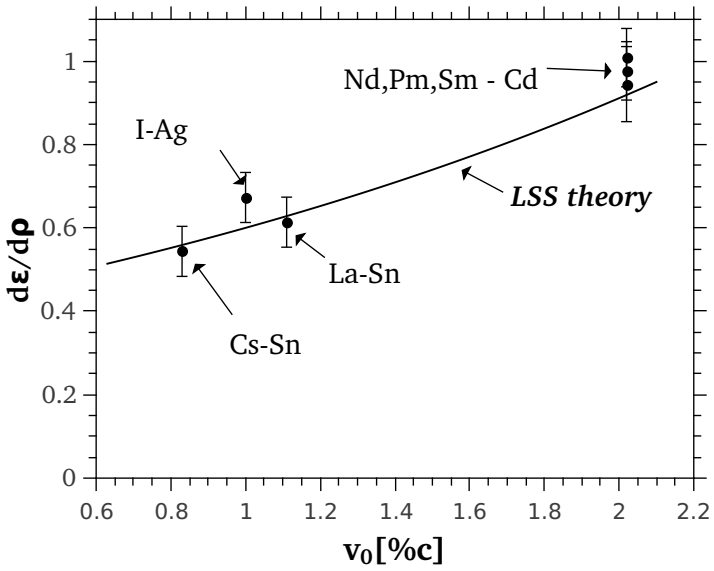


**Figure 1:** The stopping power in universal units versus velocity for all experimental points including the results of [3, 4]. The solid line is for the LSS theory approximation.

**Table 1:** The experimental results for different recoils and targets. The first column gives the recoil-target system, the second the initial velocity, the third the universal energy according to the LSS convention, the forth and fifth columns the coefficients $f_e(f_n)$, the sixth and seventh columns are the stopping powers in universal units (dimensionless) and in MeV/mg/cm$^2$, respectively.

| Recoil — target | $v_0/c$ (%) | $\varepsilon_0^{1/2}$ | $f_e$ | $f_n$ | $\frac{d\varepsilon}{d\rho}$ | $\frac{dE}{dx}$ ($\frac{\text{MeV}}{\text{mg/cm}^2}$) | ref. |
|---|---|---|---|---|---|---|---|
| Nd — Cd | 2.02 | 5.19 | 1.12 | 0.90 | 1.01 | 12.04 | [3] |
| Pm — Cd | 2.02 | 5.19 | 1.08 | 0.90 | 0.97 | 12.27 | [3] |
| Sm — Cd | 2.02 | 5.19 | 1.04 | 0.90 | 0.94 | 12.49 | [3] |
| La — Sn | 1.11 | 2.76 | 1.08 | 0.72 | 0.61 | 7.22 | this work |
| I — Ag | 1.00 | 2.57 | 1.27 | 0.77 | 0.67 | 7.85 | [4] |
| Cs — Sn | 0.83 | 2.08 | 1.17 | 0.66 | 0.54 | 6.17 | this work |

### Acknowledgment

This work was supported by grant DEC-2013/10/M/ST2/00427 of the Polish National Science Center.

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# C.2 Life-time measurements of $^{138}$Nd using the reaction $^{19}$F($^{123}$Sb,4n)$^{138}$Nd

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Measurements of the lifetime of the low excited states of $^{138}$Nd were performed at the Horia Hubei tandem facility in Bucharest, Romania using the reaction $^{19}$F($^{123}$Sb,4n)$^{138}$Nd. This was the result of the EAGLE cooperation between Oslo University, Bucharest and HIL. The additional aim of the lifetime measurements was the study of the deorientation phenomena of the electromagnetic interaction of nuclear levels with the electron shell.

Life time measurements were recognized as an important issue of nuclear physics a long time ago. The problem is challenging as the time scale ranges from $10^{-20}$ to infinity. At the Horia Hubei laboratory measurement techniques based on the Recoil Distance Doppler Shift (RDDS) method using the ROSPHERE spectrometer and plunger device [1] were used. The ROSPHERE spectrometer, in its mixed configuration consisting of 14 HPGe detectors and 11 $LaBr_3$(Ce) fast scintillators, also allows sub-nanosecond lifetime measurements through the in-beam fast timing method, thus enabling combined lifetime measurements in the range from several picoseconds to several nanoseconds. In the case of $^{138}$Nd we expect halflife of the $2^+$ state of the order of 10–15 ps. From singles spectra we expect to get an angular distribution dependence on time for the $2^+$ state. We expect to get the attenuation coefficients in a standard Legendre expansion to follow the deorientation phenomenon.

The ROSPHERE spectrometer together with the PLUNGER device gives the opportunity for the EAGLE group to measure firstly the lifetime of nuclear levels, secondly the magnetic interaction with the electron shell and the magnetic moments.

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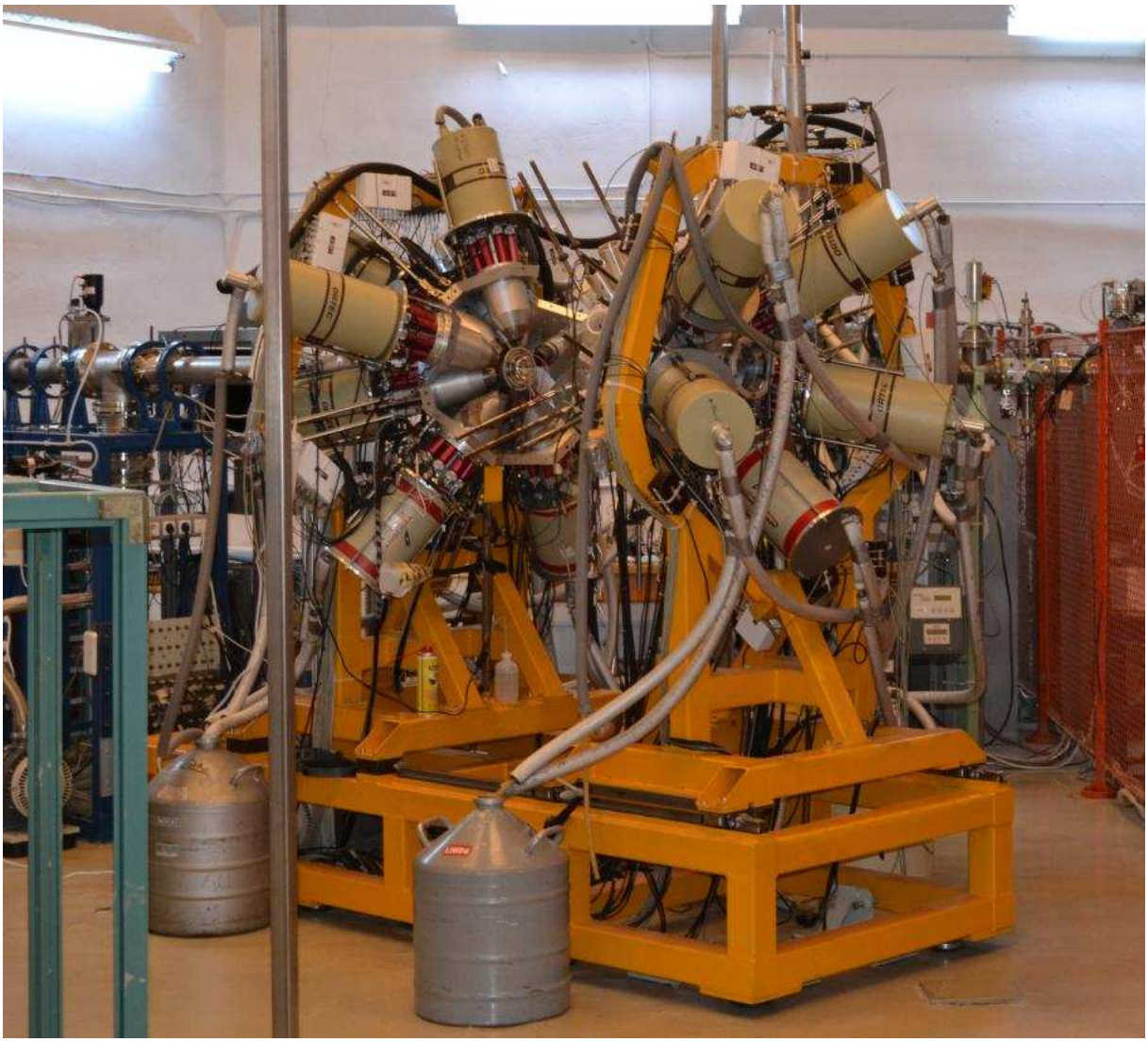

**Figure 1:** The ROSPHERE spectrometer at the Horia Hubei Institute.

# C.3 Revised spin values of the 991 keV and 1599 keV levels in $^{140}$Sm

*J. Samorajczyk[1,2], M. Klintefjord[3], T. Abraham[1], F.L. Bello Garrote[3], Ch. Droste[4], A. Görgen[3], E. Grodner[4], K. Hadyńska-Klęk[3], M. Kisieliński[1,5], M. Komorowska[1,4], M. Kowalczyk[1,4], J. Kownacki[1,5], T. Marchlewski[1,4], P. Napiorkowski[1], J. Srebrny[1], R. Szenborn[4], A. Stolarz[1], A. Tucholski[1], G.M. Tveten[3]*

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In the $^{140}_{62}Sm_{78}$ nucleus there is a state placed at a relatively low energy (991 keV) with a spin that was tentatively assigned as $0^+$ [1]. This fact could imply the shape coexistence. To get unique information about the spin value of this level (which is indispensable for further study of this nucleus) the angular correlations [2] of photons emitted from the excited states of $^{140}$Sm have been measured. The excited low-spin levels in $^{140}$Sm were populated in the $^{140}$Eu$\rightarrow^{140}$Sm and $^{140}$Gd$\rightarrow^{140}$Eu$\rightarrow^{140}$Sm decays. The $^{140}$Gd and $^{140}$Eu nuclei were produced in the $^{112}$C + $^{32}$S reaction. The $^{32}$S beam at an energy of 155 MeV was provided by the U-200P cyclotron [3] of the Heavy Ion Laboratory (University of Warsaw). The time structure of the ion beam was as follows: 2 ms of in-beam and 4 ms off-beam. Information about coincidence $\gamma$-quanta accompanying $\beta^+$/EC decays was obtained during the off-beam periods. Eleven Compton-suppressed HPGe detectors from the EAGLE array [4] were used to register $\gamma$-quanta. The relative angles between Ge detectors were : 42°, 70°, 109°, 138° and 180°.

In this work the $\gamma$-$\gamma$ angular correlation of the 460 keV and 531 keV photons (for the level scheme see Figure 1) was used for spin assignment of the 991 keV level. The resulting values of the angular correlation coefficients are the following: $A_{22}$ = -0.17(9) and $A_{44}$ = 0.29(9). These values suggest (see closed red triangle in Figure 2) that:

(i) spin of the 991 keV level is $2^+$ (instead of $(0^+)$ as given in [1]). The parity $\pi = +1$ follows from the Coulomb excitation and agrees with the systematics of parities of the second I = 2 levels in the neighbourhood of $^{140}$Sm,

(ii) the multipolarity of the 460 keV transition is pure E2 or E2 with a small admixture of M1 — 98% E2 + 2% M1.

For the spin assignment of the 1599 keV level (Figure 1) the angular correlation of the 1068 keV and 531 keV photons was studied. The result $A_{22} = 0.26(16)$ and $A_{44} = 1.00(18)$ clearly shows (see open red triangle in Figure 2) that the spin of the 1599 keV level is $0^{(+)}$ instead of 2. The parity assignment follows from the log ft value [1].

The $^{140}$Gd nucleus produced in our reaction initiates the decay chain containing, among others, the $^{140}$Pm$\rightarrow^{140}$Nd decay. In the latter nucleus the decay of the $0^+\rightarrow2^+\rightarrow0^+$ cascade occurs via emission of the 640 keV and 774 keV $\gamma$ rays. To check the correctness of our analyses the angular correlation of these photons was measured and the result agrees with the data from Ref. [1].

In summary, the results of our $\gamma$-$\gamma$ angular correlation measurements indicate that the spin of the 991 keV level is $2^+$ (instead of the tentative value $(0^+)$ quoted in [1]) and the

spin of the 1599 keV levels is $0^{(+)}$ instead of $2^+$. The correct spin $2^+$ was already applied in the Coulex experiment analysis and preliminary results can be found in Ref. [5].

