University of Warsaw
Heavy Ion Laboratory

ANNUAL REPORT
2008

WARSAW, June 2009

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Contents

C. Experiments using outside facilities

D. General information on HIL activities

INTRODUCTION

Fifteen years of activity at the Heavy Ion Laboratory

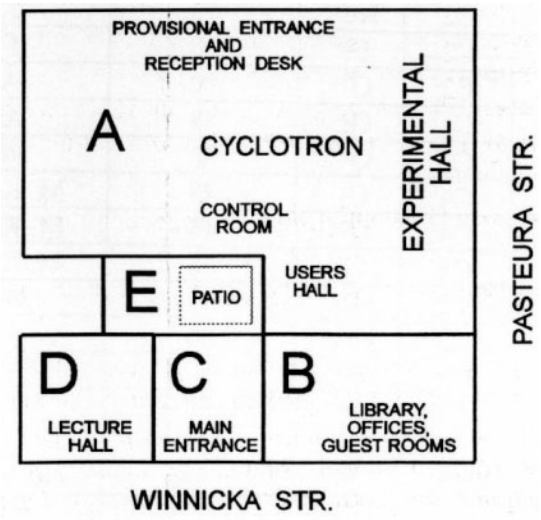
Fifteen years ago, on March 31st 1994, a heavy ion beam was extracted from the Warsaw Cyclotron for the first time and was directed towards a simple scattering chamber containing a gold target. The Rutherford scattering of $^{14}N^{2+}$ ions was measured at six laboratory angles.

At that time the experimental hall was completely empty and the only protective walls were those separating the cyclotron hall from the experimental area. After the commissioning of the new facility on May 20th 1994, the construction of beam lines and placement of further concrete walls was pursued. At the end of 1994 six caves were ready to host experimental equipment. In the following year several devices were installed: a small scattering chamber, CUDAC, for Coulomb excitation studies; a large NaI(Tl) scintillator, forming with a plastic and Pb shield the GDR JANOSIK set-up; and the large scattering chamber SYRENA (built by the Institute for Nuclear Research) for irradiation of solids and later for nuclear reaction studies. Also in 1995 HIL and IKP-Juelich signed an agreement on the installation at one of the beam lines of the Warsaw Cyclotron of the gamma-ray multidetector system OSIRIS II. The first in-beam test experiment of this set-up was performed in December 1996. In parallel with the OSIRIS-II installation, a Scandinavian-type electromagnetic mass separator was moved from Świerk to HIL and work on adapting it for use with a He-jet radioactive isotope transportation system (IGISOL device) was begun.

While the physicists were installing the experimental stations, the cyclotron technical team continued with machine upgrades. Descriptions of a number of these upgrades, crucial for the constantly improving performance of the cyclotron, can be found in the HIL Annual Reports from 1996 to 2000. Here we note only one, the most important step. Until the end of 1996 a PIG device, obtained from Dubna and improved in the Laboratory, was used as the cyclotron ion source. In July 1997 a beam of Ar ions from a new ECR ion source, built entirely in the Laboratory, was passed through the new axial beam transmission line to the centre of the cyclotron. A month later full acceleration and extraction of a beam provided by the new ECR ion source was achieved.

When, fifteen years ago, beam was extracted for the first time and directed towards the simple experimental station, the Laboratory building was still in its construction phase. The transfer of the complete staff and infrastructure in May 1995 from the provisional barracks to “Part A” of the cyclotron building was undoubtedly a landmark in the long history of the construction of the Laboratory. However, even then only this part of the building, housing the machine, the beam

lines, the first experimental stations and (temporarily) the entire staff, was completed. Parts B, C, D and E (see the figure below taken from the Annual Report 1996) were still under construction.



Building work was completed in the middle of 1998, a few days before the beginning of the first international conference organised by the Laboratory: “Nuclear Physics Close to the Barrier”, for the Centennial of the Discovery of Polonium and Radium.

Shortly after the assembly of the experimental stations the first experiments were performed. The palm of the first published paper, appearing in Acta Physica Polonica in 1996, belongs to the Giant Resonance team. Over the next few years Coulomb excitation (1997) and surface and solid state physics (1998-1999) papers appeared in international journals. Up to the present time, more than one hundred papers have been published based on experiments performed at HIL. Their authors form an international community of more than 400 people, receiving between 2000 and 3000 hours of heavy ion beam on target yearly.

Development of the facility has continued in the XXI century. At the end of 2000, after obtaining strong support from its Scientific Council, the Laboratory began to promote the idea of installing in the Laboratory building a second low-energy, high-current proton/deuteron cyclotron for the production of and research on short-lived radiopharmaceuticals for Positron Emission Tomography. The fund-raising, project design and calls for tender took a number of years. The current status of this project is presented later in this Report.

In September 2002 the Laboratory organised another international event, the XXXIII European Cyclotron Progress meeting, attended by around one hundred participants.

In 2004 the Kielce-Warsaw collaboration designed equipment for the irradiation of biological samples. In the following years a number of investigations studying the biological effects of heavy ion irradiation on living cells was conducted.

In November 2005 a new charged particle multidetector system, ICARE, designed and constructed by IRES (Strasbourg) was moved to HIL and installed on the "last free" beam line. Tested and upgraded the following year, it was first used for an experiment in 2007. It has currently replaced the SYRENA scattering chamber, substantially increasing the charged particle detection capabilities of HIL.

The same year (2005) the first suggestion to build a new gamma-ray multidetector system with a substantially enlarged (in comparison with OSIRIS II) number of HPGe detectors emerged during the Laboratory and Physics Faculty discussions. Currently this gamma-ray spectrometer, EAGLE (central European Array for Gamma Level Evaluations) is in the construction and assembly phase (see also later in this Report).

An important facility upgrade began in 2007. Based on a substantial grant from the Ministry of Science and Higher Education a new ECR ion source (SUPERNANOGAN) was ordered from PANTECHNIK (France) and will supply the Warsaw Cyclotron in parallel with the current home-made source. Metallic ion beams and higher beam intensities are expected. The installation of this source will take place at the end of 2009.

After fifteen years of operation of the Warsaw Cyclotron the Heavy Ion Laboratory of the University of Warsaw has proven to be a significant element of the European Research Area.

