Tomasz Hofmokl
1979-1983

Brunon Sikora
1983-1984

Jerzy Jastrzębski
1984-1994 2000-2009

Jan Kownacki
1994-2000

Krzysztof Rusek
2009-2021

Heavy Ion Laboratory

ANNUAL REPORT 2024

30 YEARS

UNIVERSITY OF WARSAW

HIL
Heavy Ion Laboratory

Heavy Ion Laboratory

University of Warsaw

Annual Report

2024

Warszawa, May 2025

Annual Report of the
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Introduction

In 1994 a Laboratory Portrait was published in Nuclear Physics News. Its author Tomasz Czosnyka wrote: "A new facility is born. It has been a good season for Polish heavy Ion physicists and for Warsaw champagne dealers, as well. At the end of November 1993, the stocks of champagne were depleted after the first successful acceleration of 32 MeV $^{20}Ne^{2+}$ beams in the Warsaw Heavy Ion Cyclotron, followed in March 1994 by the celebration of the first on- line measurements and finally, by the commissioning of the new facility on May 20, 1994."

Thirty years later, we proudly present the results obtained using the unique equipment installed at the Warsaw Cyclotron. During 2024 international research teams continued to study the structure of atomic nuclei using a gamma spectrometer equipped with NEDA neuron detectors, the Hungarian DIAMOND light charged particle detector and a plunger brought from the University of Cologne. The studies of fusion barrier distributions conducted at HIL were partially concluded with an article by G. Colucci et al. published in Physical Review C.

It is worth emphasizing that over the 30 years of operation of the U-200P heavy ion cyclotron, the interdisciplinary activities of research groups at HIL have significantly developed. Studies of the properties of selenium nanoparticles, the radiation resistance of glioblastoma cells and the production of new radioisotopes for medical purposes combine the ideas, skills and knowledge of chemists, biologists and physicists.

The year 2024 brought the graduation of Dr. Bogumił Zalewski - a student of Prof. Krzysztof Rusek. It is a pity that this HIL graduate will continue his career outside the Laboratory, but at the end of 2024 three young PhDs from India and France joined the HIL team. We can therefore eagerly prepare ambitious research plans for 2025, beginning the next 30 years of beams from the Warsaw Cyclotron.

Thirty years of the Warsaw Cyclotron and the SFJ PTF Symposium – Horizons: The Journey Ahead for Polish Nuclear Physics

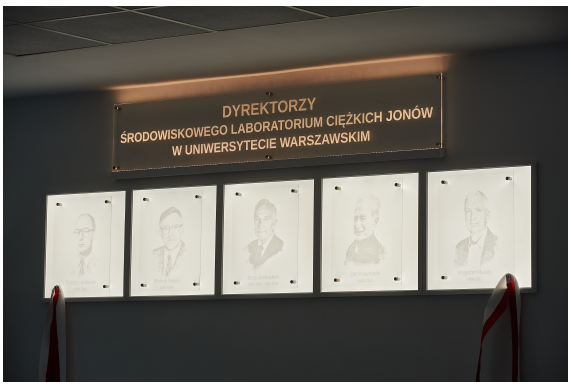
P.J. Napiorkowski, J. Matuszczak

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

In 1994, the beam of heavy ions accelerated by the Warsaw Cyclotron was first time extracted at the Heavy Ion Laboratory. This event did not complete the construction of the facility, which formally lasted until mid-1998. Nevertheless, along with the first beam, research teams with their detectors began to appear at the Laboratory, and the first measurements were carried out, which can be read about in published conference reports from the mid-nineties. The Warsaw Cyclotron began its scientific life.

30 years later, on April 8, 2024, distinguished guests gathered at the HIL participated in scientific sessions devoted to the past, present and future of nuclear physics. The anniversary ceremonies were opened by Prof. Maria Mrówczyńska, representing the Ministry of Science and Higher Education, and His Magnificence the Rector of the University of Warsaw, Prof. Alojzy Z. Nowak. The history of the Warsaw Cyclotron was recalled by the former Directors of the Laboratory, Brunon Sikora (head of HIL in 1983-1984), Jan Kownacki (1994-2000) and Krzysztof Rusek (2009-2022).

During the ceremonial anniversary session, the Medals of the University of Warsaw were presented. Twelve people were honoured for their services to the HIL UW. A gallery commemorating the former directors of the unit was also unveiled.



However, apart from the obvious historical context, an important element of the celebrations of the 30th anniversary of the Warsaw Cyclotron beam were discussions about the current condition and future of nuclear physics in Poland. The Symposium "Where Are You Going, Poland, Nuclear Physics", organised together with the Nuclear Physics Section of the Polish Physical Society, allowed present and talk about the future and upcoming research plans or Polish research groups.

Because, as we want to look at the anniversary of the Warsaw Cyclotron, "30 years is a good beginning."

Video report from 30 years of Warsaw Cyclotron celebration

UNIWERSYTET WARSZAWSKI
Rektor
prof. dr hab. Alojzy Z. Nowak

Warszawa, 8 kwietnia 2024 r.

Pan
dr Paweł Napiorkowski
p.o. Dyrektora Środowiskowego
Laboratorium Ciężkich Jonów
Uniwersytetu Warszawskiego

Szanowny Panie Dyrektorze,

w imieniu własnym oraz całej społeczności Uniwersytetu Warszawskiego, przekazuję na ręce Pana Dyrektora serdeczne gratulacje i wyrazy uznania z okazji jubileuszu 30-lecia wiązki jonów z Warszawskiego Cyklotronu.

Od wielu lat grupy eksperymentalne prowadzą badania w oparciu o wyspecjalizowaną aparaturę Środowiskowego Laboratorium Ciężkich Jonów. Dzięki Państwa otwartości, wiedzy i zaangażowaniu rozwijana jest współpraca z uczelniami i jednostkami badawczymi w kraju i za granicą. Powstające w oparciu o wyniki eksperymentów artykuły naukowe oraz organizowane przez Państwa wizyty badawcze, konferencje i cykliczne warsztaty dla studentów cieszą się uznaniem środowiska naukowego. Laboratorium jest unikatowym miejscem spotkań i wymiany doświadczeń badaczy z wielu dyscyplin.

Wszystkim pracownikom Laboratorium życzę dalszych sukcesów, a w kolejnych latach mądrej, dającej prawdziwą satysfakcję pracy naukowo-badawczej, dydaktycznej i popularyzatorskiej.

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Prezes

NGO

Warszawa, 8 kwietnia 2024 r.

Dr Paweł Napiorkowski
Środowiskowe Laboratorium
Ciężkich Jonów
Uniwersytet Warszawski

Szanowni Panie Dyrektorze,

z okazji Jubileuszu 30-lecia wiązki jonów z Warszawskiego Cyklotronu w imieniu całej społeczności Polskiego Towarzystwa Fizycznego składam na Pana ręce najserdeczniejsze życzenia i gratulacje.
Z dużym zainteresowaniem i podziwem śledzimy naukowe dokonania pracowników Laboratorium. Trzydzieści lat prowadzenia badań naukowych zaowocowały ważnymi wynikami w zakresie fizyki jądrowej, nowatorskimi rozwiązaniami i ciekawymi publikacjami.

Ogromny szacunek budzi także zaangażowanie Załogi Laboratorium w popularyzację fizyki oraz promowanie idei kształcenia przez całe życie, czego wyrazem są organizowane przez Laboratorium Ogólnopolskie Warsztaty Akceleracji i Zastosowań Ciężkich Jonów, zajęcia z fizyki w ramach festiwali nauki, pikników naukowych i dni otwartych Uniwersytetu Warszawskiego.

W tym wyjątkowym dniu życzę całej społeczności Środowiskowego Laboratorium Ciężkich Jonów wielu sukcesów naukowych, realizacji wszystkich planów oraz wiele radości i pomyślności w życiu osobistym. Życzę odważnego podejmowania nowych wyzwań, jakie wyznacza nam współczesny świat.

Z wyrazami szacunku
Teresa Rząca-Urban

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Figure 1: A congratulatory letters from the Rector of the University of Warsaw and from the Polish Physical Society

30 years of Warsaw Cyclotron Program

Ceremonial anniversary session

Paweł. J. Napiorkowski — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
Uroczysta Sesja Jubileuszowa
Ceremonial anninersary session

Marek Lewitowicz — GANIL & Chairman of the Nuclear Physics European Collaboration Committee (NuPECC), Caen, France
Wykład Jubileuszowy
Anniversary Lecture

Paweł. J. Napiorkowski — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
Uroczysta Sesja Jubileuszowa
Ceremonial anninersary session

Session: HIL past and present

Jarosław Choiński — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
Trochę historii – jak powstawało Środowiskowe Laboratorium Ciężkich Jonów w Uniwersytecie Warszawskim
A bit of history – how Heavy Ion Laboratory at the University of Warsaw was created

Marta Kicińska-Habior — Faculty of Physics, University of Warsaw, Warszawa, Poland
Początki prac badawczych w Środowiskowym Laboratorium Ciężkich Jonów na przykładzie układu JANOSIK
The beginning of research work at the Heavy Ion Laboratory on the example of the JANOSIK setup

Paweł. J. Napiorkowski — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
30 lat wiązki jonów z Warszawskiego Cyklotronu – dobry początek
30 years of ion beam from the Warsaw Cyclotron – a good start

Session: In Memoriam of prof. Jerzy Jastrzębski

Sławomir Wycech — National Center for Nuclear Research, Świerk, Poland
Jerzy Jastrzębski i Jego Halo
Jerzy Jastrzębski and His Halo

Ludwik Pieńkowski — AGH University, Krakow, Poland
Nadzieja, że to wszystko ma sens
Hope it all make sense

Piotr Lubiński — University of Zielona Góra, Zielona Góra, Poland
Fizyka antyprotonów w ŚLCJ
Antiproton physics at HIL

Barbara Kłos — University of Silesia, Katowice, Poland
Spotkanie z antyprotonami
Meeting with antiprotons

Katarzyna Szkliniarz — University of Silesia, Katowice, Poland
Radioizotopy medyczne w ŚLCJ – pierwsze kroki
Medical radioisotopes at HIL – first steps

Mateusz Sitarz — GANIL, Caen, France
Jak Jonizować Jakościowe Jaźnie Jądrowe
How to Ionize Qualitative Nuclear Selves

Wojciech Skulski — SkuTek Instrumentation, USA
Wspomnienie o Profesorze
Memories of the Professor

SFJ PTF Symposium – Horizons: The Journey Ahead for Polish Nuclear Physic Program

Ernest Grodner — National Center for Nuclear Research, Świerk, Poland
Nuclear chirality - from curiosity to mainstream. Success story of 20 years chirality research at HIL

Grzegorz Jaworski — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
Studies of neutron-deficient nulcei at HIL?

Jarosław Perkowski — University of Łódź, Łódź, Poland
A new magnetic selector and digital electronics system for the ULESE spectrometer

Magdalena Matejska-Minda — Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
Search for high-rank symmetries in medium-mass to super-heavy nuclei using high-resolution in-beam gamma spectroscopy at HIL UW

Andrej Špaček — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
Fast Timing at Heavy Ion Laboratory

Katarzyna Wrzosek-Lipska — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
Nuclear deformations studied with Coulomb excitation - perspectives and experimental needs

Katarzyna Hadyńska-Klęk — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
Forging tools to understand nuclear deformation in the light and medium mass nuclei – challenges and perspectives at the HIL Warsaw

Paweł Horodek — Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
Ions and positrons in defect studies

Rafał Walczak — Institute of Nuclear Chemistry and Technology, Warsaw, Poland
Cooperation between Heavy Ion Laboratory and Institute of Nuclear Chemistry and Technology

Renata Mikołajczak — National Centre for Nuclear Research, Radioisotope Centre POLATOM, Świerk, Poland
CERAD, Center of Design and Synthesis of Radiopharmaceuticals for Molecular Targeting and 30 MeV cyclotron for medical isotope production in Poland

Izabela Skwira-Chalot — Faculty of Physics, University of Warsaw, Poland
Experimental studies of few-nucleon systems

Andrzej Góźdź — University of Maria Curie-Skłodowska, Lublin, Poland
Quantum time and nuclear physics

Andrzej Staszczak — University of Maria Curie-Skłodowska, Lublin, Poland
Nuclear topological isomers

Michał Warda — University of Maria Curie-Skłodowska, Lublin, Poland
Challenges in the theoretical description of fission

Nicholas Keeley — National Center for Nuclear Research, Świerk, Poland
The continuing importance of stable beam facilities for understanding direct reactions: a current perspective

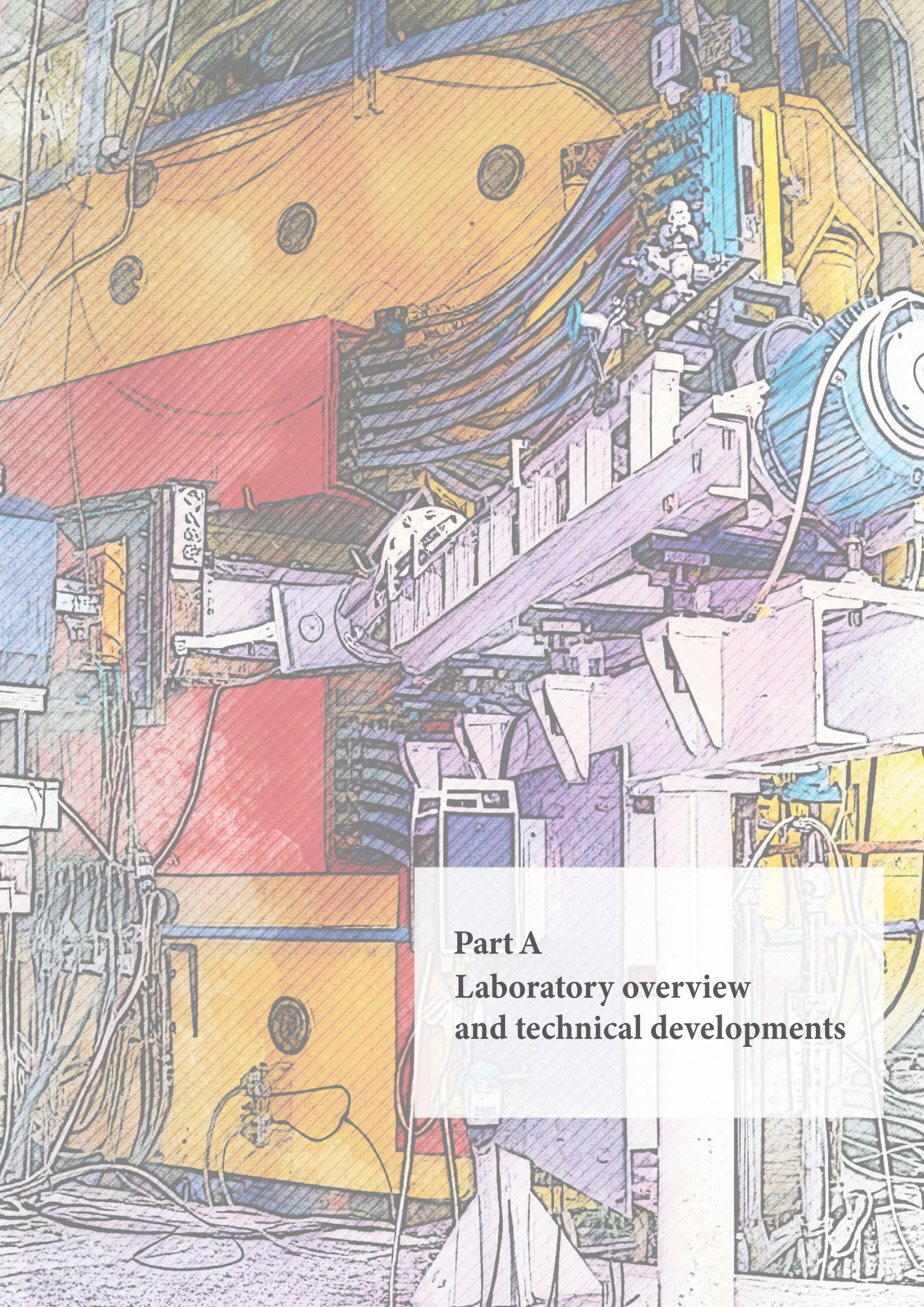
Giulia Colucci — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
Barrier distributions studies at HIL: from the most recent results to our future plans

Roman Wolski — Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland
ab initio cluster formfactors for direct reactions

Roman Skibiński — Jagiellonian University, Krakow, Poland
Towards relativistic description of reactions in two- and three-nucleon systems

Tomasz Krawczyk — Faculty of Economic Sciences / Digital Economy Lab, University of Warsaw, Warsaw, Poland
Results of survey innovation of nuclear laboratories in Europe – conclusion for the future strategy of developing nuclear physics in Poland

Paweł J. Napiorkowski — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland
Summary and general discussion



Part A
Laboratory overview and technical developments

A.1 Cyclotron operation in 2024 including tasks carried out in order to improve the infrastructure and efficiency

J. Choiński, A. Bednarek, T. Bracha, P. Gmaj, P. Jasiński, W. Kalisiewicz, M. Kopka, W. Kozaczka, P. Krysiak, K. Łabęda, K. Makowski, I. Mazur, J. Miszczak, B. Paprzycki, K. Pietrzak, B. Radomyski, O. Nassar, Ł. Standyło

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

Operation:
The basic activity of the technical team was to provide ion beams for experiments recommended by the PAC and approved by the HIL Director. The main effort was put into maintenance of the cyclotron infrastructure and the replacement of worn out elements. However, work related to the development of the cyclotron infrastructure was not neglected. The concept of a 55 mm diameter inflector, prepared for mounting through a magnetic plug, was implemented. The inflector is equipped with a regulating system on the cyclotron cover. This version of the inflector has the following advantages:
1. High voltage is supplied from the upper flange
2. Electrical connections of the inflector electrodes are simplified
3. Wide range of up and down position adjustment and rotation (+/- 12 degrees).
The results of the first tests were not entirely satisfactory, as several problems in the cyclotron center related to the new inflector were noted.

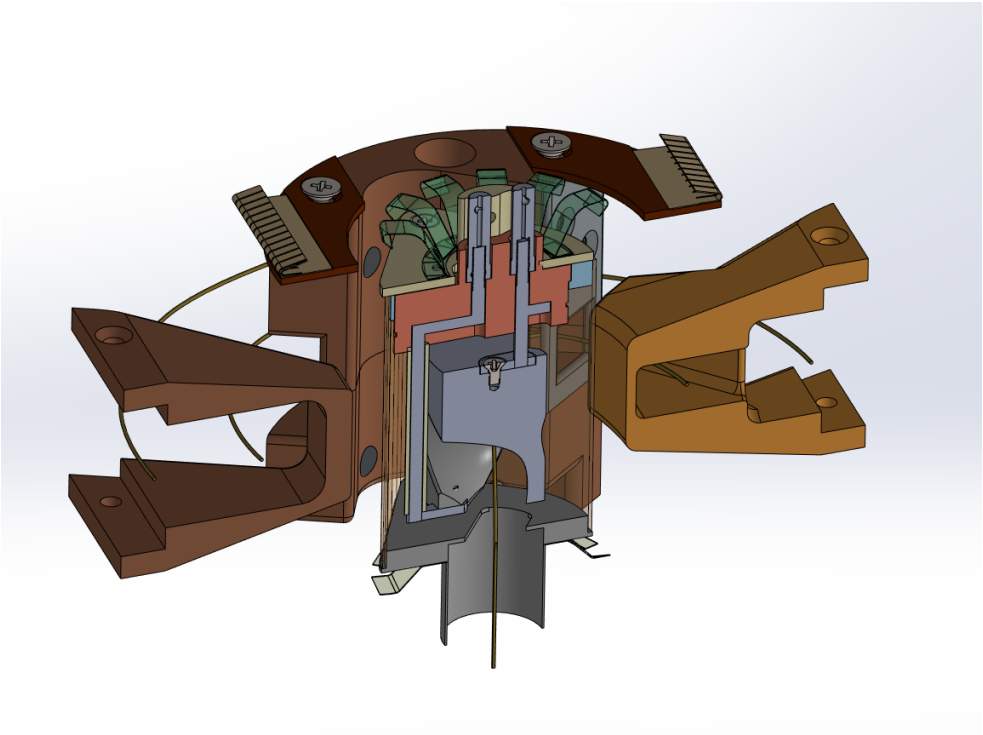


Figure 1: Cross-section through the cyclotron center and the new 55 mm diameter inflector.

At the same time, the working reflectors were modernized, duplicates were made and equipped with new solutions, e.g. the power supply and mounting of electrodes and HF contacts.

Some of the stripper adjustment components were changed to give greater reliability.

ECR Ion sources:
The 14.5 GHz ECR ion source operated for the needs of the cyclotron and experiments. Recent efforts concerning the ECR source have focused on generating and maintaining a stable **calcium-40 ion beam**. The primary objective was to achieve a reliable and efficient beam, essential for further experiments and acceleration process optimization. The most significant achievement was the production of a stable **$^{40}Ca^{6+}$ beam at 70 μA for 60 hours**. This was made possible through a series of modifications and optimizations, including:

- **Oven head modification** – Design improvements allowed for more efficient material feeding into the ionization process, enhancing emission stability.
- **Installation of a titanium shield for the oven system** – This upgrade significantly improved thermal and operational conditions, resulting in better ionization control and extended component lifespan.

For **gaseous ion beams**, an additional gas injection system increased beam intensity while reducing gas consumption **tenfold**, which is especially important for expensive isotopes. This modification involved **direct gas injection into the plasma chamber**, bypassing the main gas line. The system proved highly effective in producing a **^{22}Ne beam**. To enhance beam transport to the cyclotron, a **steering system** was installed just after the ECR source analysing magnet. This allows for more precise trajectory corrections, improving overall ion optics. Another key step in optimizing the injection line was **measuring the magnetic field distribution** in its vertical section. A detailed analysis along different segments enables the identification of inhomogeneities and further optimization of beam transport conditions—critical for achieving higher transmission efficiency.

RF system:
In 2024, the RF Generator team was responsible for carrying out current experiments on the cyclotron and maintaining the existing amplifier systems.

Failures
At the beginning of May we had to replace the high power tubes delivering RF power to dees "A" and "B" of the cyclotron. This was a major malfunction. We also experienced a few minor issues, such as in August, when we encountered a problem with a mid-power 4kW amplifier in the chain delivering power to dee "B" of the cyclotron. The amplifier was replaced by a spare. We informed the manufacturer of the failure. The unit was sent for repair. At the beginning of December we encountered a massive burn out of high voltage thyristors in the anode voltage rectifier delivering HV power to the tube in the "B" power amplifier channel of the cyclotron. We lost all the thyristors in one branch of the rectifier. Despite this, the experiment im progress at the cyclotron was completed with one phase of the rectifier switched off. The cause of this incident remains unknown. Because it happened on the night shift, we suppose that it was caused by disturbance in the 3 phase power grid outside the laboratory.

Improvements
Since we used all the spare thyristors in the repair we managed to find similar thyristors manufactured by the Polish firm KUBARA-LAMINA and adapted them mechanically to our requirements. In September, we conducted detailed inspection of both the cyclotron resonators and made some improvements to the coupling loop to improve transfer of RF power from the feeder to the accelerating dees.

Planned

We would like to hire a programmer to develop a program to control the two cyclotron generators in such a way that virtually all operations can be performed remotely which is also user-friendly for cyclotron operators.

Cyclotron:

The U-200P cyclotron itself required normal maintenance in 2024. The cyclotron team's main focus was on preparing the machine for upcoming experiments. Due to the planned reconstruction of the cyclotron's magnetic field, in order to increase the ion transmission coefficient, intensive tests of the magnetic field measurement system based on search coil technology were continued. The issue mentioned in the 2023 Report was overcome.

Experiments:

In 2024 10 experiments recommended by the PAC were performed. The list of experiments is presented in Appendices D.1.

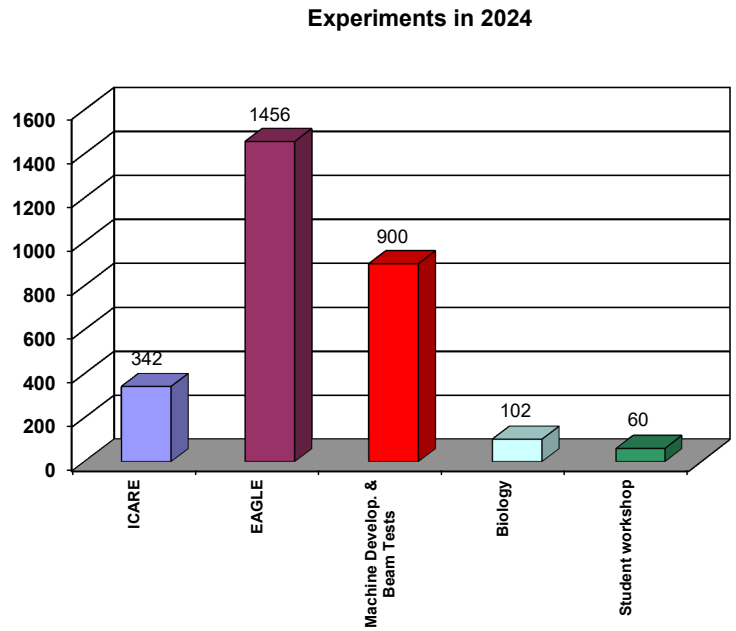


Figure 2: Number of ion beam hours used by approved experiments.

A.2 ECRIS status at HIL

Ł. Standyło, A. Górecki, K. Makowski, K. Sudlitz

Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

Long-Term Tests of the Calcium Beam

ECR ion source activity at HIL is currently focused on improving the 14.5 GHz source and reconstructing the 9.5 GHz source. The primary objective of the 14.5 GHz source development is the production of new ion beams, particularly metallic ones. The ongoing reconstruction of the magnetic trap will be detailed in future reports. Recent efforts have been directed towards optimizing and increasing the operational efficiency of the currently active ECR source. The first goal is the production and stabilization of a calcium ion beam. Several modifications have been made to the oven system and the sample preparation method: eliminating material oxidation and using a pelletized form have enabled the production of a stable beam for approximately 60 hours (Fig. 1). However, it should be noted that the graph below represents beam production tests in the ECR source only—the actual preparation time for use in the cyclotron will not exceed 24 hours. The applied microwave power ranged from 120 W to 160 W, with optimal tuning resulting in a reflected power of 2–3 W. This indicates that the sample was primarily heated by the furnace current. Helium was used as the standard buffer gas.

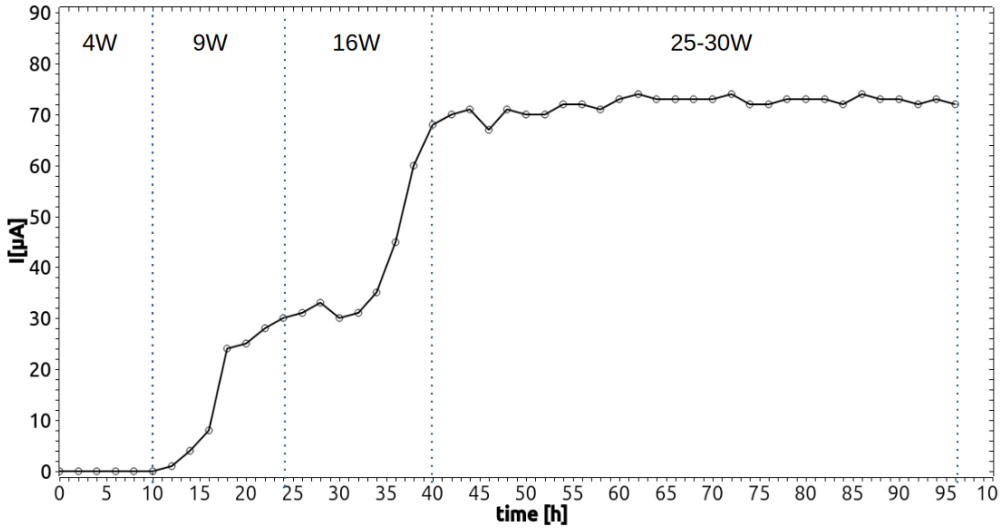


Figure 1: Long term tests of the calcium beam. The source was optimized for charge state 6^+. Final oven power was set to 26 W, 53% of the maximum heating power .

Optimization of Calcium Sample Sublimation

Previous tests have shown that to achieve optimal sublimation conditions for a calcium sample, the furnace power must not exceed 40 W. To minimize the plasma's influence, the furnace head was re-positioned 10 mm further from the plasma chamber. The balance between furnace heating (via current) and plasma heating is regulated by the negative potential of the titanium screen, which is set within the range -30 V to -250 V. Effective sublimation within the temperature range 460–600°C can only be achieved by gradually increasing the furnace power over an appropriate period while maintaining a high vacuum level of approximately 10^{-7} mbar. A significant modification involved introducing a titanium screen, which serves two key functions: shielding the furnace head from parasitic microwave heating and acting as a microwave coupler to the plasma chamber. The diameter and length of the titanium screen were carefully selected based on calculations of

microwave power input to the plasma chamber, taking into account the actual dimensions of the resonance cavity (Fig. 2).

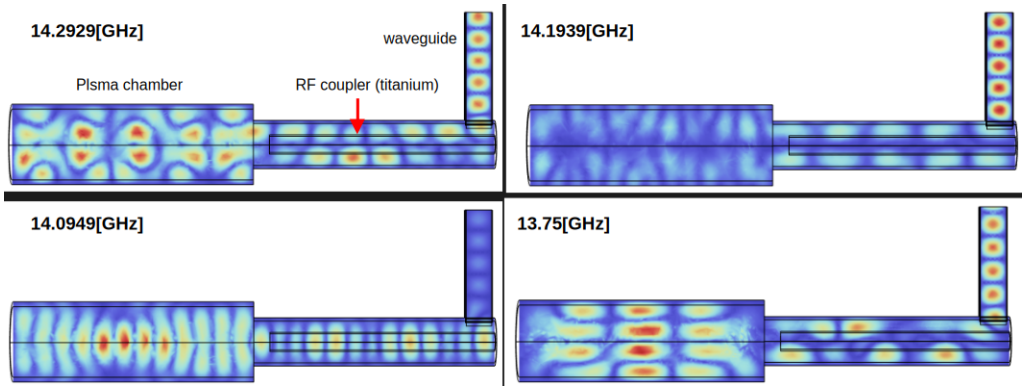


Figure 2: Simplified calculations of the electromagnetic field distribution of microwaves entering the plasma chamber for different frequencies and a constant continuous power of 100 W. The calculations take into account the external magnetic field of the trap and the actual dimensions and type of material: copper for the chamber and waveguide, and titanium for the microwave coupler.