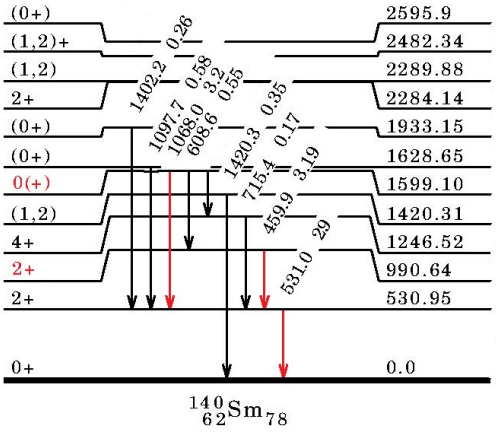


**Figure 1:** Partial level scheme of the $^{140}$Sm nucleus relevant to our work taken from Ref. [1]. Spin values for the 991 keV and 1599 keV levels are shown according to our results. Red numbers — our spin values. Red arrows — $\gamma$ transitions studied in the work. The 352 keV transition [1] is not shown since, as follows from our work, it is located in another place.

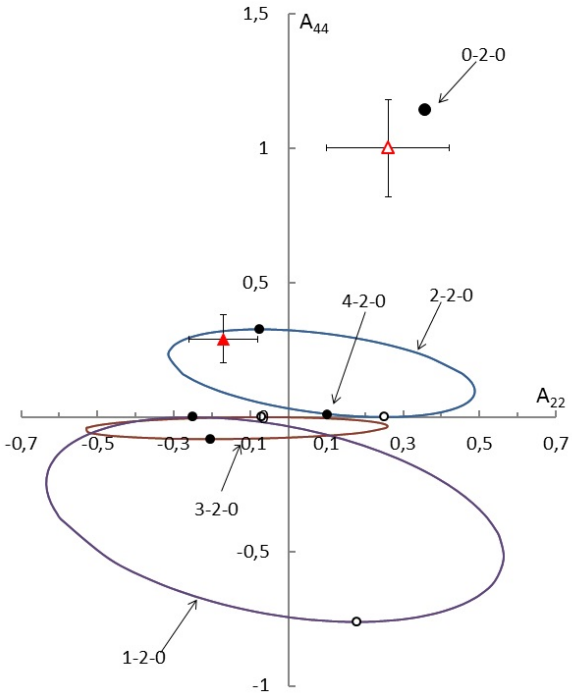


**Figure 2:** Parametric plot of the $A_{22}(\delta)$ and $A_{44}(\delta)$ angular correlation coefficients for the I→2→0 cascades (for initial spin I = 0, 1, 2, 3, 4). Closed and open circles — $A_{22}$, $A_{44}$ coefficients for pure quadrupole ($\delta = \pm\infty$) and for pure dipole ($\delta = 0$) transitions, respectively. Closed and open triangles are experimental points for the 460–531 keV and 1068–531 keV cascades in $^{140}$Sm, respectively.

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# C.4 Alpha cluster transfer in the elastic scattering of $^{20}$Ne on $^{16}$O nuclei at an energy of 50 MeV

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In the scattering of nuclei with alpha cluster structure, such as $^{16}$O and $^{20}$Ne, the exchange of the α-cluster should contribute to the observed cross sections and this contribution is most pronounced at backward angles [1]. Previously, scattering of $^{20}$Ne on $^{16}$O nuclei was measured by Stock et al. [2] up to 156° in the centre of mass system. A backward angle rise in the cross sections was observed. We performed a new experiment with a significant extension of the angular range up to 170° in the centre of mass system.

The measurements were carried out with a $^{20}$Ne beam extracted from the $K = 160$ cyclotron of the Heavy Ion Laboratory, University of Warsaw. The energy of the beam was 2.5 MeV per nucleon.

The charged particles were detected and identified by four $\Delta E - E$ counter telescopes which were installed in the ICARE experimental chamber. The overall energy resolution was about 700 keV. Self-supporting targets of aluminium-oxide with a thickness of 150 mg/cm$^2$ were mounted in the chamber.

Our measurements showed a typical scattering pattern in the forward hemisphere, while a significant increase in the differential cross sections in the backward hemisphere was observed as seen in Figure 1. This increase could be interpreted as due to the contribution of α-cluster transfer [3].

The experimental data for elastic scattering in the forward hemisphere were analysed within the framework of the optical model (OM) as shown in Figure 1 by the blue line. Only including the α-transfer mechanism allows the cross section rise at large angles to be described. This is done by coupled channel calculations [4] using the code FRESCO [4] and the optical model potential parameters from Table 1. The result of the calculation is shown in Figure 1 by the red line. The spectroscopic factor $S = 1$ for the reaction $^{20}$Ne→$^{16}$O+α was extracted from the present analysis. It can be seen from the figure that the coupled reaction channels calculation taking into account the α-particle elastic transfer reproduces the character of the cross sections in the full angular range quite well.

**Table 1:** Potential parameters.

| $E$ (MeV) | $V_0$ (MeV) | $r_V$ (fm) | $a_V$ (fm) | $W_0$ (MeV) | $r_W$ (fm) | $a_W$ (fm) |
|---|---|---|---|---|---|---|
| 50.0 | 100.0 | 1.20 | 0.49 | 35.0 | 1.31 | 0.49 |

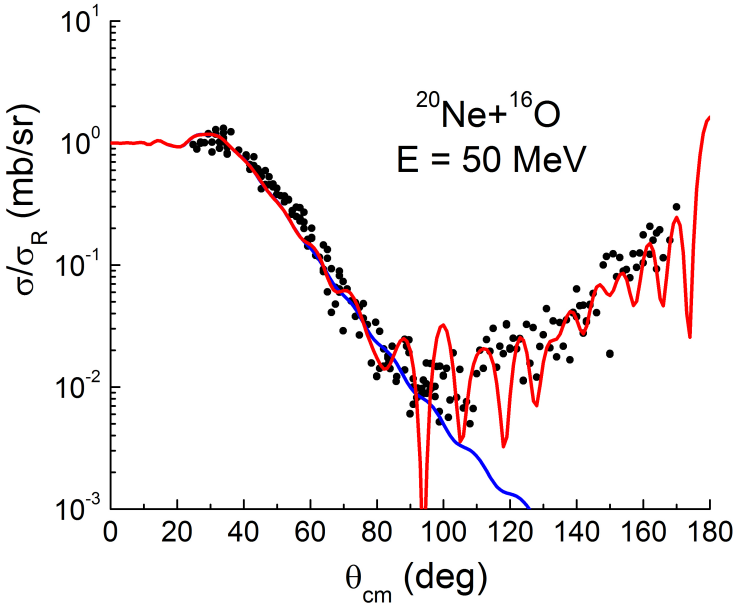


**Figure 1:** Angular distribution of the elastic scattering of $^{20}$Ne on $^{16}$O at 50 MeV. Circles are experimental data; the blue line is the optical model prediction, and the red line represents the coupled reaction channels calculation using the code FRESCO, taking into account the exchange mechanism of the α-cluster transfer.

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# C.5 Search for quasi molecular states in the interaction of $^{40}$Ar with light nuclei

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During the last few years, there has been a renewed interest in the manifestations of α clustering in atomic nuclei. New possibilities of using rare isotope beams, together with the permanent astrophysical interest in nuclear reactions involving helium and the expectation of new effects due to the Bose-Einstein condensation make this field very broad and promising. One would expect similar developments for the previously very popular field of studies of quasi molecular states, which is also of the current astrophysical interest. However, after the controversy of the $^{16}$O+$^{40}$Ca case [1], there has been no evident progress in studies of quasi molecular resonances in systems heavier than $^{16}$O+$^{16}$O.

Many recent achievements in the investigation of the α cluster structure (see [2], for example) are related to the application of the Thick Target Inverse Kinematics method (TTIK) [3] which has the advantage of measuring excitation functions for the elastic scattering with a single beam energy. In this technique, the incoming ions ($^{40}$Ar) are slowed in the thick target (a gas can be used as the target) and the lighter recoil ions of the target are detected. These recoils emerge from the interaction with the beam and hit a Si detector telescope located at forward angles while the beam ions are stopped in the target, as the the lighter recoils have smaller energy losses than the ions of the beam. A very important feature of this approach is easy access to measurements at zero degrees in the lab system corresponding to 180 degrees in the centre of mass. A extreme CM backward angles the potential scattering should be small and the resonance scattering should reach its maximum. This is especially important for resonances with heavy ions, because one would expect population of high spin states in such cases.

In this experiment a 220 MeV $^{40}$Ar beam from the Warsaw Cyclotron, with intensity 30–160 enA after collimating to 5 mm diameter (C1, see Fig. 1), bombarded a 100 μg/cm$^2$ Au foil placed in the reaction chamber. Two semiconductor detectors (R1, R2) were placed upstream of the main scattering chamber and were used to monitor the beam intensity. Then, the beam passed through a window made of 4 μm Havar foil (H) and entered the main scattering chamber. In the main chamber (the 600 mm long cylinder) we placed either a solid carbon target (T) of 50 μm thickness or filled the chamber with gas ($^4$He, $^{20}$Ne or $CO_2$).

The thickness of the targets was chosen to stop the beam, as required for the TTIK method. The target-like reaction products were detected by a telescope consisting of Si

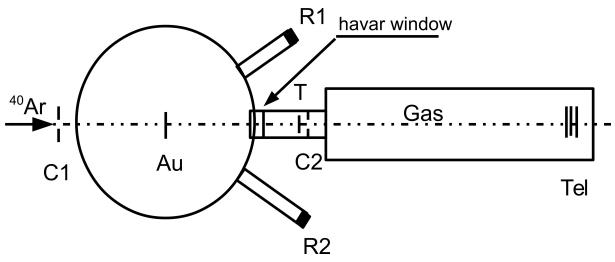


**Figure 1:** Scheme of the experimental set-up.

detectors of 10 μm, 250 μm and 1350 μm thickness, placed on the beam axis at zero degrees. The telescope provided for the resolution needed to separate elements up to Mg, but was not good enough to separate the isotopes (starting with A=12).

As a result we have obtained thick target spectra of different light elements at the extreme CM angle (180 degrees) using targets of $^{4}$He, $^{12}$C, $^{20}$Ne and $CO_2$ and a beam of $^{40}$Ar. We observed sharp resonances (with CM resolution of 50 keV) in the interaction of $^{40}$Ar with $^{4}$He which were the manifestations of the alpha cluster structure under conditions of high density of compound states and many open decay channels.

We did not observe evident resonances in any other studied cases. At present we are trying to understand the origin of the continuous spectra of elements obtained in the unusual conditions of the present experiment (see Fig. 2). In spite of the absence of evident resonances, the yield of the target element was much higher than the neighbouring ones. This can be considered as a dominance of elastic scattering. We are working on the interpretation of the data.

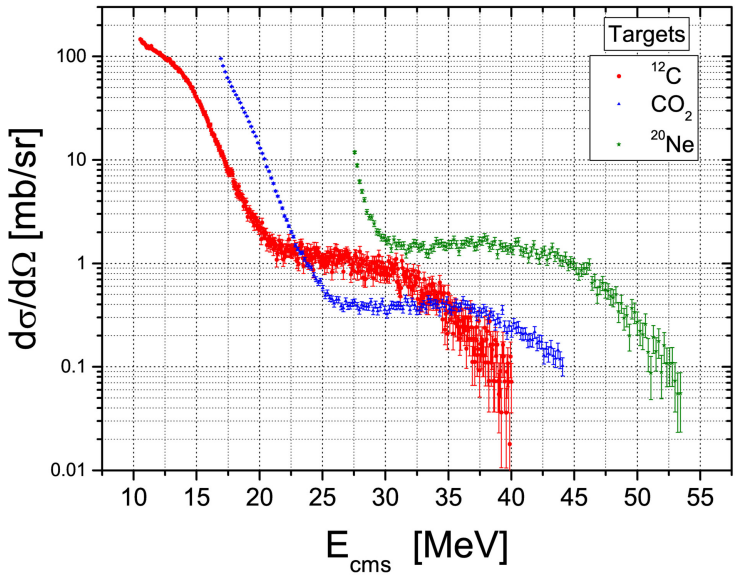


**Figure 2:** Excitation functions obtained during the experiment.

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# C.6 Investigation of γ-ray emission in heavy ion induced fission during the cyclotron beam-on periods

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The $^{16}$O+$^{208}$Pb fusion-fission reaction was used to produce excited fission fragments from the region of neutron-rich nuclei. The 15 HPGe detectors of the EAGLE array, located at the Heavy Ion Laboratory of the University of Warsaw, were employed. One way to carry out spectroscopic studies of neutron-rich systems is to analyse the prompt gamma rays from nascent fission fragments produced either in spontaneous fission or in heavy-ion-induced fission. After neutron emission, when the excitation energy is lower than their binding energy, the γ-ray cascade starts taking away the remaining excitation energy.