Laboratory directors

Jerzy Jastrzębski

1985-1994; 2000-2008

Jan Kownacki

1994-2000

Krzysztof Rusek

from 2009

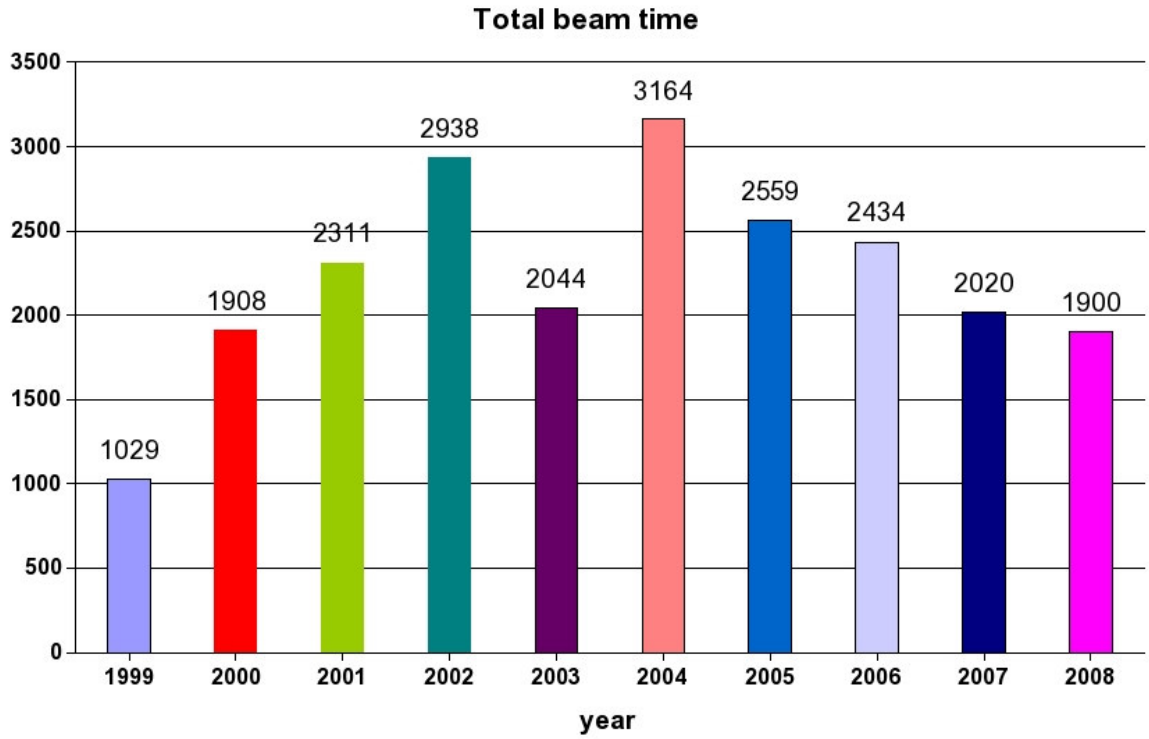
Part A:
Laboratory overview

1. Operation of the cyclotron during 2008

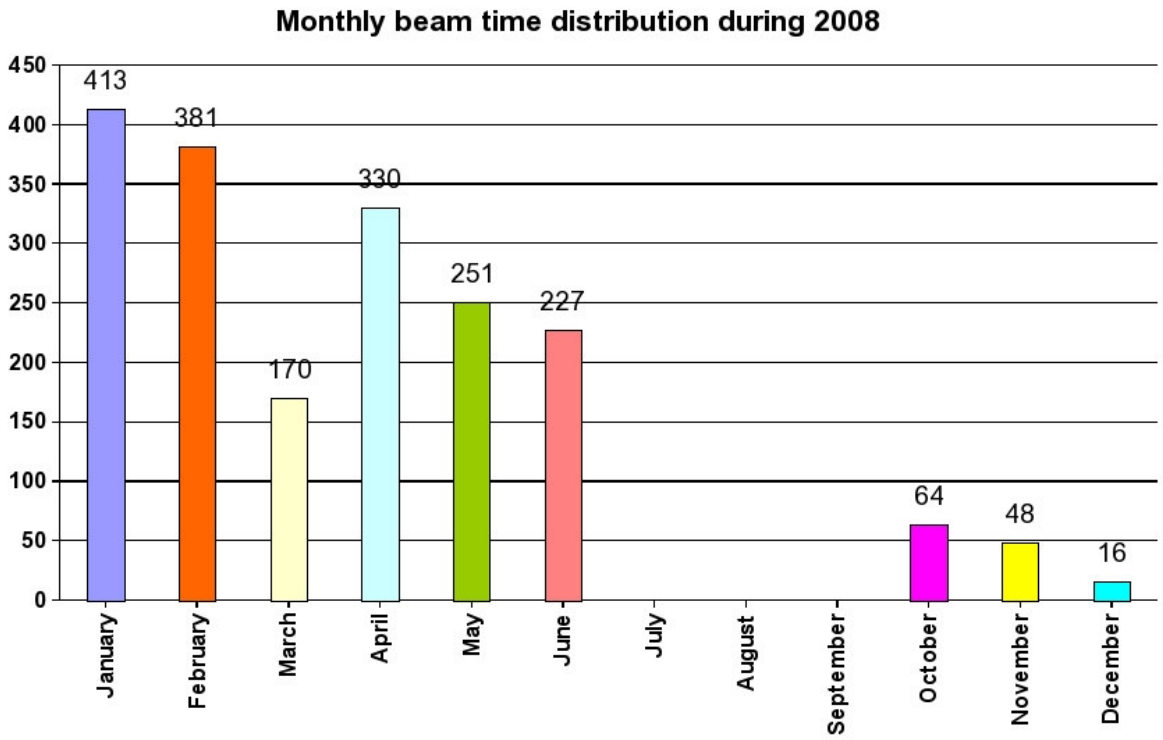
J. Choiński, M. Wolińska-Cichocka, W. Kalisiewicz, M. Kopka, J. Kurzyński, J. Miszczak, B. Paprzycki, O. Steczkiewicz, J. Sura

Cyclotron facility

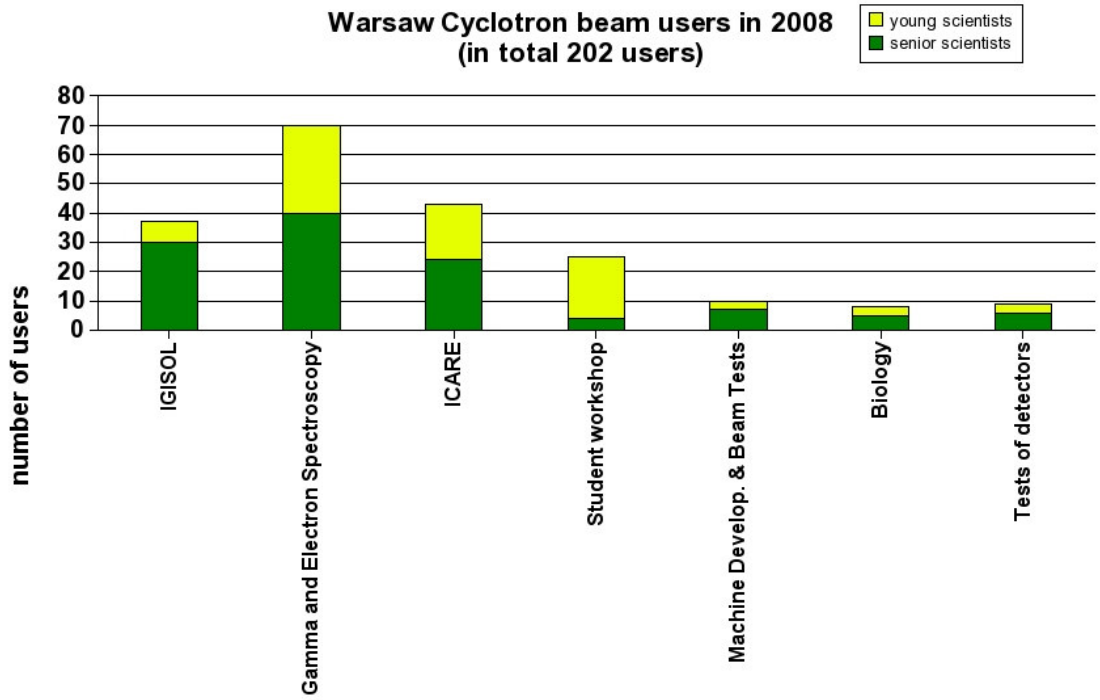
Over the last year, altogether 1900 hours of beam have been delivered to various experimental arrangements. The figure below shows usage of cyclotron beams over the last ten years. After the maximum number of over 3000 beam hours delivered in 2004, the total number of beam-time per year has been decreasing, which is mostly due to severe problems with the water cooling system of the machine. In spite of repairs and modifications, the system was not efficient enough to allow normal operation during the hot summer months, and every year since 2005 the Laboratory was forced to curtail some of the experiments due to overheating.



Following the complete replacement of the water heat exchange system, which had taken place in 2007, this year the cyclotron was fully operational during May and June. This is illustrated by the following figure, showing the monthly distribution of the beam time during 2008. After the traditional summer vacation in July and August, serious machine development and conservation works were undertaken, including modifications of the centre of the machine and the re-alignment of the duants. In the last quarter of the year access to the experimental areas was restricted due to heavy construction works at the site of PET Radiopharmaceutical Centre, which is situated in the nearest neighbourhood of the experimental hall, and most of experiments planned for this period had to be postponed until 2009.



Participation of undergraduate and graduate students in the experimental campaigns strongly reinforces the experimental teams currently working at HIL and helps them maintaining the research momentum. Involvement of young researchers is illustrated by the figure below which shows the number of HIL beam users* for each of the research projects performed in 2008 on beams of the Warsaw Cyclotron. Detailed description of experimental set-ups can be found at the Heavy Ion Laboratory website.



* User means here: any participant of a HIL experiment

Despite the fact that basic nuclear physics research consumed most of the beam-time, a fair share of it was allocated to other areas: the program of radiobiological studies using heavy-ion beams was continued, ^{12}C and ^{20}Ne beams were used for tests of nuclear track detectors, and traditionally a week of beamtime was allocated for the student workshop.

More detailed data concerning developments of the apparatus for research projects can be found in articles describing the on-going activities, published further in this section. Reconstruction of the C2 beamline, which was essential for installation of the EAGLE multidetector array, is especially worth mentioning.

The histogram and the table showing the number of hours used for different projects in 2008 are presented below.