Optimization of the Furnace and Gas Injection Systems

The implementation of replaceable oven heads containing pre-prepared material in a corundum crucible, together with modifications to the furnace system adapted for vacuum feedthrough, is currently underway. These improvements will enable continuous source operation without the need for interruptions due to source conditioning. For ion beams generated from gaseous materials, the design of an additional gas injection system has not only increased beam intensity but also reduced gas consumption by a factor of 10. This is particularly important when working with expensive isotopes. The modification involved direct gas injection into the plasma chamber, bypassing the main gas line, which, although effective for gas buffering, has a large volume. The direct gas dosing system has proven highly effective in the production of the ^{22}Ne beam (Fig. 3). The gas is injected directly into the chamber through the center of the microwave coupler, which is a concentric extension of the waveguide.

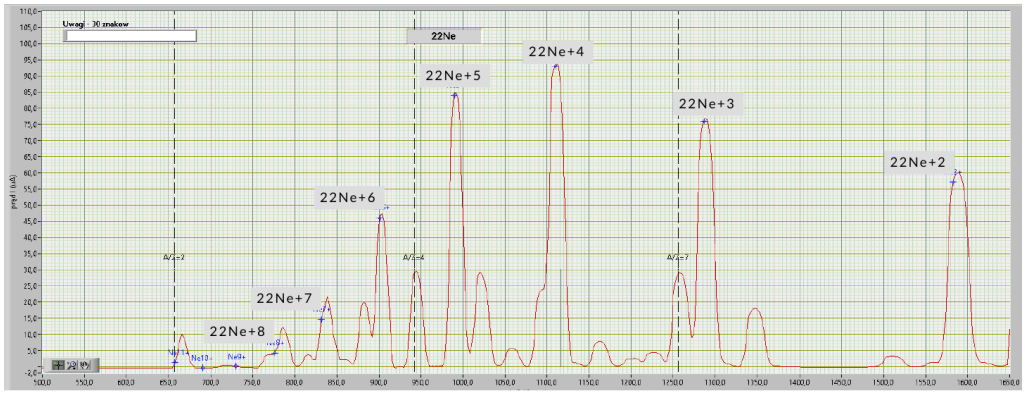


Figure 3: Example spectrum for ^{22}Ne produced from gas enriched with this isotope - 99.9%. Average gas consumption during direct injection was 0.05 - 0.06 cm^3/min. The spectrum was collected at a microwave power of 150 W.

Future Plans and Developments

Future research will focus on investigating the impact of the corundum crucible on the stability and efficiency of the generated calcium ion beam. The goal is to establish optimal conditions for

material sublimation, with upcoming studies exploring different forms of calcium pellets—recent tests indicate that sample density significantly affects this process.

Oven System Improvements (for Metallic Ion Beams such as Ni)
Planned enhancements to the oven system include:

- Reducing the oven head casing size to develop a more compact and efficient design, improving thermal and mechanical performance.
- Implementing interchangeable oven heads and a vacuum feedthrough, which will eliminate the need to vent the ion source when replacing the oven head or crucible.

Additionally, modifications to the ion beam extraction system from the plasma chamber are planned, particularly in the plasma lens – puller set. Initial calculations and mechanical components are currently in preparation.

A.3 New LabVIEW Program to remotely control the EA-PS8040 Power Supply and changes in the XTRD-400K Amplifier control interface

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The malfunctioning current supply for the magnrtic lens in the ion injection line, which delivers ion beams to the U-200P cyclotron, was replaced with the EA-PS8040 510 power supply produced by Elektro-Automatic. Most of the devices, including the faulty power supply, in the injection line are remotely controlled using the LabVIEW program called WHIL Control. In order to continue using WHIL Control to regulate all the ion source subsystems, a new module to manage the EA-PS8040 had to be developed. Electro-Automatic provides basic LabVIEW drivers for their EA-PS8040 510, therefore these drivers were used and incorporated into WHIL Control system so the user experiences virtually no difference in using the new device compared to the exchanged one. The new current supply responds to commands sent over RS-232 interface, so the already existing connection was used. With the drivers ready and tested, the new interface was incorporated into the WHIL Control system (see Fig. 1).

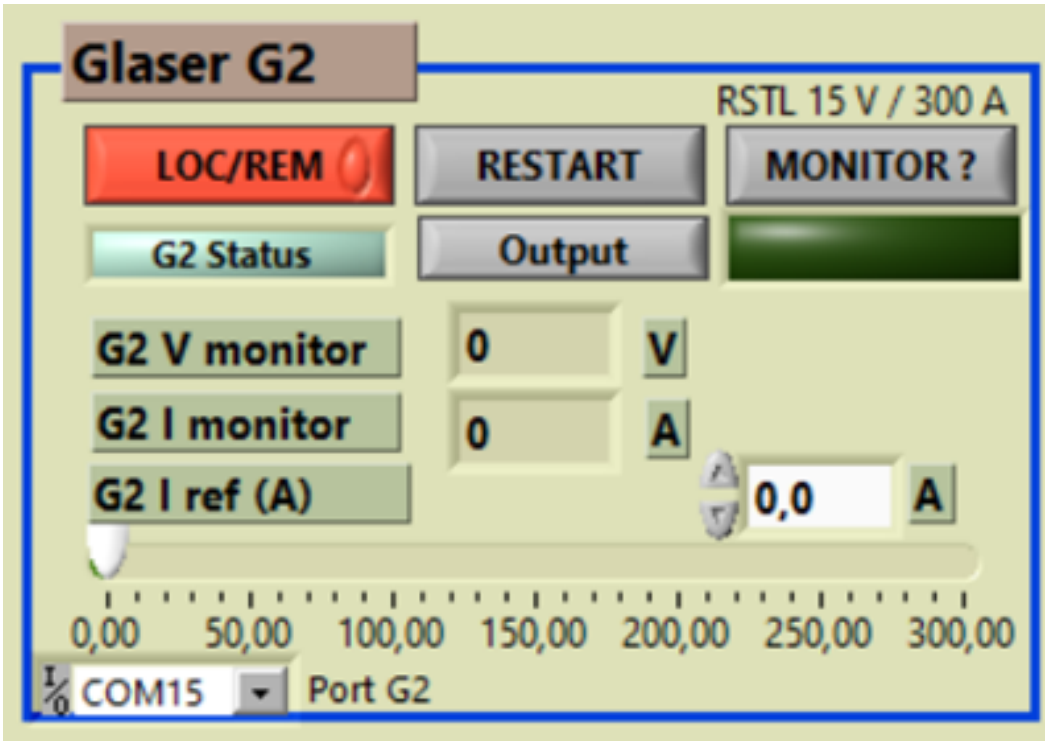

Figure 1: EA-PS8040 510 power supply control panel in WHIL Control ("Glaser G2" section).

The interface passed the tests sukcesfully and has been in use since the end of 2024.

A.4 Status of the EAGLE array

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The central European Array for Gamma Levels Evaluations (EAGLE) is an array of High Purity Germanium (HPGe) detectors located at HIL [1], see also [2]. Up to 30 HPGe detectors with anti-compton shields can be installed in the EAGLE frame, and the setup can be augmented with various ancillary devices. The Heavy Ion Laboratory operates a number of HPGe detectors on loan from the GAMMAPOOL [3]. At present, 15 complete sets of a HPGe detector and its anti-compton shield are allocated by GAMMAPOOL to HIL. The laboratory also owns 19 smaller detectors with anti-compton shields, which may also be installed in the frame of EAGLE.

The year 2024, like 2023, was a period of high experimental activity with the EAGLE array. Six in-beam measurements were performed. Details are given in Chapter D.1 and in separate contributions to this Annual Report. EAGLE was used in a configuration with the NEDA and DIAMANT detectors (3 experiments [4–6]) and in combination with the plunger (2 experiments [7, 8]). The sixth measurement was of a commissioning character, and was run to check the interaction of the EAGLE system with the new SilCa scattered beam detector, constructed for studies employing Coulomb excitation methods [9]. Up to 13 HPGe detectors on loan from GAMMAPOOL and up to 6 detectors belonging to HIL were employed in the experiments. In total, EAGLE saw beam on target for about 55 days. Five of the measurements were completed as planned by the proposers, the sixth had to be aborted due to a cyclotron failure [8].

Extensive work was also carried out to maintain and repair the HPGe detectors, to improve the detector cooling system, and to optimise the electronics [10]. Preparations for experiments where fast stintillators will be installed in the EAGLE frame to measure sub-nanosecond lifetimes were also pursued [11].

The EAGLE experiments were partly supported by the National Science Centre, Poland (NCN) (grant No. 2020/39/D/ST2/00466).

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[10] M. Komorowska *et al.*, this Report, page 23
[11] A. Špaček *et al.*, this Report, page 24

A.5 HPGe Detector Laboratory

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In 2024, the main focus of the Detector Laboratory activities was the maintenance and operational support of the HPGe detectors used in EAGLE experiments. As in previous years, the core effort was devoted to maintaning the large volume 60% efficiency detectors leased from GAMMAPOOL. Tests and repairs of the smaller-volume detectors (owned by HIL) were also progressively undertaken. In total, neutron damage and vacuum-related repairs were successfully carried out on 23 detectors during the year. In addition, field-effect transistors (FETs) were replaced in two detectors, and numerous preamplifiers were repaired or adjusted.

During the NEEDI (EAGLE-NEDA-DIAMANT) experimental campaign, which started in late 2023 and continued until mid-2024, the setup consisted of 13 GAMMAPOOL detectors and two smaller-volume detectors. In the second half of 2024 several NEDA detectors were replaced by additional HPGe detectors. The final experiment in 2024 used 12 GAMMAPOOL detectors and six smaller detectors.

In addition to the maintenance of the detectors, considerable efforts were made to improve the infrastructure of the Detector Laboratory. A clean-box glove chamber was designed to allow the safe opening of detector cryostats, critical for maintenance tasks such as FET replacement. The assembly and deployment of this chamber are planned for 2025.

Challenges associated with the use of multiple preamplifier types within the EAGLE array have also been addressed. Currently, the array uses detectors equipped with different preamplifier models, including ORTEC 132 CN-2, 137 CN-2, and 257N, as well as MIRION PSC821, PSC822, and PSC823. To optimize detector performance and simplify system integration, the development of a new, unified preamplifier specifically tailored for the EAGLE digital pulse-processing acquisition system has been initiated, with assembly and initial testing planned for 2025.

Improvements were made to the liquid nitrogen cooling auto-fill monitoring system. Previously, notifications were limited to SMS alerts triggered by excessively long filling durations. The current monitoring system now sends comprehensive email reports, including detailed filling duration data and highlighting errors or anomalies. The cooling status was also integrated into the EAGLE GRAFANA monitoring system.

In addition to the key activities related to EAGLE, tests and repairs were undertaken in the Detector Laboratory on three dipstick detectors from the low-background laboratory: ORTEC GEM, ORTEC LOAX, and a Canberra BE2825 detector. Additionally, an ORTEC Pop-Top detector belonging to the Nuclear Physics Department of the Faculty of Physics was repaired. As part of these maintenance efforts, degraded rubber nitrogen-filling collars were replaced with new Teflon components, significantly improving the reliability of the cooling system.

A.6 Expanding the EAGLE Array at HIL: The FLASH Campaign for Fast-Timing Spectroscopy

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The measurement of electromagnetic transition strengths is of paramount importance for nuclear spectroscopy. At HIL, there is a long and successful tradition of obtaining such observables from Coulomb excitation or lifetime measurements. The latter experiments mainly applied Doppler techniques, e.g. DSAM or RDDS, which are sensitive to lifetimes from a few 100 fs up to a few 10 ps. For longer lifetimes up to a few ns, the fast-timing technique using fast scintillators has been developed and successfully employed in several places in the last 20 years. The population of excited states by charged-particle induced reactions is complementary to the prompt spectroscopy of fission fragments where the range of isotopes accessible is determined by the fission process. On the other hand, delayed decay spectroscopy is only feasible for states which are populated in the preceeding radioactive decay.

For fast timing, coincident detection of two γ-rays by fast scintillation detectors is required. In order to enhance the selectivity, coupling to additional devices like HPGe and charged particle detectors is required in most cases. Thus, 15 of the 30 positions in the EAGLE (central European Array for Gamma Levels Evaluations) frame [4] will be occupied by HPGe detectors while the remaining positions will be equipped with $LaBr_3$(Ce) detectors with PMT read-out. Compared to the EAGLE-EYE campaign [2], where three $LaBr_3$ detectors were installed in one position in the EAGLE array, particular care will be taken to avoid scattering between the $LaBr_3$(Ce) detectors by the use of the active anti-Compton shields (ACS) originally provided for the HPGe detectors. Additional selectivity and sensitivity can be provided by charged particle detectors available at HIL: the SILCA [3] double-sided silicon strip detector and the DIAMANT [4] array.

As part of the preparations for the FLASH campaign (Fast-Timing $LaBr_3$(Ce) Array for Spectroscopy at HIL), a holder for the $LaBr_3$(Ce) detectors in an ACS was designed and tested.

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A.7 A standalone station with automatic loading, dedicated to the PETtrace cyclotron

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In 2024, a total of 15 target exposures were performed, including four exposures related to the production of $^{44/44m}$Sc in accordance with the task plan for the reported year. Our tasks were: $^{44/44m}$Sc - production and delivery of high activities ($>$ 1GBq) of the Sc radionuclides to INCT and the Jagiellonian University for medical experiments, ^{72}As - Conceptual elaboration of the production method of this radionuclide. This task is part of a joint research project entitled "Development of three-photon emitting radiotracers for positronium imaging". The project was launched on 2022-07-21, under the OPUS-2022 edition, contract No. UMO2021/43/B/ST2/02150, where the Jagiellonian University, Faculty of Physics, Astronomy and Applied Computer Science is the leading unit.

The irradiations were performed using a target holder that enables irradiation by a perpendicular incident beam on the target material. Upon a decision taken by the project team, it was agreed that a holder allowing tilted placement of the target material in relation to the beam, Fig. 1, would not be used in 2024.

Figure 1: View of the inclined target holder with pressure and turning rings.

Nevertheless, a methodology for manufacturing a calcium target (calcium carbonate) corresponding to the changed target exposure geometry has been developed and mechanically tested in a new holder, but without exposing the target itself.

The change of the target holder design resulted in a modification of the target production method. An elliptical calcium carbonate target with a surface corresponding to the size of the incident ion beam spot at an angle of 45° in relation to the target surface is mechanically unstable (Fig. 2 middle). The formation of the calcium carbonate pellet requires reinforcement to ensure proper mechanical stability. This was achieved by adding small amounts of graphite. The generated target thickness corresponds to the range of protons with an energy of 16 MeV. The tests carried out have proven that the addition of 2.5 – 5% graphite (by weight), a material that is chemically inert and does not interfere with the target treatment after exposure, ensures full mechanical durability of the target.

The production of ^{44}Sc needed for testing the J-PET scanner was envisaged in the project based on two routes: in a nuclear reaction of ^{44}Ca with protons (based on a target made of calcium carbonate) and via the production of a ^{44}Ti/^{44}Sc generator created in a nuclear reaction of ^{45}Sc with protons. The methodology for manufacturing targets using the second method has also been developed. Considering the chemical properties of scandium, the preliminary work and the

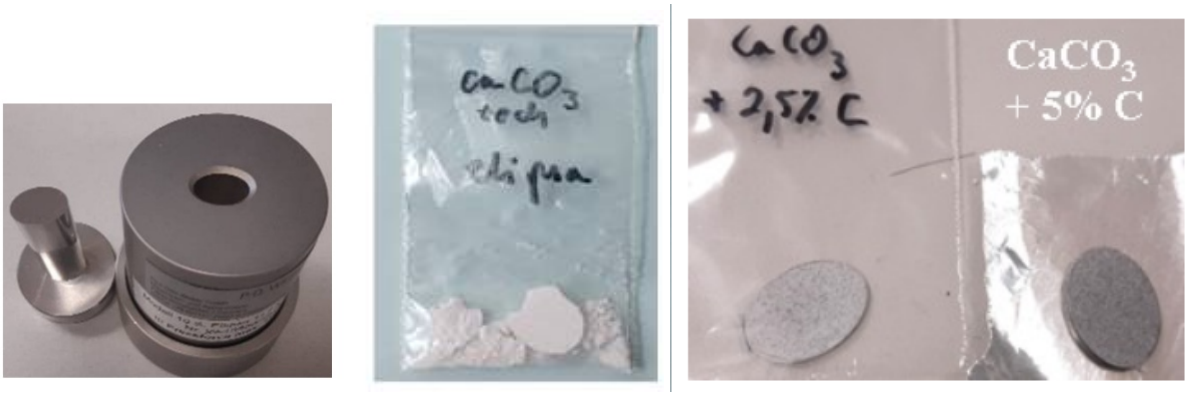

Figure 2: Calcium carbonate targets with added graphite (right) prepared in an ellipsoidal matrix (left). Unstable mechanically ellipsoidal pellet made of carbonate itself (middle).

assembly of the target to the target holder are carried out in a glove box in an argon atmosphere. The target is also prepared by the disc pellet forming method. For this purpose, ^{nat}Sc was cut into 1-2 mm pieces and then pressed in a matrix of ⌀10 mm (Fig. 3).

Figure 3: 10 mm diameter ^{nat}Sc target

To produce ^{55}Co, a ^{nat}Fe target was used, prepared by forming a pellet from mini Fe grains using a hydraulic press. The target for the production of ^{89}Zr was prepared from commercially available yttrium sheet. The suitability of both target holders, i.e. perpendicular and tilted, was analyzed for future production of ^{72}As. It was found that both versions were suitable for use and there was no need to design another version of the target holder.

A.8 Response of 21 μm silicon self-biased detectors to high doses of ^{14}N ions

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The radiation damage of 21 μm thick self-biased epitaxial ΔE detectors was tested as a function of fluence of 90 MeV ^{14}N ions. The production technology and measurement techniques of the ΔE detectors have been described. A new technique for soldering contacts to thin detector was developed. In the present work the 21 μm thick self-biased detectors marked as d4 and d5 show proper operation with a fluence of about $4{\cdot}10^{15}$ ions/cm^2 and a fluence of about $8{\cdot}10^{15}$ ions/cm^2, respectively. The charge collection efficiency of the thin ΔE d5 detector was increased by about double at a fluence of about $8{\cdot}10^{15}$ ions/cm^2. The charge collection efficiency of the thin ΔE detector d4 was increased by about 35% at a fluence of about $4{\cdot}10^{15}$ ions/cm^2 followed by a decrease of about 70% in the detector counting rate registration from a fluence of $9.1{\cdot}10^{15}$ ions/cm^2 to a fluence of about $5{\cdot}10^{16}$ ions/cm^2, due to partial removal of the evaporated Al contact from the detector surface as an effect of heavy ion irradiation.

The thin detector was constructed using a silicon epitaxial n^+ - n structure of resistivity epitaxial layer about 300 $\Omega{\cdot}$cm and thickness about 21 μm obtained by anodic dissolution of 400 μm thick substrate using a 5% HF (Hydrofluoric Acid) jet [1]. The detector n^+ - n - p^+ junctions were obtained using B^+ implantation through an Al mask into the epitaxial n type side using the low-temperature technique [2].

We have developed a new technique of ultrasonic soldering of 45 μm Cu wire contacts with 20 kHz frequency and pressure of the heated soldering tool with 2 grams to the 21 μm thick detector Al surface. The 20 kHz friction of the soldering tool on the detector surface partially removes Al oxide and gives the possibility to create good, stable soldered detector contacts.

After mounting the detector in its housing (see Fig. 3) the self-biased thin detectors operating with internal built-in-field potential (without any external bias potential), were ready to work with α particles and heavy ions.

Previously carried out tests with a 23 μm thick self-biased detector were performed with Rutheford scattering of 90 MeV ^{14}N ions on a Au target. They showed proper working of the detector with maximal available fluence of about $7.1{\cdot}10^{11}$ ions/cm^2 [3]. To increase the available fluence of 90 MeV ^{14}N ions on the thin detector we irradiated it with the beam, directly in the Faraday Cup.

The fluence of ^{14}N ions was deduced from the measured beam charge from the Faraday Cup. Before and after irradiation with ^{14}N ions of the thin 21 μm self-biased ΔE detectors, measurements with a E - ΔE telescope of 5.487 MeV α particles from a ^{241}Am source were performed. Results are presented in Figs. 1, 2 and 3. Fig. 1 and Fig. 2 present the response of the single ΔE detectors d4 and d5, respectively, for α particles before and after irradiation with a ^{14}N ion beam. Fig. 3 presents a photo of detector d4 (21 μm thick) after irradiation by ^{14}N ions with a fluence of $4.8{\cdot}10^{16}$ ions/cm^2. Detector irradiations were performed at the Exposure Station on Tract A at the Heavy Ion Laboratory of Warsaw University.

The performed spectral measurements (Fig. 1, Fig. 2) show the proper operation of the E – ΔE telescope, which enables their use in nuclear physics to identify light charged particles and heavy ions. However, the increased pulse-height of the thin self-biased ΔE detector heavy ion fluence should be taken into account. The fluence limit for a thick silicon detector, which is about 10^{14} ions/cm^2 [4–6], is much less than the values obtained in this work for self-biased 21 μm thick silicon detectors. The results obtained show an increase in the amplitudes of the thin epitaxial,

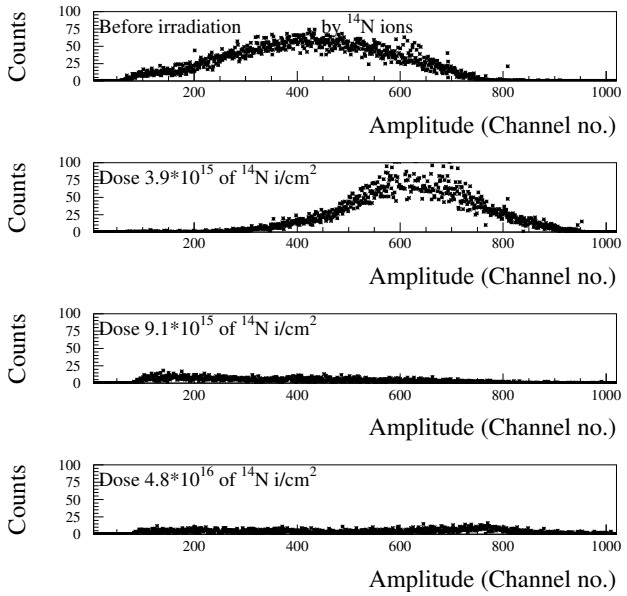

Figure 1: Energy loss of 5.487 MeV α particles from a ^{241}Am source in the d4 21 μm thick self-biased ΔE detector as a function of ^{14}N fluence. Detector d4 worked properly up to a fluence of $3.9{\cdot}10^{15}$ ions/cm^2. An increase in charge collection efficiency of about 35% at a fluence of $3.9{\cdot}10^{15}$ ions/cm^2 is evident. For greater fluences from $9.1{\cdot}10^{15}$ ions/cm^2 to $4.8{\cdot}10^{16}$ ions/cm^2 counting rate registration is decreased to about 70% by partial removal of evaporated Al contacts from the detector surface due to exposure to ^{14}N ions.

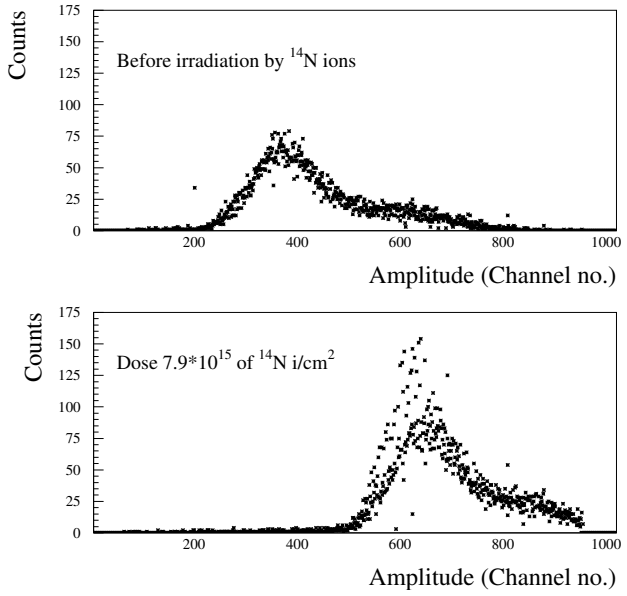

Figure 2: Energy loss of 5.487 MeV α particles from a ^{241}Am source in the d5 21 μm thick self-biased ΔE detector (upper part of figure). The detector worked properly up to a fluence of $7.9{\cdot}10^{15}$ ions/cm^2 of ^{14}N, the charge collection efficiency almost doubling for this fluence (lower part of figure).

self-biased detector signals produced by the low-temperature technique [2] which generate a shift to greater energies of the measured spectra after irradiation of the thin detectors by heavy ions. Probably ion irradiation of the thin epitaxial detector produces additional activation (similar to the baking process) of boron ions implanted in the epitaxial layer and increases the building potential difference followed by an increase of the detector charge collection efficiency.

Figure 3: Photograph showing the internal part of the 21 μm thick self-biased detector d4 after a fluence of $4.81{\cdot}10^{16}$ ions/cm^2. Note the circular spot produced by the beam of ^{14}N ions on the silicon detector surface. This spot is caused by partial removal of the Al contact from the detector surface by the ^{14}N ion beam which decreases the detector counting rate by about 70%. Close to the beam spot is seen the tin contact to the detector produced by ultrasonic soldering of 45 μm Cu wire connecting the detector to the lower part of the detector housing (the upper part of detector housing was removed for this photograph).

For the future we plan to measure spectra which have not been irradiated by heavy ions 21 μm thick detectors produced by the low-temperature technique [2] as a function of time for baking in air in an owen at 120 $^{\circ}$C for a few months. We hope to observe an increase of detector charge collection efficiency, which would confirm our expectation that thin detector irradiation by heavy ions acts in a similar way to the baking process for thin detectors produced by the low-temperature technique [2]. The results presented in this report have been published in Ref [7].

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A.9 BTS24 Basic Training School on Accelerators 2024

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The International Basic Training School on Accelerators (BTS24) was held between June 18 – 27, 2024 in Warsaw, Poland. The school was jointly organized by the Heavy Ion Laboratory, University of Warsaw (HIL) and the Institute of Nuclear Chemistry and Technology (INCT). The participants of the school included 18 students and early stage scientists selected from 39 applications. The participants were representative of 14 countries: Argentina, Botswana, Bulgaria, Costa Rica, El Salvador, France, Mexico, Poland, Portugal, Romania, Sweden, Slovenia, Spain, and Ukraine.

Figure 1: The Students of the BTS24 school in Warsaw, June 18-27, 2024 (photo. R. Klęk).

Young physicists had the opportunity to expand their knowledge following the lectures given by local and international experts and interacting with them. The subjects covered included the detection of ionizing radiation, introduction to gamma spectroscopy, basics of target preparation,

fundamentals of nuclear reactions, production of radioisotopes for medical applications, and acceleration of heavy ions. The hands-on activities were performed using a ^{20}Ne beam at an energy of 77 MeV, delivered by the Warsaw Cyclotron, and electron beams of energy < 2 MeV and 10 MeV, available at INCT. Participants carried out independent experiments in small groups, using the unique research equipment available at the HIL Warsaw, and presented their results during the final session of the school. The students were exposed to the following experimental topics:

- Gamma Spectroscopy
- Fast-timing measurement
- Target production and thickness measurements
- Study of the effects of ionizing radiation on biological material
- Gas/Si telescopes in charge particle spectroscopy,
- Neutron measurements

Practical exercises were organized at INCT for two days, providing the students with insights into industrial applications of electron beam accelerators and dosimetry methods. The exercises were carried out using two accelerators: 1) the Elektronika 10-10 accelerator generating electron beams with energy up to 10 MeV, installed at the INCT Sterilization Facility, used for both research and commercial scale irradiation; 2) the ILU-6 accelerator. The exercises included measurements with electron beams of energies of 1.3 and 1.7 MeV. In addition to the academic activities there was also time for fun and games: a rope park, air gun shooting, a barbecue and a bonfire, where international hits were sung to the accompaniment of the guitar.

Figure 2: Social event at "Rancho pod Bocianem".

A.10 Polish Workshop on the Acceleration and Applications of Heavy Ions

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The 18^{th} edition of the National Workshop on the Acceleration and Applications of Heavy Ions is now behind us.

This year, thanks to the involvement of young employees, we were able to increase the number of experimental tasks so that, we could host as many as 19 people from seven scientific institutions: the University of Warsaw, Warsaw University of Technology, the University of Gdańsk, Gdańsk University of Technology, the Jagiellonian University, AGH University of Science and Technology and Poznań University of Technology. The young researchers showed great interest and commitment in the work they were doing. Before starting practical classes, the young nuclear physics students were able to expand their knowledge by attending lectures. In 2024 the programme of the lectures was the following:

- HIL in a nutshell (P. Napiorkowski);
- Detection of gamma radiation, charged particles and neutrons (M. Palacz);
- In-beam gamma spectroscopy (K. Hadyńska-Klęk);
- Introduction to heavy ion acceleration and elements of ion optics (O. Nassar);
- Nuclear reactions (K. Rusek).
- Radiopharmaceuticals for Positron Emission Tomography (K. Kilian);
- Radiobiological studies at the Heavy Ion Laboratory (U. Kaźmierczak)

Thanks to the experimental tasks, the young nuclear physicists got to know the HIL infrastructure by performing measurements using dedicated equipment available in the Laboratory. The workshop ended with student presentations - each group prepared a 20-minute presentation on their measurements and results.