However, prompt γ-ray emission competes [1] with or follows the last stages of prompt neutron emission. Typical γ-ray multiplicities of 7–10 photons per fission are observed. Because of the significant angular momentum of the fission fragments (7–10$\hbar$) even in spontaneous fission, photon emission can compete with neutron emission.

The dependence of the number of emitted gamma rays from fission fragments vs. time has a complex character. One can distinguish a few time intervals. The first one is $10^{-12}$–$10^{-10}$ s, when the essential part of the γ rays appears (more than 70% [2]), emitted from the fission fragment levels with energies of a few MeV and low multipolarity, i.e. E1, M1, E2. Other time intervals are: $10^{-10}$–$10^{-9}$ s, $10^{-9}$–$10^{-7}$ s, and these contain about 20% of the γ rays from the fission fragments. This radiation emerges due to deexcitation of low energy states and/or isomeric states characterised by high multipolarities, i.e. M2, E3 or even higher. Production of fragments with high spins after neutron emission results in population of such states. Therefore, because of the large spin differences the isomeric states may appear in fission fragments.

When analysing in-beam γ-γ coincidences (during the cyclotron macro-pulse) we often observe the appearance of various isomeric transitions over the course of the in-beam pulse. When setting narrow gates at different points of the in-beam macro-pulse one notes in the spectra obtained the appearance of delayed γ-rays in the time region of nanoseconds and/or a few microseconds.

One can illustrate this with previously known isomers from the region of $80 < A < 120$, all observed in experiments performed at HIL. Among the γ-rays listed in Table 1 there are also possible candidates which might be associated with the decay of isomeric states. A further experiment should elucidate these expectations.

**Table 1:** A few examples of γ-rays from fission fragments as observed **only** in the "in-beam" mode using the $^{16}O+^{208}Pb$ reaction.

| Nucleus | Gate $E_\gamma$[keV] | γ-rays in coincidence | $T_{1/2}$ | Refs. |
|---|---|---|---|---|
| $^{94}_{39}Y_{55}$ | 906 ($2^-$, $3^-$) | 532 ($0^-$, $1^-$) | ? | this exp. |
| $^{94}_{39}Y_{55}$ | 770 ($5^+$) | 432 ($3^-$) | 1.35 μs | [3] |
| $^{94}_{39}Y_{55}$ | 261 ($9/2^+$) | 827 ($5/2^-$) | 53 μs | [4] |
| $^{95}_{40}Zr_{55}$ | 229 ($11/2^-$) | 115 ($9/2^+$), 1676 ($7/2^+$) | ? | this exp. |
| $^{99}_{42}Mo_{57}$ | 448 ($11/2^-$) | 138 ($7/2^-$) | 0.76 μs | [5] |
| $^{119}_{49}70_{In}$ | 152 ($25/2^+$) | 218 ($21/2^+$), 1020 ($17/2^+$) | 240 ns | [6] |
| $^{123}_{51}Sb_{72}$ | 127 ($23/2^+$) | 441($19/2^+$), 955, 1088 | 53 μs | [7] |
| $^{125}_{51}Sb_{74}$ | 902 ($15/2^-$) | 1067 ($9/2^+$) | 4.1 μs | [8] |

The values in parenthesis denote currently known spin/parity assignments of levels deexcited by given γ-lines. In the case of odd-odd and odd-A isotopes, the short γ-ray cascades produced in the fission process are observed in the in-beam mode, while in even-even nuclei longer collective γ-ray cascades up to 10–12$\hbar$ were observed in the present experiment. Further analysis to make spin-parity assignments based on the decay pattern and coincidence relations is now in progress. Concluding, one can say that investigation of prompt γ-ray emission can be useful for finding short lived isomers.

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# C.7 Surface transparency of the $^{6}$Li + $^{18}$O Optical Model potential

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It was recently shown that coupling to the single-neutron pickup reaction enhances the $^{6}$Li + $^{18}$O elastic scattering cross section at backward scattering angles by up to two orders of magnitude, being responsible for most of the observed rise in the angular distribution [1]. In this report we investigate to what extent this effect can be simulated by a component of the Optical Model (OM) potential — a dynamic polarisation potential. The effective OM potential derived from the continuum-discretized coupled-channel calculations in Ref. [1] was used as a starting point. The OM calculation with this potential described the elastic scattering data at forward angles (dotted curve in Fig. 11) but was not able to account for the backward-angle rise of the angular distribution. Next, an additional imaginary term was added to this potential, of standard W-S derivative shape and with three adjustable parameters — depth, radius and diffuseness ($W$, $R$ and $a$). An automatic search was performed on these parameters in order to minimise $\chi^2$ and obtain the best fit to the experimental data (the data are from Ref. [2]). The best result (solid curve in Fig. 1) was obtained with the following parameters: $W = -0.294$ MeV, $R = 5.841$, $a = 0.392$ fm, where the minus sign reflects the emissive nature of this additional term. In other words, the search led to a local reduction of the absorptive part of the OM potential at the surface (the strong absorption radius for this scattering system is about 7 fm). This *surface transparency* of the imaginary part of the $^{6}$Li + $^{18}$O OM potential simulates the effect of the n-transfer reactions on the elastic scattering reported previously [1].

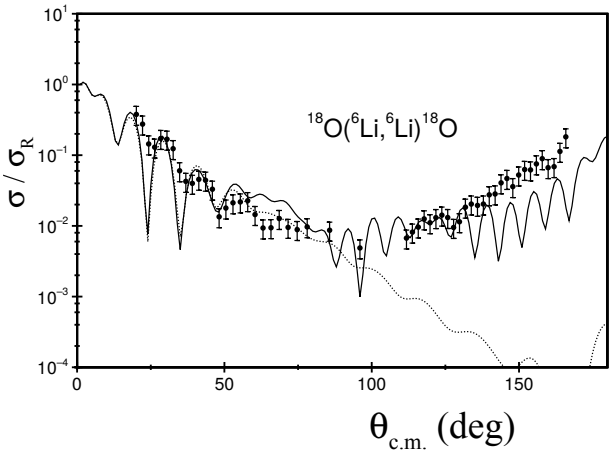


**Figure 1:** Angular distribution of the elastic scattering cross section. The dotted curve shows the result of an OM calculation with the effective potential adopted from Ref. [1] while the solid curve represents an OM calculation with reduced strength of the imaginary potential at the surface, as discussed in the text. The experimental data are from Ref. [2].

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# C.8 First tests of superthin, ion-implanted strip detectors produced by the low-temperature technique

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The technique of low-temperature ion-implanted thin silicon detectors is presented in Ref. [1]. The modification of this technique for thin strip detectors is shown in Fig. 1. The starting $n^+$-n silicon structure is shown in the upper part of Fig. 1. The low-resistivity, thick $n^+$-type substrate is removed by anodic dissolution (central part of the figure). Then 50 keV $B^+$ ion implantation is performed followed by Al metallisation on both sides of the n-type epitaxial thin silicon membrane. The essence of the present new technology is an application of the low temperature baking process for post-implantation thermal treatment instead of the high temperature annealing process used elsewhere. The new technology, thanks to the moderate temperatures, can also be applied after the evaporation of metal contacts on both sides of the detector. An additional achievement of the technology is the use of a common strip detector mask (in the form of a comb) for both $B^+$ ion implantation and Al evaporation on the junction side of the detector. The thickness of the thin detector is presented in Fig. 2.

The photo of the edge part of the thin strip 5 μm detector is illustrated in Fig. 3, as well as first experimental results measured at HIL using a 5 μm thin detector produced with this technique.

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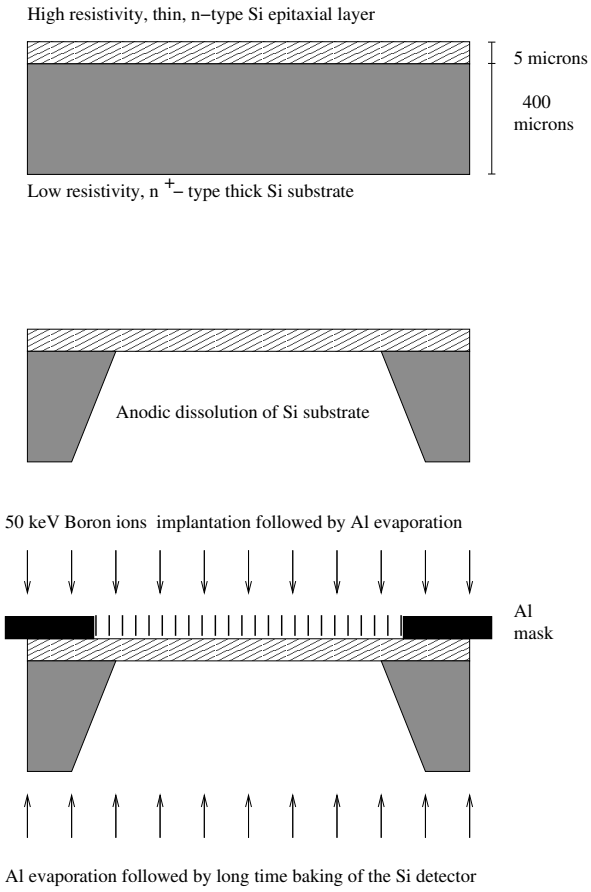


**Figure 1:** Technique of low-temperature for 5 μm thick silicon strip detector production.

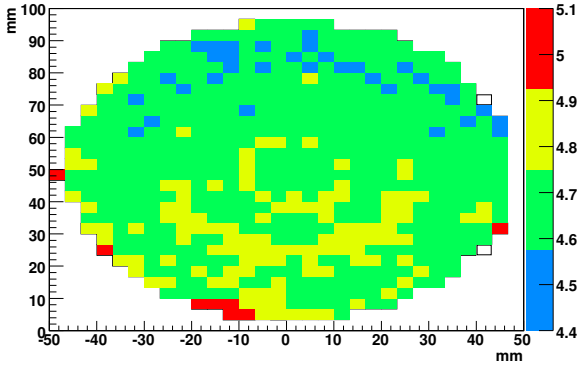


**Figure 2:** Thickness distribution of four inch epitaxial silicon membrane produced by anodic dissolution used for a thin strip detector. Measurements were performed by energy loss of α particles from an $^{241}$Am source. Colour scale is in microns.

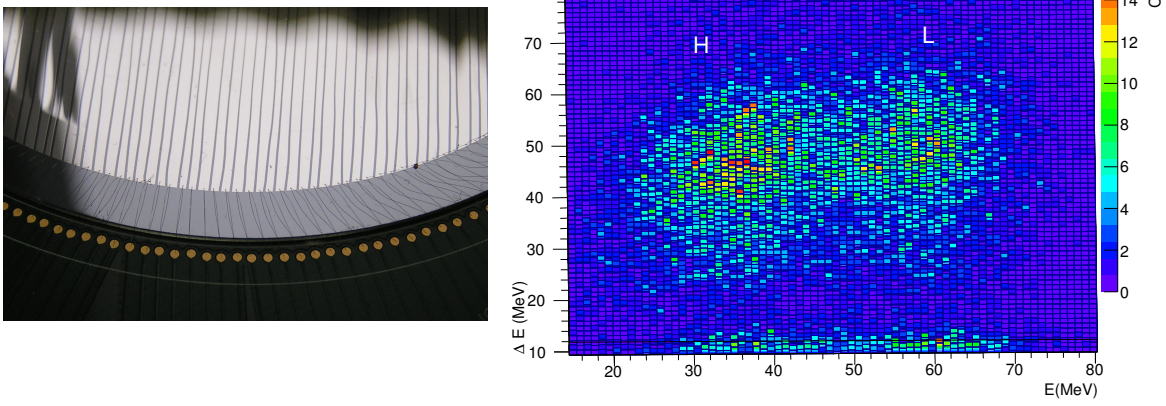


**Figure 3:** Left panel: Connections of four inch thin detector strips with gold PCB bonding pads were performed using 25 μm Al wires. Right panel: Response of 5 μm strip detector to fission fragments from $^{252}$Cf using a collimated single strip detector for the $E-\Delta E$ telescope.

# C.9 X-ray response of diamond detectors constructed using diamond layers produced by a low power Microwave Chemical Vapour Deposition (MWCVD) reactor

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A low power reactor for MWCVD process is described [1]. The rotating Mo holder of 12 mm diameter and 6 mm height with the diamond substrate, heated by 2.45 GHz microwaves to a temperature of about 800 °C in the range of (1.5–7)% $CH_4/H_2$ mixture to create a plasma at a pressure of 70 Tr is, presented in Fig. 1.