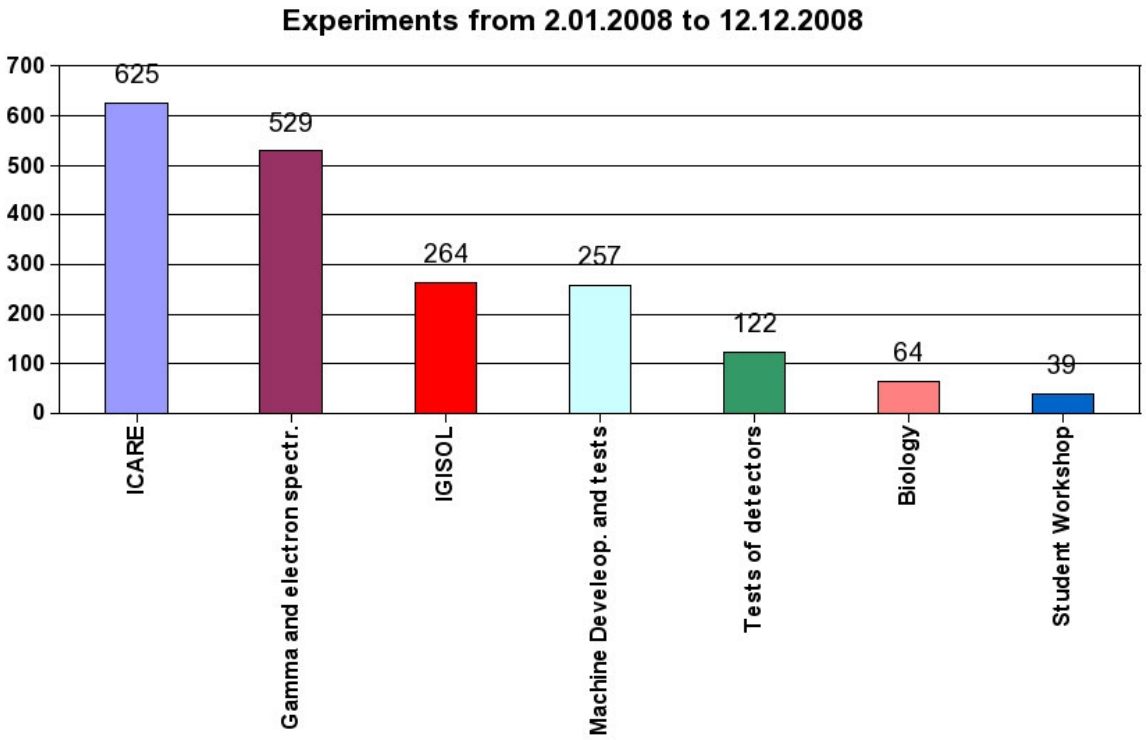


Table 1. Experiments from 07.01.2008 to 20.12.2008

Dates	Ion	Energy [MeV]	Experiment	Leading institution	Collaborating institutions
07.01 - 11.01	$^{14}N^{+3}$	50	Test of BaF_2 detectors	IEP UW	HIL, SINS Świerk, WUT
14.01 – 18.01	$^{18}O^{+4}$	103	IGISOL	IEP UW	HIL, SINS Świerk, SINS Łódź, US Katowice
21.01 - 03.02	$^{14}N^{+3}$	63	Fusion barrier exp.	HIL	IEP UW, SINS Świerk, UB
04.02 - 16.02	$^{16}O^{+3}$	76	Gamma and electron spectroscopy	UŁ	HIL, IEP UW, SINS Świerk, UBr
18.02 – 22.02	$^{20}Ne^{+4}$	103	Gamma and electron spectroscopy	UŁ	HIL, IEP UW, SINS Świerk, UBr
03.03 – 07.03	$^{18}O^{+4}$	102	IGISOL	IEP UW	HIL, SINS Świerk, SINS Łódź, US Katowice
10.03 – 12.03	$^{12}C^{+3}$	80	Test of track detectors	SINS Świerk	IEP UW
12.03 – 14.03	$^{20}Ne^{+4}$	105	Test of track detectors	SINS Świerk	IEP UW
17.03 – 21.03	$^{14}N^{+3}$	85	ICARE	HIL	SINS Świerk, NU Kharkiv, US Katowice, UB, INP Kraków
31.03 – 04.04	$^{20}Ne^{+3}$	50	Student workshop	HIL	
14.04 – 25.04	$^{20}Ne^{+4}$	96	ICARE	HIL	SINS Świerk, NU Kharkiv, US Katowice, UB, INP Kraków, JINR Dubna, KRI, St.Petersburg

Dates	Ion	Energy [MeV]	Experiment	Leading institution	Collaborating institutions
05.05 – 09.05	$^{20}Ne^{+4}$	96	ICARE	HIL	SINS Świerk, NU Kharkiv, US Katowice, UB, INP Kraków, JYFL, TUD
12.05 – 16.05	$^{14}N^{+3}$	83	IGISOL	IEP UW	HIL, SINS Świerk, IPN Orsay, SINS Łódź, US Katowice
26.05 – 30.05	$^{40}Ar^{+8}$	208	Gamma and electron spectroscopy	HIL	IEP UW, UŁ, SINS Świerk, US Katowice
02.06 – 06.06	$^{40}Ar^{+8}$	208	Gamma and electron spectroscopy	HIL	IEP UW, UŁ, SINS Świerk, US Katowice
23.06 – 27.06	$^{12}C^{+2}$	50	Radiobiology	IEP UW, IB JKU Kielce	HIL, HCC, Kielce, SINS Świerk, NCU Toruń
06.10 – 17.10	$^{20}Ne^{+4}$	96, 113	Machine dev. & test	HIL	
27.10 – 31.10	$^{20}Ne^{+4}$	96, 113	Machine dev. & test	HIL	
17.11 – 21.11	$^{20}Ne^{+4}$	96, 113	Machine dev. & test	HIL	
24.11 – 28.11	$^{20}Ne^{+4}$	96, 113	Machine dev. & test	HIL	
08.12 -12.12	$^{20}Ne^{+4}$	96, 113	Machine dev. & test	HIL	

Abbreviations used in the table above:

WUT	Warsaw University of Technology
UŁ	University of Łódź
HIL	Heavy Ion Laboratory, University of Warsaw
IB JKU Kielce	Institute of Biology, Jan Kochanowski University, Kielce
HCC, Kielce	Holycross Cancer Centre, Kielce
IEP UW	Institute of Experimental Physics, Faculty of Physics, University of Warsaw
INP Kraków	The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków
SINS Łódź	The Andrzej Sołtan Institute for Nuclear Studies. Łódź
SINS Świerk	The Andrzej Sołtan Institute for Nuclear Studies, Świerk
UBr	University of Brighton, UK
IPN Orsay	Institut de Physique Nucléaire, Orsay, France
JINR Dubna	Joint Institute for Nuclear Research, Dubna, Russia
KRI, St.Petersburg	Khoplin Radium Institute, St.Petersburg, Russia
JYFL	Department of Physics, University of Jyväskylä, Finland
NU Kharkiv	National University, Kharkiv, Ukraine
UB	University of Białystok
US Katowice	University of Silesia, Katowice
TUD	Technische Universität, Darmstadt, Germany
NCU Toruń	Nicolaus Copernicus University, Toruń

Plans of development

		Estimated completion time
1.	Cyclotron	
1.1	Factory test of the new ECR ion source	June 2009
1.2	Installation of the new horizontal part of the injection line	Second half of 2009
1.3	Installation of the new ECR ion source	Second half of 2009
1.4	Upgrade of the existing "mirror type" inflector	Second half of 2009
1.5	First runs of the cyclotron with the new ECR and the modified inflector	First half of 2010
2	Experimental hall	
2.1	Dismounting of the CUDAC set-up on the C2 beam line	First half of 2009
2.2	Dismounting of the OSIRIS II set-up on the C3 beam line	First half of 2009
2.3	Reconstruction of the C2 and C3 beam lines	First half of 2009
2.4	Installation of the new experimental set-up EAGLE on the C2 beam line	First half of 2009
2.5	Installation of the CUDAC set-up on the B beam line	Second half of 2009
2.6	Launching of a tender for a turbomolecular pomp	First half of 2010
2.7	Conclusion of the tender	Second half of 2010
3	RF generators	
3.1	Conceptual design of a new synthesizer with DDS for RF signals	End of 2009
3.2	Project, realization and implementation of a new water leak detection system inside RF generator units	First half of 2009
3.3	Preparation of a tender for new RF generators	Second half of 2009
3.4	Launching of the tender for the RF generators	First half of 2010
3.5	Conclusion of the tender	Second half of 2010
3.6	Reconstruction of the existing wiring, piping, cooling, etc. installation of the new RF generators	Second half of 2010
4	PET	
4.1	Continuation of construction works	2009
4.2	Start of assembling of the PET equipment	Second half of 2009
4.3	Completion of the PET project	First half of 2010

2. Activity report of the electrical support group

J. Kurzyński, V. Khrabrov, M. Kopka, P. Krysiak, K. Łabęda, Z. Morozowicz, K. Pietrzak

Design projects and implementation:

1. In 2008 the water level controller has been developed to include the system of slow and fast leakage of water flow. Computer control system displays in the control room the information about leakage in the cyclotron cooling system and starts an alarm when leakage flow exceeds the level of 250 ml/s for fast leakage and 5 ml/s for slow leakage;
2. The final version of hardware of water level controller is being constructed;
3. Manuals have been written:
   - "User manual for the power supplies for magnets of the U-200P Cyclotron".
   - "User manual for the water cooling system of the U-200P Cyclotron".
   - "User manual for the water level controller software".

Measurements and maintenance

1. Measurements and maintenance of the street lighting and related electrical circuits in the cyclotron building area;
2. Measurements and maintenance of the cyclotron electrical circuits in Building A, monitoring of electrical circuits during the cyclotron operation;
3. Continuous maintenance of master and slave cable network switchboards as well as the automatics and steering systems, including minor improvements of the interlocks and steering designed to facilitate the cyclotron operation.

3. Activity report of the ECR group

A. Górecki, B. Filipiak, M. Sobolewski, R. Tańczyk

In 2008 ECR ion source worked without failures, delivering the following ions to the cyclotron:

Ion	$^{12}C^{+3}$	$^{14}N^{+3}$	$^{16}O^{+3}$	$^{18}O^{+4}$	$^{20}Ne^{+3}$	$^{20}Ne^{+4}$	$^{40}Ar^{+8}$
Current on the inflector [eμA]	90	130	90	100	100	90	80

The ion source was periodically surveyed and cleaned.

The new buncher (see Ref. [1]) was installed and put into operation. The ion current obtained with the new buncher was about four times higher than without the buncher.