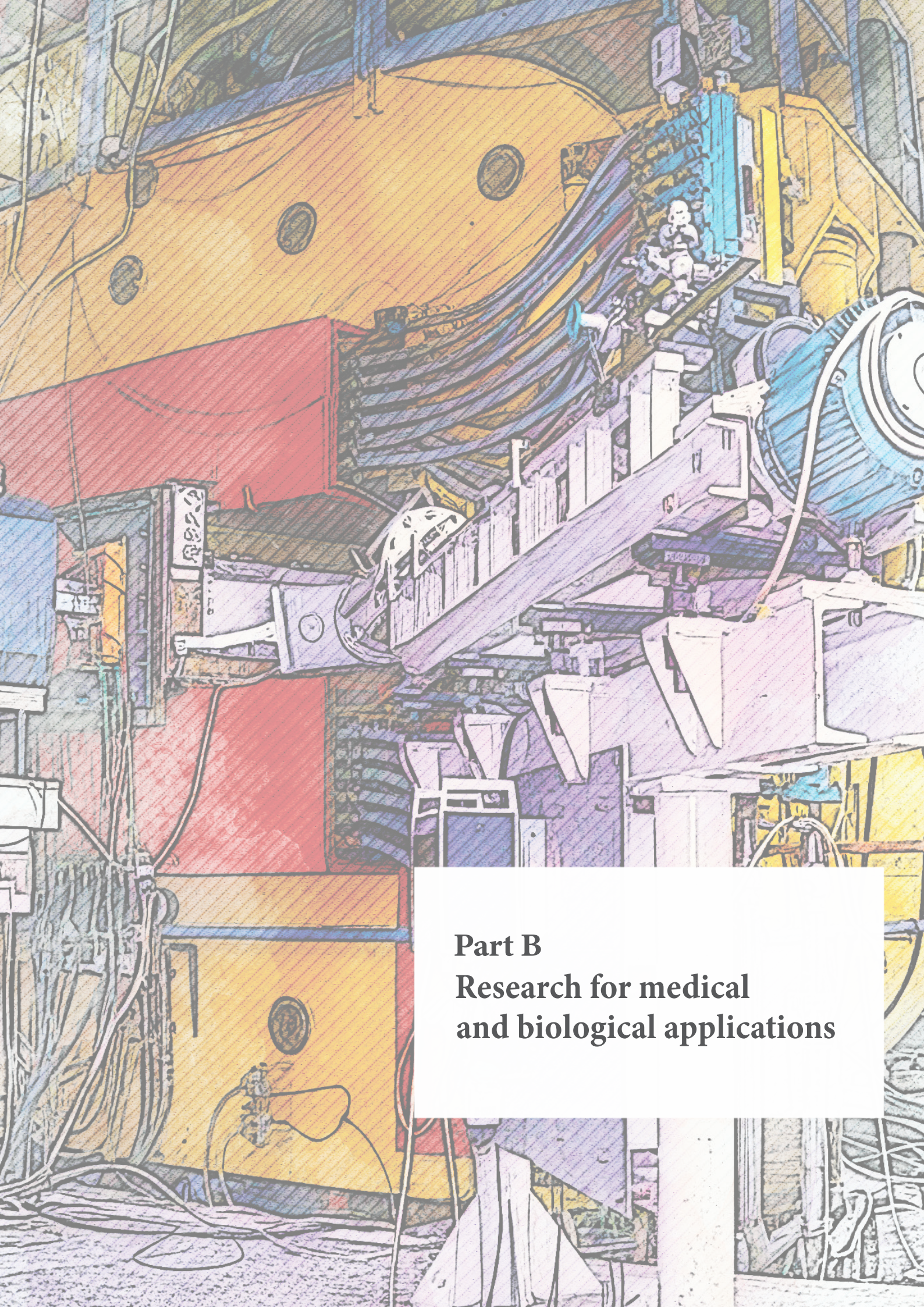
This workshop was organized for third and fourth year physics students interested in nuclear physics. Its main goal is to provide a unique opportunity to gain experience in data collection and analysis methods, cyclotron operation, including beam diagnostics measurements and charged particle and gamma radiation detection techniques.

This year the students participated in the following experimental projects:

- Rutherford scattering
- Gamma spectroscopy with the EAGLE multidetector setup;
- Targets: thickness measurements;
- Measurement of ^{137}Cs activity in environmental samples;

- Measurement of lifetimes of atomic nuclei using fast scintillators
- Study of the biological response of cells to alpha radiation.

Figure 1: Participants of the 18^{th} Polish Workshop on the Acceleration and Applications of Heavy Ions (photo. R. Klęk).



Part B
Research for medical and biological applications

B.1 An attempt to determine the correlation between the synthesis conditions and the properties of selenium nanoparticles (SeNPs)

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Selenium nanoparticles are intensively studied due to their unique properties. They show great potential in therapeutic and medical applications. It seems that among the many production methods described in the literature, the greatest attention is focused on the so-called green methods. Their main advantage is in using natural, non-toxic reagents and moderate temperatures. In the described studies, herbal extracts were used as selenium salt reducers. The extracts used are a rich source of polyphenolic compounds, which simultaneously reduce selenium compounds to the form of nanoparticles but also stabilize the obtained nanoparticles by preventing their aggregation. However, it should be remembered that control over the chemical composition of the extract used is minimal. For this reason, simply controlling the conditions of synthesis is only possible to a certain extent. This study tries to answer the key question of how the green synthesis of SeNPs affects their physical properties such as size and homogeneity and, therefore, their antibacterial and antioxidant properties. The following herbal extracts were used in the studies: yarrow (Achillea L.), blackberry (Rubus L.), sage (Salvia officinalis L.), nettle (Urtica L.), hop (Humulus L.), lemon balm (Melissa officinalis L.), Ribwort plantatin (Plantago lanceolata L.) and raspberry (Rubus idaeus L.). The syntheses were carried out with different ratios of reagents at elevated temperatures. The obtained SeNPs were measured for their size and homogeneity, as well as their ability to neutralize DPPH and OH radicals, their reducing properties using the CUPRAC method, and the antioxidant properties of their suspension were determined based on the Folin-Ciocalteu method. Furthermore, the antibacterial properties of the obtained SeNPs were tested by determining the minimum inhibitor concentration (MIC) against two model bacterial species: *Escherichia coli* (Gram-negative bacterium) and *Staphylococcus aureus* (Gram-positive bacterium).

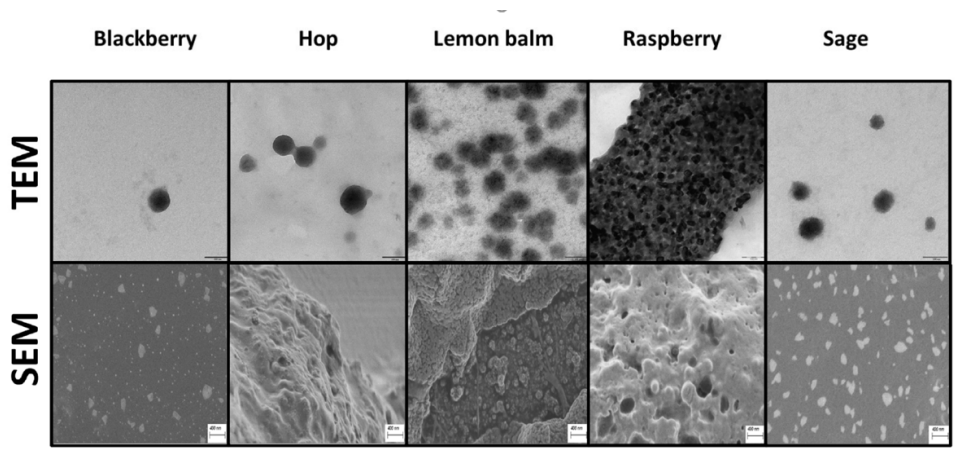

Figure 1: SEM and TEM images of selenium nanoparticles.

The main conclusions that can be drawn from this research are that the synthesis conditions have a clear influence on the size and homogeneity of the obtained nanoparticles. When the concentration of the extract used to reduce selenium salts is increased, nanoparticles of larger

dimensions are obtained. At the same time, with the increase in their size, their homogeneity increases. The correlation coefficient between nanoparticle size and reactant ratio is high and equal to 0.937 for syntheses carried out without heating and 0.914 for those carried out with sample incubation at 70°C. The smallest nanoparticles were obtained from the synthesis carried out for a 1:1 reagent ratio, regardless of the type of extract used. These nanoparticles were characterized by the greatest homogeneity and, most importantly, the highest ability to neutralize hydroxyl radicals. SEM and TEM images of these nanoparticles are shown in Fig. 1.

B.2 Optimization of synthesis of Pd-porphyrin complexes for radiopharmaceutical applications

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Bifunctional ligands are of great interest in diagnostic and therapeutical nuclear medicine. On the one hand they are able efficiently to coordinate proper radioactive nuclides and on the other hand they can effectively transport them to target tissue or include them in the desired metabolic pathway. Porphyrins are agents that can be used for both diagnostic positron emission tomography (PET) and radiotherapy [1]. Porphyrin complexes are naturally occurring molecules in the human organism (with iron as heme, or with cobalt as cobalamin). The palladium radioisotope ^{103}Pd ($T_{1/2}$ = 16.99 days) is a promising agent for radiotherapy. It is already used in the clinical procedure of brachytherapy as metal seeds. In recent years ^{103}Pd has been proposed as an agent for targeted Auger electron radiotherapy [2]. It emits Auger electron while decaying to ^{103m}Rh ($T_{1/2}$ = 56.1 min), which is another Auger electron emitter decaying to stable ^{103}Rh. ^{103}Pd can thus serve as an in vivo generator of these radionuclides. Synthesis with a cyclotron is possible via the ^{103}Rh(p,n)^{103}Pd reaction. Another radionuclide of palladium that is potentially interesting for radiopharmaceutical applications is ^{109}Pd ($T_{1/2}$ = 13.70 h), which decays via β^- to ^{109m}Ag ($T_{1/2}$ = 39.6 s) which in turn emits a cascade of conversion and Auger electrons, which makes ^{109}Pd an in vivo generator of ^{109m}Ag [3]. In this study the complexation of palladium(II) with porphyrin was investigated. The hydrophilic anionic porphyrin meso-tetrakis(4-sulfonatophenyl)porphyrin (TSPP) served as ligand for the reaction. A previous study showed that the optimal buffer for the reaction was acetate at pH 4, but the reaction time was over 4 hours [4]. The structure of the investigated porphyrin and the corresponding UV-VIS spectra are presented in Fig. 1.

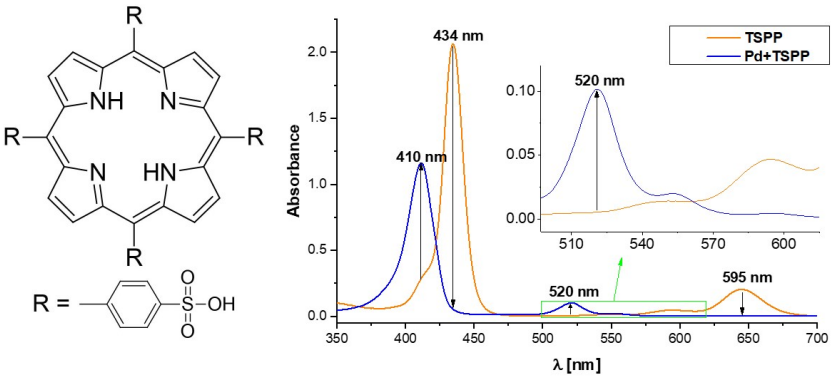

Figure 1: Structure of TSPP and changes in UV-VIS spectra after formation of palladium complex of TSPP

The natural method to increase the reaction rate is the use of sitting-a-top complex with large metal ions, which was successfully used for copper(II) complex synthesis [5]. However, the only pH value in which the Pd-complex was formed was pH 4. At this pH value the porphyrin complexes of large ions (Cd^{2+}, Pb^{2+}, Hg^{2+}) could not be synthesized and thus it was not possible to apply this method. The porphyrin ring is known for its resistance to harsh conditions, such as high temperatures. To increase the reaction rate microwave-assisted synthesis was applied. Microwave heating provides better energy transfer than conventional heating which prevents samples from

overheating near reaction vessel walls. It also allows for precise control of reaction parameters. The method consists of three steps: heating the sample to a specified temperature, the reaction itself and cooling to ambient temperature. An issue that has to be taken into consideration is that, depending on the reaction environment, the time needed to reach the specified temperature and cool the sample after the reaction is different, so the high temperature affects the sample for a longer period of time. In this study different temperatures were tested, and 120°C was selected as a compromise between reaction rate and heating and cooling time. The reaction was conducted in an acetate buffer at pH 4. Palladium standard was added to $5{\cdot}10^{-6}$ mol/L TSPP solution and the mixture was heated in a 10 mL glass reaction vessel in a Discover SP microwave synthesizer. The solution was heated to 120°C using 300W of microwave power for a specified time and was then cooled to ambient temperature before spectrophotometric measurement. The spectra confirm the formation of the complex, as characteristic changes occur. The Soret band at 434 nm, which is characteristic for free porphyrin, disappears and a shifted signal at 410 nm with a new peak at 520 nm in the Q-band is formed. The results are presented in Fig. 2.

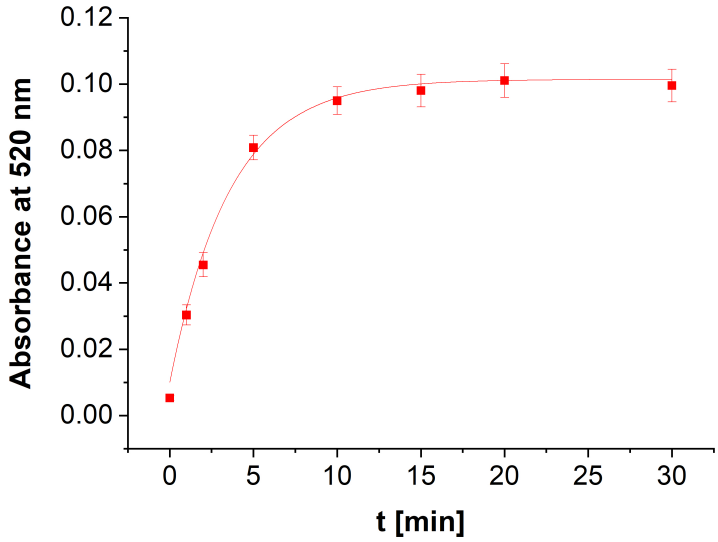

Figure 2: Rate of Pd-TSPP complex formation

As Fig. 2 shows, with the increase of reaction time more complex is formed. After 20 min of microwave heating the absorbance at 520 nm reaches its maximum and the UV-VIS spectrum shows no signs of free porphyrin. Microwave heating of free porphyrin without the addition of palladium at 120°C for longer periods of time (up to 6 hours) did not show any signs of porphyrin instability. The use of microwave synthesis caused a dramatic increase in the reaction rate, which makes the reaction kinetics much more favorable for radiopharmaceutical applications. The complexes of porphyrins with Pd(II) showed even more potential as an Auger electron therapeutic radiopharmaceutical, but further investigation is needed.

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B.3 Synthesis of ^{18}F-fluoroethyltyrosine ([^{18}F]FET) on the Synthra RN synthesizer

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^{18}F-fluoroethyltyrosine is used for the diagnostic and prognostic assessment of brain tumors, non-invasive tumor characterization, delineation of the tumor area for treatment planning, and monitoring of disease progression and treatment. It complements the conventional MRI method. The objective of this study was to perform the synthesis of the radiopharmaceutical ^{18}F-fluoroethyltyrosine (FET) using the automatic synthesizer Synthra RN, identify and confirm the identity of the obtained product, and determine its radiochemical, enantiomeric, and chemical purity.

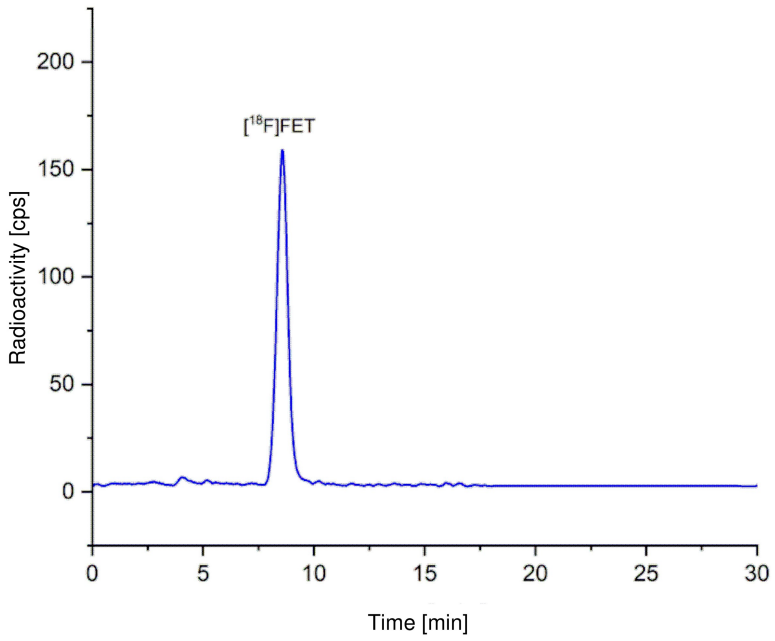

Figure 1: Chromatogram of [^{18}F]FET. Purification: C18 - RP column (Phenomenex C18 Nucleosil 250 mm × 10 mm × 7 μm); radiometric detector; flow: 4ml/min, loop volume: 5000 μl, mobile phase: H_2O:ethanol 90:10 v/v.

Synthesis of [^{18}F]FET

The fluorine-18 isotope (^{18}F) was produced in the GE PETrace 840 medical cyclotron, located at the Radioisotope Production and Research Center at the Heavy Ion Laboratory. The ^{18}O(p, n)^{18}F reaction with a proton beam at an energy of 16.5 MeV and an intensity of 40 - 45 μA for 120 minutes was employed. As a result of the reaction, activities in the range of 140.6 - 155.4 GBq were obtained. For the syntheses performed in this work, residual activity

(approximately 1-2 GBq) obtained by flushing the target after the commercial production of the [^{18}F]FDG radiopharmaceutical was used. The synthesis of ^{18}F-fluoroethyltyrosine ([^{18}F]FET) was carried out using the tert-butyl ester of O-tosyloxyethyl-N-trityltyrosine (TET) as the precursor. The reaction consisted of two steps: radioactive labeling of the precursor and hydrolysis of the intermediate product. The radioactive labeling of [^{18}F]FET involved the classical nucleophilic substitution of [^{18}F]fluoride carried out in acetonitrile with potassium carbonate and Kryptofix 2.2.2. The hydrolysis process was performed by adding a mixture of ethanol and hydrochloric acid. High-performance liquid chromatography (HPLC) was used for purification and quality control.

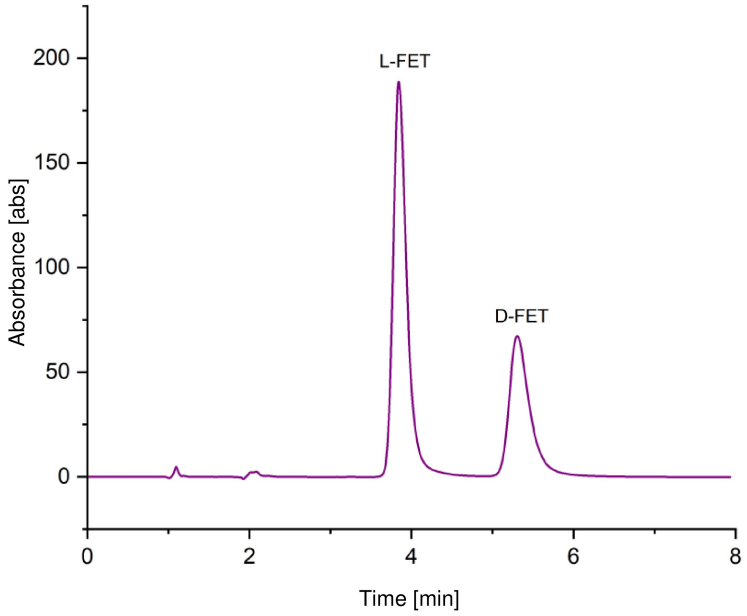

Figure 2: Chromatogram of L- and D-FET certified reference standards. Separation: Supelco Astec CHIROBIOTIC – T, 150 mm × 4,6 mm × 5 μm, detection: UV-VIS: 250 nm, flow: 1 ml/min, injection: 5 μl, mobile phase: MeOH:H_2O 80:20 v/v.

Quality control of [^{18}F]FET

Quality control of the synthesized product included confirmation of the product identity, determination of chemical, radiochemical, and enantiomeric purity. The identification of the product – L-[18F]FET – was performed using two different HPLC methods. The first method involved the use of a C18 column with the following separation parameters: column: Agilent, Eclipse XDB - C18, 150 mm × 4.6 mm × 5 μm; UV detection at 225 nm; radiometric detector: Raytest - Gabistar; flow rate: 1 ml/min, injection volume: 5 μl, mobile phase: a mixture of H_2O and EtOH in a 90:10 ratio. The second method involved the use of a chiral column: Supelco, Astec CHIROBIOTIC – T, 150 mm×4.6 mm×5 μm; UV detection at 225 nm; radiometric detector: Raytest - Gabistar; flow rate: 1 ml/min, injection volume: 5 μl, mobile phase: a mixture of H_2O and MeOH in a 20:80 ratio. To confirm the identity of the synthesized compound,

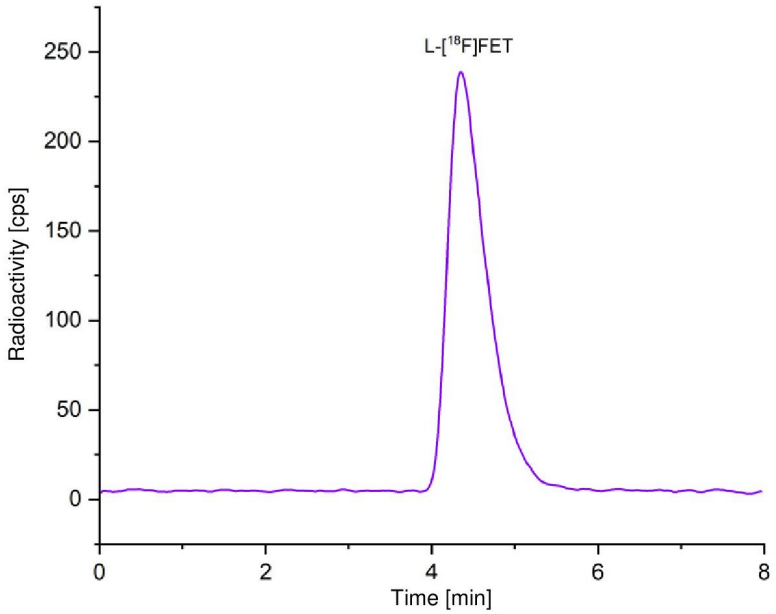

Figure 3: Chromatogram of L-[^{18}F]FET. Separation: Supelco Astec CHIROBIOTIC – T, 150 mm × 4,6 mm × 5 μm, radiometric detector; flow: 1 ml/min, injection: 5 μl, mobile phase: MeOH:H_2O 80:20 v/v.

a standard of L-[^{18}F]FET was used.

Conclusions

The experiments conducted in this study allowed for the development of an effective synthesis method for the radiopharmaceutical [18F]FET. During the research, a product with high radiochemical purity of 97.35 ± 0.87% before purification and 98.8 ± 0.5% after purification, as well as high enantiomeric purity of 99.82 ± 0.09%, was obtained, with a good radiochemical yield of 28.2 ± 5%. The synthesis procedure for [^{18}F]FET developed in this work meets the requirements outlined in the European Pharmacopoeia in terms of radiochemical purity, chemical purity, and enantiomeric purity. The results are also comparable to or better than other previously published papers. Furthermore, the obtained product demonstrates high radiochemical and enantiomeric purity, as well as good yield, making it suitable for preclinical studies.

B.4 Development of a porphyrin cellular uptake assay in HeLa cervical cancer cells

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Porphyrins, due to their biocompatibility and the high stability of their complexes with metal ions, represent a promising group of compounds for use in the construction of radiotracers employed in medical diagnostics, such as positron emission tomography (PET) and single-photon emission computed tomography (SPECT). In the context of cancer diagnostics, porphyrins used in such radiotracers should exhibit high specificity for cancer cells, meaning they should be efficiently taken up by these cells. Modern methods allow the synthesis of various porphyrin derivatives, which necessitates the development of an effective method for rapidly testing their efficiency in entering cancer cells. This procedure should be simple and cost-effective to enable the performance of numerous tests and the analysis of multiple porphyrins.

The aim of this study was to develop and test a procedure that would allow for the quantitative determination of the level of porphyrin uptake by cancer cells in vitro. The procedure was designed to compare the uptake efficiency of different porphyrins into cancer cells derived from various cell lines, in order to identify those porphyrins that exhibit the highest effectiveness in being taken up by cancer cells. Identifying such porphyrins could enable their use as components of radiotracers for isotopic diagnostics.

In 2020, a new receptor responsible for the transport of porphyrins across the cell membrane was described, namely CD320 (cluster of differentiation 320). The current literature indicates that this receptor participates in the transport of the cobalamin-transcobalamin II complex, but it also shows a high affinity for the porphyrin TCPP (5,10,15,20-tetrakis(4-carboxyphenyl)porphyrin). A significant decrease in transport efficiency was observed in CD320-deficient mutants, suggesting that this receptor may also be involved in the transport of free porphyrins across the cell membrane.

To achieve the aim of this study, experiments were conducted with HeLa cells, which were cultured in DMEM medium supplemented with 4500 mg/l glucose, 10% fetal bovine serum, and 100 U/ml penicillin and 100 μg/ml streptomycin. The cells were maintained in an incubator at 37°C with 5% CO_2, and the medium was replaced every 2-3 days. Cells were passaged once or twice a week when they reached approximately 90% confluence.

To determine the optimal conditions for measuring porphyrin fluorescence, excitation and emission spectra were recorded for each porphyrin under investigation, using a Tecan Infinite M Nano+ spectrofluorometer. Measurements were performed on porphyrin solutions in TDE at a concentration of 1 μM. Subsequently, HeLa cells were seeded on 96-well plates, replenished with DMEM medium, and treated with various concentrations of the studied porphyrins (10 μM and 100 μM) in the medium to assess their uptake by the cells. Control wells contained only DMEM medium.

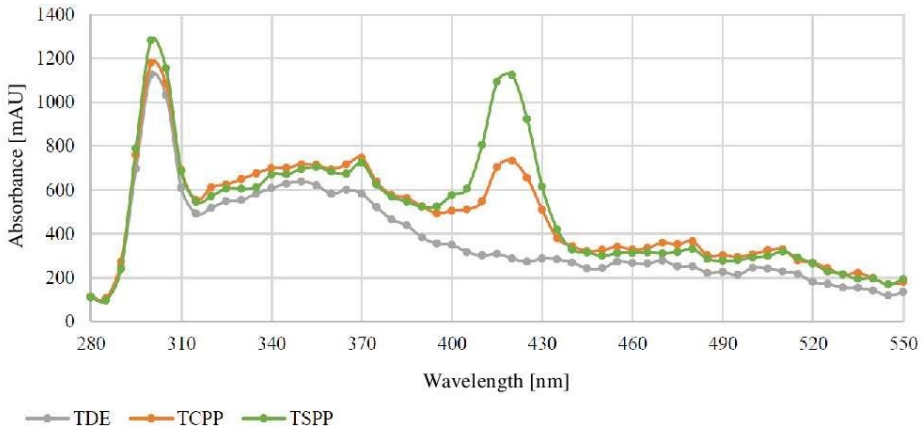

Figure 1: The absorption spectra of the studied porphyrins and TDE solution. Measurements were performed with a wavelength range from 280 nm to 550 nm.

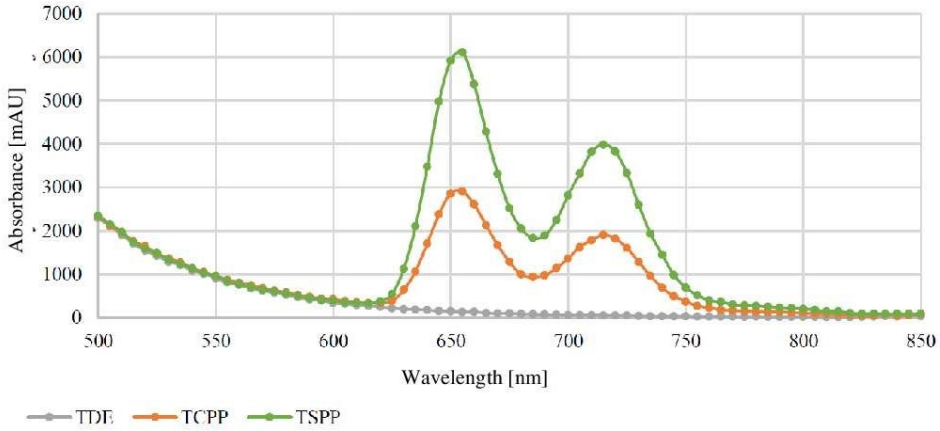

Figure 2: The emission spectra of the studied porphyrins and TDE solution. Measurements were performed with an emission wavelength range from 500 nm to 850 nm and an excitation wavelength of 360 nm.

The porphyrin uptake assay aimed to determine the amount of porphyrin, TCPP, or TSPP, that entered the cells over a specified period and at a defined concentration. Cell counting and fluorescence measurement of the cells after lysis in TDE solution allowed for the evaluation of the intensity of porphyrin uptake into the cells. The experimental results showed that for both tested porphyrins, higher concentrations in the medium led to more intense cellular uptake. However, no statistically significant differences in the amount of porphyrins taken up by HeLa cells were observed between TSPP and TCPP at comparable concentrations.