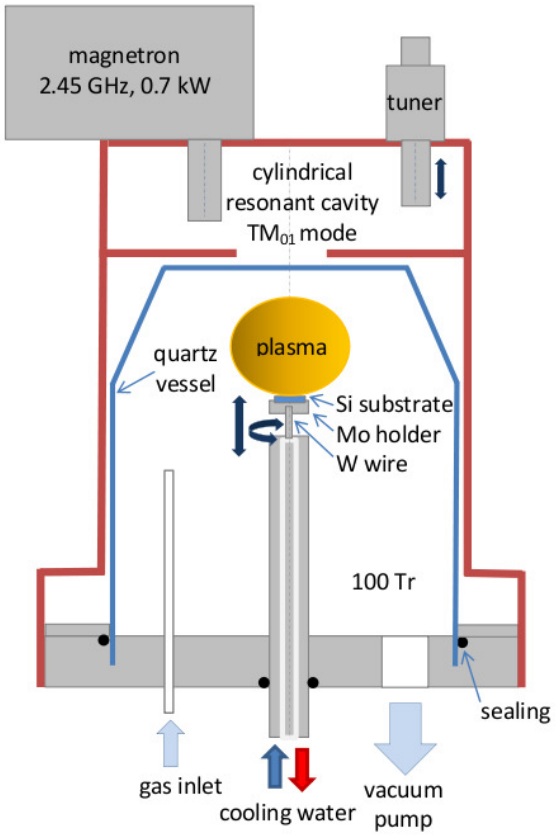


**Figure 1:** MWCVD reactor.

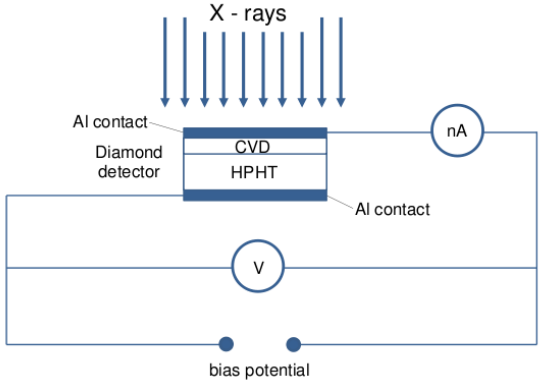


**Figure 2:** Tests of diamond detectors in the current mode.

Stabilization of the holder temperature was performed by optical observation of radiation from the holder followed by adjusting the magnetron power. Diamond detectors are

produced using MWCVD process grown on single crystal diamond High Pressure High Temperature (HPHT) Sumimoto substrates, [100] oriented. The response of diamond detectors for X rays has been measured in the current mode, see Fig. 2, using a medical X-ray tube. The response of a diamond CVD/HPHT detector to the X-ray tube operated at 40 kV is shown in Fig. 3. The detector current is linear as a function of the X-ray tube current (proportional to dose strength) for positive and negative detector bias polarization of about ± 200 Volt.

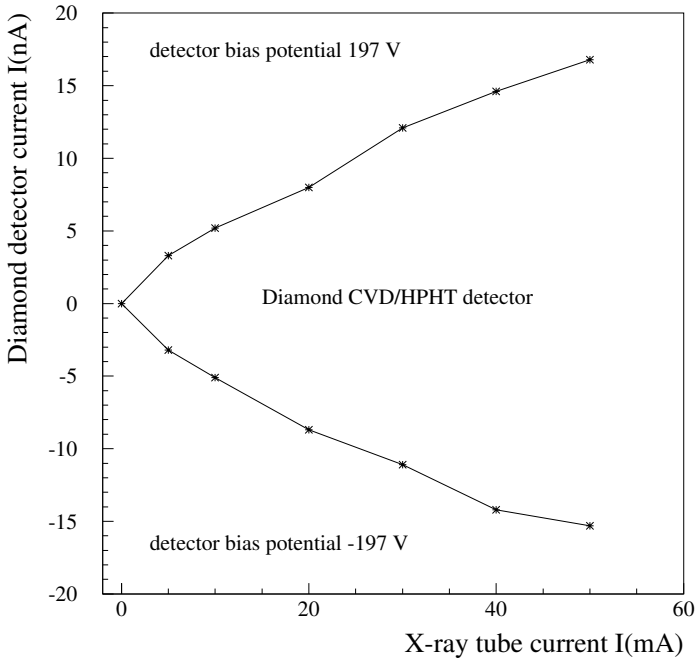


**Figure 3:** Response of diamond CVD/HPHT detector for X-ray fluence generated by X-ray tube current.

Unfortunately, the manufactured diamond detectors have not produced any response for separate α particles, fission fragments and heavy ions registered by the pulsed electronics. This is probably due to contamination by nitrogen and non-high purity reactor construction materials which stop the transport of almost all charged carriers in diamond. Only the high flux of X-ray photons generating a large number of charged carriers is sufficient for the detection of X-rays by diamond detectors operated in the current mode.

To get electronic grade diamond materials useful for registration of single charged particles with diamond detectors it is necessary to use high purity hydrogen and hydrocarbon gases and a very tight MWCVED reactor to stop leaks inside of environmental gases, mainly nitrogen.

**Acknowledgments:** We would like to express our great appreciation to Dr Krzysztof Sudlitz for collaboration in preparation of the CVD reactor. This work was supported by the National Science Centre of Poland Grant Nr N N202 031 640.

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# C.10 Tests of CVD diamond detectors

*P.J. Napiorkowski[1], M. Komorowska[1,2], P. Bednarczyk[6], J. Iwanicki[1], M. Jastrząb[3], I. Martel[5], P. Matuszczak[1,6] T. Nowak[4], M. Pomorski[7], I. Strojek[6], A. Trzcińska[1], M. Zielińska[3]*

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CVD diamond detectors are currently used in high-energy physics for monitoring of intense beams. Results of tests with heavy ions at energies of several hundred MeV/amu, as well as high-energy protons and fast neutrons (overview in [1–3]) have shown their excellent timing properties and radiation hardness. Therefore, they are considered as attractive particle detectors for Coulex with high-intensity exotic beams. However, irradiations performed with 26 MeV protons [4] as well as recent measurements at RBI Zagreb with 6.5 MeV carbon ions [5] have shown that if a CVD detector was irradiated with low-energy particles that are completely stopped in the detector material, the observed radiation damage was much higher, in some cases even higher than the one of silicon. These observations have to be verified, possibly with heavier ion beams.

Several tests of single-crystal CVD detectors with alpha radiation sources where performed in the Institute of Nuclear Physics of the Polish Academy of Sciences in Kraków and in the Heavy Ion Laboratory, University of Warsaw. The goals of these short measurements were to check the properties of various detectors and the applicability of experimental electronics solutions. The main experimental studies on the properties of diamond detectors employ a high energy proton beam from the Cyclotron Center Bronowice in Kraków and a $^{32}$S beam from the U200P cyclotron in Warsaw. The response of single-crystal CVD detectors to the protons was used to design and check the performance of newly developed electronics. The heavy ion beam from the Warsaw cyclotron allows tth spectroscopic properties and time resolution of the diamond detectors to be tested. In total 10 different single crystal CVD detectors were tested - their specifications are shown in Table 1.

Two 5-day experiments were performed at the Heavy Ion Laboratory in Warsaw: 14–18 October 2013 and 3–8 November 2014. The first measurement was focused on the spectroscopic performance of CVD detectors and the second on determining the time resolution of the diamonds response to heavy ions. In both experiments single-crystal CVD detectors were mounted in the ICARE chamber equipped with 5 Si detectors: 3 were placed at $\theta = 20$ degrees to monitor the beam parameters and 2 were movable in the range of $\theta = 25$–150 deg. The Si detectors were a reference for the diamond detectors. Diamond detectors were installed in the chamber on movable arms and in fixed positions. The experimental setup is shown on Fig. 1. The $^{32}$S beam at an energy of 90 MeV was scattered by a 100 μg/cm$^2$ $^{197}$Au or 260 mg/cm$^2$ natural Ag target. The setup allows sulphur ions in the energy range 35–85 MeV to be measured. To test the timing properties of the CVD detectors time difference between two scattering partners was measured. For this part of the measurement, both detectors (No 4 and 5 — see Table 1) were placed at 50

**Table 1:** List of scCVD detectors used for the test.

| N$^o$ | Size | Thickness | Comment |
|---|---|---|---|
| 1 | 1 mm x 1 mm | 500 $\mu$m | from RBI Zagreb |
| 2 | 4 mm x 4 mm | 500 $\mu$m | from Diamond Detectors Ltd |
| 3 | 2.5 mm | 300 $\mu$m | from INP Kraków |
| 4 | 2.5 mm | 100 $\mu$m | from INP Kraków |
| 5 | 2 mm | 50 $\mu$m | form University of Huelva |
| 6 | 4 mm x 4 mm | 300 $\mu$m | from University of Huelva |
| 7 | 1 mm | 17 $\mu$m | made in CEA Saclay |
| 8 | 1 mm | $<$10 $\mu$m | p+CVD (boron dopped), from CEA Saclay |
| 9, 10 | 1 mm | not measured | made in HIL |

and 55 degrees with respect to the beam direction, on the opposite sides of the chamber. In this way, recoils for the natural Ag target detected in one of them corresponded to scattered projectiles detected in the other one. The signals from the scCVD detectors were amplified by the new PA-10 fast amplifiers developed by dr Marcin Jastrząb from INP Kraków and recorded with a LeCroy SDA 5000 digital oscilloscope (20 GS/s).

The test of the radiation hardness of the detector could not be performed because of the polarization effect. The 100$\mu$m CVD detector got polarised at the rate of 800 ions per second. The detector recovered after a change in the BIAS polarity or after short irradiation with an $\alpha$ source.

The time of flight difference between scattered $^{32}$S and recoiled Ag was measured with two scCVD detectors and the digital oscilloscope. A FWHM resolution of 3.2 ns was achieved — see Fig. 2. The same parameter measured using the same technique between the signals taken from the fast shaping amplifiers of two Si detectors was significantly worse with a value of 23 ns.

The tests of scCVD detectors performed at the Heavy Ion Laboratory with a $^{32}$S beam at an energy of 90 MeV showed that further development of diamond detectors is required. Nevertheless, one can conclude as follows. Timing performance of the detectors is very promising. The measured width of a timing spectrum is determined by the energy loss in the target, but the result is much better than the resolution of Si detectors. The polarization observed with the heavy ion beam shows that scCVD detectors could not be used at a high rate under these experimental conditions. Further studies of the effect are required. The quality of scCVD detectors is unstable and spectroscopy of low energy heavy ions using them is difficult at the present state of technology.

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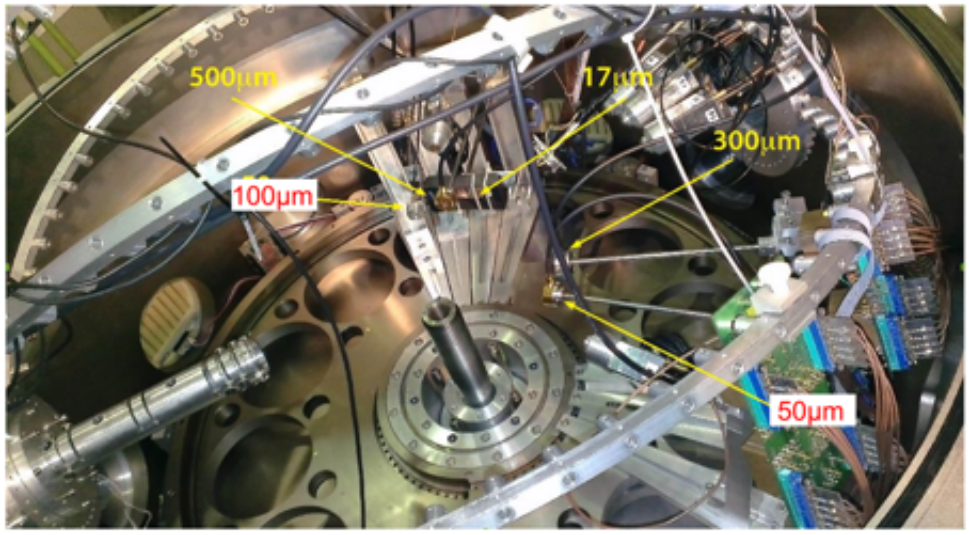


**Figure 1:** The experimental set-up used for the scCVD detector test at the Heavy Ion Laboratory, University of Warsaw. Detectors used for the coincidence measurement are labelled in white boxes.