References:

[1] A. Górecki *et al.*, HIL Annual Report 2007, p. 7

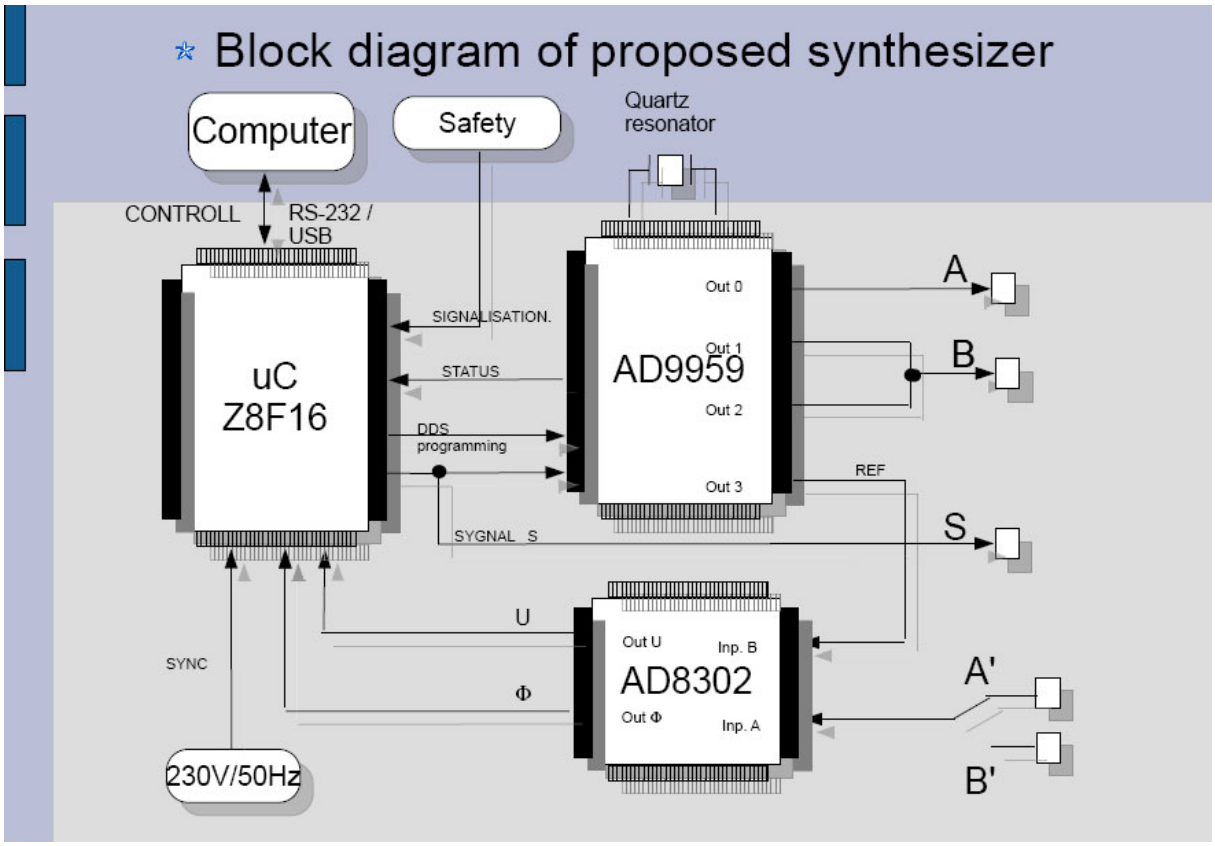
4. Direct Digital Synthesizer and modulator unit for the HIL cyclotron

A. Bednarek, J. Sura

For the efficient operation of an isochronous cyclotron, special sinusoidal radio frequency signals have to be generated for each of the accelerating electrodes (dees) of the cyclotron. Frequency, amplitude and phase of these signals should also be precisely controlled.

One way of realising this is to generate a stable, unmodulated sinusoidal signal and then add desired phase and amplitude modulation by external modulator circuits. Due to the progress in integrated circuits technology all these operations can be also done by a modern multichannel Direct Digital Synthesizer in one chip.

The block diagram of the synthesizer is shown below. The heart of the synthesizer is a four channel 500 MHz 10 bit DDS chip AD 9959. One of its channels is used for direct drive of the "dee-A" amplifier channel. Another two channels are used together for driving the "dee-B" channel. Coupling in parallel allows a precision correction of phase (and amplitude) of B-channel. The correction can be made with reference to real signals measured by AD8302 chip on feedback inputs A' and B'. The signals on these inputs come directly from couplers in the dee resonators. The fourth channel of AD9959 is used as reference for phase (and amplitude) measurements.

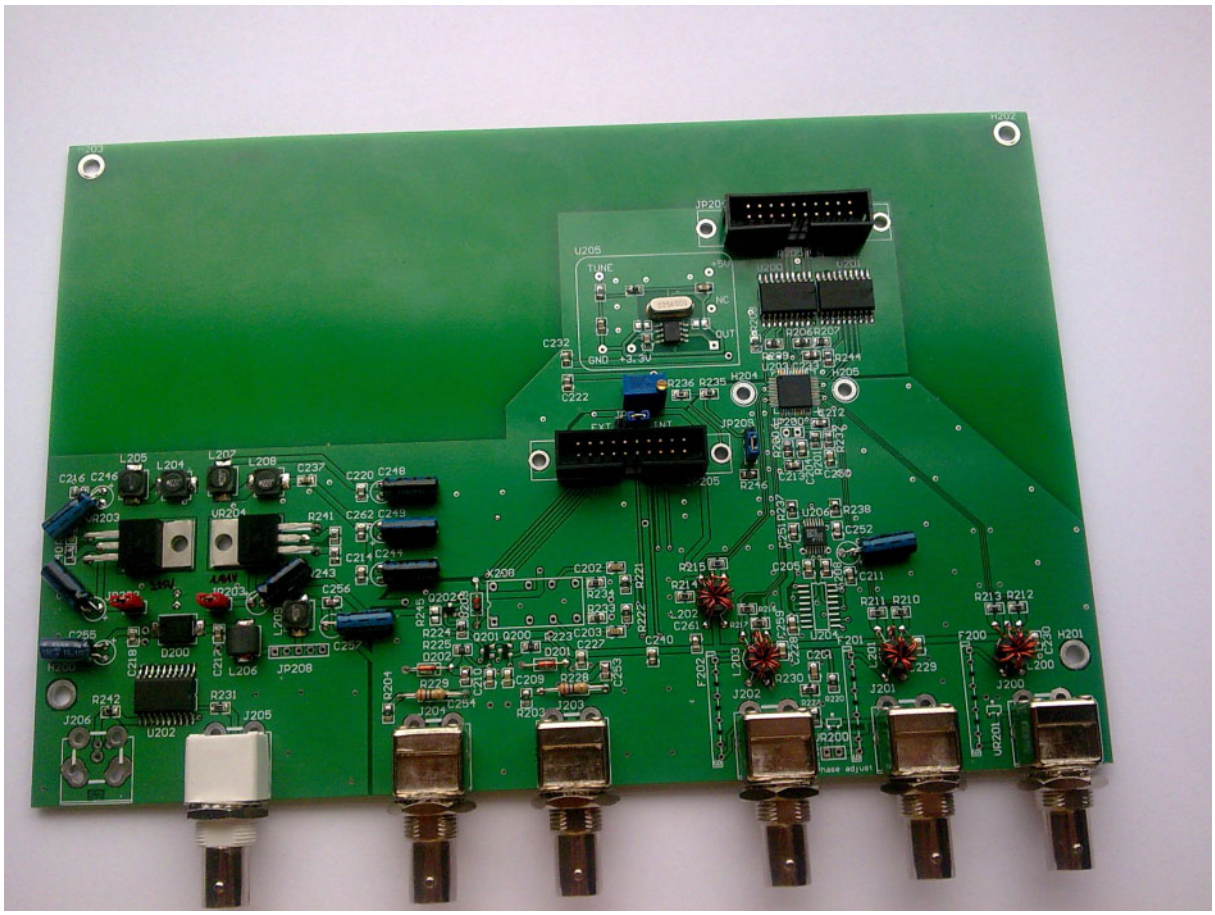


The device was constructed in the form of two PC boards.

The first one, the "analog board" includes all DDS components, analog output circuits and circuits allowing measures of phases and amplitudes of incoming signals. It has also a digital interface to program the DDS core of AD9959 chip.

The second one, the "digital board", will include power supply, microprocessor controller and interfaces for the supervising computer, safety circuits and additional signals. It will be mounted on the top of the "analog board".

The picture below presents the “analog PC board” of the synthesizer.



The board was designed, assembled, and first electrical tests were made. The next test will be the DDS functional test using direct computer control via parallel interface from the computer side. Then the “digital board” will be designed, assembled and the microcontroller program will be written.

5. Other activities of the RF Group

A. Bednarek, T. Bracha, K. Sosnowski

The activity of the RF Group was focused mostly on “Chryzolit” RF power stages and its control modules.

- Broken bulbs in meters in “Chryzolit” control panels were replaced by new superbright LEDs.
- Prototype sensors of water leak were installed in the power tube compartment of the “B” generator.
- Phase detector displays with resonator controllers were designed, built and installed in the Control Room.
- The anode power supply rectifier of the “B” generator has been repaired.
- The power AC main switch of the “A” generator has been repaired.
- The filament power supply rectifier of the “A” generator has been repaired.