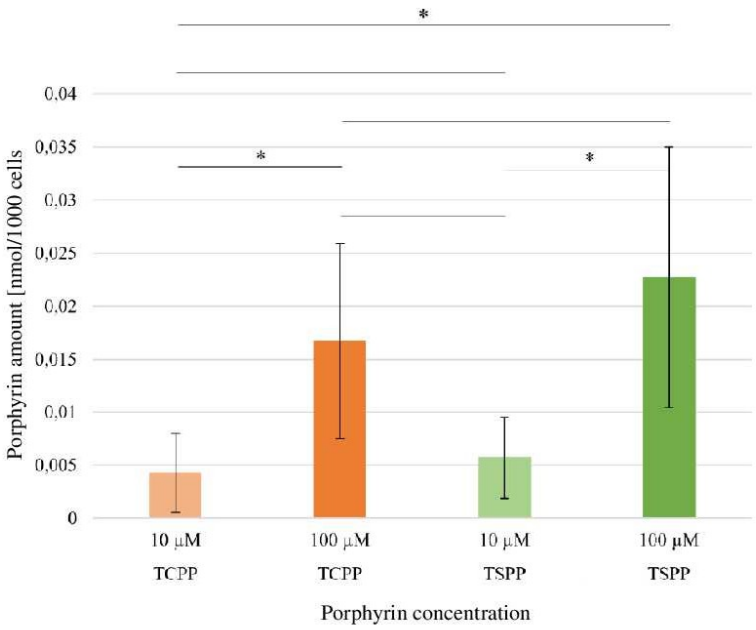

Figure 3: Comparison of the uptake efficiency of TCPP and TSPP into HeLa cells at concentrations of 10 μM and 100 μM. The results indicate more intense uptake of both porphyrins at higher concentrations. Asterisks indicate the level of statistical significance: * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

The results suggest that both porphyrins accumulate in HeLa cells with similar intensity, confirming their ability effectively to enter cancer cells. These porphyrins could potentially serve as valuable components in the design of radiotracers for diagnostic applications in oncology.

B.5 Three-dimensional in vitro culture of glioma cells as a model for radiobiological studies

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In vitro cell culture is a technique commonly used in radiobiological research. Unfortunately, popular two-dimensional (2D) cell cultures do not reproduce the microenvironment of tumour tissue [1]. In recent years, many innovative techniques and tools have been introduced, enabling the creation of three-dimensional (3D) cell cultures. The spherical aggregates (spheroids) of cells formed in this way serve as effective tumour models. In classical monolayer cell cultures, cells grow in two dimensions, exhibiting a flat and elongated shape. In contrast to monolayer cultures, cells in spheroids are tightly packed and interact with each other in three dimensions, as well as through the extracellular matrix. This induces radioresistance, which is observed in 3D models as well as in patients. The percentage of cells in spheroids that are in the active phase of the cell cycle depends on the size of the spheroid and ranges from 40% to 70%, whereas in monolayer cultures, over 90% of cells progress through the cell cycle. Additionally, spheroids exhibit gradients of oxygen, nutrients, and substances such as drugs added to the culture medium. In each case, the concentration and penetration of all three decrease towards the spheroidal core, often leaving the cells in the core deprived of adequate nutrients and oxygen. In contrast, in monolayer cultures, oxygen, nutrients, and drugs can reach each cell with equal efficiency [2]. Three-dimensional cultures can therefore account for various aspects of tumour tissue, such as cell density, intercellular interactions, vascular barrier, and hypoxia. A key advantage of 3D functional assays is their ability to assess the effectiveness of therapies at different stages of tumour development. Tumour spheroids allow for the study of cell proliferation, migration, invasion, angiogenesis, and responses to drug therapies [3]. This allows for a more precise assessment of the impact of drugs on tumour growth dynamics, metastatic potential, and possible side effects. Additionally, three-dimensional functional assays based on spherical aggregates of cancer cells are used to validate therapeutic targets. By applying molecular techniques and imaging, it is possible to analyse signalling pathway activity, gene expression, DNA repair capacity, and interactions with the tumour microenvironment. This enables a better understanding of the molecular mechanisms associated with tumour development and its response to treatment [2].

There are various methods of three-dimensional cell culture, differing in factors such as the complexity of culture protocols and the number of materials required. The simplest 3D culture methods include the hanging drop method and culture on a non-adhesive surface. A slightly more advanced approach involves the use of scaffolds made from synthetic gels or biologically derived hydrogels, as well as scaffolds composed of nanofibres or polystyrene. Methods that require additional equipment include rotary culture, magnetic culture, and the microfluidic "lab-on-a-chip" technique.

The first technique to be used in the radiobiology laboratory of the HIL for 3D culture of the M059K cell line (glial cells) was the hanging drop method [4]. Three different cell densities were prepared (10^5, 5×10^5, and 7.3×10^5). Four 50 mm diameter Petri dishes were therefore prepared for each cell density. Two drops of a 10 μL and 20 μL cell suspension were spotted on the bottom of each Petri dish lid. Cells were incubated for 7 days at 37°C and 5% CO_2. Figure 1a shows glioma tumour cells after 4 days of incubation in a culture flask. Figure 1b shows a formed spheroid in a hanging drop of 10 μL (density of 7.3×10^5) after two days of incubation.

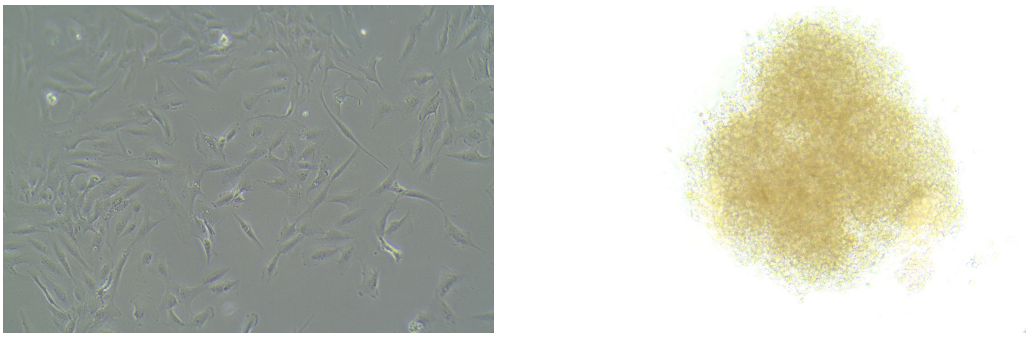

Figure 1: Comparison of brain tumour cells in flat and three-dimensional cell culture.

The second 3D culture method used was with agarose gels. For this purpose, 24 gels (eight gels per cell density) were prepared on silicon forms. Three different cell densities of the M059K cell line were prepared in 190μL of medium (1.6×10^4, 3.2×10^4, and 7.16×10^4). Cells were incubated for 8 days at 37°C and 5% CO_2 in 6-well dishes in 4 mL of culture medium. After three days of incubation, six gels (two from each cell density) were selected for the live-dead assay (Live Dead Cell Viability Assay Kit for 3D and 2D cell culture, Merck). Figure 2 shows the spheroid from the highest density imaged under an inverted phase contrast microscope, with a filter showing living cells and a filter showing dead cells in the spheroid. The dead cells in the spheroid represent its core, while the living cells are located in the outer layer of the spheroid.

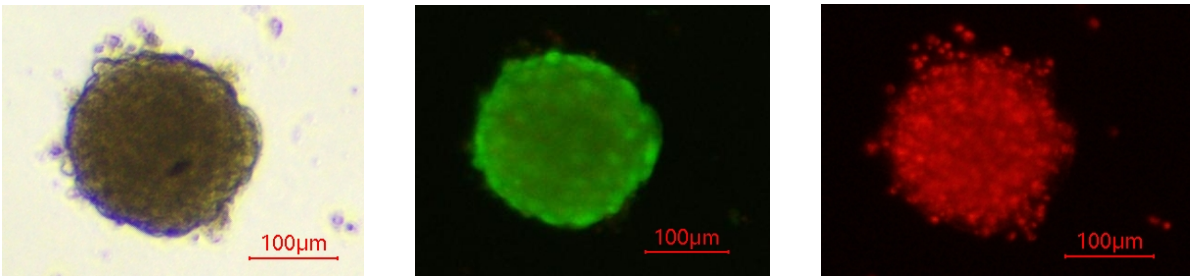

Figure 2: Spheroid imaged under an inverted microscope with phase contrast and filters showing live and dead cells.

The agarose gel culture method was chosen for the development of further work on conducting three-dimensional cell culture. The spherical aggregates formed by this method have a clear structure, and the method itself is more efficient and allows a larger number of spheroids to be prepared than the hanging drop method. The size of the spheroids prepared on agarose gels largely depends on the size of the mould on which they were grown and the density of the cells in the suspension from which they were seeded into the gel. Figure 3a shows spheroids growing on a gel with elongated wells (density of 7.16×10^4), while Figure 3b shows a photograph of spheroids growing on a gel with round wells (5×10^4).

Both methods produced stable spheroids with a structure close to the natural tumour microenvironment. However, the analysis of the viability tests carried out showed that the agarose gel culture method had a higher yield – allowing the preparation of a larger number of spheroids with reproducible morphology, a significant advantage when planning further radiobiological experiments.

The results confirm that three-dimensional glioma cell culture provides a valuable model for the study of radiobiological mechanisms of resistance to therapy. The use of two different methods for generating spheroids made it possible to compare their efficiency. Although the hanging drop method allows rapid preparation of spheroids, culture on agarose gels shows better reproducibility and the possibility of mass production, which is crucial for screening new anti-cancer therapies.

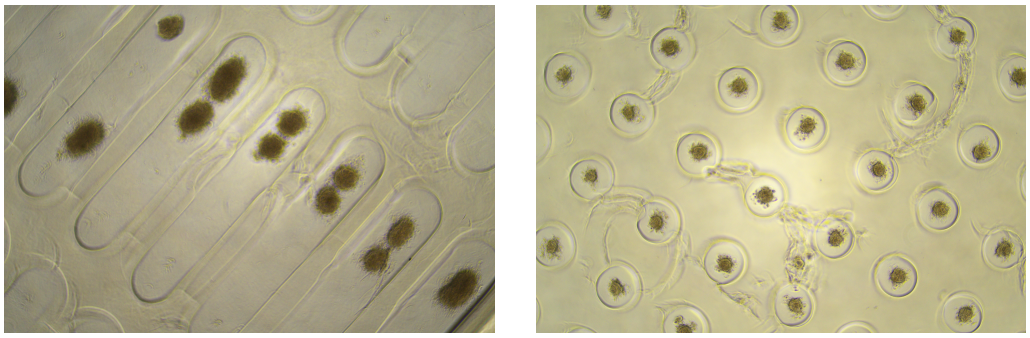

Figure 3: Spheroids grown on agarose gels with different well types for two different densities of seeded cells.

This study has confirmed the usefulness of three-dimensional cell cultures as an advanced model for radiobiological research. The method of culture on agarose gels, due to their efficiency and reproducibility, appears to be the preferred technique for further research into testing the efficacy of anti-cancer therapies. In future studies, a detailed evaluation of the biological activity of spheroids is planned, including analysis of their response to radiation and investigation of potential side effects.

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B.6 Study of the impact of different radiation dose deposition methods from a medical accelerator on the biological response of glioblastoma cell cultures.

P. Chuchała[1,2], A. Lenartowicz-Gasik[3], M. Araszkiewicz[1,3], P. Kamińska[1,2], U. Kaźmierczak[2], A. Korgul[1], J. Rzadkiewicz[3], W. Sroka[3]

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Introduction

Radiotherapy is one of the primary adjunctive tools for cancer treatment, particularly in cases of tumors that are difficult to access surgically. However, conventionally fractionated radiotherapy requires multiple patient visits to oncology centres, which can be a logistical and medical burden. Depending on the patient's health, treatment may be interrupted or delayed. Interruptions in therapy can lead to incomplete eradication of cancer cells and an increased risk of recurrence. Additionally, healthy tissues along the radiation beam path are exposed to damage, contributing to the side effects of therapy. An alternative approach is intraoperative radiotherapy (IORT), which allows for the delivery of a high single dose of radiation directly to the tumor site, minimizing exposure to healthy tissues. A crucial aspect of this method is the impact of dose delivery on the biological response of both cancerous and surrounding healthy tissues.

Objectives of the Experiments

FLASH irradiation appears to cause less DNA damage in healthy cells while maintaining therapeutic efficacy against cancer cells. In recent years, the FLASH-RT technique, which involves delivering very high doses of radiation in a fraction of a second, has gained significant interest. Experimental studies suggest that this method may provide better protection for healthy tissues while preserving its therapeutic effectiveness. However, the full mechanism of this effect and its implications for treatment planning remain incompletely understood. Better to understand the biological effects of different irradiation methods, preliminary studies were conducted in collaboration with the National Centre for Nuclear Research (NCBJ) in Świerk, aiming to assess the impact of different dose deposition methods from a medical accelerator on glioblastoma multiforme cells.

Materials and Methodology

The study utilized a medical accelerator (see Fig. 1: the AQURE FLASH-RT accelerator available at NCBJ in Świerk), which allowed testing of both methods while modifying specific parameters.

Cell Culture

The cell culture preparation for irradiation experiments was conducted at the Radiobiology Laboratory of the Heavy Ion Environmental Laboratory at the University of Warsaw (HIL UW). Two glioblastoma cell lines were used in the experiments:

- **M059K**: Derived from glioblastoma multiforme (GBM), this cell line expresses functional ATM protein (Ataxia Telangiectasia Mutated), crucial in DNA damage repair following radiation exposure.
- **M059J**: This cell line lacks functional ATM protein and exhibits increased sensitivity to radiation.

M059K and M059J cells were cultured in Dulbecco's Modified Eagle Medium (DMEM) supplemented with 10% fetal bovine serum (FBS) and 1% antibiotics (penicillin/streptomycin). The

Figure 1: the AQURE FLASH-RT accelerator available at the National Centre for Nuclear Research in Świerk.

cultures were maintained in an incubator under controlled conditions (5% CO_2, 37^{o}C). Before irradiation, cells undergo 3-4 passages to ensure homogeneity. They were grown in culture flasks, and on the day of irradiation, the medium was replaced with a fresh growth medium. Cells were transported to NCBJ in a portable incubator with controlled CO_2 levels, ensuring stable conditions during transport. The irradiation was performed in T-25 flasks. After exposure, the cells are immediately transported back to the Radiobiology Laboratory at HIL UW, where they were seeded into Petri dishes and incubated for two weeks before fixation and clonogenic survival analysis. Additionally, proper controls and standardization protocols were applied throughout the process to ensure experimental consistency. Moreover, an MTT assay was performed several hours post-irradiation to assess metabolic activity.

Research Methodology

Three independent biological replicates were performed for both assays. The MTT assay, conducted in collaboration with the Department of Biophysics at the Faculty of Physics, University of Warsaw, provided data on radiation-induced cytotoxicity, while the clonogenic assay - entirely performed at the Radiobiology Laboratory - evaluated cell survival after irradiation. Differences in cellular response to doses ranging from 1 to 11 Gy were observed. Further stages of the study

will enable more detailed analyses, in which selected doses will be used to compare two irradiation methods: conventional radiotherapy and the FLASH technique.

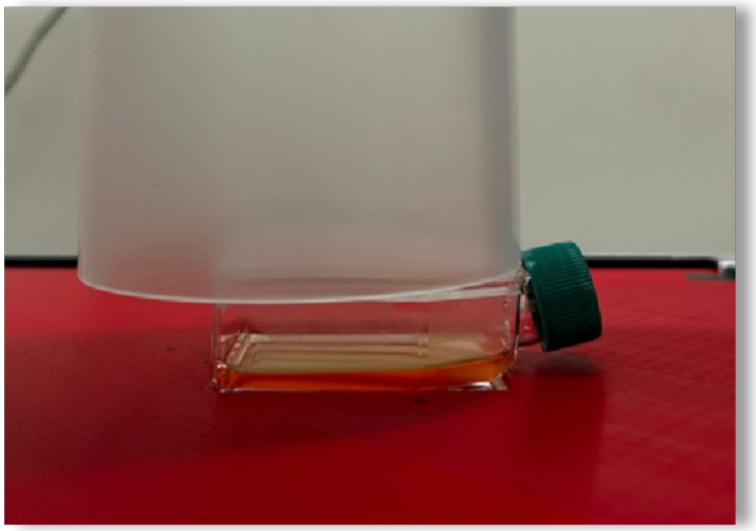

Figure 2: Setup for irradiating M059K glioblastoma cells with an electron beam at the National Centre for Nuclear Research in Świerk.

Future Research Directions

Future research will include additional methods for assessing cytotoxicity and oxidative stress and expanding experiments to three-dimensional cell culture models. Glioblastoma spheroids better mimic in vivo conditions, allowing a more realistic evaluation of radiotherapy effects. The results of these studies contribute to a better understanding of the biological effects of FLASH radiotherapy and the optimization of therapeutic strategies for patients with glioblastoma multiforme.

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B.7 Cyclotron Production of the theranostic pair ^{55}Co and ^{58}Co, their separation from the target and applications for the β^+ - γ coincidence PET method

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Close cooperation between HIL and INCT in 2024 was continued.

Proton beams accelerated in a PETtrace cyclotron were used for cobalt radioisotope production. At the Heavy Ion Laboratory, University of Warsaw the appropriate targets were manufactured and then irradiated with a beam of protons on a special stand connected to the cyclotron. The thicknesses of the targets were selected in such a way that the proton beam was completely stopped in the target. After irradiation, targets were then transported to the Institute of Nuclear Chemistry and Technology for further processing.

As a β^+ emitter (β^+ = 77% Emax = 1498 keV) Cobalt-55 ($t_{1/2}$ = 17.53 h) is a promising radionuclide for Positron Emission Tomography (PET). Moreover, ^{55}Co emits a high energy and intensity gamma line (931.30 keV, 75%), which makes it the perfect candidate for the β^+ - γ coincidence PET technique. Thanks to this correlation, it is possible to imagine positronium, which is a bound state of a positron and an electron produced in intra-molecular voids.

^{58m}Co, on the other hand, emits Auger electrons as a result of internal conversion decay ($t_{1/2}$=9.10 h, 100% IC) and, as such, can be used to produce therapeutical radiopharmaceuticals. Therefore, ^{55}Co and ^{58m}Co form a promising theranostic pair due to their similar half-lives, identical chemical properties, and compatibility with biomolecules such as DOTATATE, DOTATOC, or nanobodies. Both of these radionuclides can be produced at low-energy medical cyclotrons with metallic iron-enriched targets utilizing the following nuclear reactions.

$$^{54}\mathrm{Fe(d,n)}^{55}\mathrm{Co},\ ^{58}\mathrm{Fe(p,n)}^{58m}\mathrm{Co}$$

Fraction No	% of ^{56}Co
1	0.36
2	0.41
3	3.69
4	24.58
5	12.35
6	10.53
7	8.40
8	7.73
9	6.39
10	8.89
Σ	83.33

Table 1: Elution of ^{56}Co

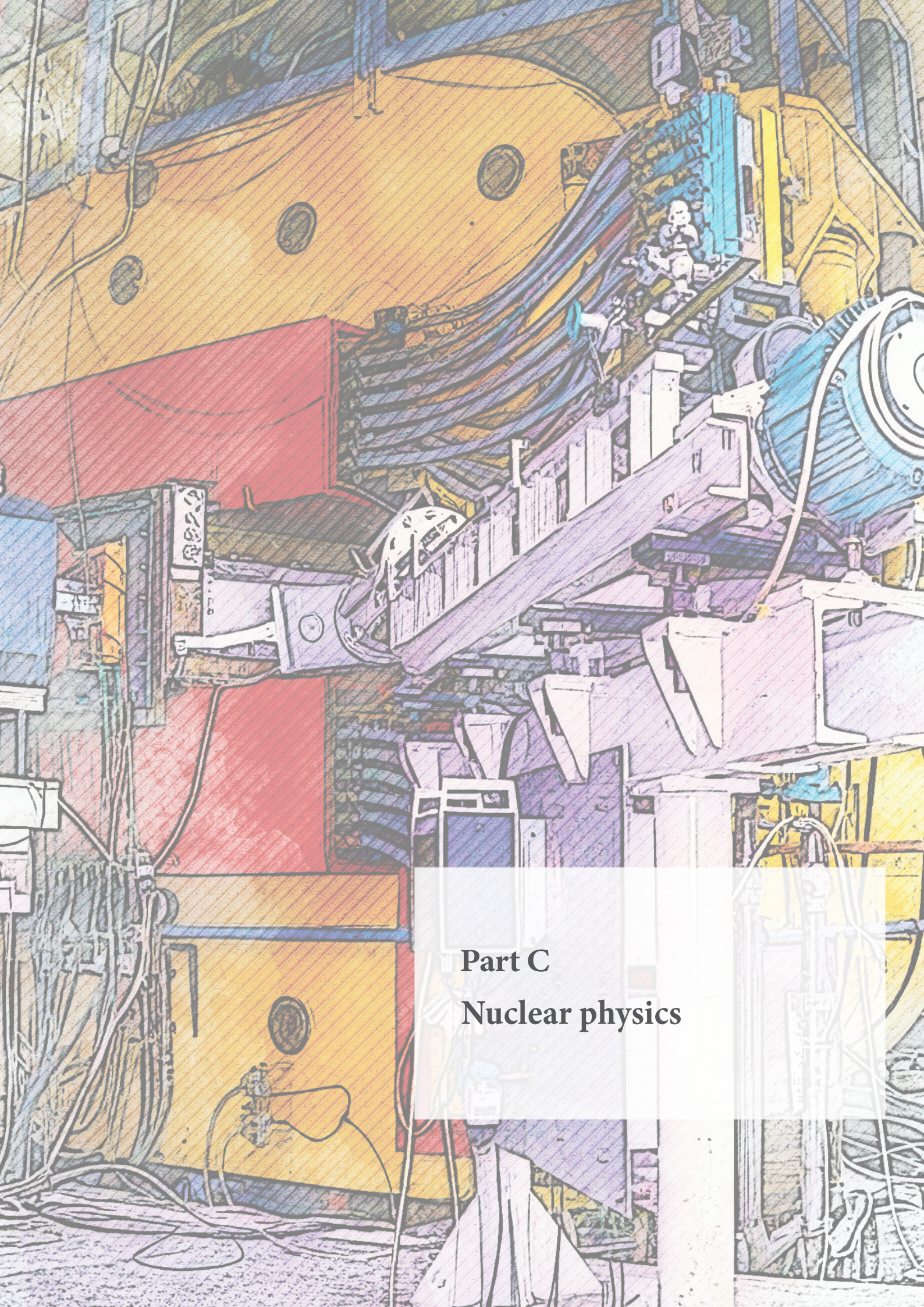
In the first step of our work, which is the separation of the cobalt radionuclides from the target material, we use ^{56}Co, due to the identical chemical properties and general conditions of production, as a surrogate for ^{55}Co and ^{58m}Co.

^{56}Co was produced on a natural metallic iron target (468 mg/cm^2) in the $^{nat(56)}$Fe(p, n)^{56}Co nuclear reaction. The target was irradiated for 1 h 20 minutes with a proton beam (16 MeV, 15 μA). The measured activity of the produced ^{56}Co was about 28 MBq.

After irradiation, the target was dissolved in 3 ml of 6M HCl and mixed with 57 ml of 99.8% ethanol and 100μl 30% H_2O_2. The target material solution was then loaded on a column filled with 4 g of Dowex 1-x8 resin and equilibrated with 20 ml of 0.3M HCl/95% EtOH. Residual iron was eluted with 20 ml of 0.1M HCl and Co radionuclides with 10 ml (1 ml per fraction) of 4 M HCl. Results of the separation are presented in Table 1.

Such high recovery efficiency makes this separation method appropriate for further work with ^{55}Co and ^{58m}Co.

Moreover, for the concentration of the eluent, the second step of the separation process with DGA resin (N, N, N', N'- tetrakis-2-ethylhexyldiglycolamide) is being considered.



Part C
Nuclear physics

C.1 Gamma-ray Spectroscopy of ^{134}Sm

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An experiment to study the ^{134}Sm nucleus was carried out in January 2024 using the EAGLE [1] gamma spectrometer in conjunction with the NEDA [2, 3] neutron and DIAMANT [4, 5] charged particle detectors. The main objective of the experiment was to extend the level scheme of ^{134}Sm to study shape coexistence and gamma vibrational states. In addition, the experiment should explore possible shape differences of ^{134}Sm compared to other Sm isotopes such as ^{136}Sm [6] and ^{138}Sm [7], arising from the arrangement of protons and neutrons in the $h_{11/2}$ orbitals. Only six yrast excited states of ^{134}Sm are currently known, forming a ground state band with spins and parity up to 12^+ [8].

A 147 MeV beam of ^{32}S was used to bombard an isotopically pure ^{106}Cd target with a thickness of 4.6 mg/cm^2. In this reaction, two protons and two neutrons must be emitted from the compound nucleus ^{138}Gd to form ^{134}Sm. However, the reaction is dominated by the emission of protons, possibly accompanied by one neutron and/or an alpha particle. The NEDA and DIAMANT arrays are essential to select events of interest, see Fig. 1, which illustrates the effect of gating on 2 neutrons.

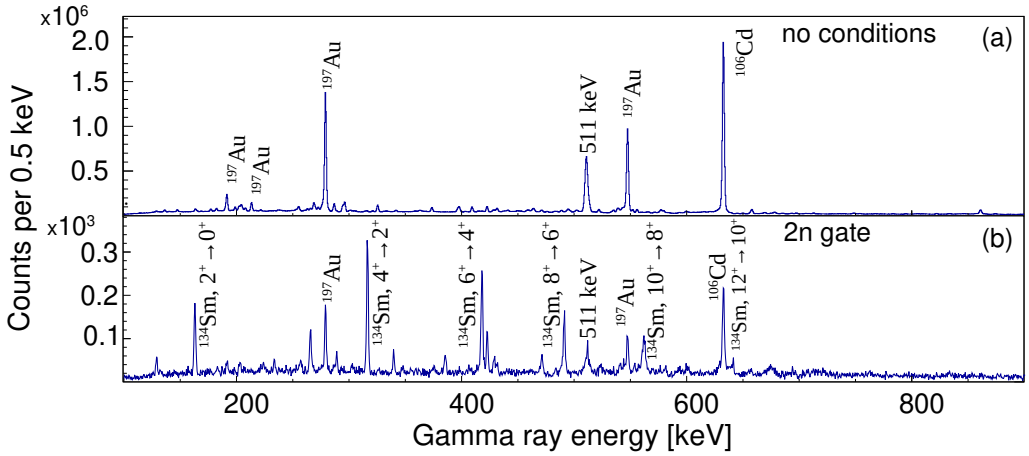

Figure 1: Gamma-ray spectra collected in the experiment. No condition on detected neutrons and charged particles was applied for spectrum (a), while spectrum (b) is gated by the detection of 2 neutrons. The spectra correspond to 6 hours of data taking.

Data analysis is in progress. The energy and efficiency calibrations of the HPGe detectors has been completed. Data from DIAMANT, EAGLE, and NEDA have been merged, and events built. Work is in progress on checks of the stability and on applying the necessary corrections. A number of new software tools were developed for this purpose.

This work is supported by the National Science Centre (NCN), Poland (grant No.2020/39/D/ST2/00466).

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C.2 ^{32}S + ^{112}Sn fusion-fission studies

K. Miernik[1], G. Jaworski[2], I. Kuti[3], K. Wrzosek-Lipska[2], M. Palacz[2], M. Araszkiewicz[1], M. Chotkowski[4], P. Chuchała[1], J. Cięciel[1], J. Cwynar[1], A. Fijałkowska[1], P. Garczyński[1], V. Guadilla[1], K. Hadyńska-Klęk[2], Z. Janas[1], P. Kamińska[1], M. Kisieliński[2], M. Komorowska[2], M. Kondzielska[1], A. Korgul[1], M. Kowalczyk[2], R. Kuczma[1], A. Malinowski[1,2], M. Młynarczyk[1], J. Molnar[3], W. Okliński[2], S. Panasenko[2], I. Piętka[2], J. Samorajczyk-Pyśk[2], P. Sekrecka[2], K. Solak[2], A. Špaček[2], J. Wilson[5]

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Fission is often associated with heavy isotopes and spontaneous or neutron-induced reactions, but it can also be studied in a heavy-ion reaction leading to an excited compound nucleus after fusion. Such a method of production opens the possibility of fission studies for a much wider range of nuclides [1] than those accessible by fission induced by light particle or Coulomb interaction. Proton-rich medium mass isotopes ($A < 180$) have not been extensively studied experimentally in terms of fusion-fission reactions. Particularly deficient in experimental data is the region of masses $120 < A < 152$ where just a handful of cases is known, and in none of which gamma spectra or fragment yields were measured.

The main goal of this experiment was therefore to study, using γ and particle spectroscopy, fusion-fission of ^{144}Dy* created in the reaction of a 215 MeV beam of ^{32}S impinging on a thin ^{112}Sn target. During the 7 days of the experiment in total 4.3×10^9 $\gamma - \gamma$ and 1.8×10^8 $\gamma - \gamma - \gamma$ coincidences were collected by the EAGLE spectrometer, accompanied by the NEDA (1.0×10^{10} neutrons collected) and DIAMANT (1.9×10^{10} protons, and 6.0×10^{10} α detected) detectors.

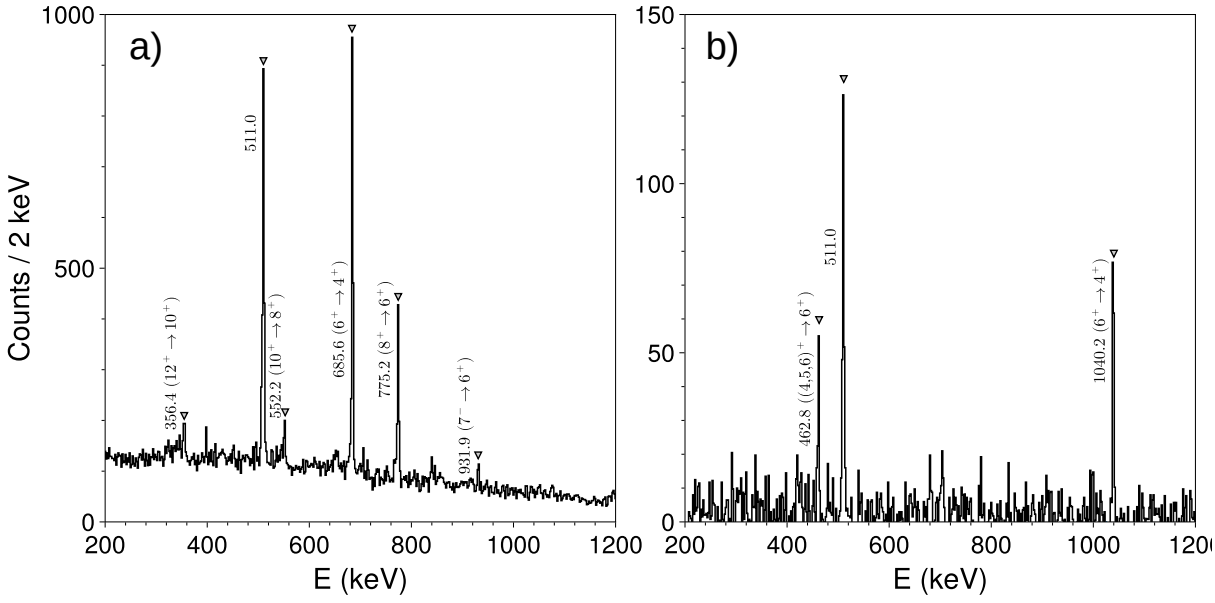

Figure 1: Example of $\gamma - \gamma - \gamma$ gates: a) 346.7-544.4 keV (^{138}Sm $4^+ \rightarrow 2^+ \rightarrow 0^+$), and b) 793.2-974.5 keV (^{84}Sr $4^+ \rightarrow 2^+ \rightarrow 0^+$).