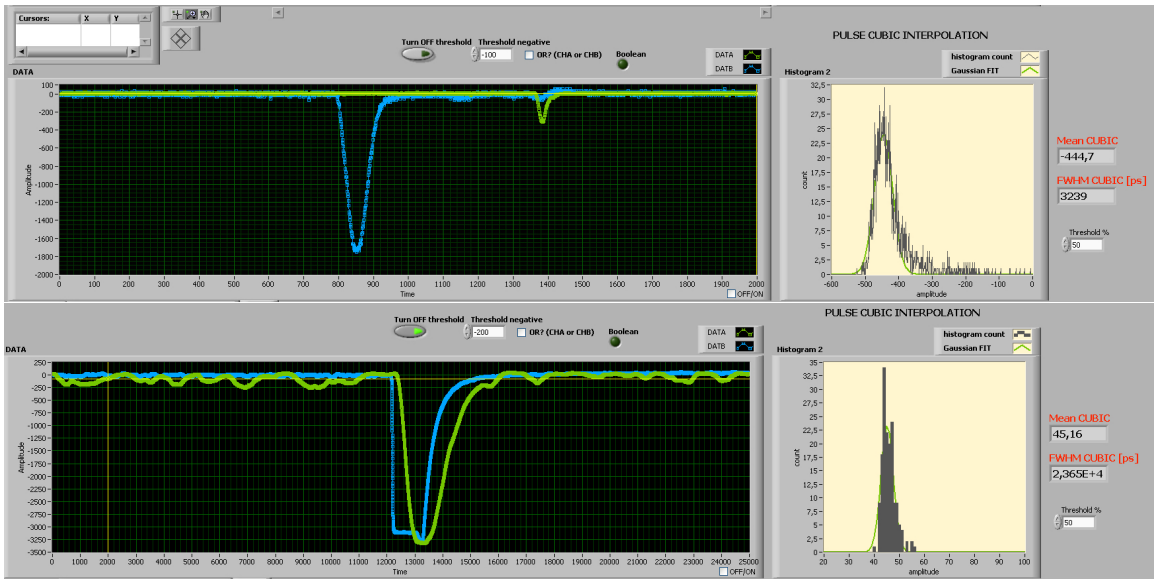


**Figure 2:** The result of the time of flight difference measurements for scCVD (upper) and Si (lower) detectors. Left: signals from the fast amplifiers: $^{32}$S in blue and $^{107,108}$Ag in green. Right: time of flight difference spectrum.

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# Part D

# Appendices

## D.1 List of experiments performed at HIL in 2014

A list of the experiments performed in 2014 is presented below. The following acronyms of institution names are used in the table:

- HIL — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland;
- CEA — French Alternative Energies and Atomic Energy Commission, Saclay, France;
- FP UW — Faculty of Physics, University of Warsaw, Warszawa, Poland;
- INP Kraków — The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland;
- NCBJ Świerk — National Centre for Nuclear Research, Otwock, Świerk, Poland;
- NNC — Institute of Nuclear Physics of the National Nuclear Center, Almaty, Kazakhstan;
- PTB — PTB, Braunschweig, Germany;
- UŁ — Faculty of Physics and Applied Computer Science, University of Lodz, Łódź, Poland;
- U.Huelva — University of Huelva, Huelva, Spain;
- U.Oslo — University of Oslo, Norway;
- US — University of Silesia, Katowice, Poland;
- INCT Warsaw — Institute of Nuclear Chemistry and Technology, Warszawa, Poland;
- AGH — AGH University of Science and Technology, Kraków, Poland;
- PS — Silesian University of Technology, Gliwice, Poland;
- PW — Warsaw University of Technology, Warszawa, Poland;
- IP JKU Kielce — Institute of Physics, Jan Kochanowski University, Kielce, Poland;
- IB JKU Kielce — Institute of Biology, Jan Kochanowski University, Kielce, Poland;
- JINR — Joint Institute for Nuclear Research, Dubna, Russia;
- GENE — L.N. Gumilyov Eurasian National University, Astana, Kazakhstan;
- NURIS — Nazarbayev University Research and Innovation System, Astana, Kazakhstan;
- JYFL — Department of Physics, University of Jyväskylä, Finland;
- SPSU — Saint-Petersburg State University, Saint-Petersburg, Russia;
- KNU Almaty — Kazakh National University, Almaty, Kazakhstan;
- RC Russia — National Research Center "Kurchatov Institute", Moscow, Russia;
- INP Uzbekistan — Uzbek. Acad. Sci., Inst. Nucl. Phys., Tashkent, Uzbekistan;
- GANIL — GANIL, Caen, France.

Experiments performed in 2014 — part 1

| Dates | Ion and Energy | Experiment type | Leading institution | Collaborating institutions |
|---|---|---|---|---|
| 27.01 – 31.01 | $^{4}He^{+1}$ 30 MeV | Medical isotope production studies (internal beam) | HIL | US, INP Kraków, INCT Warsaw |
| 14.03 | $^{12}C^{+3}$ | Test of the cyclotrom | HIL | |
| 17.03 – 21.03 | $^{12}C^{+3}$ 90 MeV | Nanodosimetry | PTB, NCBJ Świerk | HIL, FP UW |
| 24.03 – 26.03 | $^{4}He^{+1}$ 30 MeV | Medical isotope production studies (internal beam) | HIL | US, INP PAS Kraków, INCT Warsaw |
| 02.04 – 04.04 | $^{20}Ne^{+3}$ 54 MeV | HTRPL workshop | HIL | AGH, PS, INS Puławy, PW |
| 07.04 – 11.04 | $^{12}C^{+3}$ 90 MeV | Radiobiology | IP JKU Kielce, HIL | FP UW, NCBJ Świerk, INCT Warsaw , IB JKU Kielce |
| 14.04 – 17.04 | $^{4}He^{+1}$ 30 MeV | Medical isotope production studies (internal beam) | HIL | US, INP Kraków, INCT Warsaw |
| 28.04 – 29.04 | $^{32}S^{+6}$ | Test of the cyclotron | HIL | |
| 05.05 – 12.05 | $^{32}S^{+6}$ 155 MeV | electron-$\gamma$ spectroscopy studies (EAGLE) | HIL, U. Oslo | FP UW, UŁ, NCBJ Świerk |
| 13.05 – 21.05 | $^{40}Ar^{+8}$ 184 MeV | electron-$\gamma$ spectroscopy studies (EAGLE) | UŁ | HIL, NCBJ Świerk, FP UW, CEA |
| 26.05 – 30.05 | $^{12}C^{+3}$ 90 MeV | Nanodosimetry | NCBJ Świerk | HIL, FP UW |
| 02.06 – 06.06 | $^{4}He^{+1}$ 30 MeV | Medical isotope production studies (internal beam) | HIL | US, INP Kraków, INCT Warsaw |
| 09.06 – 13.06 | $^{12}C^{+3}$ $^{16}O^{+4}$ 90 MeV/A 118 MeV | Radiobiology | IP JKU Kielce, HIL | FP UW, NCBJ Świerk, INCT Warsaw , IB JKU Kielce |

Experiments performed in 2014 — part 2

| Dates | Ion and Energy | Experiment | Leading institution | Collaborating institutions |
|---|---|---|---|---|
| 23.06 – 27.06 | $^{40}Ar^{+8}$ 217 MeV | CUDAC | HIL | JINR, GENU Kazakhstan, INP Kraków, NURIS, NCBJ Świerk, JYFL, SPSU |
| 30.06 – 09.07 | $^{13}C^{+2}$ 32 MeV | Elastic scattering cross section measurements (ICARE) | INP NNC Kazakhstan, INP Kraków | NCBJ Świerk, HIL, KNU Almaty, RC Russia, INP Uzbekistan |
| 20.10 – 23.10 | $^{20}Ne^{+3}$ 54 MeV | Student workshop | HIL | |
| 24.10 | $^{14}N^{+3}$ | Test of the cyclotron | HIL | |
| 03.11 – 07.11 | $^{32}S^{+5}$ 91 MeV | Test of the diamond detectors (ICARE) | HIL, CEA Saclay, INP Kraków | U. Huelva |
| 17.11 – 28.11 | $^{40}Ar^{+8}$ 186 MeV | electron-$\gamma$ spectroscopy studies (EAGLE) | UŁ | HIL, NCBJ Świerk, FP UW |
| 30.11 – 05.12 | $^{4}He^{+1}$ 30 MeV | Medical isotope production studies (internal beam) | HIL | US, GANIL, INP Kraków, INCT Warsaw |
| 15.12 – 16.12 | $^{14}N^{+3}$ 89 MeV | IGISOL | FP UW | HIL |

# D.2 Degrees and theses completed in 2014 or in progress

## D.2.1 DSc (habilitation) degrees of HIL staff members

Marcin Palacz
The degree was awarded in November 2014 by the Scientific Council of the Faculty of Physics, University of Warsaw, for the work entitled
***Stany wzbudzone jąder atomowych z obszaru $^{100}$Sn***
*Excited states of nuclei in the vicinity of $^{100}$Sn.*

## D.2.2 PhD theses of students affiliated to HIL, of HIL staff members, and supervised by HIL staff

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

Grzegorz Jaworski, Faculty of Physics, Warsaw University of Technology
***Detekcja neutronów prędkich w badaniach struktury egzotycznych jąder atomowych***
*Fast neutron detection in investigations of the structure of exotic nuclei*
Supervisor: prof. dr hab. J. Kownacki. Defended in June 2014.

Anna Pękal, Faculty of Chemistry, University of Warsaw
***Wpływ doboru procedury analitycznej na wyznaczanie właściwości antyutleniających próbek żywności***
*Influence of analytical procedure on antioxidant properties of food samples*
Supervisor: prof. dr hab. K. Pyrzyńska. Defended in November 2014.

Anar Dalelkhankyzy, Al-Farabi Kazakh National University, Almaty, Kazachstan
***Microscopic foundations of the boson theory of collective excitations in many-nucleon systems.***
Supervisor: dr hab. L. Próchniak. Defended in December 2014.

Łukasz Standyło, National Centre for Nuclear Research, Otwock, Świerk, Poland
***Badanie oddziaływania $^{6}$He z jądrami $^{206}$Pb przy energiach blisko bariery kulombowskiej***
*Study of the interaction of $^{6}$He with $^{206}$Pb nuclei at energies close to the Coulomb barrier*
Supervisor: prof. dr hab. K. Rusek. Expected completion time: 2015.

Urszula Kaźmierczak, Faculty of Physics, University of Warsaw
***Local dose and its role in biological response of mammalian cells in vitro***
*Dawka lokalna i jej rola w biologicznej odpowiedzi linii komórkowych ssaków in vitro*
Supervisors: dr hab. Z. Szefliński, dr hab. A. Lankoff. Expected completion time: 2015.

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
Supervisor: dr hab. L. Próchniak, dr P. Napiorkowski, dr M. Zielińska.
Expected completion time: 2018.

### D.2.3 Other PhD theses based on experiments performed at HIL

Łukasz Janiak, University of Łódź
***Spektrometr elektronów konwersji wewnętrznej w badaniach jąder atomowych***
*Internal conversion electron spectrometer for studying atomic nuclei* Supervisor: prof. dr hab. J. Andrzejewski. Defended in April 2014.

Yurij M. Stepanenko, Institute for Nuclear Research, The National Academy of Sciences of Ukraine, Kyiv, Ukraine
***Nuclear reactions $^{7}$Li($^{18}$O, X) with the production of unstable nuclei***
Supervisor: prof. A.T. Rudchik. Defended in 2014.

Justyna Samorajczyk, University of Łódź
***Gamma-ray angular correlation studies with the EAGLE setup***
Supervisor: prof. dr hab. J. Andrzejewski. Expected completion time: 2015.

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.

### D.2.4 MSc and BSc theses supervised by HIL staff members

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

Aleksandra Naziębło, Faculty of Physics, University of Warsaw
***Gaz łupkowy w Polsce i Europie — warunki wydobycia i wpływ na środowisko***
*Shale gas in Poland and Europe — the conditions of extraction and the impact on the environment*
Supervisor: dr hab. Z. Szefliński. BSc thesis completed in July 2014.

Patrycja Dąbrowska, Faculty of Physics, University of Warsaw
***Biologiczne oddziaływanie wiązki jonów węgla na komórki CHO-K1***
*Biological effects in CHO-K1 cells after $^{12}C$ ion irradiation*
Supervisors: dr B. Brzozowska, U. Kaźmierczak. BSc thesis completed in September 2014.