6. New ECR ion source and injection line

O. Steczkiewicz, L. Pieńkowski, J. Choiński, P. Napiorkowski, J. Sura, M. Wolińska-Cichocka, R. Tańczyk, J. Jastrzębski

On 11 January 2008 the first contract of ECR purchase and Memorandum of Understanding concerning the second contract were signed by Heavy Ion Laboratory University of Warsaw and PANTECHNIK S.A. (see HIL Annual Report 2007, p. 13). On 27 October 2008 the second contract of purchase of complementary elements of the ECR ion source and the whole horizontal injection line was signed (some of the elements of this line are being manufactured by the Laboratory workshop). After the renovation of the ECR area, including the installation of new electric power connections, in-site installation of all equipment with commissioning and training will be done in November and December 2009. The object of the second contract is the delivery of the items listed below.

1 – Detailed conceptual and mechanical design study of the horizontal injection beam line for the HIL cyclotron, the coupling with the present vertical line and the magnetic circuit design of all optical elements.

2 – Complementary system for SUPERNANOGAN.

#	Items	Qt
1	Wave guides & DC breaker	1
2	VCO & RF attenuator	1
3	Complete gas supply 5 gases, remote	1
4	Injection pumping system	1
5	Pumping tank	1
6	High temperature oven (< 1400°C)	1
7	Sputtering system (all metals)	1
8	Extraction & focusing system	1
9	Extraction pumping system	1
10	HV source - potential power supply	1
11	HV puller - potential power supply	1
12	HV focus - potential power supply	1
13	Support stand for the source	1
14	Command and control system	1
15	Water cooling block	1
16	HV & X-rays shielding	1
17	Standard factory and site acceptance test with gas, oven and sputtering - included	1

3 – Beam line elements.

#	Item	Qt.
1	“T” - dipole	1
2	Quadrupole with alignment table	5

#	Item	Qt.
3	Water cooling for dipoles	1
4	Pumping systems for the beam line	1
5	Vacuum meters for the beam line	1
6	Bellow	3
7	Insulation valve	2
8	Diagnostic setup	1
9	Complementary command & control	1
10	Power supply for the dipole	1
11	Power supply for 4 quadrupoles	5
12	Power supply for steerers	2
13	Power supply for glaser (VE line)	1

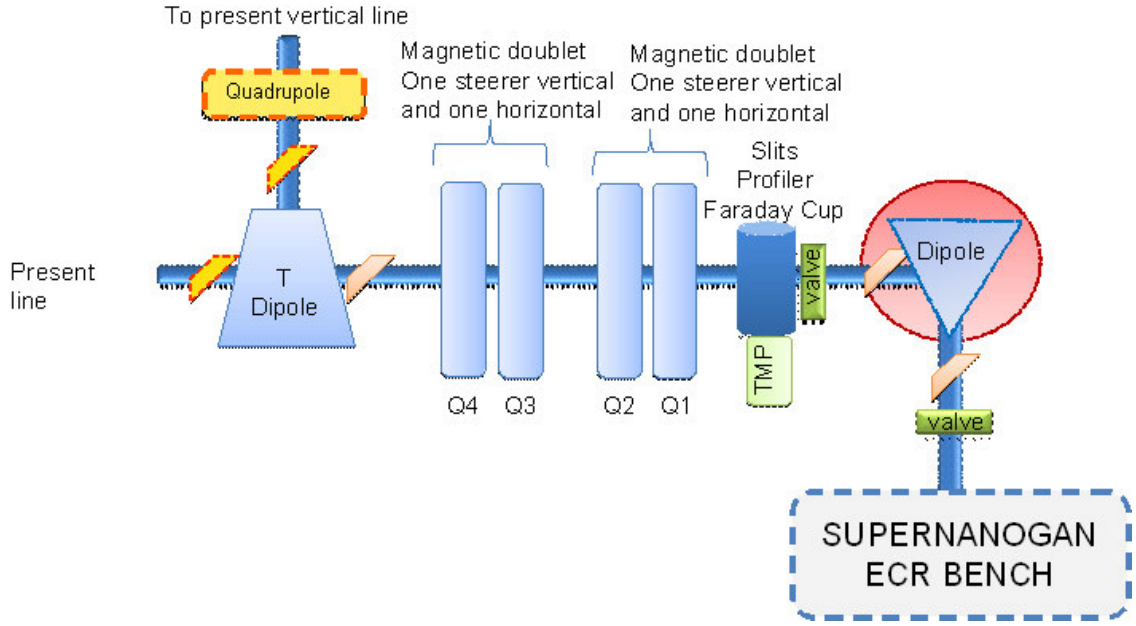


Figure 1. The general view of the new horizontal injection line.

7. Interlock system for vacuum valves at the Warsaw Cyclotron

M. Sobolewski, J. Miszczak, Z. Kruszyński, T. Bracha, K. Sosnowski

An interlock system was built to protect expensive vacuum equipment, especially vacuum pumps, from human error or hardware malfunction. Over 50 m of beamlines connect the cyclotron to the experimental stations. Vacuum valves separate the ion-guides into 18 independent sections. Each section has its own vacuum pump and vacuum meter. The procedure to open a vacuum valve is simple, but stressful to the person performing the task - accidental opening of a valve that had high vacuum at one side and atmospheric pressure at the other can easily lead to heavy damage to the equipment. Vacuum pumps have an embedded protection system, but it is not 100% reliable, and a malfunction of a vacuum pump could not be detected quickly.

To improve reliability and manageability of the vacuum system, the interlock system for the vacuum valves was built. Each section of the beamline was equipped with the additional vacuum meter, independent from the existing one. The new meter uses small incandescent bulb

as the sensing element. The bulb is glued to the beamline, but before attaching it to the beamline a small hole was drilled in the glass envelope of the bulb to expose the filament to the inside of the beamline. The filament is tough enough to survive even abrupt changes in pressure. The meter is somewhat nonlinear, and its working range extends from atmospheric pressure to only 10^{-5} torr but such range is sufficient. The meter is equipped with some additional electronics and mounted directly on each vacuum valve. The electronics receives signal from the neighbouring meter, so pressure at both sides of the valve is known. If both sides of the valve are not at high vacuum, than the valve is closed immediately and disabled in closed position to prevent accidental opening. Status of the valve (open/closed) along with vacuum level is displayed by the electronics module.

Before the system could become operational, cables had to be laid out along beamlines – this includes 12 V DC to power the electronics, 230 V AC for the vacuum valve's actuators, and the cables from one control box to its neighbour to transmit info about vacuum level.

The interlock electronics is ready for info about vacuum to be displayed in the control room and remote control of the vacuum valves, but it will require even more cabling work, and software for the computer control.

8. European Array for Gamma Level Evaluation (EAGLE) in beam of the Warsaw Cyclotron at HIL UW – status report

J. Srebrny, H. Mierzejewski[1] for the EAGLE collaboration[*]

1) Faculty of Production Engineering, Warsaw University of Technology, Poland

The **EAGLE** array (central **E**uropean **A**rray for **G**amma **L**evel **E**valuation) is designed as a multi-configuration detector set-up adjustable to the needs of several research groups, dealing with different branches of nuclear spectroscopy, gathered around the Heavy Ion Laboratory, University of Warsaw. The setup is presently in the construction phase.

In 2008 the supporting structure of EAGLE was assembled at the experimental hall of the Heavy Ion Laboratory (see Fig. 1).

Figure 1: Supporting structure of the EAGLE array (left) with three different kinds of detectors mounted (right).

[*] The EAGLE collaboration includes more than 50 scientists from 9 Polish institutions as well as from CEA Saclay, ATOMKI Debrecen, Lund and Sofia Universities. For the full list, see the EAGLE website: `http://www.slcj.uw.edu.pl/eagle`

Germanium detectors with two different kinds of anti-Compton shields were mounted as well as one element of the Inner Ball (consisting of five Barium Fluoride cristals). All mechanical elements worked properly.

The array is now being installed on the dedicated beamline (see the following contribution). First experiments with 12 HPGe detectors (of 20 - 35% efficiency) are expected to start in June 2009. For these studies the EAGLE-Phase I array will be coupled with:

- conversion electron spectrometer (including 12 silicon detectors cooled to -30°C),
- Coulex chamber (including up to 100 PiN Si diodes),
- Si-ball (30 thick Si detectors in 4π geometry),
- $LaBr_3$ scintillators.

Data acquisition system from the OSIRIS-II setup [1] will be used.

At the end of 2008 our application to the European Gamma Pool for 20 Phase-I HPGe detectors (70% efficiency) with anti-Compton shields has been accepted [2]. Detectors will be loaned for one year period (July 2010 - June 2011). The main research subject of the EAGLE-Phase II campaign in beam of the Warsaw U200P cyclotron is the experimental study of the spontaneous symmetry breaking in nuclear excited states, including:

- Spontaneous chiral symmetry breaking investigated by measurements of picosecond lifetimes of excited states using Doppler effect;
- Coulex studies of non-spherical and non-axial nuclear shapes in ground and excited states;
- Study of the weakening of K-quantum number selection rules by electron conversion measurements for electromagnetic transitions depopulating K isomers;
- Complete and incomplete fusion reaction mechanism studied by gamma transition measurements in coincidence with protons or alpha particles.