The collected raw data set (about 5 TB) was scanned using a code written in the Julia programming language [2]. Careful stability and timing analysis allowed for short event correlation times (10-128 ns, depending on the detector type), which resulted in precise and clean event

building. Figure 1 shows sample triple γ coincidences for the fusion-evaporation nuclide ^{138}Sm, and fusion-fission nuclide ^{84}Sr.

By studying all known $\gamma - \gamma$ and $\gamma - \gamma - \gamma$ transitions leading to the ground state of a given fragment, the independent fission fragment yield can be calculated [3, 4]. The High yield of fusion-evaporation reactions also allows for the spectroscopy study of yrast states of nuclei in the vicinity of the compound nucleus. The light particle detectors (NEDA, DIAMANT) will help to determine the reaction channels, including the possible influence of incomplete fusion followed by fission [5].

The installation and use of NEDA and DIAMANT at HIL, digital electronics and DAQ of EAGLE with its ancillary devices are supported by the National Science Centre (NCN), Poland (grant No. 2020/39/D/ST2/00466).

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C.3 Search for candidate wobbling bands in ^{103}Pd and ^{101}Ru

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Bohr and Mottelson introduced the concept of nuclear wobbling motion [1], which is observed in triaxially deformed nuclei. In this phenomenon, the nucleus rotates around the principal axis with the largest moment of inertia, and this axis undergoes harmonic oscillations around the space-fixed angular momentum vector. In classical mechanics, this motion is akin to the movement of a free asymmetric top, while in quantum systems, it is comparable to the rotation of molecules with distinct moments of inertia along their three principal axes.

In nuclei, the anticipated energy spectra associated with the wobbling motion display a series of rotational E2 bands, each corresponding to different oscillation quanta (n). In particular, the yrast and yrare bands, linked to n=0 and n=1, respectively, exhibit characteristics reminiscent of signature partner bands, featuring substantial signature splitting. The yrare band decays by ΔI=1 M1+E2 transitions to the yrast band. However, contrary to the expectations from signature partner bands, the multipole mixing ratios in this scenario are remarkably large, and the transitions primarily show E2 characteristics.

The phenomenon has been reported in the lower-energy bands of the odd-neutron ^{105}Pd [2] nucleus. However, most recently, doubts have been raised about the wobbling interpretation of these bands [3]. An alternative interpretation, "tilted precession" (TiP), was suggested instead. Both TiP rotation and wobbling describe excited rotational bands for which the rotational angular momentum tilts away from the intermediate axis. However, the wobbling description demands specific quantization of the excitation energies and transition probabilities of the wobbling bands, which is not required in the case of TiP bands.

Studying the neutron $h_{11/2}$ side bands in the neighbouring odd-neutron ^{103}Pd and ^{101}Ru nuclei could help to clarify the existence of wobbling motion at low energy in this region, and could also provide us with information on the border of this triaxiality region.

A 14-day experiment was performed in May 2024 at the Heavy Ion Laboratory of theUniversity of Warsaw to populate the negative-parity neutron $h_{11/2}$ side bands in ^{103}Pd and ^{101}Ru. A ^{12}C beam was accelerated by the U200-P Cyclotron to 69 MeV energy, and impinged on a 1 mg/cm^2 ^{96}Zr target. The beam current was 2 pnA on average. The NEEDI setup — the EAGLE spectrometer [4] together with the NEDA detectors [5] and the DIAMANT charged-particle array [6] — was used. Analysis of the collected data is in progress.

This work is supported by the National Science Centre (NCN), Poland (grant No.2020/39/D/ST2/00466).

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C.4 Lifetime studies in neutron-deficient ^{172}Os using the RDDS technique

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In the vicinity of $Z = 82$ and $N = 104$ the phenomena of shape-coexistence of near-spherical and well-deformed prolate/oblate intruder configurations, has been well-studied [1] and is understood in terms of multi-particle multi-hole excitations across the proton shell closure at $Z = 82$. Going further away from the proton shell closure to the $_{76}$Os isotopes the picture gets more complex. Signatures for the critical point of the spherical - axialsymmetric rotor shape transition (X(5)) were found in ^{176,178}Os [2]. For lighter Os isotopes, the excitation energy systematics $E_{4/2} = E(4_1^+)/E(2_1^+)$ hint at a transition towards triaxial/γ-soft rotors at $N \approx 92$ (^{168}Os) [3] to single-particle excitations near the $N = 82$ closed shell [4, 5].

This systematic picture is not supported by existing data on yrast transition strengths for the neutron deficient Os isotopes. The $B(E2; 2_1^+ \rightarrow 0_1^+)$ values remain fairly constant close to mid-shell, i.e., around $N = 104$, where a slight increase appears for ^{174}Os, but towards ^{172}Os a sharp drop appears. For the $B(E2; 4_1^+ \rightarrow 2_1^+)$ values this effect is even more pregnant where it drops even much below the $B(E2; 2_1^+ \rightarrow 0_1^+)$ value for ^{168,170}Os with $B_{4/2}(^{168}\text{Os}) = 0.34(18)$ [6] and $B_{4/2}(^{170}\text{Os}) = 0.38(11)$ [7]. This $B(E2)$ anomaly is not anticipated far from closed shells and cannot be described with collective models. Different more sophisticated theoretical approaches, e.g., a QCD-inspired relativistic energy-density functional approach [8] and IBM-2 calculations based on the SKM* energy-density functional done in [6] reproduce the excitation energies of the lowest states reasonably well, but fail completely for the lowest yrast $B(E2)$ values. Small $B_{4/2}$ ratios were also found in some neighboring nuclei, e.g., in ^{166}W [9]. Only very recently, $B_{4/2} < 1$ ratios in this region were reproduced within an extension of the consistent-Q IBM Hamiltonian, originating from a strong band mixing induced by a third-order term of the triaxial rotor realization [10]. In a follow up publication [11], a general procedure for constructing triaxial rotor modes in the IBM was demonstrated including the collective mechanism for the $B(E2)$ anomaly.

For ^{172}Os, the $B_{4/2}$ ratio of $B_{4/2} = 1.50(16)$ deduced from [12] is consistent with the expectation value for a rotor nucleus of $B_{4/2,\text{rotor}} = 1.43$ within the error bars where the $E_{4/2}$ ratio of 2.66 hints for a triaxial or γ-soft nucleus. Therefore, from these existing data it seems that ^{172}Os is right at the "edge" of the region of the $B(E2)$ anomaly, i.e., the region with very small $B_{4/2}$ ratios. The authors of [12] state that cranked HFB calculations of the yrast band within their work do not reproduce the experimental yrast transition quadrupole moments Q_t between the lowest yrast states. In addition, these Q_t values do not scatter around a more or less constant value as a function of rotation frequency as predicted by the cranked HFB calculations but show a sharp increase for the $6_1^+ \rightarrow 4_1^+$ and $8_1^+ \rightarrow 6_1^+$ transitions (see Fig. 1) consistent with anomalies in the moments of inertia observed for these states as depicted in Fig. 1 in [12]. As pointed out in Ref. [12], such an anomaly can be reproduced with band mixing, involving a large collectivity

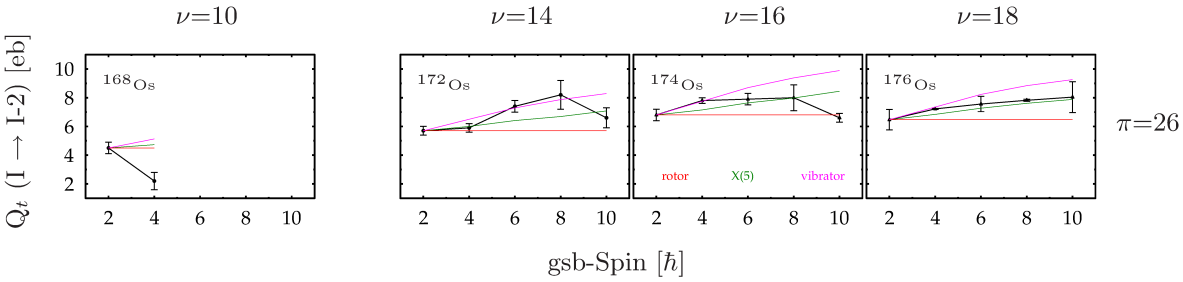

Figure 1: Transition quadrupole moments Q_t between the lowest yrast states in neutron-deficient Os isotopes prior to this work. Data were taken from [6], [12], [16], [2]. The purple, green and red lines give the expectation values for rotor, X(5) and vibrator nuclei, respectively.

from the quasi-β band that influences the 6_1^+ and 8_1^+ states in ^{172}Os strongly. On the other hand, shape coexistence in ^{172}Os was proposed in Refs. [13–15] from the excitation energies and moments of inertia of the yrast states. In contrast, beyond-mean-field calculations in [7] reproduce the characteristics of the 2_1^+ and 4_1^+ states in ^{172}Os well.

It should be stressed that the yrast level lifetimes in ^{172}Os used to determine $E2$ transition strengths and Q_t values were deduced from an experiment with the recoil distance Doppler-shift technique (RDDS) where only one HPGe detector at 0 degrees with respect to the beam axis was employed to determine the intensities of Doppler-shifted and unshifted components of the respective γ-ray lines [12]. An additional ring of 6 HPGe detectors was used at 90 degrees to reduce the complexity of the spectra, and to avoid some contributions from delayed feeding. Therefore, the experimental setup used in Ref. [12] does not completely allow the exclusion of significant contributions from delayed feeding and thus the results on level lifetimes and transition strengths might be questionable. However, for a structural interpretation of ^{172}Os precise data on yrast transition strengths are essential to clarify the puzzling situation in this nucleus.

This motivated the experiment realized in this work aiming to measure yrast level lifetimes in ^{172}Os up to the 10_1^+ state with a precision of $< 10\%$ using the RDDS technique and $\gamma\gamma$ coincidences. For the first time energy gates on shifted components of the feeding transitions of the levels of interest were employed to exclude any contribution from delayed feeding, i.e., to eliminate any need for assumptions on delayed feeding. The experiment was performed in November 2024 at the EAGLE γ-ray spectrometer at the HIL [17] in combination with the Cologne coincidence plunger device [18] using the fusion-evaporation reaction ^{144}Nd(^{32}S,4n)^{172}Os with a ^{32}S beam energy of 170 MeV. A ^{144}Nd plunger target with a thickness of 0.6 mg/cm^2 was used where the ^{144}Nd was evaporated onto a 1.3 mg/cm^2 Ta support foil. The latter was facing the beam. Recoiling reaction products were stopped in a Au stopper foil. The RDDS measurement was made at 11 distances between the target and stopper foils ranging from nearly electrical contact up to 1000 μm and ran for seven days. A preliminary sorting of the data was carried out during the measurement to create $\gamma\gamma$ coincidence matrices. These show that sufficient statistics were achieved for the decay transitions of interest in ^{172}Os to meet the aim of the experiment, i.e., the determination of (yrast) lifetimes in ^{172}Os with adequate precision. Fig. 2 depicts a γ-ray spectrum of ^{172}Os gated on the $2_1^+ \rightarrow 0_1^+$ transition from the preliminary sorting of the data, proving that the spectra will allow us to deduce the level lifetimes of interest in ^{172}Os with sufficient precision.

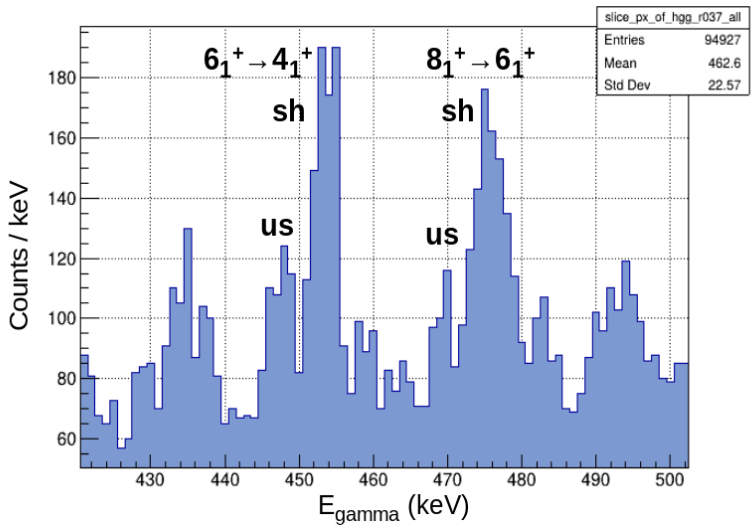

Figure 2: Spectrum of ^{172}Os gated on the $2_1^+ \rightarrow 0_1^+$ transition in the energy range of the $6_1^+ \rightarrow 4_1^+$ and $8_1^+ \rightarrow 6_1^+$ transitions for a target - stopper distance of 120 μm. The Doppler-shifted ("sh") and unshifted ("us") components of the respective γ-ray transitions can be clearly seen.

The data analysis will be carried out as a part of a PhD thesis at the Institute for Nuclear Physics at the University of Cologne very soon.

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C.5 Search for the transition between chiral and non-chiral configuration in ^{128}Cs by lifetime measurement of I=11^+, 12^+ states with the PLUNGER technique

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Introduction

Nuclear chirality has become the a subject of intense theoretical as well as experimental research in recent years. While effects of the chirality phenomenon have been found in many odd-odd nuclei [1–3], the mechanisms underpinning the nuclear chirality are not yet well established. It is still unclear how stable chirality emerges with increasing nuclear spin. Such a process has been theoretically discussed [4] but not yet studied/observed experimentally. Recent results have proven that at spin I=9$\hbar$ the ^{128}Cs isotope does not have a chiral nature [5] and a similar conclusion has been drawn for the 10^+ state [6]. Conversely, for spins I≥13 nuclear chirality is clearly observed [3] and is considered one of the best studied examples of this phenomenon. The aim of the presented experiment was to verify the nature of the 11^+ and 12^+ states in ^{128}Cs as the continuation of the experiment carried out in July 2022, which limited those lifetimes to the range of 1-10 ps [6].

Experiment

The experiment was carried out in December 2024. The EAGLE array with 18 germanium detectors (12 HPGe 70% from GAMMAPOOL and 6 with around 30% efficiency) with Anti-Compton Shields (ACS) was used: 5 detectors at 37°, 5 detectors at 143°, and the remaining ones at 63°, 79°, 101° and 117°. The ^{110}Pd(^{22}Ne, p3n)^{128}Cs reaction at a beam energy of 89 MeV was used.

The PLUNGER device from the University of Cologne was used for the Recoil Distance Method to measure lifetimes in the few picoseconds range. A thin, self-supporting ^{110}Pd target, with 1.0 mg/cm^2 thickness, was used, allowing the ^{128}Cs nuclei to recoil with a velocity slightly over 1% c. The offset of the PLUNGER was obtained to as low as 14 μm, corresponding to a 4.6 ps flight time.

The expected lifetime of the 12^+ state was around 3 ps with 1 ps average feeding time. Therefore, it was planned to measure at 5 distances from 14 to 30 μm, since over 30 μm at least 95% of nuclei should deexcite during flight, so the measurement accuracy would decrease for higher distances.

For the 11^+ state, only 3 of these distances are in the sensitive range, as the expected lifetime is around 1-2 ps with 2 ps average feeding time. An aditional distance of 370 μm was planned to measure the FLIGHT peak shape, in case the 349 keV gamma line STOP and FLIGHT peaks were too close to seperate them easily.

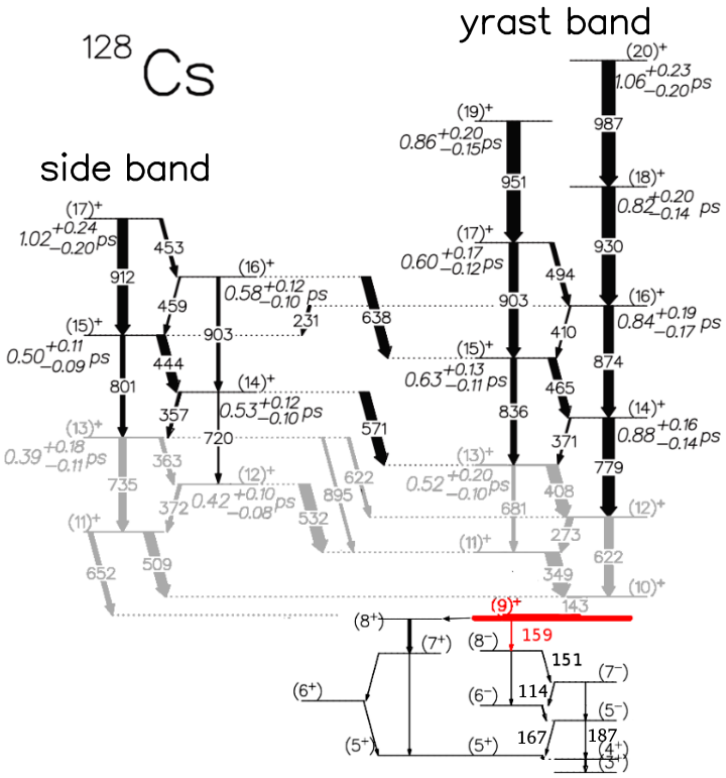

Figure 1: The ^{128}Cs level scheme. The lifetimes of the 12^+ and 11^+ states in the yrast band were the main purpose of the experiment. 114, 151, 159 and 187 keV transitions (from below the 9^+ isomeric state) as well as the 143 keV 10^+ to 9^+ transition, were used to create coincidence spectra.

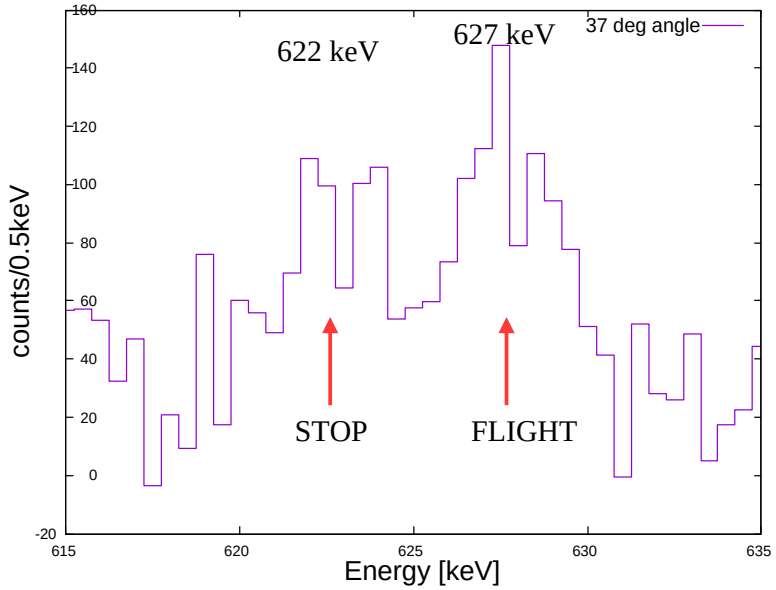

Figure 2: Summed spectra from 5 HPGe detectors placed at 37° gated on 114, 143, 151, 159 or 187 keV each. The target/stopper distance was around 17 μm. Both STOP and FLIGHT peaks are visible, but the height of the fluctuations, due to insufficient statistics, prevents the determination of the ratio of these peaks with the necessary precision.

Unfortunately, final conclusions could not be drawn mainly due to the low beam intensity (up to 0.3-0.4 pnA) and cyclotron failure. It was estimated that only about 20% of the required data was collected.

Conclusions

In the interaction of ^{22}Ne with ^{110}Pd the main reaction channel is the emission of 4 neutrons, leading to ^{128}Ba. Even though the cross section for ^{128}Cs production, calculated by the COMPA program [7], is only 7% of the total, most of the lines from below the 9^+ isomeric state (see Fig. 1) were visible in single gamma spectra.

Gating on 5 peaks from the 100-200 keV region we were able to obtain a relatively pure ^{128}Cs spectrum. As shown in Fig. 2, both STOP and FLIGHT peaks of the 622 keV transition were visible. However, the background fluctuations are too large and the statistics too low to determine the relative intensities of the flight and stopped components of this gamma-ray line with sufficient precision.

Therefore, if repeated with enough beam intensity, the experiment should produce the expected results. Unfortunately, data obtained from this interrupted experiment will not provide any better estimates of the lifetimes of the 11^+ and 12^+ states than those obtained from the experiment performed in July 2022 [6].

Acknowledgements

The installation and use of NEDA at HIL and the digital electronics and DAQ of EAGLE with its ancillary devices are supported by the National Science Centre (NCN), Poland (grant No. 2020/39/D/ST2/00466).

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C.6 The lifetime of the 2_2^+ state in ^{110}Cd from Coulomb-excitation measurements

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The increasingly precise experimental knowledge of the electromagnetic properties of stable even-even Cd isotopes does not agree with the widely accepted description provided by the collective vibrational model [1]. A recent detailed gamma-ray spectroscopy study (summarized in Refs. [2–4]) provided a number of measured $B(E2)$ values, which clearly disagree with vibrational model predictions. Moreover, two advanced theoretical models, i.e.,the symmetry-conserving configuration-mixing (SCCM) method [5, 6] and the General Bohr Hamiltonian (GBH) approach [7], suggest the presence of multiple shape coexistence in the ^{110}Cd isotope. To verify this hypothesis the shapes of the 0^+ states in ^{110}Cd need to be established. This requires experimental information such as transitional and diagonal $E2$ matrix elements and their relative signs, which can be obtained using the Coulomb-excitation technique [8].

This investigation began at the Heavy Ion Laboratory, University of Warsaw, and focused on the lowest-lying states in ^{110}Cd, Coulomb excited with 35-MeV ^{14}N [9] and 91-MeV ^{32}S [10] beams delivered by the Warsaw cyclotron. In the experiment with the ^{14}N beam, 5 excited states were populated. Based on the obtained γ-ray yields and known spectroscopic data, a set of electromagnetic matrix elements was determined using the GOSIA code [11]. This allowed us to determine the lifetime of the 2_2^+ state, $\tau(2_2^+) = 1.40(-8;+6)$ ps [12]. This value is much more precise, with a relative uncertainty of 3%, than those reported in the literature, having uncertainties ranging from 22% to 37% [4, 13–15].

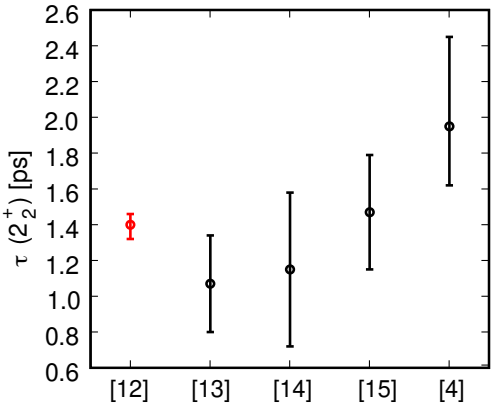

Figure 1: The 2_2^+ lifetime obtained from Coulomb excitation of ^{110}Cd [12] compared with the literature values [4, 13–15].

Building on the successful experiments carried out at HIL we performed a Coulomb-excitation experiment with a 187-MeV ^{60}Ni beam at Legnaro National Laboratories in Italy [12, 16] to explore non-yrast states in ^{110}Cd at higher excitation energies. The experiment was carried out using a combination of the gamma-ray spectrometer AGATA [17, 18] and the particle detection array SPIDER [19]. In total 19 excited states were populated up to 2.8 MeV excitation energy, including particularly the 0_3^+ state at 1731 keV. Precise knowledge of spectroscopic data related to their decay, such as the 2_2^+ lifetime, will provide important constraints for the data analysis

aiming at the extraction of matrix elements between all states populated in the ^{60}Ni + ^{110}Cd experiment.

The ongoing analysis of data collected during the experiment performed at LNL is the subject of the PhD thesis of I.Z. Piętka at the University of Warsaw, Poland.

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C.7 First report on the SilCA(DSSD) + EAGLE (+NEDA) in-beam commissioning at the HIL Warsaw: Coulomb excitation of ^{104}Pd.

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The versatile SilCA scattering chamber, designed and built at the Heavy Ion Laboratory in Warsaw in 2022 to accommodate various particle detectors, including CD-like annular DSSD (Double-Sided Silicon Strip Detector) detectors [1], was placed in the frame of the EAGLE spectrometer [2] in late 2023, after a successful experimental campaign at the IJC Lab in Orsay [3], see Fig. 1. The DSSD detector, after maintenance performed at the University of Lund (Sweden), was tested with ^{241}Am α source in February 2024. The tests were carried out with CAEN V1725(S,SB) digitizers using COMPASS [4] and XDAQ CERN-LNL software [5].

During the November 12-15th experiment, the SilCA(DSSD) array set-up was commissioned in-beam with the EAGLE spectrometer using the XDAQ and the readout of the CAEN V1725 digitizers (+ AGAVA module, for data synchronisation).

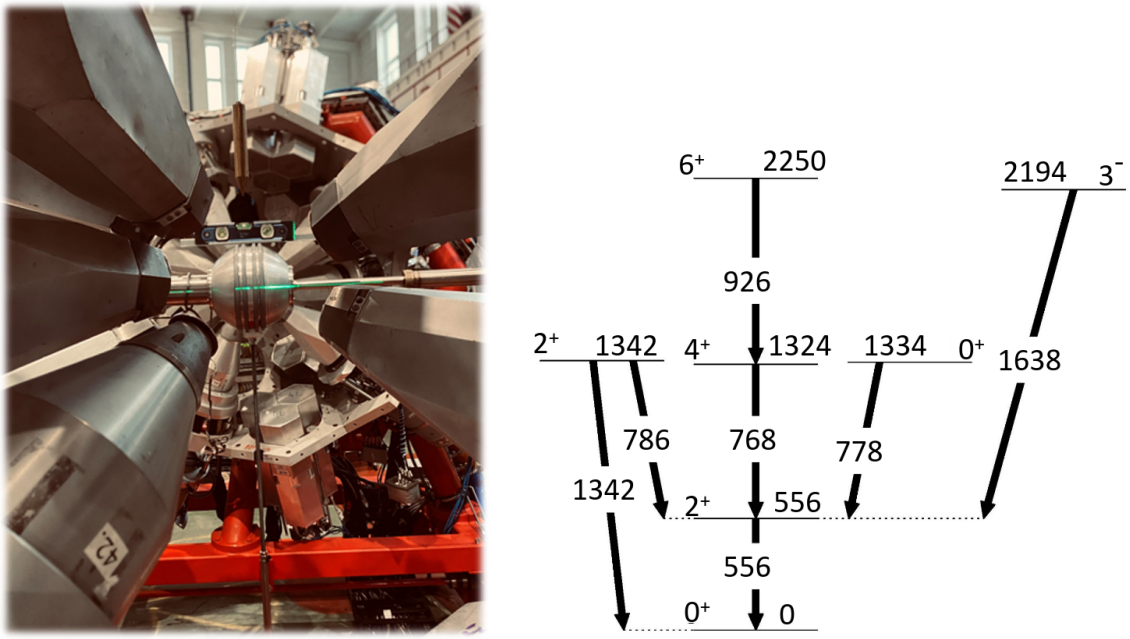

Figure 1: Left panel: The Warsaw DSSD detector in the SilCA scattering chamber, placed in the EAGLE frame. Right panel: ^{104}Pd level scheme [7].

In this experiment, the γ-rays emitted from the Coulomb-excited ^{104}Pd target nuclei were measured in coincidence with the ^{32}S projectiles delivered by the Warsaw cyclotron with 90 MeV energy and 1.5 pnA intensity.

The DSSD array was biased on the ring's (ohmic) side (+220 V) using a CAEN NDT1419 module with the online monitoring option that allowed quick compensation of the increased dark current (observed due to irradiation of the detector with heavy ions, causing possible radiation damage) with an increase in the voltage on the DSSD.

The signals from the DSSD array were collected using three Mesytec MPR16 preamplifiers (one for the 16 ring channels (R), two for the 32 channels of the radial sectors - the readout from the left and right sides of the DSSD array, denoted S1 and S2, 16 channels each). The signals were then transferred through in-house made differential-to-single-ended converters to CAEN V1725 modules, used for the final electronic data processing.

In the present experiment, two CAEN 1725 cards were used for the readout of the EAGLE HPGe detectors (on loan from the GAMMAPOOL consortium), three for the DSSD array and one for the signals from 15 NEDA fast scintilator detectors [6], which were also included in the data stream for the purpose of testing the timing properties.

The data were collected in the *particle* : (*Ring*&*Sector*) trigger mode, which means that only events with particles registered in the DSSD (front and back) were taken into account. In this way, the volume of the data was significantly limited, compared to the $\gamma - only$ trigger condition. The γ-ray spectrum collected in the experiment is presented in Fig. 2.