Sergij O. Odrzykovskyi, National University of "Kyiv-Mohyla Academy", Kyiv, Ukraine
***Elastic and inelastic scattering of $^{14}N$ ions on $^{11}B$ nuclei at 88 MeV***
Supervisor: prof. A.T. Rudchik. MSc thesis completed in 2014.

Bogdan V. Mishchenko, Taras Shevchenko National University, Kyiv, Ukraine
***Elastic and inelastic scattering of $^{10}B$ ions on $^{6}Li$ nuclei***
Supervisor: prof. A.T. Rudchik. MSc thesis completed in 2014.

Marta Konop, Faculty of Physics, Warsaw University of Technology
***Konstrukcja i badanie własności epitaksjalnych krzemowych detektorów pozycyjnych przeznaczonych do rejestracji pierwiastków superciężkich***
*Construction and properties of epitaxial silicon position sensitive silicon detectors for superheavy element detectors*
Supervisors: dr hab. A. Kordyasz, prof. dr hab. J. Pluta. MSc thesis completed in 2014.

Mateusz Pęgier, Faculty of Chemistry, Warsaw University of Warsaw
***Identyfikacja i dystrybucja zanieczyszczeń metalicznych i radionuklidowych w procesie wytwarzania $^{18}F$-fluorodeoksyglukozy***
*Identification and distribution of metallic and radionuclidic impurities in the synthesis of $^{18}F$-fluorodeoxyglucose*
Supervisor: dr K. Kilian. MSc thesis completed in 2014.

Julia Juszczyk, Faculty of Physics, University of Warsaw
***Synteza i ocena jakości procesu produkcyjnego $^{11}C$-metioniny***
*Synthesis and quality assesment of the production of $^{11}C$–methionine*
Supervisor: dr K. Kilian. BSc thesis completed in 2014.

Agnieszka Tofil, Faculty of Physics, University of Warsaw
***Oprogramowanie i opracowanie strategii optymalizacji syntezy $^{11}C$-octanów na syntezerze Synthra GP-Extend***
*Strategy and optimization of $^{11}C$-acetate synthesis with the Sythra GP-Extend automatic synthesis unit*
Supervisors: dr K. Kilian. BSc thesis completed in 2014.

Mateusz Sitarz, Faculty of Physics, University of Warsaw
***Produkcja radioizotopów Sc-43 i Sc-44 z użyciem wiązki cząstek α jako emiterów pozytronów do obrazowania medycznego — ocena wydajności procesu***
*Production of positron emiters: Sc-43 and Sc-44 using an alpha particle beam — process efficiency evaluation*
Supervisor: dr R. Kuś, dr A. Trzcińska. MSc thesis, expected completion time: 2015.

Roman Szenborn, Faculty of Physics, University of Warsaw
***Analysis of random $\gamma$-$\gamma$ coincidences in DSA experiments with the EAGLE array***
Supervisors: dr E. Grodner, dr J. Srebrny. MSc 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: 2015.

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, expected completion time: 2015.

### D.2.5 Other MSc and BSc theses based on experiments performed at HIL

Klaudia Szpik, Silesian University
***Producja radioizotopów selenu i arsenu dla celów medycyny nuklearnej na cyklotronie U-200P***
*Production of radioisotopes of selenium and arsenic for nuclear medicine, with the use of the U-200P cyclotron*
Supervisors: dr hab. A Konefał, prof. dr hab. W. Zipper. MSc thesis completed in 2014.

Marzan Nassurlla, Al-Farabi Kazakh National University, Almaty, Kazachstan
***Investigation of scattering processes in light nuclear systems***
Supervisor: prof. N. Burtebayev. Msc thesis completed in 2014.

Błażej Mleczko, Silesian University
***Opracowanie metody wyznaczania aktywności radioizotopu At-211 za pomocą radiometru***
*Preparation of a method of determining At-211 activity using a radiometer*
Supervisors: dr hab. A Konewał, prof. dr hab. J. Jastrzębski.
MSc thesis, expected completion time: 2015.

# D.3 Publications

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

A. Bantsar, M. Pietrzak, M. Jaskóła, A. Korman, S. Pszona, and Z. Szefliński. *Status report: Nanodosimetry of carbon ion beam at HIL.* Rep. Pract. Oncology and Radiotherapy **19**, S42 (2014).

J. C. Batchelder, N. T. Brewer, C. J. Gross, R. Grzywacz, J. H. Hamilton, M. Karny, A. Fijałkowska, S. H. Liu, K. Miernik, S. W. Padgett, S. V. Paulauskas, K. P. Rykaczewski, A. V. Ramayya, D. W. Stracener, and M. Wolińska-Cichocka. *Structure of low-lying states in $^{124,126}$Cd populated by $\beta$ decay of $^{124,126}$Ag.* Phys. Rev. C **89**, 054321 (2014).

S. Bottoni, S. Leoni, B. Fornal, R. Raabe, G. Benzoni, A. Bracco, F. C. L. Crespi, A. Morales, B. Bednarczyk, N. Cieplicka, W. Królas, A. Maj, B. Szpak, M. Callens, J. Bouma, J. Elseviers, F. Falvigny, R. Orlandi, K. Rusek, P. Reiter, M. Seidlitz, S. Klupp, D. Mucher, G. Georgiev, D. Balabanski, M. Sferrazza, M. Kowalska, and E. Rapisarda. *$\gamma$ Spectroscopy of Neutron-rich Nuclei with $A < 100$ Produced by Cluster Transfer Reactions at REX-ISOLDE.* Acta Phys. Pol. B **45**, 343 (2014).

R. Bougault, G. Poggi, S. Barlini, B. Borderie, G. Casini, A. Chbihi, N. Le Neindre, M. Pârlog, G. Pasquali, S. Piantelli, Z. Sosin, G. Ademard, R. Alba, A. Anastasio, S. Barbey, L. Bardelli, M. Bini, A. Boiano, M. Boisjoli, E. Bonnet, R. Borcea, B. Bougard, G. Brulin, M. Bruno, S. Carboni, C. Cassese, F. Cassese, M. Cinausero, L. Ciolacu, I. Cruceru, M. Cruceru, B. D'Aquino, B. De Fazio, M. Degerlier, P. Desrues, P. Di Meo, J. A. Dueñas, P. Edelbruck, S. Energico, M. Falorsi, J. D. Frankland, E. Galichet, K. Gasior, F. Gramegna, R. Giordano, D. Gruyer, A. Grzeszczuk, M. Guerzoni, H. Hamrita, C. Huss, M. Kajetanowicz, K. Korcyl, A. Kordyasz, T. Kozik, P. Kulig, L. Lavergne, E. Legouée, O. Lopez, J. Łukasik, C. Maiolino, T. Marchi, P. Marini, I. Martel, V. Masone, A. Meoli, Y. Merrer, L. Morelli, F. Negoita, A. Olmi, A. Ordine, G. Paduano, C. Pain, M. Pałka, G. Passeggio, G. Pastore, P. Pawłowski, M. Petcu, H. Petrascu, E. Piasecki, G. Pontoriere, E. Rauly, M. F. Rivet, R. Rocco, E. Rosato, L. Roscilli, E. Scarlini, F. Salomon, D. Santonocito, V. Seredov, S. Serra, D. Sierpowski, G. Spadaccini, C. Spitaels, A. A. Stefanini, G. Tobia, G. Tortone, T. Twaróg, S. Valdré, A. Vanzanella, E. Vanzanella, E. Vient, M. Vigilante, G. Vitiello, E. Wanlin, A. Wieloch, and W. Zipper. *The FAZIA project in Europe: R&D phase.* Eur. Phys. J. A **50**, 47 (2014).

N. Bree, K. Wrzosek-Lipska, A. Petts, A. Andreyev, B. Bastin, M. Bender, A. Blazhev, B. Bruyneel, P. A. Butler, J. Butterworth, M. P. Carpenter, J. Cederkall, E. Clement, T. E. Cocolios, A. Deacon, J. Diriken, A. Ekstrom, C. Fitzpatrick, L. M. Fraile, C. Fransen, S. J. Freeman, L. P. Gaffney, J. E. Garcia-Ramos, K. Geibel, R. Gernhauser, T. Grahn, M. Guttormsen, B. Hadinia, K. Hadyńska-Klęk, M. Hass, P.-H. Heenen, R.-D. Herzberg, H. Hess, K. Heyde, M. Huyse, O. Ivanov, D. G. Jenkins, R. Julin, N. Kesteloot, T. Kroll, R. Krucken, A. C. Larsen, R. Lutter, P. Marley, P. J. Napiorkowski, R. Orlandi, R. D. Page, J. Pakarinen, N. Patronis, P. J. Peura, E. Piselli, P. Rahkila, E. Rapisarda, P. Reiter, A. P. Robinson, M. Scheck, S. Siem, K. S. Chakkal, J. F. Smith, J. Srebrny, I. Stefanescu, G. M. Tveten, P. V. Duppen, J. V. de Walle, D. Voulot,

N. Warr, F. Wenander, A. Wiens, J. L. Wood, and M. Zielińska. *Shape Coexistence in the Neutron-Deficient Even-Even $^{182-188}$Hg Isotopes Studied via Coulomb Excitation.* Phys. Rev. Lett. **112**, 162701 (2014).

M. Şenyiğit, A. Ataç, S. Akkoyun, A. Kaşkaş, D. Bazzacco, J. Nyberg, F. Recchia, S. Brambilla, F. Camera, F. C. L. Crespi, E. Farnea, A. Giaz, A. Gottardo, R. Kempley, J. Ljungvall, D. Mengoni, C. Michelagnoli, B. Million, M. Palacz, L. Pellegri, S. Riboldi, E. Şahin, P. A. Söderström, and J. J. Valiente Dobon. *Identification and rejection of scattered neutrons in AGATA.* Nucl. Instrum. Methods Phys. Res. A **735**, 267 (2014).

T. Cap, K. Siwek-Wilczyńska, I. Skwira-Chalot, J. Wilczyński, F. Amorini, L. Auditore, G. Cardella, E. D. Filippo, E. Geraci, L. Grassi, A. Grzeszczuk, E. L. Guidara, J. Han, T. Kozik, G. Lanzalone, I. Lombardo, R. Najman, N. G. Nicolis, A. Pagano, M. Papa, E. Piasecki, S. Pirrone, R. Planeta, G. Politi, F. Rizzo, P. Russotto, A. Trifiro, M. Trimarchi, G. Verde, and W. Zipper. *Aligned ternary partitioning of the $^{197}Au$ $^{197}Au$ system at 23 A MeV beam energy.* Phys. Scr. **89**, 054005 (2014).

A. Fijałkowska, M. Karny, K. P. Rykaczewski, M. Wolińska-Cichocka, R. Grzywacz, C. J. Gross, J. W. Johnson, B. C. Rasco, E. F. Zganjar, D. W. Stracener, L. Cartegni, K. C. Goetz, R. Goans, C. Jost, M. Madurga, K. Miernik, D. Miller, S. W. Padgett, S. V. Paulauskas, M. Al-Shudifat, E. Spejewski, J. H. Hamilton, and A. V. Ramayya. *First Results from the Modular Total Absorption Spectrometer at the HRIBF.* Acta Phys. Pol. B **45**, 545 (2014).

A. Fijałkowska, M. Karny, K. P. Rykaczewski, M. Wolińska-Cichocka, R. Grzywacz, C. J. Gross, J. W. Johnson, B. C. Rasco, E. F. Zganjar, D. W. Stracener, C. Jost, K. C. Goetz, R. Goans, E. Spejewski, L. Cartegni, M. Madurga, K. Miernik, D. Miller, S. W. Padgett, S. V. Paulauskas, M. Al-Shudifat, J. H. Hamilton, and A. V. Ramayya. *First Results from the Modular Total Absorption Spectrometer at the HRIBF.* Nucl. Data Sheets **120**, 26 (2014).

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M. Pantea, P. Reiter, T. R. Rodriguez, T. Rolke, H. Scheit, A. Scherillo, D. Schwalm, M. Seidlitz, T. Sieber, G. S. Simpson, I. Stefanescu, S. Thiel, P. G. Thirolf, J. V. de Walle, P. V. Duppen, D. Voulot, N. Warr, W. Weinzierl, D. Weisshaar, F. Wenander, A. Wiens, and S. Winkler. *Coulomb excitation of neutron-rich Cd isotopes.* Phys. Rev. C **89**, 014313 (2014).

M. Imadalou, D. E. Medjadi, P. Quentin, and L. Próchniak. *Quadrupole collective dynamics of medium-heavy even-even nuclei within the highly truncated diagonalization approach.* Phys. Scr. **89**, 054025 (2014).