References:

[1] Short description of the OSIRIS-II setup is available at its Web site: `http://www.slcj.uw.edu.pl/en/11.html`

[2] Decision of the EGP OC concerning the loan of the detectors, available at the EAGLE project Web site: `http://www.slcj.uw.edu.pl/en/experiments/eagle/EAGLE.pdf`

9. Reconstruction of the C2 beam line for the EAGLE project

A. Jakubowski, H. Mierzejewski[1], M. Antczak, T. Bracha, J. Choiński, M. Figat, A, Górecki, P. Jasiński, W. Kalisiewicz, V. Khabrov, M. Kopka, Z. Kruszyński, P. Krysiak, K. Łabęda, J. Miszczak, Z. Morozowicz, B. Paprzycki, A. Pietrzak, K. Pietrzak, R. Pozorek, M. Sobolewski, K. Sosnowski, O. Steczkiewicz, J. Sura, M. Wolińska-Cichocka

1) Faculty of Production Engineering, Warsaw University of Technology, Warsaw, Poland

To meet the requirements of the EAGLE project, the existing C2 and C3 beam lines had to be reconstructed. The existing set-ups: CUDAC in the C2 beam line and OSIRIS II in the C3 beam line were dismounted, as well as the wall dividing the two caves. The present arrangement of the experimental hall enables coupling of relatively large ancillary devices to the EAGLE setup, for example the Recoil Filter Detector. The beam transmission tests performed in May 2009 were

very promising. Presently the EAGLE array is being installed in the tract and the first experiments using this set-up are scheduled for June 2009.

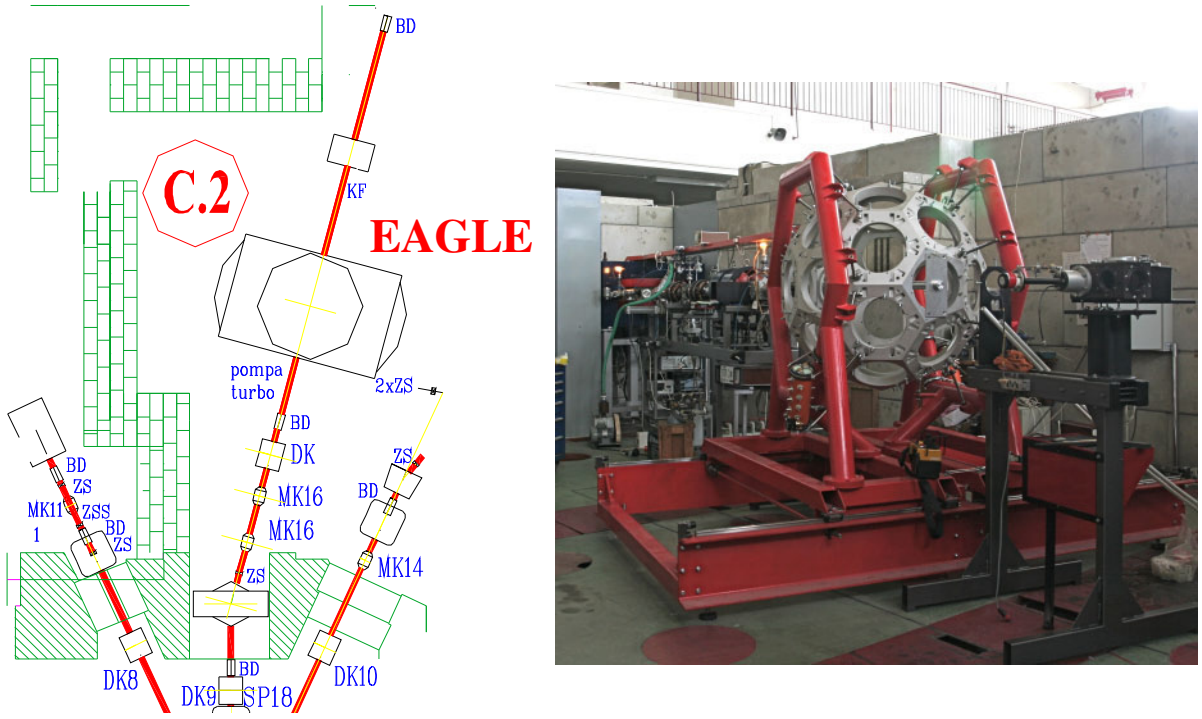


Figure 1: *Left*: Present arrangement of the C2 beamline. *Right:* C2 beamline and EAGLE supporting structure – status at the beginning of May 2009.

10. Collaborative SPIRAL2 Preparatory Phase Web site

M. Palacz, A. Trzcińska for the SPIRAL2 Preparatory Phase project

Within the SPIRAL2 Preparatory Phase Project (SP2PP), the Heavy Ion Laboratory has been assigned a task of creating and maintaining a Web site which would facilitate circulation of information among the participants of the projects. A preliminary version of such a site has been created and is available as `http://spiral2pp.slcj.uw.edu.pl`. The content of the site is gradually provided by the SP2PP management group, as well as work package and task leaders, and it is available to all the members of the project, subject to registration. Limited information is also accessible for general public. The HIL staff is responsible for the maintenance and further development of the site.

14. The Warsaw PET Project – Radiopharmaceuticals Production Centre at HIL UW

J. Jastrzębski, J. Choiński, I. Cydzik, D. Hechner, K. Kilian, I. Mazur, P.J. Napiorkowski

Information on the Warsaw Consortium for PET Collaboration (WCPC), the Warsaw PET Project and its Radiopharmaceuticals Production Centre (RPC) has been already presented

in previous HIL Annual Reports [1-3]. Fig. 1 shows the location of the RPC in the Laboratory building with respect to other equipment. Fig. 2 shows a detailed layout of the Centre, located in the underground area (-6 m, 360 m^2).

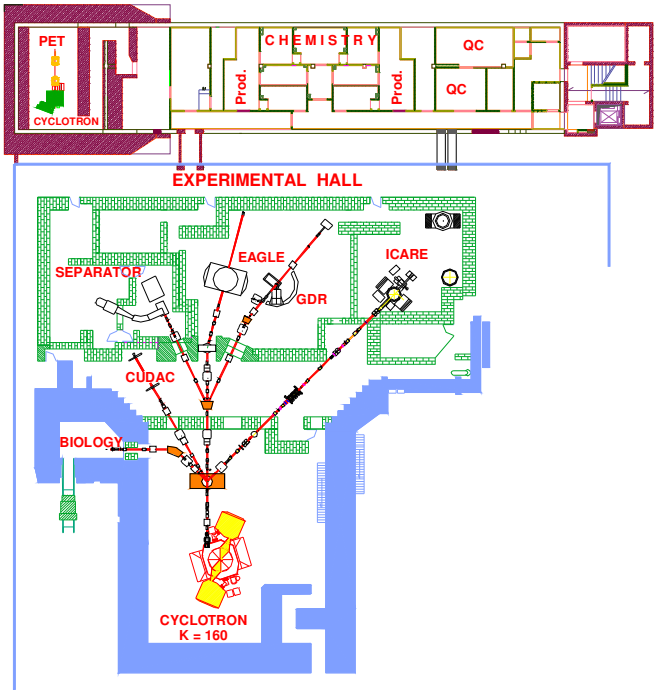


Figure 1: The location of the Radiopharmaceuticals Production Centre in the Laboratory building in the basement of 360 m^2 at 6 m depth. The figure shows also the K=160 heavy ion cyclotron, beam lines and presently operating experimental set-ups.

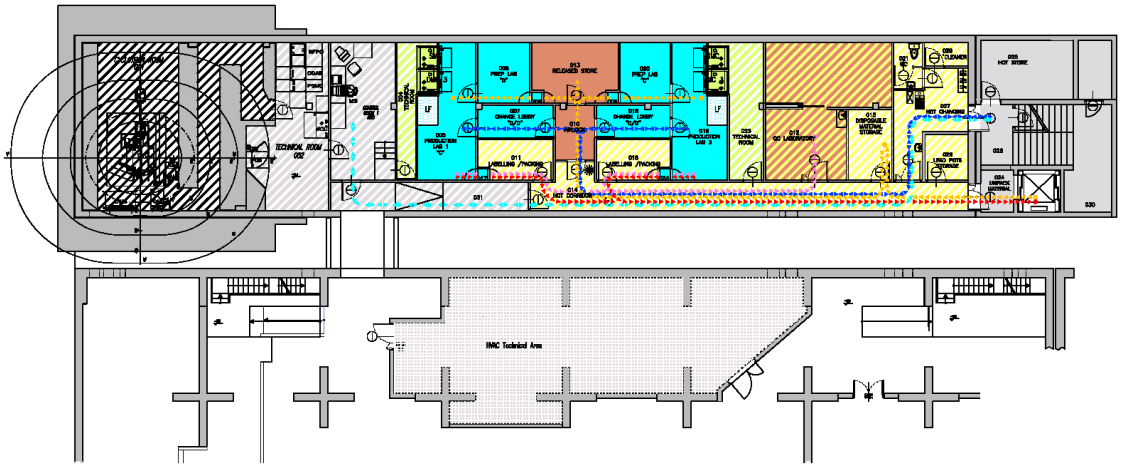


Figure 2: The layout of the Radiopharmaceuticals Production Centre at HIL.
The 16 MeV p / 8 MeV d PETrace cyclotron with its protection walls is shown on the left. The RPC will include two production areas (in blue): one for everyday production of FDG, the other one for research on innovative radiopharmaceuticals. The area foreseen for the QC (Quality Control) is indicated by orange and yellow diagonal stripes. The ventilation and air-conditioning equipment (HVAC) is installed in the basement of the main building (lower part of the figure).