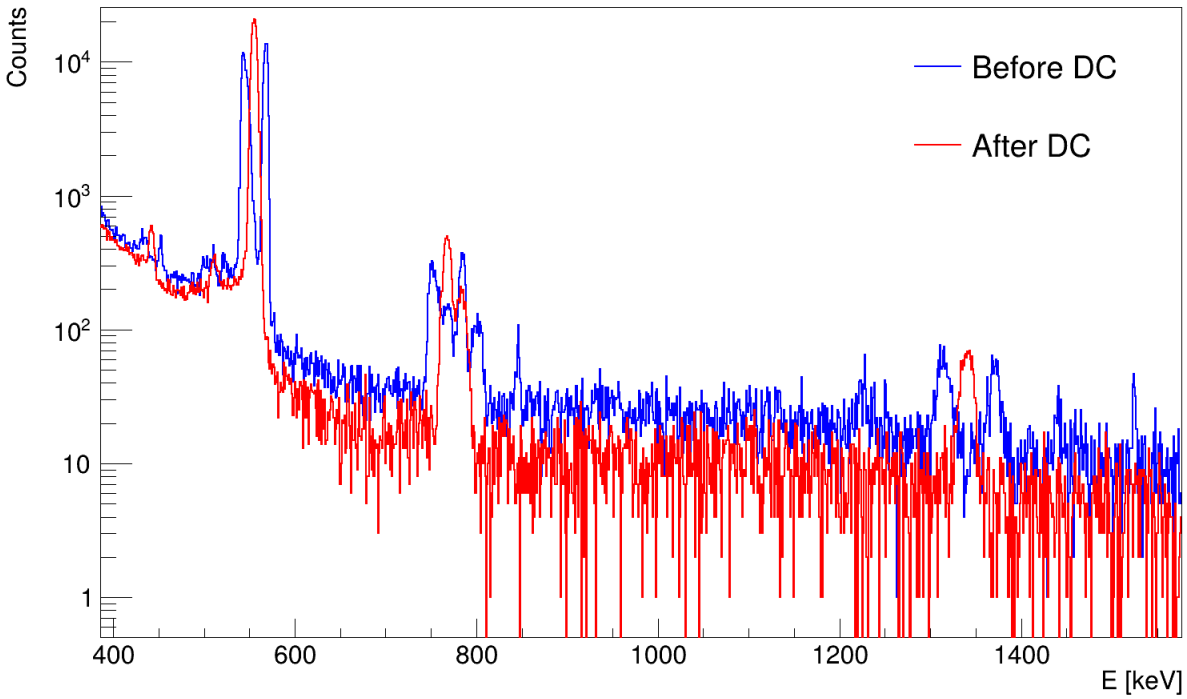

Figure 2: The $p - \gamma$ coincidence prompt-gated γ-ray spectrum, Doppler-corrected for the ^{104}Pd velocity (red) compared with the spectrum without any correction (blue).

Individual prompt-gated and random-subtracted γ-ray spectra were added for all HPGe to produce the total statistics from approximately 18 hours of data collection. The spectrum presented in Fig. 2 is still preliminary because proper optimization of the DSSD angles, random coincidence subtraction, and the event-by-event velocity calculation must be carefully applied. The data are currently being processed to improve the Doppler correction. At this stage of the analysis we can distinguish the lines coming from the excited 2_1^+ state at 555 keV, 2_2^+, 4_1^+, 0_2^+ states (a triplet of γ lines of energy about 750-800 keV), as well as the 1342 and 1638 keV transitions deexciting the 2_2^+ and 3_1^- levels; see the level scheme presented in the right panel of Fig. 1. As a reference point, we use the data from a ^{104}Pd Coulomb excitation reaction with a ^{32}S beam, performed at HIL Warsaw in 2015 in similar conditions, published in Ref. [7].

The commissioning experiment was successfully completed and will be followed by a campaign of measurements with the EAGLE+SilCA(DSSD) setup, foreseen for spring 2025.

Additionally, the chamber is currently being redesigned to accommodate a set of side detectors mounted in the forward hemisphere, extending from around 90 degrees towards lower angles. This work is being pursued in parallel to the in-beam experimental campaign.

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C.8 Transfer cross sections at near-barrier energies for the ^{20}Ne + ^{92,94,95}Mo systems

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The quasielastic barrier distributions (D_{qe}) of the ^{20}Ne+^{92,94,95}Mo systems were measured [1] to investigate the influence of dissipation due to non-collective excitations on the shape of the barrier distributions [2–5]. In this perspective, the strongly deformed ^{20}Ne was chosen as the projectile, while isotopes, which differ in their single particle level densities, were used as target nuclei. In particular, the density of the single particle (s.p.) levels gradually increases with the atomic masses of the three Mo isotopes, thus a smoothing of the barrier distributions should be manifest in the heavier Mo nuclei.

The preliminary experimental results for D_{qe} are compared with theoretical calculations in Fig. 1. As shown in Fig. 1, the experimental D_{qe} is still structured for the ^{92}Mo target, where the level density is low. On the other hand, such structure is significantly smoothed out for the ^{94}Mo and ^{95}Mo targets, which present a higher s.p. level density.

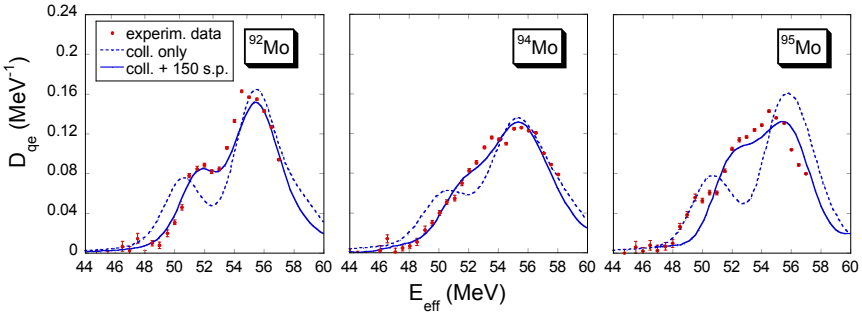

Figure 1: Comparison of the experimental barrier distributions (preliminary results) of the ^{20}Ne+^{92,94,95}Mo systems with the theoretical predictions obtained including (solid blue lines) and not (dashed blue lines) dissipation due to non-collective excitations.

The theoretical calculations were performed within the Coupled Channel (CC) model [6–8] (dashed lines) by including the rotational coupling to the first three excited states of ^{20}Ne and vibrational couplings up to the two-phonon excitations of the first quadrupole and octupole excited states of the ^{92,94}Mo isotopes. In the case of ^{95}Mo, the couplings to the one phonon excitation of the $3/2^+$ and the two phonon excitations of the $5/2^+$ excited states were included. The couplings to the first 150 s.p. levels of the target nuclei were included (solid lines) within the CCRMT model [9, 10]. When the couplings to the non-collective excitations are taken into account, the calculations nicely reproduce the experimental D_{qe} of the ^{20}Ne+^{92,94,95}Mo systems, supporting the hypothesis that the dissipation caused by non-collective excitations plays an important role in the smearing of the barrier distribution.

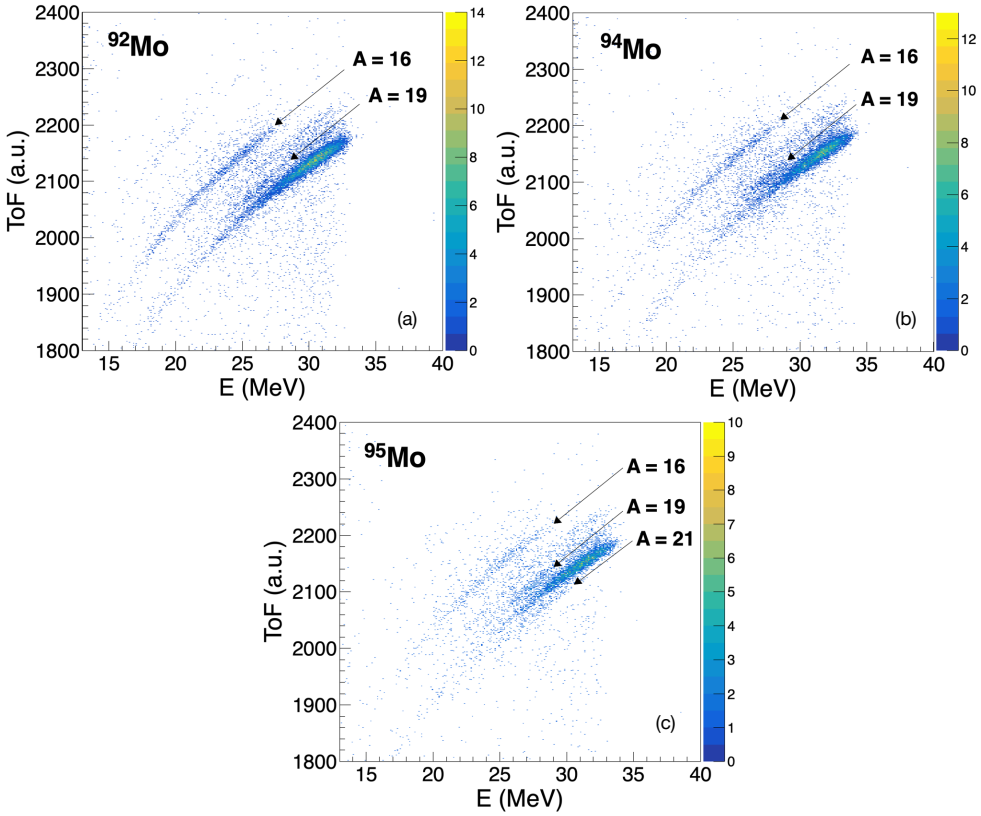

Figure 2: Transfer product identification in mass for the ^{20}Ne+^{92,94,95}Mo systems at a beam energy of 73 MeV.

However, another dissipative mechanism, namely the mutual projectile-target transfer of light particles, might also be responsible for the structureless shapes of the two Mo isotopes.

The effect of couplings to nucleon transfer channels proved to be certainly important in the near and sub-barrier fusion processes. Nevertheless, their role in fusion reactions is still controversial [11–14]. Recently, an upgrade of the CCFULL-SC [8] code was implemented by improving the method of coupling to the transfer channels during fusion and backscattering processes [15]. In particular, in the modified code, several transfer channels can be included simultaneously and the dependence of the strength of the transfer coupling on the transferred particle and experimental Q-value distributions were introduced. The upgraded code was employed for the investigation of the influence of transfer on the smoothing of the measured D_{qe} of the ^{20}Ne + ^{208}Pb system [15], for which the Q-value distributions were measured at two projectile kinetic energies. It turned out that at the higher beam energy it is the one-neutron pick-up which mainly influences the smoothing of the D_{qe}, while the one-neutron pick-up and one proton stripping transfers are dominant for the lower beam energy. Such results suggest the need to include a dependence of the transfer coupling on the projectile kinetic energy.

The most direct method to obtain experimental information about the influence of the dissipation due to transfer channels on the D_{qe} is a measurement of the transfer cross sections. By measuring the transfer cross sections for various transfer channels and comparing the results for neighboring isotopes, it is possible to determine whether the transfer couplings might play a significant role in the dynamics of the reaction [16–18]. This can be performed by the direct measurement of the transfer cross sections at a backward angle, since at energies near the Coulomb barrier the transfer angular distribution has a flat maximum at backward angles. Such measurements should give good information about the contributions of the various transfer channels on the D_{qe}.

An experiment of this kind was performed recently at the Heavy Ion Laboratory (HIL) of the University of Warsaw for the ^{20}Ne + ^{92,94,95}Mo systems. The U200-P Cyclotron at HIL provided the ^{20}Ne beam at an average current of 20 enA and energies of 73 and 71 MeV, while lower energies of 68 and 66 MeV were obtained by employing thin ^{nat}Ni and ^{nat}Au degraders. The four different beam energies were chosen to investigate the evolution of the Q-value distributions and therefore study the influence of dissipation due to transfer on the barrier distribution structure [15]. Targets of $^{92,94,95}MoO_3$ were used with a thickness of 181, 156 and 162 $\mu g/cm^2$, respectively, and a C-backing of 40 $\mu g/cm^2$. The identification in mass of the products was performed using the Time of Flight (ToF) method. The set-up consisted of an array of 13 silicon detectors combined with a Microchannel Plate (MCP) detector placed at 142 degrees. An E-ΔE telescope placed at the same angle provided the charge identification of the transfer products. Three silicon detectors at forward angles were used for precise beam energy measurement and monitoring.

Figure 2 shows the E-ToF matrices for the three systems at a beam energy of 73 MeV. Such preliminary results indicate transfers leading to mass A = 19 and 16 as the main transfer channels in all three systems, but in the case of ^{95}Mo one neutron pick-up (A=21) also occurred. The ongoing analysis should clarify the influence that such transfer channels might have on the structures of the barrier distributions.

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C.9 Decomposition of the GBH wave functions into seniority components

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Quadrupole collective excitations, an important part of the low and mid-energy nuclear spectrum, are commonly described by operators acting in the five-dimensional space of the rank-2 mass tensor components. A very fruitful concept is to employ the so-called intrinsic (INT, principal-axes) frame of reference. Here, the quadrupole variables are β, γ, which describe the deformation of the nucleus and the Euler angles Ω, that define the orientation of the intrinsic frame with respect to the LAB frame. Construction of an INT frame basis which spans the domain of Hamiltonians used in nuclear physics, from a simple harmonic oscillator to a more complicated General Bohr Hamiltonian, is not entirely straightforward. There are two main approaches to accomplishing this task.

In the first approach, called GT here, one exploits the group-theoretical properties of the harmonic oscillator (H.O.) Hamiltonian to construct its eigenfunctions. The chain of subgroups with corresponding Casimir operators plays here a primary role

$$U(5) \supset SU(5) \supset SO(5) \supset SO(3) \tag{1}$$

The kinetic part of the H.O. can be written (assuming the mass parameter $B = 1$)

$$T = -\frac{1}{2}\beta^{-4}\partial_\beta\beta^4\partial_\beta - \frac{1}{2}\beta^{-2}(\sin 3\gamma)^{-1}\partial_\gamma \sin 3\gamma\partial_\gamma + \frac{1}{2}\sum_{k=1}^{3} I_k^2/W_k \tag{2}$$

where I_k is the component of the angular momentum operator in the INT frame, and $W_k = 4\beta^2\sin^2(\gamma - 2\pi k/3)$ is the moment of inertia. The full H.O. Hamiltonian $(T + \beta^2/2)$ is a linear Casimir operator of the $U(5)$ group and the quadratic Casimir operator of $SO(5)$ is built from the two last parts of Eq. 2

$$C_{2,SO(5)} = -\frac{1}{2}\beta^{-2}(\sin 3\gamma)^{-1}\partial_\gamma \sin 3\gamma\partial_\gamma + \frac{1}{2}\sum_{k=1}^{3} I_k^2/C_k \tag{3}$$

The eigenfunctions of the H.O. Hamiltonian have the form

$$F^{N,\nu,\kappa,J,M}(\beta,\gamma,\Omega) = \tilde{\Lambda}^{N,\nu}(\beta)\tilde{\Xi}^{\nu,\kappa,J,M}(\gamma,\Omega) = \tilde{L}^{\nu+3/2}_{(N-\nu)/2}(\beta^2)\beta^\nu e^{-\beta^2/2}\sum_K \xi_K^{\nu,\kappa,J}(\gamma)\Phi^J_{MK}(\Omega) \tag{4}$$

where $\tilde{L}^a_b$ is a normalized associated Laguerre polynomial of degree b and $\Phi^J_{KM} = N_W(D^{*J}_{MK} + (-1)^J D^{*J}_{M,-K})$ is a symmetrized and normalized combination of the Wigner matrices D. The functions ξ, the only really hard to find components, are trigonometric polynomials of degree ν. The explicit form of the ξ functions can be found e.g. in [1, 2].

The eigenvalues of the $C_{1,U(5)}$ and $C_{2,SO(5)}$ operators can be expressed through the indices N and ν, respectively. The N number is interpreted as the phonon number, and ν is the so-called (phonon) seniority number. It appears that for some values of N and ν there can be several equivalent representations of $SO(3)$ (with the same J), and an additional index (here, κ) is needed to distinguish them. The κ number does not have a group-theoretical meaning and can be chosen arbitrarily to a large extent. This problem occurs only for $J \geq 6$.

In the second approach [3], called PS here, the starting point is the set of products

$$\exp(-Q)\beta^n t_m(\gamma)D^{*J}_{MK}(\Omega), \tag{5}$$

where $t_m = \cos m\gamma$ or $\sin m\gamma$ and $Q(\beta,\gamma)$ is a function invariant against the action of the discrete subgroup O_h of the rotation group. This subgroup leaves three intersecting perpendicular straight lines in R^3 invariant (a prototype of the coordinate frame). Moreover, Q must ensure integrability of the product (Eq. 5) over the whole deformation space. The most important example, and most useful in practice, is $Q = \beta^2/2$. In the following, I assume this form of Q.

The construction of the basis then comprises three steps.

1. Projection on the subspace invariant w.r.t. the group O_h and selection of linearly independent functions.

2. Construction of functions that lie in the domain of the rotational energy operator (here, one should check the behaviour of the functions at the $\gamma = k\pi/3$ axes)

3. Orthonormalization (after proper ordering of the functions).

As a result, one obtains functions

$$\Psi^{n,m,L,J,M}(\beta,\gamma,\Omega) = \tilde{\Lambda}^{n,m}(\beta)\tilde{G}^{m,L,J,M}(\gamma,\Omega) = \tilde{L}^{m+3/2}_{(n-m)/2}(\beta^2)\beta^m e^{-\beta^2/2}\sum_K g^{m,L,J}_K(\gamma)\Phi^J_{MK}(\Omega) \tag{6}$$

where $\tilde{L}$ are again associated Laguerre polynomials and g are trigonometric polynomials of degree m. However, the range of, and interrelations between, indices n, m, L and J are different from those in the first approach. It is not evident a priori if and how ξ and g are linked. However, inspection of the cases of the lowest values of N, ν and n, m shows that ξ and g are quite similar.

The following is the reason for a deeper analysis of the connections between the two bases. The PS basis is used in numerical codes to solve the eigenvalue problem of the most general Bohr Hamiltonian. On the other hand, the notion of seniority (inherent in the GT approach) is widely used in the simplified, quasi-solvable models where the kinetic part is taken from the H.O. while the potential energy exhibits a more general dependence on the deformation variables. In particular, when the potential is independent of γ the seniority is a good quantum number. Moreover, the $SO(5)$ group also plays an important role in algebraic IBM-type approaches. Hence, to get a more qualitative interpretation of the GBH results and compare them with other models, it would be helpful to decompose the GBH eigenfunctions into representations of $SO(5)$ (labelled by the seniority number). One possible way to achieve this aim is to express the orthonormal eigenfunctions of the $C_{2,SO(5)}$ operator as linear combinations of the functions $\tilde{G}$, (Eq. 6). The subsequent calculations were done using the symbolic algebra package Maxima. Hence, the obtained results are analytical, without any numerical inaccuracies.

The calculations have been performed for a finite range of n, m and J. However, the range is sufficiently large for numerical applications. The results can be summarized as follows.

1. For $J < 6$ we have

$$C_{2,SO(5)}\tilde{G}^{m,J,M} = m(m+3)\tilde{G}^{m,J,M}, \tag{7}$$

hence, the functions g are identical (up to a phase factor) to ξ. The m index is equal to the seniority number ν, and ranges of relevant indices are identical for both approaches.

2. For $6 \le J$ the eigenfunctions of $C_{2,SO(5)}$ (and in consequence the $\tilde{\Xi}$ functions) are finite linear combinations of $\tilde{G}$. For the $m(m+3)$ eigenvalue the combination contains the $\tilde{G}^{m'}$ functions with $m' \le m$. It is worth adding that the inverse transformation is not so simple. A given $\tilde{G}$ can be expressed by $\tilde{\Xi}$'s only as an infinite series.

Below, I give one of the simplest examples of the obtained eigenfunctions

$$\tilde{\Xi}^{\nu=4,J=6} = \frac{11}{2\sqrt{3}\sqrt{13}}\tilde{G}^{m=2,J=6} + \frac{\sqrt{5}\sqrt{7}}{2\sqrt{3}\sqrt{13}}\tilde{G}^{m=4,J=6} \tag{8}$$

Additional labels (κ and L) are unnecessary here.

Within the GT approach, a projection operator of a given seniority for a fixed J can be written immediately (cf. Eq. 4)

$$P_{\nu,J,M} = \sum_{N,\kappa} |F^{N,\nu,\kappa,J,M}\rangle\langle F^{N,\nu,\kappa,J,M}| \tag{9}$$

Now, when we have expressed the F functions through the Ψ functions, we can easily apply the operator $P_{\nu,J,M}$ to any function defined in the PS basis.

As an example of the application of the method presented in this report, I show in Fig. 1 plots of the seniority decomposition of the wave functions of the 2_3^+ states in ^{110}Cd calculated within the GBH model with the SLy4 and UNEDF0 interactions. The plotted quantity $p(\nu)$ is the probability of a given seniority and can written as $p(\nu) = |\langle 2_3^+ | P_{\nu,J=2} 2_3^+ \rangle|^2$. The visible difference between these decompositions reflects the fact that the SLy4 interaction predicts greater deformation than the UNEDF0 interaction.

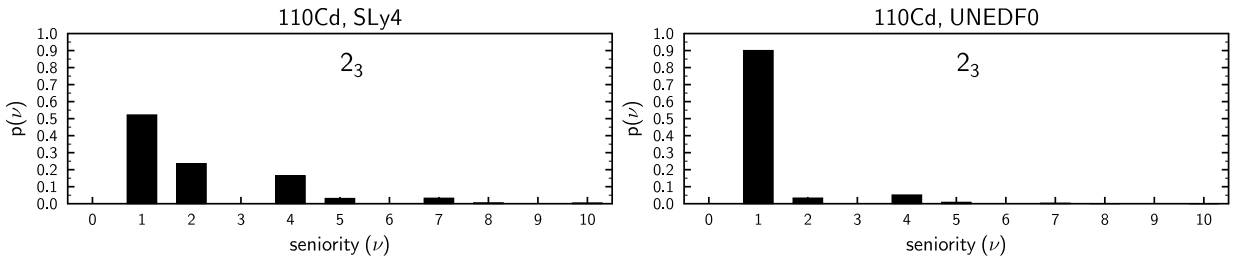

Figure 1: Plots of the seniority decomposition of wavefunctions of the 2_3^+ states in ^{110}Cd calculated within the GBH model with the SLy4 and UNEDF0 interactions.

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C.10 Energy and target dependence of deuteron elastic breakup

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Many of the theoretical calculations of the elastic breakup of the deuteron are performed with some artificialy adjusted parameters. One of the most used models is the continuum-discretized coupled-channel (CDCC) method,which is based on a knowledge of the nucleon-target interaction [1]. Quite often such an optical potential at the proper energy is not known and, instead, a potential that is as close as possible to the target and the energy appropriate to the investigated process is adopted. Usually, in such a case normalization factors the its real and imaginary parts of the potential are introduced in the calculations as free parameters [5, 9].

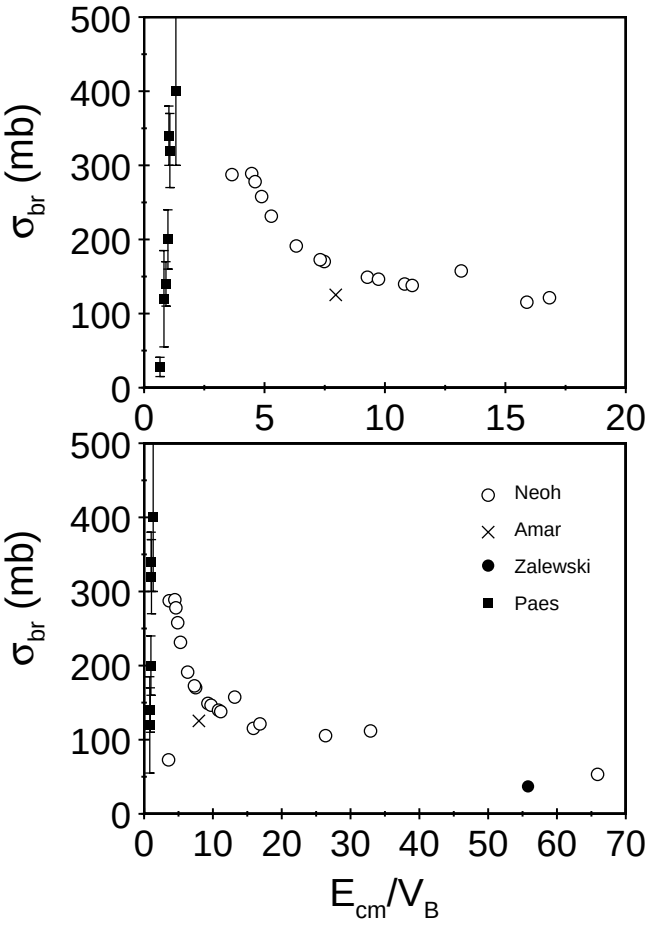

Figure 1: Comparison of calculated [2, 9, 11] and measured [7] values of the elastic deuteron breakup cross sections.

The calculated values of the deuteron breakup cross section depend on these factors. Specifically, a decrease in the normalization factor of the imaginary part leads to larger values of the calculated breakup cross section [9]. Thus, a knowledge of the global dependence of the breakup cross section on the deuteron energy for various scattering systems can serve as an important criterion for the choice of this factor.

Recently, d+^{6}He elastic scattering data were analyzed by means of CDCC calculations that included elastic breakup of the deuteron [2]. The calculations were free of any adjustable parameters as the input p+^{6}He potential at the corresponding energy was known [8]. In this contribution we compare the value of the calculated breakup cross section with the results obtained from similar studies performed for many d+target systems and energies [9, 11], as well as with a recent experimental data set [7].

The results are plotted in Fig.1 as a function of the ratio of the center of mass energy (E_{cm}) to the Coulomb barrier height (V_B). The lower panel of the figure presents all the results from Refs [2, 7, 9, 11]. The calculations were performed at energies above the Coulomb barrier and they show an exponential decrease of the values with increasing of the E_{cm}/V_B. The data measured for the d+^{197}Au system at energies below the barrier show a rapid decrease of the cross section.

In the upper panel, a selected amount of the data from the lower panel is presented, for a reduced range of E_{cm}/V_B values, in order to illustrate better the results close to the Coulomb barrier. The point corresponding to the d+^{58}Ni scattering at 21.6 MeV was removed from the CDCC calculations of Neoh *et al.* since, according to the Authors, at this low energy the calculations were not sufficiently converged. The presented data form an evident trend, typical for other direct processes, with the largest values of the cross section at energies close to the Coulomb barrier.

The experimental data of Paes *et al.* [7] were well reproduced by calculations performed using the computer code EMPIRE [8]. It would be of great interest to continue these calculations for the higher energies, as well as to collect more experimental data in the higher energy range.

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C.11 Breakup of the deuteron and its effect on the d+^{6}He elastic scattering at 52 MeV

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Breakup of the deuteron in the field of a target nucleus has been studied for many scattering systems involving stable target nuclei [1–3], but a study with the radioactive ^{6}He "target" has not previously been performed. The d+^{6}He system is an interesting case since it allows for an extention of standard theoretical models for many body systems [4–6]. In this report we present some theoretical predictions for the deuteron breakup and its effect on the d+^{6}He elastic scattering. Recently, Descouvmont analyzed a similar system, d+^{11}Li, using two methods - standard three-body (p+n)+^{11}Li continuum discretized coupled channel (CDCC) calculations and his five-body (p+n)+(n+n+^{9}Li) model [4]. Both methods yielded similar results showing that the effects of the ^{11}Li structure were incorporated into the effective nucleon+^{11}Li optical model potential used as input to the three-body calculations. Thus, taking advantage of the fact that the p+^{6}He elastic scattering has previously been analysed and the effective p+^{6}He potential at the proper energy is thus known [7, 8], in the present analysis of the d+^{6}He interaction only breakup of the deuteron was explicitly included.

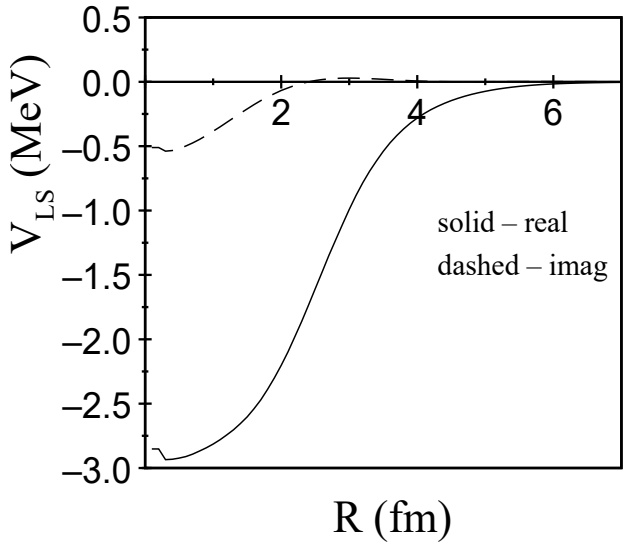

Figure 1: Calculated spin-orbit potential for d+^{6}He scattering at 52 MeV.

In the analysis, the potential binding the neutron and proton was adopted from the study of Amar *et al.* [9]. The wave function of the ground state of the deuteron was the sum of the S+D components, with the spectroscopic amplitudes given in [9].

The optical potential for d+^{6}He was calculated by folding the effective p+^{6}He optical potential from the previous study [8] with the wave function of the deuteron ground state, assuming that the n+^{6}He nuclear potential is the same as the p+^{6}He. Since the effective p+^{6}He optical potential included a spin-orbit part, the complex spin-orbit potential for the deuteron scattering was calculated according to Ref [10] and it plotted in Fig. 1. The dashed curve plotted in Fig. 2 shows optical model calculations for the d+^{6}He elastic scattering at a deuteron beam energy of 52 MeV.

The effects of the deuteron breakup were included by means of the CDCC method. The breakup S and D-states were truncated at a momentum of 1.0 fm^{-1} and these states were represented by bins of equal width of 0.125 fm^{-1}. All the coupling potentials were calculated from the input p+^{6}He optical potential. Thus, the calculations were free of any adjustable parameters. The applied procedure followed closely the so called Kyushu model [1].