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N. Keeley, K. W. Kemper, and K. Rusek. *Strong coupling effects in near-barrier heavy-ion elastic scattering.* Eur. Phys. J. A **50**, 145 (2014).

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# 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. Miernik — Inst. of Exp. Physics, Univ. of Warsaw 9 January 2014
***Emisja neutronów opoźnionych po rozpadzie beta***
*Emission of delayed neutrons after beta decay*

K. Rykaczewski — Oak Ridge National Laboratory, Oak Ridge, USA 16 January 2014
***Synteza najcięższych jader atomowych***
*Synthesis of the heaviest atomic nuclei*

P. Gąsior — Inst. of Plasma Physics and Laser Microfusion, Warszawa, Poland 23 January 2014
***Rozwój fizyki plazmy i służących jej metod diagnostycznych w eksperymentalnych reaktorach termojądrowych***
*Developement of plasma physics and applied diagnostic methods in experimental thermonuclear reactors*

B. Szpak — Institute of Nuclear Research, Kraków, Poland 20 February 2014
***Ocena możliwości przewidywania modeli struktury jadra***
*Predictive power of nuclear structure models*

D. Tarpanov — Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria 27 February 2014
***Polarization corrections to single-particle energies***

K. Siwek-Wilczyńska — Inst. of Exp. Physics, Univ. of Warsaw 6 March 2014
***Modelowanie reakcji syntezy jąder superciężkich***
*Modelling synthesis reactions for super-heavy nuclei*

J. Dobaczewski — Inst. of Theoretical Physics, Univ. of Warsaw 13 March 2014
***Samozgodny opis jąder superciężkich***
*Self-consistent approach to super-heavy nuclei*

W. Krzemień — Inst. of Physics, Jagiellonian University, Kraków 20 March 2014
***Poszukiwanie stanów związanych mezonu $\eta$ z jądrem atomowym***
*Search for the $\eta$ meson bound states with the atomic nucleus*

G. Verde — INFN Laboratori Nazionali del Sud, Catania, Italy 27 March 2014
***Reaction dynamics and space-time probes of isospin asymmetric nuclear systems***

J.W. Mietelski — Institute of Nuclear Research, Kraków, Poland 3 April 2014
***Katastrofa w Fukushimie widziana z Krakowa***
*Fukushima accident observed in Cracow*

P. Bednarczyk — Institute of Nuclear Research, Kraków, Poland 10 April 2014
***Europejski spektrometr promieni gamma AGATA — udział IFJ PAN w budowie instrumentu, pierwsze wyniki i dalsze perspektywy badań***
*European spectrometer for gamma-rays AGATA — IFJ PAN participation in construction, first measurement results and future research perspectives*

A. Jokinen — Department of Physics, University of Jyväskylä, Finland 24 April 2014
***Nuclear and applied research at the IGISOL-facility and JYFL Accelerator Laboratory***

A. Gałkowski — Inst. of Plasma Physics and Laser Microfusion, Warszawa, Poland 8 May 2014
***Ograniczenia fizyczne przestrzeni operacyjnej fuzji jądrowej***
*Physical limitations for the nuclear fusion operational space*

M. Pfützner — Inst. of Exp. Physics, Univ. of Warsaw 15 May 2014
***Emisja dwóch protonów jako granica spektroskopii jądrowej — obraz całościowy***
*Two-proton emission as a limit of nuclear spectroscopy*

M.J.G. Borge — ISOLDE, CERN, Geneve, Switzerland 22 May 2014
***The ISOLDE Facility, recent highlights and the HIE-ISOLDE project***

Ł. Janiak — Fac. of Phys. and Appl. Comp. Sci., U. of Lodz, Łódź, Poland 29 May 2014
***Spektrometr elektronów konwersji wewnętrznej w badaniach jąder atomowych***
*Internal conversion electron spectrometer for studying atomic nuclei*

T. Cap — Inst. of Exp. Physics, Univ. of Warsaw 5 June 2014
***Polarna i poprzeczna emisja ciężkich fragmentów w zderzeniach $^{197}$Au + $^{197}$Au przy energii 23 MeV na nukleon***
*Polar-side emission of heavy IMFs in $^{197}$Au + $^{197}$Au collisions at 23A MeV/A*

R. Kumar — Inter University Accelerator Centre, New Delhi, India 17 September 2014
***An Overview of the Inter University Accelerator Centre***

G. Casini — INFN e Università di Firenze, Firenze, Italy 22 September 2014
***From light to heavy nuclear systems, production and decay of fragments studied with powerful arrays***

W. Satuła — Inst. of Theoretical Physics, Univ. of Warsaw 2 October 2014
***The isospin- and angular-momentum-projected density functional theory and***

***beyond: formalism and applications***

M. Demiański — Inst. of Theoretical Physics, Univ. of Warsaw 9 October 2014
***Miraże ciemnej materii***
*Dark matter mirages*

W. Broniowski — Jan Kochanowski University, Kielce, Poland 16 October 2014
***Throwing triangles against the wall: ultrarelativistic heavy-ion collisions and the shape of light nuclei***

K. Kilian — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 30 October 2014
***Synteza i badanie własności radiofarmaceutyków do Pozytonowej Tomografii Emisyjnej***
*Synthesis and study of radiopharmaceutical properties for PET*

M. Pomorski — IRFU/SPhN, CEA Saclay, Gif-sur-Yvette, France 6 November 2014
***CVD diamond, a novel "miraculous" material for sensor fabrication? — Diamond activities at LCD CEA-LIST***

W. Przygoda — Inst. of Physics, Jagiellonian University, Kraków 13 November 2014
***Production and Dalitz decays of baryon resonances in p+p interactions at 1.25 and 3.5 GeV beam energy with HADES***

T. Oishi — Department of Physics, University of Jyväskylä, Finland 20 November 2014
***Role of Pairing Correlation in Two-proton Emission***

I. Skwira-Chalot — Inst. of Exp. Physics, Univ. of Warsaw 27 November 2014
***Efekty siły trójciałowej w reakcji breakupu***
*Triaxial force effect in breakup reaction*

K. Riisager — Aarhus University, Dania 4 December 2014
***Beta decay at the dripline***

M. Zielińska — IRFU/SPhN, CEA Saclay, Gif-sur-Yvette, France 11 December 2014
***Deformacja jąder atomowych w sąsiedztwie $^{100}$Zr badana poprzez pomiary prawdopodobieństw przejść i momentów kwadrupolowych***
*Nuclear deformation in the vicinity of $^{100}$Zr studied via measurements of transition probabilities and quadrupole moments*

## D.4.2 Other seminars organised at HIL

**Internal semi-formal HIL seminars**

M. Palacz — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 12 February 2014
***Eksperyment w Jyväskylä z JUROGAM/RITU/GREAT***
*Experiment at Jyväskylä with JUROGAM/RITU/GREAT*

J. Srebrny — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 05 March 2014
***Najbliższe plany eksperymentów EAGLE na przykładzie $^{140}$Sm***
*Future experimental plans for EAGLE demonstrated with $^{140}$Sm*

K. Kilian — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 14 May 2014
***Radiofarmaceutyki z Ośrodka Produkcji i Badania Radiofarmaceutyków***
*Radiopharmaceuticals from the Radiopharmaceuticals Production and Research Centre*

R. Kumar — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 17 September 2014
***The Inter University Accelerator Centre (IUAC) — An overview***

G. Casini — INFN e Università di Firenze, Firenze, Italy — 22 September 2014
***From light to heavy nuclear systems, production and decay of fragments studied with powerful arrays***

A. Kordyasz — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 8 December 2014
***X-ray response of diamond detectors constructed using diamond layers produced by low power Microwave Chemical Vapour Deposition (MVCVD) reactor***

S. Bogomolov — Joint Institute for Nuclear Research, Dubna, Russia — 12 November 2014
***Production of metal ion beams by the MIVOC method***

B. Gikal — Joint Institute for Nuclear Research, Dubna, Russia — 18 November 2014
***Development of the FLNR JINR heavy ion accelerator complex***

**Life Sciences meeting — 9 April 2014**

J. Choiński — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
***Radioizotopy medyczne z cyklotronów U200P i PETtrace***
*Medical radioisotopes produced in the U200P and PETtrace cyclotrons*

Z. Rogulski — Biological and Chemical Research Centre UW
***Obrazowanie molekularne w Centrum Nauk Biologiczno-Chemicznych UW***
*Molecular imaging in the Biological and Chemical Research Centre UW*

S. Krajewski — Institute of Nuclear Chemistry and Technology
***Nowe cyklotronowe radioizotopy dla terapii i diagnostyki PET***
*New cyclotron radioisotopes for therapy and PET diagnostics*

P. Komiski — Institute of Nuclear Chemistry and Technology
***Cząsteczki biologicznie czynne jako wektory w projektowaniu nowych radiofarmaceutyków***
*Biologically active molecules as vectors in designing new radiopharmaceuticals*

E. Leszczuk — Institute of Nuclear Chemistry and Technology
***Nanocząstki jako nośniki emiterów alfa w celowanej terapii***
*Nano-molecules as alpha emitter carriers in targeted therapy*

A. Bancer — National Centre for Nuclear Research
***Nanodozymetria $^{211}$At***
*$^{211}$At nanodosimetry*

K. Kilian — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
***Radiofarmaceutyki z Ośrodka Produkcji i Badania Radiofarmaceutyków ŚLCJ***
*Radiopharmaceuticals from the Radiopharmaceuticals Production and Research Centre HIL*

J. Czub — Jan Kochanowski University, Kielce, Poland
***Skutki działania ciężkich jonów na komórki CHO-K1***
*Effects of heavy ion irradiation of CHO-K1 cells*

M. Elas — Inst. of Physics, Jagiellonian University, Kraków
***Badanie efektów protonoterapii przeciwnowotworowej u zwierząt i w układzie komórkowym***
*Study of proton therapy effects on animals and cell systems*

K. Zabielska — Warsaw University of Life Science
***Badania przedkliniczne w onkologii weterynaryjnej***
*Preclinical trials in veterinary oncology*

A. Lankoff — Institute of Nuclear Chemistry and Technology
***Główne kierunki badań prowadzonych w Centrum Radiobiologii i Dozymetrii Biologicznej ICHTJ w Warszawie***
*Leading research at the Centre For Radiobiology and Biological Dosimetry INChT*

P. Kukołowicz — Oncology Centre — M. Skłodowska-Curie Institute
***Dozymetria i optymalizacja radioterapii. Kierunki badań prowadzonych w ZFM Centrum Onkologii***
*Dosimetry and optimisation of radiotherapy. Research at ZFM Oncology Centre*

Z. Szefliski — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
***Mikrowiązka ciężkojonowa do badań radiologicznych w ŚLCJ. Wprowadzenie do dyskusji o projekcie***
*Heavy ion microbeam for radiological research at HIL. Introduction to project discussion*

W.M. Kwiatek — Cyclotron Centre Bronowice
***Konsorcjum Radiobiologiczne dla nowoczesnej radioterapii (koncepcja inicjatywy)***
*Radiobiological consortium for modern radiotherapy (initiative conception)*

### D.4.3 External seminars given by the HIL staff

P. Napiorkowski 7–10 January 2014
***Coulomb Excitation — a Complex Tool for Nuclear Structure Studies***
Joint LEA COLLIGA-COPIGAL Workshop, Paris, France

M. Palacz 7–10 January 2014
***Investigations of nuclei close to N=Z =50 with $\gamma$-ray, charged particle and neutron detectors (at GANIL)***
Joint LEA COLLIGA-COPIGAL meeting, Paris, France

K. Rusek 7–10 January 2014
***Laboratory portrait — Heavy Ion Laboratory at the University of Warsaw;***
***Dynamic polarization potentials for light, exotic nucleai;***
***Concluding remarks — astrophysics interdisciplinary sessions***
Joint LEA COLLIGA-COPIGAL Workshop, Paris, France

A. Trzcińska 7–10 January 2014
***Barrier height distributions — the influence of weak channels***
Joint LEA COLLIGA-COPIGAL Workshop, Paris, France

P. Napiorkowski 29–30 April 2014
***JACOB — Genetic algorithm implementation***
Leuven, Belgium

E. Piasecki May 2014
***Weak channels and barrier distributions***
Trento, Italy

J. Choiński 15–17 May 2014
***Radioisotope and radiopharmaceutical production centre for PET***
Warsaw Medical Physics Meeting 2014