After this layout had been accepted by the Laboratory in April 2008, the building adaptation project was submitted to city authorities and the building permit was obtained at the end of August.

Starting from 15 September 2008, the demolition and construction works were undertaken. Unfortunately, accumulated delays in these activities as well as contractor problems with the timely completion of execution drawings substantially delayed the building adaptation works. At present it is expected that the RPC construction will be finished in the first half of 2010.

References:

[1] J. Jastrzębski *et al.,* HIL Annual Report 2006, p. 42
[2] J. Choiński *et al.,* HIL Annual Report 2007, p. 14
[3] http://www.slcj.uw.edu.pl/PET

12. Nuclear-coal synergy project

L. Pieńkowski for the Nuclear-Coal Synergy Consortium

The High Temperature Reactor (HTR) technology is recognized in Poland since 2006 as a promising option to provide process heat for the industry, including use of nuclear process heat for coal chemistry. The programme in Poland, which originated in our Laboratory, is still at a preliminary, preparatory stage and our efforts are coordinated by the University of Science and Technology in Kraków (AGH) that leads the Consortium formed in 2006. The following goals were achieved in 2008:

1. Two Polish companies PROCHEM SA and ZAK Kędzierzyn Koźle are partners of the FP7 programme EUROPAIRS (*End-User Requirements fOr industrial Process heat Applications with Innovative nuclear Reactors for Sustainable energy supply*). The goals of this project are:
   - To identify boundary conditions for connecting a HTR cogeneration plant to an industrial processing site;
   - To identify market opportunities for HTR in European conventional industry;
   - To elaborate a joint roadmap between nuclear and non-nuclear partners for developing a demonstration plant coupling a HTR heat source with industrial process heat applications.

2. The workshop with participation of professor Jerzy Buzek, Member of European Parliament and of senator Zbigniew Romaszewski, Deputy Speaker of Senat RP was organised at HIL on 11 January 2008. The deputy rectors of AGH, University of Warsaw and Warsaw University of Technology were present during this event. It was concluded that HTR technology development is an attractive and important option for Poland.

3. Our Laboratory participated in the HTR working group under Sustainable Nuclear Energy Technology Platform (SNE-TP). The final workshop was organized in our Laboratory on 19 September 2008. The strategic plan for HTR development in Europe is now included in the final SNE-TP report (see http://www.snetp.eu).

4. The nuclear-coal synergy project has been presented to Polish Ministry of Economy and is included in the strategic vision of energy plans in Poland (see http://www.mg.gov.pl). It is worth noting that in March 2009 the recommendation for this project was issued by the Council for Science of the Ministry of Science and Higher Education (http://www.nauka.gov.pl).

13. Educational and science popularisation activities at HIL

A. Trzcińska, K. Wrzosek-Lipska[1], G. Jaworski[2], K. Kilian, J. Kownacki, J. Mierzejewski[1], P.J. Napiorkowski, M. Palacz, L. Pieńkowski, J. Srebrny, O. Steczkiewicz, M. Wolińska-Cichocka, M. Zielińska

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

This year we attracted the highest number of visitors since 2002 – 40 organized groups, which amounts to more than 1000 people. Among those were groups of students from various faculties of the University of Warsaw, including Physics, Chemistry and Biology, as well as from the University of Silesia and Dominican College of Theology. Finalists of the Interschool Competition in Physics and Chemistry "EUREKA", participants of the Summer School of Physics and several groups of physics teachers were also among our visitors.

In 2008 for the 12th time HIL participated in the annual Warsaw Festival of Science. This year, in addition to our more traditional activities like guided tours of the facility or lectures on nuclear physics and its applications, we decided to organise a more informal presentation of our Laboratory in the friendly atmosphere of the cafe Kawangarda. Our guests had an opportunity to talk to physicists and ask them all kind of questions, concerning not only the science, but also their motivations of choosing this career path. We opened the door for general public on 27 September, when more than 200 people visited the Laboratory. Guests were invited to participate in guided tours of the cyclotron and other experimental facilities and lectures on applications of nuclear physics: "High temperature reactors: history and perspective", "Is there enough uranium for nuclear power plants?" (both by L. Pieńkowski) and "Radiation and health – a story about PET and tumour therapy" (by Z. Szefliński). During the preceding festival week we also organized so-called Festival Lessons for secondary school classes. These simple lectures, addressed to youths of age 14-15, attracted large attention.

The Fourth Polish Workshop on Acceleration and Applications of Heavy Ions was organized at HIL in April 2008. The participants gained experience in methods of data acquisition and analysis, in operating the cyclotron including the beam diagnostics measurements and in charged particle and gamma-ray detection techniques (see Sec. 14 of this Report).

HIL staff members are also engaged in supervising MSc and PhD theses – see Part D of this Report. In summer a four-weeks training was organized for several students from the University of Warsaw, Warsaw University of Technology and the Gdańsk University of Technology.

14. Polish Workshop on Acceleration and Applications of Heavy Ions

P.J. Napiorkowski, A. Trzcińska, K. Hadyńska, G. Jaworski[1], K. Kilian, J. Kownacki, M. Palacz, J. Srebrny, O. Steczkiewicz, Ł. Świderski[2], M. Wolińska-Cichocka, K. Wrzosek-Lipska[3], M. Zielińska

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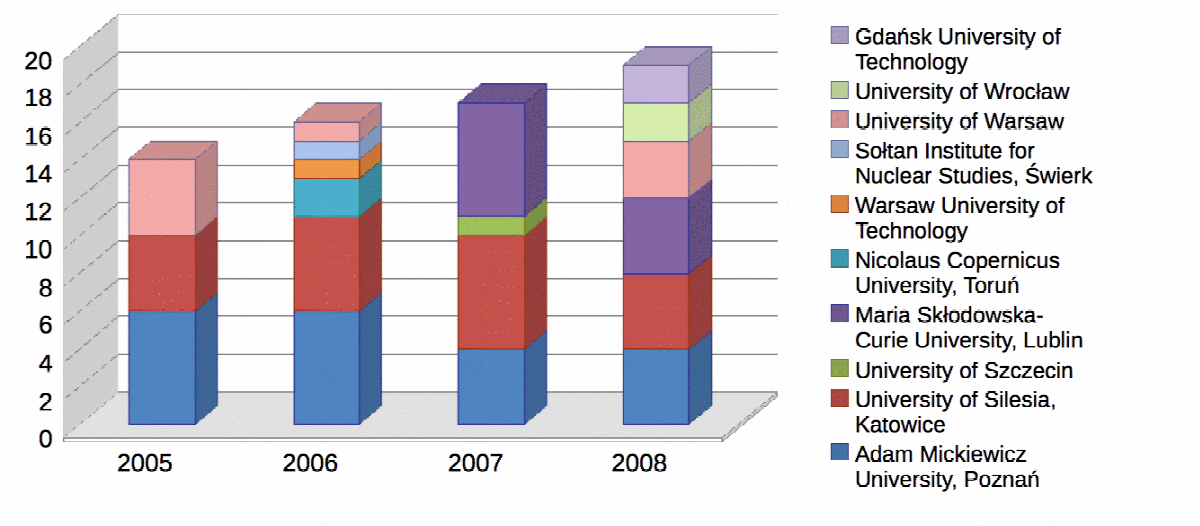
Polish Workshop on Acceleration and Applications of Heavy Ions is organised at HIL every spring since 2005. It is intended for third year physics students interested in nuclear physics, and offers them a unique opportunity to gain experience in methods of data acquisition and analysis, in operating the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



The number of participants has been increasing every year, reaching nineteen in 2008. Unfortunately we are limited by the capacity of our guesthouse, so it seems that without additional funding this is the maximum number of students we can accept. After success of the first editions, we usually receive over two times more applications than the number of places available.

It should be also noted that each year new institutions join the list of universities interested in sending their students to the Workshop. The participants are often interested in continuing the collaboration with HIL in a form of a summer internship or at the MSc stage. The first MSc thesis prepared at HIL by a former Workshop participant was defended in 2008 by K. Hadyńska at the Adam Mickiewicz University in Poznań. Three others theses are currently being prepared, two of them at the University of Silesia and one at the Gdańsk University of Technology.

During the Workshop participants attend a series of lectures on subjects related to heavy ion physics. The experimental tasks allow them to get acquainted with HIL infrastructure by performing measurements using dedicated apparatus available in the Laboratory. The Workshop is concluded by student presentations – each group prepares a 20 minutes talk on their measurements and results.