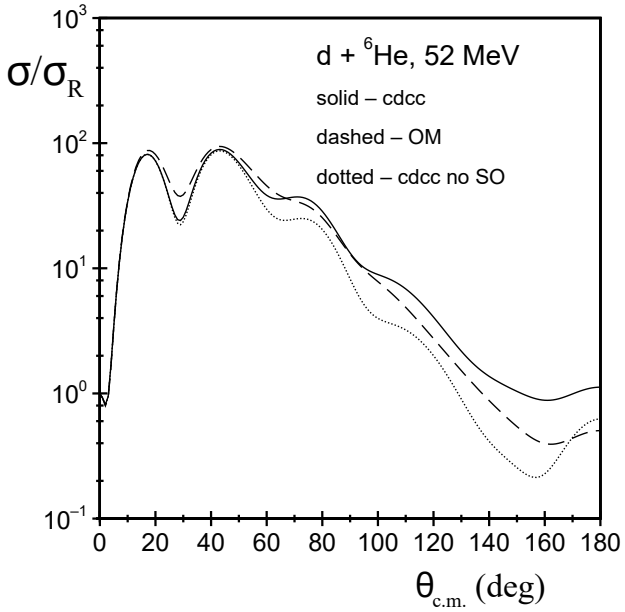

Figure 2: Calculated angular distribution for the d+^{6}He elastic scattering at 52 MeV using optical model (dashed curve), CDCC method (solid curve) and CDCC method with the spin-orbit potential in the elastic channel omitted (dotted curve).

Results of the CDCC calculations are shown in Fig.2. Coupling to the p-n breakup states modifies the angular distribution obtained with the optical model. However, the effect is very modest, changing the corresponding total reaction cross section values by a few percent. The spin-orbit potential in the elastic channel plays an important role, affecting the final result of the CDCC calculations at scattering angles greater than 40 degrees (comparison of the solid and dotted curves). The calculated breakup cross section was dominated by couplings with the D-states of the continuum. Its value was smaller than the values for other systems investigated in a similar way [9, 11].

All the calculations presented in this report were performed by means of code Fresco [12].

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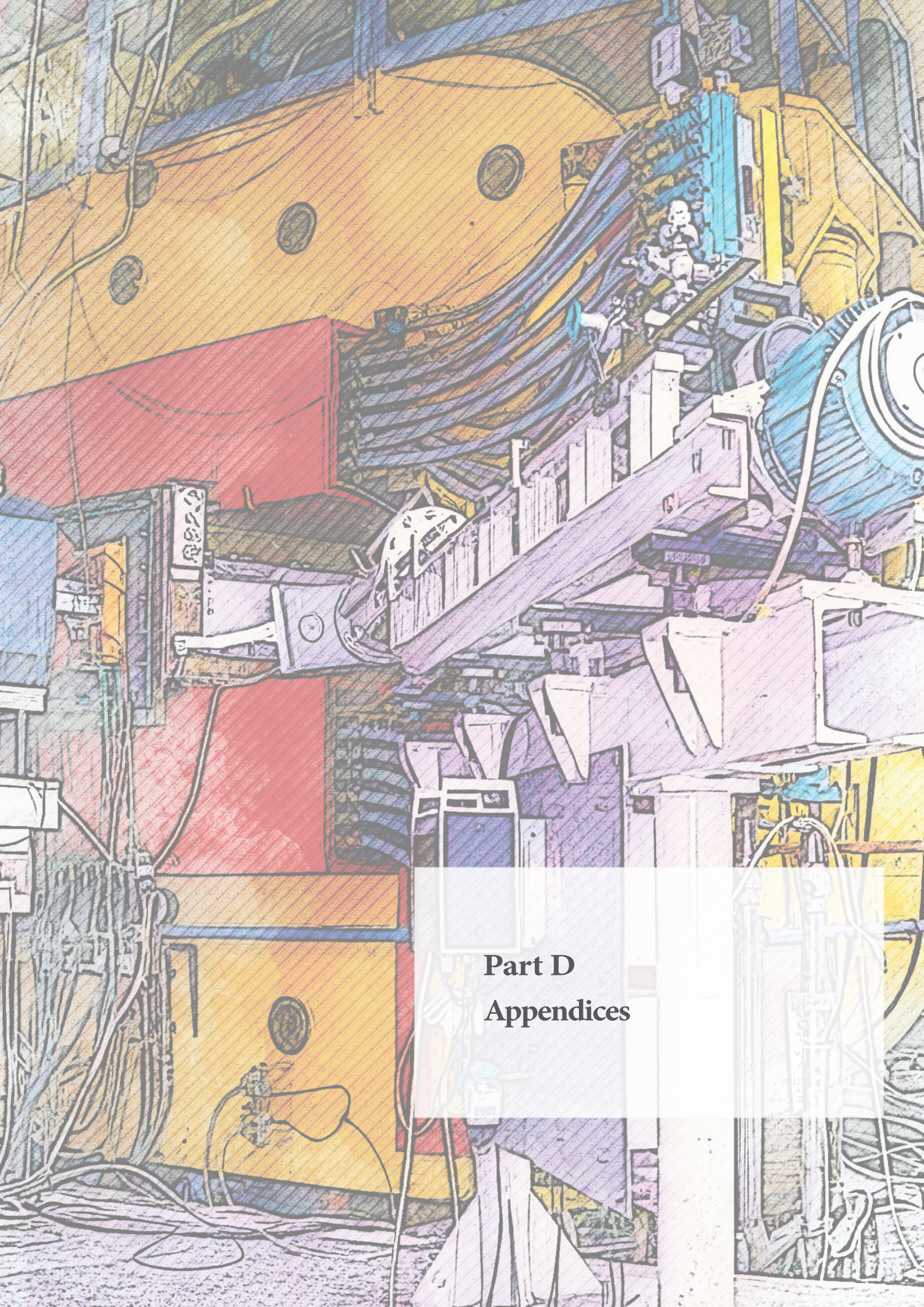

Part D
Appendices

D.1 List of experiments performed at HIL in 2024

A list of the experiments performed in 2024 is presented in the following pages.
The following acronyms of institution names are used in the list:

- HIL — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland;
- ANKARA — Ankar University, Ankar, Turkey;
- ARGONNE — Argonne National Laboratory, Argonne, USA;
- ATOMKI — HUN-REN ATOMKI, Debrecen, Hungary;
- CH UW — Faculty of Chemistry, University of Warsaw, Warszawa, Poland;
- DP UL — Depatartment of Physics, University of Liverpool, Liverpool, UK;
- ECNU — Department of Physics, East China Normal University, Shanghai, China;
- FP UW — Faculty of Physics, University of Warsaw, Warszawa, Poland;
- GANIL — GANIL, Caen, France;
- GSI — GSI Helmholtz Center for Heavy Ion Research, Darmstadt, Germany;
- IJCLab Orsay — Lab. de Physique des 2 infinis Irène Joliot-Curie, Orsay, France;
- IMP CAS — Inst. of Modern Physics, Chinese Academy of Science, Lanzhou, China;
- INFN-LNS Catania — LNS, INFN e Università di Catania, Catania, Italy;
- INP PAN Kraków — Institute of Nuclear Physics PAN, Kraków, Poland;
- INP UK Cologne —Institute for Nuclear Physics, University of Cologne, Germany;
- KTH Stockholm — KTH Royal Institute of Technology, Stockholm, Sweden;
- NCNR Świerk — National Centre for Nuclear Research, Otwock, Poland;
- U Bordeaux —LP2I, Bordeaux-Gradignan, France
- U Fraser—Department of Chemistry, Simon Fraser University, Burnaby, Canada
- U Jyväskylä — Department of Physics, University of Jyväskylä, Finland;
- U Szczecin—Institute of Physics, University of Szczecin, Szczecin, Poland;

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

^{32}S — 150 MeV — EAGLE + NEDA + DIAMANT 16.01 – 31.01
HIL114 — Gamma Ray Spectroscopy of ^{134}Sm (B. Saygi)
FP UW, HIL, GSI, GANIL, ATOMKI, INP PAN Kraków, ANKARA, TENMAK, NCNR Świerk

^{20}Ne — 65-73 MeV — ICARE 01.03 - 13.03
HIL111 — Transfer cross sections at near-barrier energies for the ^{20}Ne + ^{92,94,95}Mo systems (G. Colucci, E. Piasecki, A. Trzcińska)
HIL, INFN-LNS Catania, U Jyväskylä, FP UW, U Szczecin

^{32}S — 200-220 MeV — EAGLE + NEDA + DIAMANT 18.03 – 26.03
HIL117 — ^{144}Dy fission studies (K. Miernik)
FP UW, HIL, INP PAN Kraków, CH UW, IJCLab Orsay, ATOMKI, U Bordeaux

^{14}N — 70-98 MeV — Exposure station 22.04 - 26.04
HIL104 — Investigation of radiation hardness of a 10 μm, self-biased epitaxial silicon detector operated in a built-in-field bias potential (A. Kordyasz)
HIL

^{12}C — 68-72 MeV — EAGLE + DIAMANT + NEDA 07.05 – 24.05
HIL126 — Search for candidate wobbling bands in ^{103}Pd and ^{101}Ru (I. Kuti)
ATOMKI, HIL, IJCLab Orsay, IMP CAS, U Fraser, DP UL

^{20}Ne — 77 MeV— EAGLE + NEDA, Radiobiology, ICARE 18.06 – 27.06
HIL-BTS —Basic Training School on Accelerators
HIL

^{20}Ne — 57 MeV — EAGLE + NEDA, Radiobiology, ICARE 20.10 – 26.10
HIL001 — Student Workshop
HIL

^{32}S — 90 MeV — EAGLE + SilCA 12.11 – 15.11
HIL000 — The SilCA Double-Sided Silicon Strip Detector commissioning (K. Hadyńska-Klęk)
HIL, IJCLab Orsay, INP PAN Kraków

^{32}S — 164.8-169 MeV — EAGLE + Cologne Plunger 20.11 – 27.11
HIL109 — Lifetime studies in neutron-deficient ^{172}Os using the RDDS technique (C. Fransen, C. Lakenbrink, F. von Spee)
INP UK Cologne, HIL, U Jyväskylä, KTH Stockholm, ARGONNE

^{22}Ne — 85-90 MeV — EAGLE + Cologne Plunger 04.12 – 16.12
HIL124 — Search for transition between chiral and non-chiral configuration in ^{128}Cs by lifetime measurement of I=11$^+$, 12$^+$ states with a plunger technique (A. Nałęcz-Jawecki)
NCNR Świerk, HIL, INP UK Cologne, FP UW, ECNU

D.2 Degrees and theses completed or in progress during 2024

D.2.1 DSc degrees of HIL staff members

Auganbek Sabidolda, Al-Farabi Kazakh National University, Almaty, Kazakhstan
Study of nucleon transfer reactions in the $^{10}B+^{12}C$ interaction at energies near the Coulomb barrier for nuclear astrophysics
Supervisors: prof. N. Burtebayev, K. Rusek. Thesis completed in June 2024.

Bogumił Zalewski, Heavy Ion Laboratory, University of Warsaw
Study of the $^{6}He+d$ interaction
Supervisor: prof. dr hab. K. Rusek. Thesis completed in September 2024.

Monika Mietelska, Faculty of Physics, University of Warsaw
Ionisation Detail Parameters for DNA Damage Evaluation in Charged Particle Radiotherapy: Simulation Study Based on Cell Survival Database
Supervisors: dr hab. Z. Szefliński and dr hab. B. Brzozowska. Thesis completed in December 2024.

Mateusz Filipek, Faculty of Physics, University of Warsaw
From radiobiology to radiotherapy: dose homogeneity in cells after alpha irradiation in measurements and Monte Carlo simulations
Supervisors: dr hab. Z. Szefliński and dr hab. B. Brzozowska. Expected completion date: 2025.

Grzegorz Wałpuski, Faculty of Biology, University of Warsaw
Badanie wpływu promieniowania jonizującego na procesy fizjologiczne ujednokomórkowych glonów z gromady Cyanidiophyceae
Study of the influence of ionizing radiation on physiological processes in single-celled algae from the class Cyanidiophyceae
Supervisors: dr hab. Z. Szefliński and dr hab. M. Zienkiewicz. Expected completion date: 2027.

Adam Nałęcz-Jawecki, Graduate School of Physics and Chemistry, National Centre for Nuclear Research, Otwock, Poland
Search for nuclear chirality in low excitation energy states of odd-odd isotopes
Supervisors: dr hab. E. Grodner and dr J. Srebrny. Expected completion date: 2025.

Iwona Piętka, Heavy Ion Laboratory, University of Warsaw
Badanie współistnienia kształtów w jądrze ^{110}Cd metodą wzbudzeń kulombowskich
Study of multiple shape coexistence in ^{110}Cd using the Coulomb-excitation method
Supervisor: dr hab. L. Próchniak and dr K. Wrzosek-Lipska. Expected completion date: 2027.

D.2.2 MSc and BSc theses supervised by HIL staff members

Magda Bielecka, Faculty of Biology, University of Warsaw
Ocena powinowactwa tetrakarboksyfenyloporfiryny i tetrasulfofenyloporfiryny do komórek nowotworowych nabłonkowego raka szyjki macicy linii HeLa
Assessment of the affinity of tetracarboxyphenylporphyrin and tetrasulfophenylporphyrin for HeLa cervical epithelial cancer cells
Supervisors: dr hab. K. Kilian. Thesis completed in July 2024.

Ewa Bieniasz, Faculty of Chemistry, University of Warsaw
Synteza 18F-fluoroetylotyrozyny (FET) na syntezerze Synthra RN
Synthesis of 18F-fluoroethyltyrosine (FET) on the Synthra RN synthesizer
Supervisors: dr hab. K. Kilian. Thesis completed in July 2024.

Stanisław Bitner, Paweł Pilarski, Kamil Pilkiewicz, Marek Zbysiński, Faculty of Mathematics, Informatics, and Mechanics, University of Warsaw
Sterowanie zasilaczami cewek korekcyjnych w cyklotronie (16 x 300A)
Control of power supplies for correction coils in a cyclotron Supervisor: mgr. P. Gołąb and mgr. inż. J. Miszczak. Thesis completed in July 2024.

Agnieszka Klempis, Jacek Muszyński, Jan Rogówski, Marcin Żołek, Faculty of Mathematics, Informatics, and Mechanics, University of Warsaw
Sterowanie zasilaczami 200A oraz 100A w Cyklotronie Warszawskim (ŚLCJ UW)
Control of 200A and 100A power supplies at the Warsaw Cyclotron(HIL UW)
Supervisors: dr J. Sroka and mgr. inż. J. Miszczak. Thesis completed in July 2024.

Agata Krzysiek, Faculty of Physics, University of Warsaw
Pomiary wydajności oraz liniowości rejestracji detektora typu DSSD układu SiLCA przy wykorzystaniu elektroniki cyfrowej
Efficiency and linearity measurements of a DSSD silicon detector for the SiLCA detector system using digital electronics
Supervisor: dr K. Hadyńska-Klęk. Thesis completed in September 2024.

Klaudia Koszel, Faculty of Physics, University of Warsaw
Oznaczanie pozostałości rozpuszczalników organicznych w radiofarmaceutyku 18F-fluorocholina
Determination of organic solvent residues in the radiopharmaceutical 18F-fluorocholine
Supervisor: dr hab. K. Kilian. Thesis completed in December 2024.

Wiktoria Dworak, Faculty of Chemistry, University of Warsaw
Synteza i kontrola jakości radiofarmaceutyków ^{18}F
Synthesis and quality control of ^{18}F radiopharmaceuticals
Supervisor: dr hab. K. Kilian. Expected completion date: 2025.

Katarzyna Głazowska, Faculty of Chemistry, University of Warsaw
Synteza radiofarmaceutyku 18FAZA na syntezerze Synthra RN
Synthesis of the radiopharmaceutical 18FAZA on the Synthra RN synthesizer
Supervisor: dr hab. K. Kilian. Expected completion date: 2025.

Julianna Hausman, Faculty of Chemistry, University of Warsaw
Oznaczanie związków polifenolowych w oleju kawowym
Determination of polyphenolic compounds in coffee oil
Supervisor: dr hab. A. Sentkowska. Expected completion date: 2025.

Michał Janiszewski, Faculty of Chemistry, University of Warsaw
Chromatograficzne oznaczanie selenu w miodzie-opracowanie nowej metodyki ekstrakcji i konserwacji próbek
Chromatographic determination of selenium in honey - development of a new methodology for sample extraction and preservation
Supervisor: dr hab. A. Sentkowska. Expected completion date: 2025.

Aniela Jakubowska, Faculty of Chemistry, University of Warsaw
Zastosowanie chromatografii HILIC do oznaczenia związków biologicznie aktywnych w fermencie chlebowym
Application of HILIC chromatography for the determination of B vitamins in bread ferment
Supervisor: dr hab. A. Sentkowska. Expected completion date: 2025.

Zuzanna Napora, Faculty of Chemistry, University of Warsaw
Jednodomenowe przeciwciało anty-HER2 znakowane teranostycznym ^{177}Lu – charakterystyka fizykochemiczna i biologiczna
Single-domain anti-HER2 antibody labeled with theranostic ^{177}Lu – physicochemical and biological characterization
Supervisors: dr hab. K. Kilian and prof M. Pruszyński. Expected completion date: 2025.

Michał Przystaś, Faculty of Chemistry, University of Warsaw
Kinetyka powstawania i zanikania ognisk naprawczych gamma-H2AX w komórkach glejaka eksponowanych na promieniowanie jonizujące
Kinetics of formation and disappearance of gamma-H2AX repair foci in glioma cells exposed to ionizing radiation Supervisors: dr hab. A. Korgul and dr U. Kaźmierczak. Expected completion date: 2025.

Justyna Sykuła, Faculty of Chemistry, University of Warsaw
Badanie akumulacji porfiryn w liniach komórkowych glejaka M059K i M059J
Porphyrin accumulation study in glioma cell lines M059K and M059J
Supervisors: dr hab. K. Kilian and dr U. Kaźmierczak. Expected completion date: 2025.

D.3 Publications

[1] M. Araszkiewicz, U. Kaźmierczak, A. Korgul, R. Kwiatkowski, A. Malinowska, K. Męczynska-Wielgosz, S. Męczynska-Wielgosz, A. Stolarz, Z. Szefliński, K. Tyminska. *The irradiation system for studying biological effects in glioblastoma cell lines after exposure to high let α particles appearing in bnct therapy.* Acta Phys. Pol. B Proc. Suppl. **17** (2024) A36.

[2] A. A. Bezbakh, M. S. Golovkov, A. S. Denikin, R. Wolski, S. G. Belogurov, D. Biare, V. Chudoba, A. S. Fomichev, E. M. Gazeeva, A. V. Gorshkov, G. Kamiński G., B. R. Khamidullin, M. Khirk, S. A. Krupko, B. Mauyey, I. A. Muzalevskii, W. Piątek, A. M. Quynh, S. I. Sidorchuk, R. S. Slepnev, A. Swiercz, G. M. Ter-Akopian, B. Zalewski. *Properties of the ^{7}He ground state studied by the ^{6}He(d,p)^{7}He reaction.* Int. J. Mod. Phys. E **33** (2024) 2450002.

[3] A. Camaiani, R. Alba, L. Baldesi, S. Barlini, M. Bini, A. Boiano, E. Bonnet, B. Borderie, R. Bougault, M. Bruno, G. Casini, A. Chbihi, C. Ciampi, M. Cicerchia, M. Cinausero, M. D'Agostino, J. Duenas, P. Edelbruck, D. Fabris, Q. Fable, J. D. Frankland, C. Frosin, F. Gramegna, D. Gruyer, M. Henri, B. Hong, S. Kim, A. Kordyasz, T. Kozik, M. Kweon, N. L. Neindre, I. Lombardo, O. Lopez, C. Maiolino, T. Marchi, K. Mazurek, A. Olmi, P. Ottanelli, M. Parlog, G. Pasquali, S. Piantelli, G. Poggi, M. F. Rivet, A. Rebillard-Soulie, E. Rosato, F. Salomon, A. A. Stefanini, G. Tortone, S. Upadhyahya, S. Valdre, G. Verde, E. Vient, M. Vigilante. *Reviewing the experimental achievements of the early years of FAZIA at INFN-LNS.* Eur. Phys. J. Plus **139** (2024) 1134.

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[5] G. Colucci, A. Trzcińska, P. W. Wen, E. Piasecki. *Dissipation by transfer and its influence on fusion.* EPJ Web of Conferences **306** (2024) 01018.

[6] G. Colucci, A. Trzcińska, E. Piasecki, E. Geraci, B. Gnoffo, K. Hadyńska-Klęk, G. Jaworski, M. Kisieliński, P. Koczon, M. Kowalczyk, Y. Leifeld, B. Lommel, F. Ristini, J. Samorajczyk-Pyśk, M. Trimarchi, W. H. Trzaska, A. Tucholski, M. Wolińska-Cichocka, C. Zagami, B. Zalewski. *Quasielastic barrier distributions for the ^{20}Ne+^{92,94,95}Mo systems: Influence of dissipation.* Acta Phys. Pol. B Proc. Suppl. **17** (2024) A23.

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[8] Q. Fable, L. Baldesi, S. Barlini, E. Bonnet, B. Borderie, R. Bougault, A. Camaiani, G. Casini, A. Chbihi, C. Ciampi, J. A. Duenas, J. D. Frankland, T. Genard, D. Gruyer, M. Henri, B. Hong, S. Kim, A. Kordyasz J., T. Kozik, A. Le Fevre, N. Le Neindre, I. Lombardo, O. Lopez, T. Marchi, P. Marini, S. H. Nam, A. Ono, J. Park, M. Parlog, S. Piantelli, A. Rebillard-Soulie, G. Verde, E. Vient, INDRA INDRA FAZIA Collaborations. *Isospin diffusion from ^{40,48}Ca+^{40,48}Ca experimental data at fermi energies: Direct comparisons with transport model calculations.* Phys. Rev. C **109** (2024) 064605.

[9] M. Filipek, B. Pszczolkowska-Kepa, B. Kocinski, M. Senkowska, Z. Szefliński, B. Brzozowska. *From radiobiology to radiotherapy: dose homogeneity in cells after alpha irradiation in measurements and monte carlo simulations.* Pol. J. Med. Phys. Eng. **30** (2024) 79.

[10] M. S. Golovkov, A. A. Bezbakh, A. S. Denikin, R. Wolski, S. G. Belogurov, D. Biare, V. Chudoba, E. M. Gazeeva, A. V. Gorshkov, G. Kamiński, B. R. Khamidullin, S. A. Krupko, B. Mauyey, I. A. Muzalevskii, W. Piątek, A. M. Quynh, R. S. Slepnev, A. Swiercz, P. Szymkiewicz, B. Zalewski. *Observation of a positive-parity wave in the low-energy spectrum of ^{7}He.* Phys. Rev. C **109** (2024) L061602.

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M. Komorowska, M. Kopec, R. Kopik, M. Kowalczyk, J. Kowalska, A. Krako, B. Kruzsicz, A. Malinowski, M. Matuszewski, B. M. Nyako, I. Piętka, P. Sekrecka, D. Sohler, A. Stolarz, J. Timar, EAGLE, NEDA, DIAMANT Collaborations. *Diamant - on board with needle.* Acta Phys. Pol. B Proc. Suppl. **17** (2024) A13.

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T. Kozik, W. Krzemien, K. Kubat, D. Kumar, J. Kunikowska, J. Maczewska, W. Migdal, G. Moskal, W. Mryka, S. Niedzwiecki, S. Parzych, E. P. del Rio, L. Raczynski, S. Sharma, S. Shivani, R. Y. Shopa, M. Silarski, M. Skurzok, F. Tayefi, K. T. Ardebili, P. Tanty, W. Wislicki, L. Krolicki, E. L. Stepien. *Positronium image of the human brain in vivo.* Sci. Adv. **10** (2024) eadp2840.

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D.4 Seminars

D.4.1 Seminars organised at HIL

H. Maridi — Department of Physics and Astronomy, The University of Manchester — 24 January 2024

Simultaneous calculations for elastic scattering, fusion, breakup and other direct cross sections for reactions of exotic nuclei

K. Rusek — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 20 March 2024

Czy neutrony lubią być razem?
Do neutrons like being together?

B. Zalewski — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland — 24 April 2024

Interaction of ^{6}He with hydrogen isotopes at 26 MeV/nucleon energy

K. Starosta — Simon Fraser University w Burnaby, B.C., Canada — 08 May 2024

Structure of nuclei far from stability from the TIP/TIGRESS program at TRIUMF

M. Janiszewski — Faculty of Chemistry, University of Warsaw, Warszawa, Poland — 29 May 2024

Chromatograficzne oznaczanie selenu w miodzie – opracowanie nowej metodyki ekstrakcji i koserwacji próbek
Chromatographic determination of selenium in honey - development of a new method of sample extraction and preservation

J. Hausman — Faculty of Chemistry, University of Warsaw, Warszawa, Poland — 29 May 2024

Oznaczanie związków polifenolowych w oleju kawowym
Determination of polyphenolic compounds in coffee oil

A. Jakubowska — Faculty of Chemistry, University of Warsaw, Warszawa, Poland — 29 May 2024

Zastosowanie chromatografii HILIC do oznaczenia związków biologicznie aktywnych w fermencie chlebowym
Application of HILIC chromatography to determine biologically active compounds in bread ferment

K. Rani — Variable Energy Cyclotron Centre, India — 28 June 2024

Reaction Studies from below to well above the Coulomb Barrier energies

H. Maridi — Department of Physics and Astronomy, The University of Manchester — 16 October 2024

Simultaneous calculations of elastic scattering, breakup, and transfer cross sections the d+^{197}Au

R. Wolski — Institute of Nuclear Physics PAN, Kraków, Poland — 05 November 2024

Applications of ab initio results for nuclear reactions calculations

G. Wałpuski — Faculty of Biology, University of Warsaw, Warszawa, Poland 20 November 2024
Wpływ ploidalności na przebieg choroby popromiennej: Studium na przykładzie ekstremofilnej algi Galdieria sulphuraria
The influence of ploidy on the course of radiation sickness: A study of the example of the extremophilic alga Galdieria sulphuraria

O. Wieland — INFN. Sezione di Milano, Milano, Italy 11 December 2024
Two decades of search for extra strength below the Giant Dipole Resonance

D.4.2 Seminars co-organised by HIL

Warsaw Nuclear Physics Seminar

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

M. Dąbrowski — National Centre for Nuclear Research 11 January 2024
Plan budowy badawczego reaktora wysokotemperaturowego HTGR-POLA (POLski Atomowy) w Świerku
Plan for the construction of a high-temperature research reactor HTGR-POLA (POLski Atomowy) in Świerk

W. Królas — Institute of Nuclear Physics PAN, Kraków, Poland 18 January 2024
IFMIF-DONES - laboratorium neutronowe dla programu syntezy termojądrowej, fizyki i badań interdyscyplinarnych
IFMIF-DONES - a neutron laboratory for the thermonuclear fusion program, physics and interdisciplinary research

N. Sokołowska — Faculty of Physics, University of Warsaw, Warszawa, Poland 25 January 2024
Badanie emisji cząstek naładowanych w przemianie beta ^{11}Be
Testing the emission of charged particles in ^{11}Be beta decay

K. Miernik — Faculty of Physics, University of Warsaw, Warszawa, Poland 29 February 2024
Badanie reakcji fuzji-rozszczepienia metodami spektroskopii gamma
Study of fusion-fission reactions using gamma spectroscopy

R. Kopeć — Institute of Nuclear Physics PAN, Kraków, Poland 07 March 2024
Przebieg radioterapii protonowej i badania interdyscyplinarne z zakresu fizyki medycznej i radioterapii w Centrum Cyklotronowym Bronowice IFJ PAN
The course of proton radiotherapy and interdisciplinary research in the field of medical physics and radiotherapy at the Bronowice Cyclotron Center of the IFJ PAN

J. Perkowski — Faculty of Physics and Applied Computer Science, University of Lodz, Łódź, Poland 14 March 2024
Pomiary przekroju czynnego na reakcje wychwytu radiacyjnego na izotopie ^{239}Pu przeprowadzone przy spalacyjnym źródle neutronów w CERN
Measurements of the cross section for radiative capture reactions on ^{239}Pu carried out at the spallation neutron source at CERN

S. Wycech — National Centre for Nuclear Research 21 March 2024
Skóra i kości (neutronowe)
Skin and bones (neutron)

M. Palacz — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 04 April 2024
EAGLE – spektroskopia gamma na wiązkach warszawskiego cyklotronu, w Środowiskowym Laboratorium Ciężkich Jonów UW
EAGLE – gamma spectroscopy with the beams from the Warsaw cyclotron, at the Heavy Ion Laboratory of the University of Warsaw

P. G. Thirolf — Ludwig-Maximilians-Universität München, Garching, Germany 11 April 2024
The Thorium Isomer ^{229m}Th: From the Atomic to the Nuclear Clock

K. Cichy — Adam Mickiewicz University, Poznań, Poland 18 April 2024
Three-dimensional structure of the nucleon from lattice QCD

A. Augustyn — National Centre for Nuclear Research 25 April 2024
Multidimensional random walk for calculating the fusion/fission probabilities of superheavy elements

Z. K. Czerski — National Centre for Nuclear Research 09 May 2024
Reakcje deuteron-deuteron przy ekstremalnie niskich energiach – zimna fuzja w eksperymentach akceleratorowych
Deuteron-deuteron reactions at extremely low energies - cold fusion in accelerator experiments

M. Ciemała — Institute of Nuclear Physics PAN, Kraków, Poland 16 May 2024
RPARIS@VAMOS – wgląd w proces rozszczepienia z użyciem pomiaru promieniowania gamma
PARIS@VAMOS – insight into the fission process using gamma radiation measurements

A. Špaček — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 23 May 2024
Decay spectroscopy of the neutron-deficient isotopes ^{179}Hg and ^{177}Au

P. Gasik — GSI/FAIR i TU Darmstadt, Germany 06 June 2024
Towards the CBM Experiment at FAIR

G. Colucci — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 13 June 2024
Barrier distribution studies at HIL: recent results and future plans

K. Wrzosek-Lipska — Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland 03 October 2024
Koegzystencja kształtów w izotopach Cd
Coexistence of shapes in Cd isotopes

N. Bernier — Departament of Physics and Astronomy University of the Western Cape and National Institute for Theoretical and Computational Sciences, South Africa — 10 October 2024
Nuclear Structure of Neutron-Rich ^{128}In using β-decay Spectroscopy

P. Nowakowski — National Centre for Nuclear Research — 17 October 2024
50 lat reaktora MARIA
50 years of the MARIA reactor