K. Kilian 15–17 May 2014
***Radiopharmaceuticals for PET imaging — current status and perspectives***
Warsaw Medical Physics Meeting 2014

K. Kilian 27 May 2014
***Projekty naukowe i komercyjne realizowane w laboratoriach środowiskowych CePT UW***
*Scientific and commercial projects implemented in UW CePT laboratories*
V Konferencja CePT

O. Steczkiewicz 16 June 2014
***Improvement of the beam transmission in the central region of the Warsaw U200P Cyclotron***
5th International Particle Accelerator Conference, Dresden, Germany

T. Marchlewski 25 June 2014
***DSA lifetime measurements of chiral $^{124}$Cs — presence of the s-symmetry***
4th EGAN workshop, Darmstadt, Germany

K. Wrzosek-Lipska 25–29 August 2014
***Shape coexistance nature in the Pb region at REX Isolde***
15th International Symposium on capture Gamma-Ray Spectroscopy and Related Topics, Dresden, Germany

P. Napiorkowski 2 September 2014
***Coulomb excitation for quadrupole moment measurements***
Zakopane Conference on Nuclear Physics, Zakopane, Poland

T. Marchlewski 5 September 2014
***Spontaneous time-reversal symmetry breaking in $^{124}$Cs***
Zakopane Conference on Nuclear Physics, Zakopane, Poland

J. Choiński 21–24 September 2014
***Radiopharmaceuticals production for PET imaging in Poland***
II Symposium on PET, M. Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland

K. Kilian 21–24 September 2014
***Beyond FDG: Manufacturing of $^{11}$C and $^{18}$F radiopharmaceuticals***
II Symposium on PET, M. Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland

Z. Szefliński 21–24 September 2014
***Heavy ion beams for radiobiology — dosimetry and nanodosimetry at HIL***
II Symposium on PET, M. Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland

L. Próchniak 25 September 2014
***Collective properties of Xe isotopes***
21th Nuclear Physics Workshop, Kazimierz, Poland

J. Srebrny October 2014
***Highlights of the scientific programme of the Heavy Ion Laboratory, University of Warsaw***
EWIRA 2014 conference, Bukareszt, Romania

O. Steczkiewicz 9 October 2014
***Improvement of the beam transmission in the central region of Warsaw U200P Cyclotron***
XXIV Russian Particle Accelerators Conference, Obnińsk, Russia

J. Choiński 13–14 November 2014
***Radioisotope and radiopharmaceutical production centre for PET***
"CYCLEUR" Cyclotron Research Workshop, "JRC Enlargment and Integration Programme"
Joint Research Center, Ispra, Italy

### D.4.4 Poster presentations

K. Kilian 16 May 2014
***Synthesis and quality control of 11Cmethionine***
Warsaw Medical Physics Meeting, Warszawa, Poland

M.Wolińska-Cichocka 1–6 June 2014
***Testing the on-line response of the Modular Total Absorption Spectrometer: $^{142}$Ba$\rightarrow^{142}$La$\rightarrow^{142}$Ce decay chain***
Conference on "Advances in Radioactive Isotope Science 2014" (ARIS 2014), Tokyo, Japan

G. Jaworski 2 July 2014
***Building the neutron multiplicity filter NEDA***
Summer School on Neutron Detectors and Related Applications, Riva del Garda, Italy

M.Wolińska-Cichocka 31 August – 7 September 2014
***The response of the Modular Total Absorption Spectrometer tested with the $^{142}$Ba$\rightarrow^{142}$La$\rightarrow^{142}$Ce decay chain***
The Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland

R. Szenborn 31 August – 7 September 2014
***The disappearance of signature splitting and energy staggering in $^{124}$Cs***
The Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland

U. Kaźmierczak, Z. Szefliński 18 September 2014
***Dosimetry in radiobiological studies with the heavy ion beams of the Warsaw cyclotron***
19th International Conference on Ion Beam Modification of Materials, IBMM, Leuven, Belgium

A. Bednarek, A. Kordyasz 24–27 September 2014
***X-ray response of diamond detectors constructed using diamond layers, produced by a Microwave Chemical Vapour Deposition (MWCVD) reactor***
II Symposium on applied nuclear physics and innovative technologies, Jagiellonian University, Kraków, Poland

K. Kilian 24 October 2014
***Wysokosprana chromatografia cieczowa z detekcją radiometryczną w syntezie i badaniu jakości radiofarmaceutyku 11C-metioniny***
*HPLC with radiometric detection as a tool in synthesis and quality control of 11C-methionine*
VIII Conference "Analityczne zastosowania chromatografii cieczowej", Warszawa, Poland

### D.4.5 Lectures for students and student laboratories

Z. Szefliński summer semester of the academic year 2013/2014, 30 hours
***Energetyka Jądrowa***
*Nuclear power industry*
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński summer semester of the academic year 2013/2014, 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 2014/2015, 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 2014/2015, 45 hours
***Fizyka I***
*Physics 1, mechanics, Lecture*
Faculty of Physics, University of Warsaw, Warszawa, Poland

Z. Szefliński winter semester of the academic year 2014/2015, 15 hours
***Fizyka I — ćwiczenia do wykładu***
*Physics 1, mechanics, Class plenary*
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian winter semesters of the academic years 2013/2014 and 2014/2015, 90 hours
***Pracownia Analityki Środowiska***
*Environmental Analysis Laboratory*
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of the academic year 2013/2014, 60 hours
***Pracownia radiofarmaceutyków***
*Laboratory of Radiopharmaceuticals*
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian winter semester of the academic year 2013/2014, 30 hours
***Metody izotopowe i chemia radiofarmaceutyków***
*Radiochemistry and radiopharmacy*
Faculty of Physics, University of Warsaw, Warszawa, Poland

M. Palacz academic year 2013/2014 (72 hours), and 2014/2015 (110 hours)
***Pracownia ochrony radiologicznej***
*Radioprotection Laboratory*
Faculty of Physics, University of Warsaw, Warszawa, Poland

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

L. Próchniak lecture for MSc and PhD students, 30 hours, 12–24.05.2014
***Selected topics in nuclear structure theory***
Al-Farabi Kazakh National University, Almaty, Kazakhstan

### D.4.6 Science popularisation lectures

P. J. Napiorkowski lectures for middle school pupils

***Fizyka dla bramkarzy*** (3x60 min)
*Physics for goalkeepers*

Z. Szefliński lectures for high school pupils

***Zrównoważona Energia Wiatr i Słońce*** (2x45 min)
*Sustainable Energy Wind and the Sun*

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

***Obrazowanie medyczne. Gamma Kamera, Tomografia Pozytonowa,NMR*** (2x45 min)
*Medical imaging. Gamma Camera, Positron Emission Tomography, NMR*

***Fizyka jądrowa w diagnostyce medycznej. Tomografia pozytonowa*** (4x45 min)
*Nuclear physics in medical diagnostics. Positron emission tomography*

***Promieniowanie jonizujące — radon w naszym otoczeniu*** (45 min)
*Ionizing radiation — radon in our environment*

## D.5 Awards

### Heavy Ion Laboratory Prize founded by Prof. T. Inamura

The prize was established by Professor Takashi Tom Inamura who worked at the Heavy Ion Laboratory in the years 1998–2002 and made a great contribution to its development. An award in the amount of 5.000 USD is granted every second year to recognise and support young researchers with outstanding experimental or technical achievements in the field of nuclear and atomic physics or related subjects. The results should be obtained using the Warsaw Cyclotron or other HIL apparatus. Candidates must be scientists or PhD students below the age of 36 on the day of application. The most important selection criterion is the candidate's academic achievement, demonstrated by publications in international journals and presentations at international conferences. Achievements in the field of interdisciplinary applications of the HIL cyclotron are highly valued.
In the sixth edition, in 2014, the Heavy Ion Laboratory Prize was awarded to **Urszula Kaźmierczak** from the Heavy Ion Laboratory, for her studies of the biological response of cells irradiated with heavy ions at the Warsaw Cyclotron.

### University of Warsaw Medal

The following employees of the Heavy Ion Laboratory received the University of Warsaw Medal at the 20th aniversary of the first beam extraction from the Warsaw Cyclotron:
Tomasz Bracha, Andrzej Jakubowski, Wiesław Kalisiewicz, Krzysztof Kilian, Maciej Kisieliński, Marian Kopka, Michał Kowalczyk, Ireneusz Mazur, Jan Miszczak, Bogusław Paprzycki, Andrzej Pietrzak, Anna Stolarz, Julian Srebrny, Józef Sura, Roman Tańczyk

### The Rector of the University of Warsaw awards

In 2014 the following employees of the Heavy Ion Laboratory received the Rector of the University of Warsaw award:
Marek Budziszewski, Jarosław Choiński, Przemysław Gmaj, Jerzy Jastrzębski, Wiesław Kalisiewicz, Krzysztof Kilian, Agnieszka Maciejewska, Ireneusz Mazur, Paweł Napiorkowski, Bogusław Paprzycki, Krzysztof Rusek, Julian Srebrny, Olga Steczkiewicz, Anna Stolarz, Zygmunt Szefliński

## D.6 Laboratory staff

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

**Senior scientists:**

Jerzy Jastrzębski[a], Jan Kownacki[a b], 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, Izabela Cydzik[c], Jarosław Choiński, Przemysław Gmaj, Andrzej Jakubowski, Krzysztof Kilian, Maciej Kisieliński[a], Marian Kopka, Michał Kowalczyk, Magdalena Matejska-Minda[d], Paweł Matuszczak[a e], Ireneusz Mazur, Jan Miszczak, Paweł Napiorkowski, Wojciech Piątek[f], Bogdan Radomyski[e], Mateusz Sobolewski, Łukasz Standyło, Olga Steczkiewicz, Julian Srebrny[a], Roman Tańczyk, Agnieszka Trzcińska, Andrzej Tucholski, Marzena Wolińska-Cichocka, Katarzyna Wrzosek-Lipska[e]

**Doctoral candidates:**

Grzegorz Jaworski[g], Urszula Kaźmierczak[h], Michalina Komorowska[h], Tomasz Marchlewski[h], Jan Mierzejewski[h], Mateusz Pęgier[i], Anna Pękal[i]

**Technicians:**

Mariusz Antczak, Tomasz Bracha, Marek Figat, Andrzej Górecki, Piotr Jasiński, Wiesław Kalisiewicz, 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[j], Barbara Kowalska[a], Joanna Kowalska[f], Agnieszka Maciejewska, Jolanta Matuszczak[k], Jolanta Ormaniec, Piotr Piegat[a], Joanna Strojek, Ewa Sobańska, Lidia Strzelczyk, Krystyna Szczepaniak, Wanda Wesoły, Andrzej Wiechowski, Katarzyna Włodarczyk[a], Irena Żejmo[a]

**Voluntary scientists:**

Jan Kownacki, Andrzej Wojtasiewicz

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[a] part time
[b] until 28 February 2014
[c] until 3 March 2014
[d] since 1 December 2014
[e] since 1 August 2014
[f] since 1 September 2014
[g] PhD student at the Faculty of Physics, Warsaw University of Technology
[h] PhD student at the Faculty of Physics, University of Warsaw
[i] PhD student at the Faculty of Chemistry, University of Warsaw
[j] on leave since 1 June 2014
[k] since 1 October 2014

## D.7 Laboratory Council

1. Prof. dr hab. Józef Andrzejewski
Nuclear Physics Division
University of Łódź
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2. Prof. dr hab. Rajmund Bacewicz
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3. Prof. dr hab. Janusz Braziewicz
Institute of Physics
Jan Kochanowski University
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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)
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02-093 Warszawa, ul. Pasteura 5A

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

9. Prof. dr hab. Zenon Janas
Inst. of Experimental Physics
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10. Prof. dr hab. Jerzy Jastrzębski
Heavy Ion Laboratory
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11. Prof. dr hab. Marta Kicińska-Habior
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12. Prof. dr hab. Stanisław Kistryn
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31-007 Kraków, ul. Gołębia 24

13. Prof. dr hab. Adam Maj
The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences
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14. Prof. dr hab. Wojciech Nawrocik
Faculty of Physics
Adam Mickiewicz University
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15. Prof. dr hab. Sławomir Nazarewski
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02-091 Warszawa, ul. Żwirki i Wigury 61

16. Prof. dr hab. Paweł Olko
The Henryk Niewodniczański
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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
00-681 Warszawa, ul. Hoża 69

21. Prof. dr hab. Adam Sobiczewski
The National Centre for Nuclear Research
00-681 Warszawa, ul. Hoża 69

22. Prof. dr hab. Ryszard Sosnowski
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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 PAN, 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, Otwock, 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 (Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland).

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