Ki Sig Kang — KINGS, Republic of Korea — 24 October 2024
Key Success Factors for Nuclear Power Plant Construction Management

H. Witała — M. Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland — 07 November 2024
Znaczenie szybkich rozwiązań równań Faddeeva z siłami chiralnymi dla określenia Hamiltonianu układów jądrowych
The importance of fast solutions of Faddeev equations with chiral forces for determining the Hamiltonian of nuclear systems

P. Plattner — ISOLDE, CERN, Geneve, Switzerland — 14 November 2024
The nuclear charge radius of ^{26m}Al and its implication for V_{ud} in the quark mixing matrix

M. Skurzok — M. Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland — 21 November 2024
Investigation of exotic bound systems with the WASA-at-COSY and SIDDHARTA-2 facilities

P. Moskal — M. Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland — 28 November 2024
First positronium imaging of the human brain using a multi-photon J-PET scanner

M. Wolter — Institute of Nuclear Research, Kraków, Poland — 05 December 2024
From Perceptrons to Deep Learning: Nobel Prize for Hopfield and Hinton

M. Gaździcki — Institute of Physics, Jan Kochanowski University, Kielce, Poland — 12 December 2024
Large charge-symmetry violation in high-energy collisions of atomic nuclei

P. Sękowski — Faculty of Physics, University of Warsaw, Warszawa, Poland — 19 December 2024
Badanie reakcji protonów na jądrach węgla, azotu i tlenu w stosach tarcz tkankopodobnych oraz nieorganicznych
Study of proton reactions on carbon, nitrogen and oxygen nuclei in stacks of tissue-like and inorganic targets

D.4.3 External seminars given by HIL staff

M. Palacz — 25 January 2024
Gamma-ray spectroscopy at HIL
First INTRANS Workshop, Orsay, France

G. Colucci 09-10 April 2024
Barrier distributions studies at HIL: from the most recent results to our future plans
Research horizons of Polish nuclear physics; PPS Nuclear Physics Section, Warsaw, Poland

K. Hadyńska-Klęk 09-10 April 2024
Forging tools to understand nuclear deformation in light and medium mass nuclei; challenges and perspectives at the HIL Warsaw
Research horizons of Polish nuclear physics; PPS Nuclear Physics Section, Warsaw, Poland

G. Jaworski 09-10 April 2024
Studies of neutron-deficient nuclei at HIL
Research horizons of Polish nuclear physics; PPS Nuclear Physics Section, Warsaw, Poland

Andrej Špaček 09-10 April 2024
Fast Timing at Heavy Ion Laboratory
Research horizons of Polish nuclear physics; PPS Nuclear Physics Section, Warsaw, Poland

Katarzyna Wrzosek-Lipska 09-10 April 2024
Nuclear deformations studied with Coulomb excitation- perspectives and experimental needs
Research horizons of Polish nuclear physics; PPS Nuclear Physics Section, Warsaw, Poland

G. Colucci 21 May 2024
Role of dissipation in the quasielastic barrier distribution of $^{20}Ne+^{92,94,95}Mo$
International Workshop on Multi facets of Eos and Clustering (IWM-EC202), Catania, Italy

K. Hadyńska-Klęk 25 May 2024
Coulomb excitation of ^{44}Ti and ^{62}Zn - the need for the beam development at GANIL
AGATA @ GANIL workshop, Caen, France

E. Piasecki 27-30 May 2024
The influence of dissipation on the quasielastic barrier distributions of the $^{20}Ne+^{92,94,95}Mo$ systems
The V International Conference on Nuclear Structure and Dynamics NSD2024, Valencia, Spain

M. Paluch-Ferszt 27 June 2024
Promieniowanie jonizujące w służbie ochrony zdrowia i życia - historia i teraźniejszość
Ionizing radiation in health and life protection - history and present status
"Spotkania z historią techniki" w Narodowym Muzeum Techniki w Warszawie, Poland

J. Choiński 26 June - 07 July 2024
Possibility of producing scandium isotopes in Poland
5th Jagiellonian Symposium on Advances in Particle Physics and Medicine, Collegium Novodvorscianum, Kraków, Poland

K. Hadyńska-Klęk 03-05 July 2024
The Warsaw SiLCA array - status and perspectives
Scientific Workshop on nu-Ball2 2024 -Reports from the last campaign and prospects for future experiments, Milano, Italy

K. Hadyńska-Klęk 03-05 July 2024
Coulomb excitation of ^{60}Ni at the IJC Lab with the Nuball2+SiLCA DSSD setup(+ a brief report on the Coulomb excitation of ^{40}Ca)
Scientific Workshop on nu-Ball2 2024 - Reports from the last campaign and prospects for future experiments, Milano, Italy

G. Colucci 21 August 2024
Role of dissipation in the quasielastic barrier distribution of ^{20}Ne+^{92,94,95}Mo
14th International Conference on Nucleus Nucleus Collisions (NN2024), Whistler, Canada

K. Hadyńska-Klęk 25 August- 01 September 2024
Probing nuclear deformation in the vicinity of ^{40}Ca and ^{56}Ni
ZAKOPANE CONFERENCE ON NUCLEAR PHYSICS 2024 "Extremes of the Nuclear Landscape" Zakopane, Poland

I. Piętka 25 August- 1 September 2024
Coulomb excitation of ^{110}Cd studied with AGATA at LNL
ZAKOPANE CONFERENCE ON NUCLEAR PHYSICS 2024 "Extremes of the Nuclear Landscape" Zakopane, Poland

K. Wrzosek-Lipska 25 August- 1 September 2024
Shape coexistence in Cd isotopes studied with safe and un-safe Coulomb excitation
ZAKOPANE CONFERENCE ON NUCLEAR PHYSICS 2024 "Extremes of the Nuclear Landscape" Zakopane, Poland

K. Hadyńska-Klęk 09 - 12 September 2024
Report on the AGATA@LNL experiment 23.08: Coulomb excitation of ^{60}Ni
The 24th AGATA Week – ACC Meeting, Milano, Italy

I. Piętka 13 September 2024
Report on the AGATA@LNL experiment E22.41: "Probing Multiple Shape Coexistence in ^{110}Cd with Coulomb Excitation"
The 24th AGATA Week – ACC Meeting, Milano, Italy

I. Piętka 24 September 2024
Probing Multiple Shape Coexistence in ^{110}Cd with Coulomb Excitation
Sympozjum Młodych Naukowców Wydziału Fizyki UW

K. Hadyńska-Klęk 23-28 September 2024
Coulomb excitation of (exotic) nuclei - Projects conducted within the Polish-French collaboration over the past decades
The 30th Nuclear Physics Workshop, Kazimierz Dolny, Poland

G. Jaworski 23 August 2024
The first year of Physics with NEEDLE at HIL
14th International Conference on Nucleus Nucleus Collisions (NN2024), Whistler, Canada

J. Choiński 09 October 2024
Possibilities of producing radioisotopes and radiopharmaceuticals in Poland
4th International Conference "Nuclear and Radiation Technologies in Medicine, Industry and Agriculture" Almaty, Kazakstan

K. Hadyńska-Klęk 28-30 October 2024
Studies of proton-rich nuclei with EAGLE-NEDA-DIAMANT
Third Annual Meeting (TAM) of the EURO-LABS, CERN

K. Hadyńska-Klęk 28-29 November2024
Nuclear deformation in excited states – Superdeformation at low spins
COPIGAL mini-WORKSHOP, Paris, France

M. Palacz 28-29 November 2024
Nuclear structure close to N=Z=50
COPIGAL mini-WORKSHOP, Paris, France

D.4.4 Poster presentations

K. Rusek 24-28 June 2024
Interaction of ^{6}He with hydrogen isotopes
The 12th International Conference on Direct Reactions with Exotic Beams DREB2024, Wiesbaden, Germany

A. Sentkowska 24-28 June 2024
Does green mean better? A critical look at the green synthesis of selenium nanoparticles
ESAS (European Symposium on Analytical Spectrometry),Warsaw, Poland

K. Kilian 25-27 June 2024
Determination of radionuclidic impurities in the production process of ^{18}F labeled Radiopharmaceuticals
NOMRad – NOMATEN International Radiopharmaceutical Conference, Warsaw, Poland

J. Choiński, O. Nassar, Ł. Standyło 27 - 29 June 2024
Selected modifications in the U-200P cyclotron at the Heavy Ion Laboratory
42nd European Cyclotron Progress Meeting, University of Jyväskylä, Finland

M. Wolińska-Cichocka 25 August – 01 September 2024
Beam position monitoring system at HIL based on SiC detectors
57th Zakopane Conference on Nuclear Physics, Zakopane, Poland

U. Kaźmierczak 07-14 September 2024
Effect of dose delivery method on survival of brain tumour cells
Ecole Joliot Curie 2024, Radiations for Health, Oléron, France

U. Kaźmierczak 07-14 September 2024
Simulation of energy deposition and dose assessment in brain tissue for radiation research
Ecole Joliot Curie 2024, Radiations for Health, Oléron, France

K. Hadyńska-Klęk 28-30 October 2024
The Heavy Ion Laboratory at the University of Warsaw - a facility portrait
Third Annual Meeting (TAM) of the EURO-LABS, CERN

D.4.5 Lectures for students and student laboratories

Z. Szefliński 07 May 2024
Fizyka w diagnostyce medycznej PET-SPECT
Physics in PET-SPECT medical diagnostics
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Hadyńska-Klęk June 2024
In beam gamma spectroscopy
Basic Training School on Accelerators, Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

K. Kilian June 2024
Chemical methods in the production of radionuclides for medical applications
Basic Training School on Accelerators, Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

P. J. Napiorkowski June 2024
30 years of heavy ion beams at the Heavy Ion Laboratory
Basic Training School on Accelerators, Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

M. Palacz June 2024
Detection of gamma radiation, charged particles and neutrons
Basic Training School on Accelerators, Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

K. Rusek June 2024
Introduction to nuclear reactions
Basic Training School on Accelerators, Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

A. Stolarz June 2024
Targets for nuclear physics experiments: production and characterisation
Basic Training School on Accelerators, Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

K. Hadyńska-Klęk October 2024
Spektroskopia gamma na wiązce
Gamma spectroscopy- in beam measurements
XVIII Warsztaty Akceleracji i Zastosowań Ciężkich Jonów, ŚLCJ UW

U. Kaźmierczak October 2024
Badania radiobiologiczne w ŚLCJ UW
Radiobiological research at HIL UW
XVIII Warsztaty Akceleracji i Zastosowań Ciężkich Jonów, ŚLCJ UW

K. Kilian October 2024
Radiofarmaceutyki do pozytonowej tomografii emisyjnej (PET)
Radiopharmaceuticals for positron emission tomography (PET)
XVIII Warsztaty Akceleracji i Zastosowań Ciężkich Jonów, ŚLCJ UW

P.J. Napiorkowski October 2024
30 lat wiązki ciężkich jonów
30 years of heavy ion beams at the Heavy Ion Laboratory
XVIII Warsztaty Akceleracji i Zastosowań Ciężkich Jonów, ŚLCJ UW

O. Nassar October 2024
Akceleracja ciężkich jonów i elementy optyki jonowej
Heavy ion acceleration and elements of ion optics
XVIII Warsztaty Akceleracji i Zastosowań Ciężkich Jonów, ŚLCJ UW

K. Rusek October 2024
Wstęp do fizyki reakcji jądrowych
Introduction to the physics of nuclear reactions
XVIII Warsztaty Akceleracji i Zastosowań Ciężkich Jonów, ŚLCJ UW

M. Palacz October 2024
Detekcja promieniowania gamma, cząstek naładowanych i neutronów
Detection of gamma radiation, charged particles and neutrons
XVIII Warsztaty Akceleracji i Zastosowań Ciężkich Jonów, ŚLCJ UW

Z. Szefliński 03 December 2024
Fizyka w diagnostyce medycznej PET-SPECT
Physics in PET-SPECT medical diagnostics
Faculty of Physics, University of Warsaw, Warszawa, Poland

A. Sentkowska 09-10 December 2024
Aspekty metodologiczne w oznaczaniu specjacji selenu
Methodological aspects in determining selenium speciation
XXVII Konferencja „Nowoczesne Metody Instrumentalne w Analizie Śladowej", Łódź, Poland

M. Palacz 20 December 2024
Prezentacja ŚLCJ dla studentów Politechniki Warszawskiej
Presentation of HIL for students of the Warsaw University of Technology
Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland

U. Kaźmierczak winter semester of the academic year 2023/2024
Biofizyka - ćwiczenia
Biophysics - exercises
Faculty of Physics, University of Warsaw, Warszawa, Poland

U. Kaźmierczak winter and summer semesters of the academic year 2023/2024
Kontrola jakości gamma kamery przy użyciu fantomu Jaszczaka- pracownia
Gamma camera quality control using the Jaszczak phantom - laboratory
Faculty of Physics, University of Warsaw, Warszawa, Poland

U. Kaźmierczak summer semester of the academic year 2023/2024
Laboratorium Technik Obrazowania- ćwiczenia
Imaging Techniques Laboratory- exercises
Faculty of Physics, University of Warsaw, Warszawa, Poland

U. Kaźmierczak summer semester of the academic year 2023/2024
Biofizyka - ćwiczenia
Biophysics - exercises
Faculty of Physics, University of Warsaw, Warszawa, Poland

U. Kaźmierczak summer semester of the academic year 2023/2024
Biofizyka - ćwiczenia
Biophysics - exercises
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of the academic year 2023/2024
Radiofarmaceutyki, synteza, wytwarzanie i zastosowania
Radiopharmaceuticals, synthesis, production and applications
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of the academic year 2023/2024
Badania przedkliniczne radiofarmaceutyków
Preclinical testing of radiopharmaceuticals
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

K. Kilian summer semester of the academic year 2023/2024
Pracownia radiofarmaceutyków
Laboratory of Radiopharmaceuticals
Faculty of Physics, University of Warsaw, Warszawa, Poland

K. Kilian winter semester of the academic year 2023/2024
Metody izotopowe i chemia radiofarmaceutyków
Radiochemistry and radiopharmacy
Faculty of Physics, University of Warsaw, Warszawa, Poland

A. Sentkowska winter semester of the academic year 2023/2024
Environmental Analysis Laboratory
Faculty of Chemistry, University of Warsaw, Warszawa, Poland

Z. Szefliński summer semester of the academic year 2023/2024
Podstawy Obrazowania Medycznego
Basics of Medical Imaging
Faculty of Physics, University of Warsaw, Warszawa, Poland

D.4.6 Science popularization lectures

Z. Szefliński LXI LO Specjalne im. Janiny Zawadowskiej 20.03.2024

Radon wokół nas
Radon around us

Z. Szefliński LXI LO Specjalne im. Janiny Zawadowskiej 16.04.2024

Słońce atom czy wiatr
Sun, atom or wind

Z. Szefliński LO im. Adama. Mickiewicza w Piastowie 20.03.2024

Radon wokół nas
Radon around us

Z. Szefliński 28 Festiwal Nauki 22.09.2024

Słońce atom czy wiatr
Sun, atom or wind

Z. Szefliński 28 Festiwal Nauki 24.09.2024

Słońce atom czy wiatr
Sun, atom or wind

Z. Szefliński 28 Festiwal Nauki 24.09.2024

Radon wokół nas – gdzie jest promieniowanie
Radon around us – where is the radiation?

A. Sentkowska 28 Festiwal Nauki 25.09.2024

Kawa, herbata a może...wino? Co pić aby „delikatnie" się odmłodzić?
Coffee, tea or maybe... wine? What to drink to "gently" rejuvenate yourself?

A. Sentkowska Naukowa Krowa TVP Nauka 30.09.2024

Czym są pierwiastki?, Po co nam chemia?, Moc roślinnej apteki
What are elements? Why do we need chemistry? The power of a plant pharmacy

D.5 Honours and Awards

The Rector of the University of Warsaw distinction award for scientific achievements 2024:

Dr. Katarzyna Hadyńska-Klęk.

The Rector of the University of Warsaw awards 2024:

Eliza Balcerowska,
Jarosław Choiński,
Michalina Komorowska,
Robert Kopik,
Jolanta Matuszczak,
Piotr Orłowski,
Bogusław Paprzycki,
Robert Ratyński,
Bogdan Radomyski,
Łukasz Standyło,
Lidia Strzelczyk,
Magdalena Zawal.

D.6 Laboratory staff

Director: Paweł Napiorkowski
Deputy directors: Jarosław Choiński, Leszek Próchniak
Financial executive: Eliza Balcerowska

Senior scientists:

Krzysztof Kilian, Andrzej Kordyasz[a], Marcin Palacz, Ernest Piasecki[a], Krzysztof Rusek[a], Aleksandra Sentkowska, Anna Stolarz, Zygmunt Szefliński[a]

Scientific staff and engineers:

Tomasz Abraham, Andrzej Bednarek, Giulia Colucci, Piku Dey[b], Przemysław Gmaj[c], Katarzyna Hadyńska-Klęk, Grzegorz Jaworski, Grzegorz Kamiński[d], Urszula Kaźmierczak, Maciej Kisieliński[a], Michalina Komorowska, Marian Kopka, Michał Kowalczyk, Joanna Kowalska, Katarzyna Krutul-Bitowska[d], Ireneusz Mazur[e], Jan Miszczak, Olga Nassar, Wojciech Okliński[a], Krzysztof Olejarczyk[f], Monika Paluch-Ferszt, Serhii Panasenko, Mateusz Pęgier, Bogdan Radomyski, Justyna Samorajczyk-Pyśk, Paulina Sekrecka, Andrej Špaček, Julian Srebrny[a], Łukasz Standyło, Agnieszka Trzcińska, Andrzej Tucholski, Marzena Wolińska-Cichocka, Katarzyna Wrzosek-Lipska, Bogumił Zalewski[g]

Doctoral candidates:

Patrycja Chuchała, Patrycja Kamińska, Iwona Piętka,

Technicians:

Mariusz Antczak, Tomasz Bracha, Piotr Jasiński, Wiesław Kalisiewicz, Robert Kopik, Wojciech Kozaczka, Zbigniew Kruszyński[ah], Piotr Krysiak, Krzysztof Łabęda, Kamil Makowski, Mariusz Matuszewski, Bogusław Paprzycki, Krzysztof Pietrzak, Robert Ratyński, Mariusz Szperkiewicz, Łukasz Świątek

Administration and support:

Anna Błaszczyk-Duda, Agnieszka Borowik[ai], Antoni Dąbkowski[j], Leon Deluga[k], Maciej Durkiewicz, Andrzej Giziński[j], Tadeusz Jagielski[l], Rafał Klęk, Jolanta Matuszczak, Andrzej Młociński[m], Aleksander Morantowicz, Dariusz Noceń[i], Olga Oborska[n], Anna Odziemczyk, Piotr Orłowski[am], Jolanta Ormaniec[d], Anna Ratyńska, Mirosław Rogalski[j], Ewa Sobańska, Nurullo Sobirov, Lidia Strzelczyk, Andrzej Suchecki[i], Edyta Szeląg[a], Lech Szeląg, Katarzyna Włodarczyk[a], Magdalena Zawal, Andrzej Żuryński[o]

Voluntary scientists:

Jędrzej Iwanicki, Jan Kownacki, Andrzej Wojtasiewicz.

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[a] part time
[b] since 1 November
[c] until 20 August
[d] on leave
[e] until 27 July
[f] since 16 October
[g] until 15 October
[h] until 31 May
[i] since 1 August
[j] until 30 June
[k] since 1 August, until 8 September
[l] until 18 February
[m] since 1 February
[n] since 1 March
[o] since 1 May

D.7 Laboratory Council

1. Prof. dr hab. Józef Andrzejewski
Nuclear Physics Division
University of Łódź, Łódź

2. Prof. dr hab. Mieczysław Budzyński
Institute of Physics
Maria Curie-Skłodowska University, Lublin

3. Prof. dr hab. Ewa Bulska
Biological and Chemical Research Centre
University of Warsaw, Warszawa

4. Dr Jarosław Choiński
Heavy Ion Laboratory
University of Warsaw, Warszawa

5. Prof. dr hab. Zbigniew Czerski
Institute of Physics
University of Szczecin, Szczecin

6. Prof. dr hab. inż. Andrzej Chmielewski
(**Member of the Council Presidium**)
Institute of Nuclear Chemistry
and Technology, Warszawa

7. Prof. dr hab. Bogdan Fornal
The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences, Kraków

8. Dr hab. Krzysztof Kilian
Heavy Ion Laboratory
University of Warsaw, Warszawa

9. Prof. dr hab. Stanisław Kistryn
(**Member of the Council Presidium**)
M. Smoluchowski Institute of Physics
Jagiellonian University, Kraków

10. Dr hab. Agnieszka Korgul, prof. UW
Faculty of Physics
University of Warsaw, Warszawa

11. Dr hab. Michał Kowal, prof. NCBJ
The National Centre for Nuclear Research
Świerk

12. Prof. dr hab. n. med Leszek Królicki
Department of Nuclear Medicine
Medical University of Warsaw, Warszawa

13. Prof. dr hab. inż. Krzysztof Kurek
(**Member of the Council Presidium**)
The National Centre for Nuclear Research
Świerk

14. Prof. dr hab. Adam Maj
(**Chairman of the Council**)
The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences, Kraków

15. Prof. dr hab. inż Piotr Magierski
Faculty of Physics
Warsaw University of Technology,
Warszawa

16. Dr hab. Krzysztof Miernik, prof. UW
Faculty of Physics
University of Warsaw, Warszawa

17. Dr Paweł Napiorkowski
(**Director of HIL**)
Heavy Ion Laboratory
University of Warsaw, Warszawa

18. Dr hab. Marcin Palacz
Heavy Ion Laboratory
University of Warsaw, Warszawa

19. Dr hab. Leszek Próchniak
Heavy Ion Laboratory
University of Warsaw, Warszawa

20. Prof. dr hab. Krzysztof Rusek
Heavy Ion Laboratory
University of Warsaw, Warszawa

21. Prof. dr hab. Wojciech Satuła
(**Deputy Chairman of the Council**)
Faculty of Physics
University of Warsaw, Warszawa

22. Dr hab. Elżbieta Stephan, prof. US
Institute of Physics
University of Silesia, Katowice

23. Dr Agnieszka Trzcińska
(representative of the HIL staff)
Heavy Ion Laboratory
University of Warsaw, Warszawa

D.8 Programme Advisory Committee

PAC members

- Piotr Bednarczyk (Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland)
- Gilles de France (GANIL, Caen, France)
- Nicholas Keeley (National Centre for Nuclear Research, Otwock, Poland)
- Marco Mazzocco (Padova University, Padova, Italy)
- Chiara Mazzocchi (Faculty of Physics, University of Warsaw, Warszawa, Poland)
- Leszek Próchniak (Heavy Ion Laboratory, University of Warsaw, Warszawa, Poland)
- **Władysław Trzaska (Department of Physics, University of Jyväskylä, Finland) - Chair**

The international Programme Advisory Committee of the Heavy Ion Laboratory usually meets twice a year, in spring and autumn. The deadline for submitting proposals is 3 - 4 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 Jarosław Perkowski (University of Łódź).

D.9 HIL external users

From 2023, HIL external users have had to register before arrival. In 2024 **126** such users were registered. The Laboratory was visited by **104** external users and visitors from **51** scientific institutions, including 36 from 13 institutes in Poland, 54 from 24 institutions in the European Union and associated countries and 14 from 14 institutes in other countries.

HIL external users and visitors were from:

Poland

- AGH University of Science and Technology, Kraków, Poland
- Faculty of Biology, University of Warsaw, Warszawa, Poland
- Faculty of Chemistry, University of Warsaw, Warszawa, Poland
- Faculty of Physics, University of Warsaw, Warszawa, Poland
- Faculty of Physics and Applied Computer Science, University of Lodz, Łódź, Poland
- Institute of Nuclear Chemistry and Technology, Warszawa, Poland
- Institute of Physics, University of Szczecin, Szczecin, Poland
- Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland
- Jagiellonian University, Kraków, Poland
- National Centre for Nuclear Research, Otwock, Poland
- Poznań University of Technology, Poznań, Poland
- University of Silesia, Katowice, Poland
- Warsaw University of Technology, Warszawa, Poland

European Union and associated countries

- Department of Physics, University of Jyväskylä, Finland
- Department of Physics and Astronomy, University of Catania, Catania, Italy
- Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
- Dipartimento di scienze MIFT, Università di Messina, Messina, Italy
- Extreme Light Infrastructure, IFIN-HH, Bucharest, Romania
- GANIL, Caen, France
- GSI Helmholtz Center for Heavy Ion Research, Darmstadt, Germany
- HUN-REN Institute for Nuclear Research, ATOMKI, Debrecen, Hungary
- Instituto de Estructura de la Materia-Consejo Superior de Investigaciones Científicas, Madrid, Spain
- INRNE Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria
- Institute for Nuclear Physics, University of Cologne, Germany
- INFN Sezione di Catania, Catania, Italy
- INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy
- IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
- Jozef Stefan Institute, Ljubljana, Slovenia
- KTH Royal Institute of Technology, Stockholm, Sweden
- Laboratoire de Physique des 2 infinis Irène Joliot-Curie – IJCLab, Orsay, France
- Laboratory of Instrumentation and Experimental Particle Physics (LIP), Lisboa, Portugal
- LP2I, Bordeaux-Gradignan, France
- Physics Department, University of Lund, Lund, Sweden
- Taras Shevchenko National University of Kiev, Kiev, Ukraine
- University of Helsinki, Helsinki, Finland
- Universidad de Sevilla, Sevilla, Spain
- University of Vigo, Vigo, Spain

Other countries

- Ankar University, Ankar, Turkey
- Argonne National Laboratory, Argonne, USA
- Asociación de Física Argentina, Buenos Aires, Argentina
- Botswana International University of Science and Technology, Palapye, Botswana
- Department of Physics, East China Normal University, Shanghai, China
- Depatartment of Physics, University of Liverpool, Liverpool, UK
- Department of Chemistry, Simon Fraser University, Burnaby, Canada
- Department of Physics, University of York, York, UK
- Faculty of Engineering and Natural Sciences, Istanbul Sabahattin Zaim University Istanbul, Turkey
- Institute of Modern Physics, Chinese Academy of Science, Lanzhou, China
- Nigde University, Fen-Edebiyat Falkültesi, Fizik Bölümü, Nigde, Turkey
- Physics Department, Ege University, Izmir, Turkey
- University of the West of Scotland, Paisley, UK
- Variable Energy Cyclotron Centre, Kolkata, India

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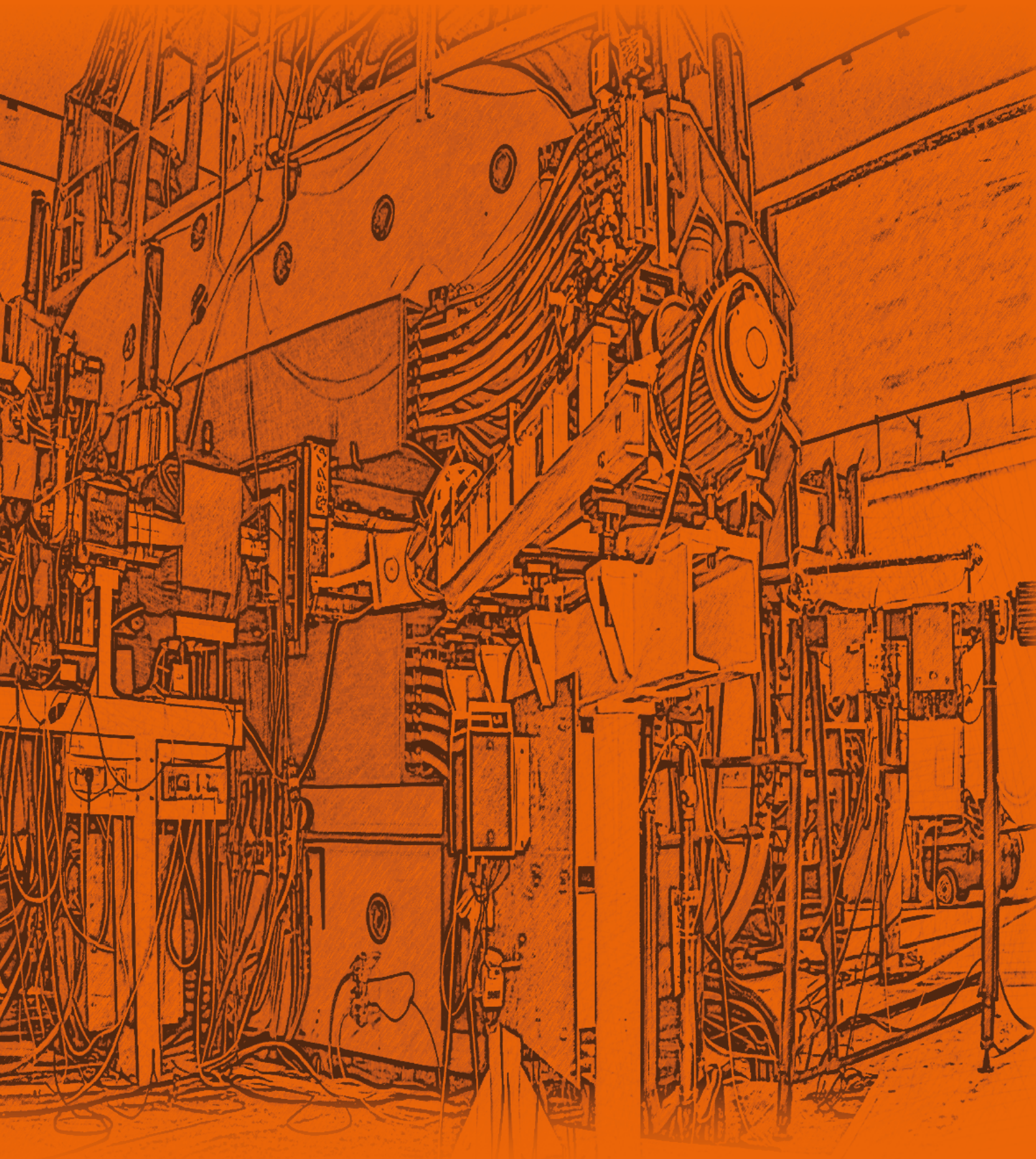

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ŚRODOWISKOWE LABORATORIUM CIĘŻKICH JONÓW
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