In 2008 the programme of the lectures was the following:

- Radioprotection at HIL (R. Tańczyk),
- Introduction to heavy ion acceleration and elements of ion optics (M. Wolińska-Cichocka),
- Methods of gamma-ray analysis (M. Palacz),

- In-beam gamma spectroscopy (M. Zielińska),
- Nuclear-coal synergy (L. Pieńkowski),
- Physics against cancer – facts and myths (Z.Szefliński).

Students took part in the following experimental tasks:

- Beam focusing in heavy ion acceleration,
- Beam energy measurements based on the Rutherford scattering,
- Determination of cross section in the Rutherford scattering,
- Identification of excited bands in gamma-gamma coincidences,
- Measurements of ^{137}Cs activity in environmental samples.

Part B:
Experiments and experimental set-ups

1. Transfer probabilities for ^{20}Ne+^{90}Zr and ^{20}Ne+^{92}Zr

E. Piasecki[1,2], A. Trzcińska[1], W. Gawlikowicz[1], J. Jastrzębski[1], N. Keeley[2], M. Kisieliński[1,2], S. Kliczewski[3], A. Kordyasz[1], M. Kowalczyk[1,4], S. Khlebnikov[5], E. Koshchiy[6], E. Kozulin[7], T. Krogulski[8], T. Lotkiev[7], M. Mutterer[9], K. Piasecki[4], A. Piórkowska[10], K. Rusek[2], A. Staudt[10], I. Strojek[2], M. Sillanpää[11], S. Smirnov[7], G. Tiourin[11], W.H. Trzaska[11], K. Hagino[12], N. Rowley[13]

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3) *The Henryk Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland*
4) *Institute of Experimental Physics, University of Warsaw, Warsaw, Poland*
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6) *Kharkiv University, Kharkiv, Ukraine*
7) *Joint Institute for Nuclear Research, Dubna, Russia*
8) *Faculty of Physics, University of Białystok, Białystok, Poland*
9) *Institute für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany*
10) *Institute of Physics, University of Silesia, Katowice, Poland*
11) *University of Jyväskylä, Jyväskylä, Finland*
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13) *Institut Pluridisciplinaire Hubert Curien, Strasbourg, France*

In the last few years the experimental program of the Barriers Collaboration has been focused on the ^{20}Ne projectile [1-4]. A series of measurements has been performed in order to determine barrier height distribution for ^{20}Ne interacting with relatively inert targets. One of the most interesting results concerns ^{20}Ne + ^{90}Zr and ^{20}Ne + ^{92}Zr systems: the shapes of the experimentally determined barrier distributions for the neighbouring Zr isotopes differ significantly. Namely, the shape of the distribution for ^{90}Zr has a "structure" (two maxima) whereas the distribution for ^{92}Zr is wider and no structure can be seen [4]. On the other hand the Coupled Channels calculations predict identical barrier distributions for both Zr isotopes. The possible explanation of discrepancy between experiment and theoretical predictions was the influence of transfer channels in the scattering process, difficult to take into account in calculations. According to the Rehm's systematics [5] the transfer probability for ^{92}Zr should be higher than for ^{90}Zr. This suspicion was also consistent with previous observations for ^{20}Ne + ^{nat}Ni and ^{20}Ne + ^{118}Sn [3].

There were no experimental data on transfer probability for these systems. Thus, measurements of transfer probabilities for the ^{20}Ni + ^{90}Zr and ^{20}Ne + ^{92}Zr were performed in order to verify the predictions of the systematics. The first measurements were performed in Jyväskylä and carefully repeated in 2008 at HIL using the multidetector system ICARE [6].

The scheme of the experimental set-up is shown in Fig. 1. The ToF (Time of Flight) technique was used to identify the masses of backscattered ions. The "start" signal was given by the MCP (Microchannel Plate) detector. The "stop" signal was triggered by any of four 20x20 mm Si detectors placed at a laboratory angle of 142º with respect to the beam. These detectors measured the energy of the reaction products. The base length of the ToF system was 82 cm. Very good time resolution of 250 ps was achieved, which gave the mass resolution of 0.15 amu (FWHM). Two ancillary detectors were employed simultaneously: a telescope identifying charge of the reaction products and a silicon ("Rutherford") detector placed at a forward angle, used to monitor the beam energy. The targets were bombarded with ^{20}Ne ions accelerated by the Warsaw U200-P Cyclotron. The effective beam energy $E_{eff} = E*2/(1+\mathrm{cosec}(\theta/2))$, with E being the beam energy in the cms system, was adjusted in order to investigate the "structure" region in the barrier distribution: $E_{eff} \approx 50$ MeV. The ^{90}Zr and ^{92}Zr targets were 100 μm/cm^2 thick on 20 μm/cm^2 carbon backings.

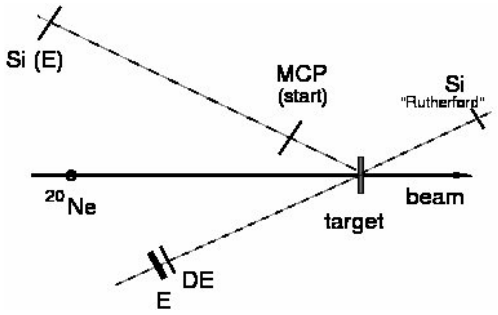

Figure 1: Schematic view of the experimental set-up (see detailed description in the text).

The experimental results were surprising: the total transfer probability for both investigated Zr isotopes turned out to be very similar: 5.7(3) % for ^{90}Zr and 6.6(3) % for ^{92}Zr (see Fig. 2 for details). This was in contradiction with the systematics predictions, where the total transfer cross section for ^{92}Zr was two times higher than for ^{90}Zr target. It is itself not very surprising, as the transfer systematics [5] is based on reaction Q values only and does not take into account structural factors of the interacting nuclei. However, importance of this result consists in the fact that this excludes the possibility of explaining the difference in the ^{20}Ne + ^{90,92}Zr barrier distributions by transfer effects. This points to significance of other weak channels, e.g. single-particle ones, up to now never considered as important ones for the shape of barrier distributions.

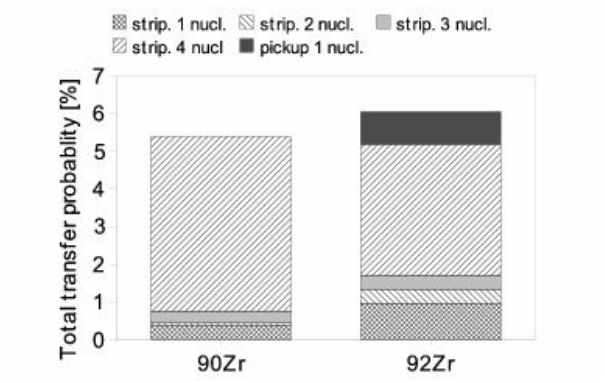

Figure 2: The transfer probability determined for backscattering of ^{20}Ne on ^{90,92}Zr targets (at E_{eff} = 50.5 MeV). "Pickup 1 nucl." denotes 1 neutron pickup by ^{20}Ne projectile; stripping means mainly charged particle stripping, stripping of 4 nucleons corresponds mainly to α-particle stripping.

This work was funded in part by Grant No. N202 152 31/ 2796 and supported by the cooperation agreement (03-110) between the IN2P3 (France) and the Polish Laboratories.

References:

[1] Ł. Świderski *et al*., Int. J. Mod. Phys. **E13** (2004) 315
[2] Ł. Świderski *et al*., Int. J. Mod. Phys **E14** (2005) 341
[3] E. Piasecki *et al*., Phys. Lett. **B615** (2005) 55
[4] E. Piasecki *et al*., Int. J. Mod. Phys. **E16** (2007) 025
[5] K.E. Rehm *et al*., Phys. Rev. **C42** (1990) 2497
[6] E. Piasecki *et al*., HIL Ann. Report 2007, p. 24

2. Fuzzy barrier distributions

E. Piasecki[1,2], Ł. Świderski[2], W. Gawlikowicz[1], J. Jastrzębski[1], N. Keeley[2], S. Khlebnikov[3], M. Kisieliński[1,2], S. Kliczewski[4], A. Kordyasz[1], E. Koshchiy[5], M. Kowalczyk[1,6], E. Kozulin[7], T. Krogulski[8], T. Lotkiev[7], M. Mutterer[9], K. Piasecki[6], A. Piórkowska[10], K. Rusek[2], M. Sillanpää[11], S. Smirnov[7], A. Staudt[10], I. Strojek[2], G. Tiourin[11], W.H. Trzaska[11], A. Trzcińska[1], K. Hagino[12], N. Rowley[13]

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5) *Kharkiv University, Kharkiv, Ukraine*
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13) *Institut Pluridisciplinaire Hubert Curien, Strasbourg, France*

The Barrier Collaboration continued investigations of the barrier distributions. The barrier distributions D_{qe} were experimentally obtained as the first derivative of the quasi-elastic excitation function σ_{eq} for projectile-like nuclei divided by the Rutheford cross section [1-3].

Among the studied systems were: ^{20}Ne + ^{90}Zr and ^{20}Ne + ^{92}Zr, where the shapes of the experimentally determined barrier distributions differ significantly, whereas, according to Coupled Channels (CC) calculations, both systems should have the same D_{qe}. The results of the first measurement were reported in HIL Annual Report 2007. However, the statistical errors were large, so the measurements were repeated. We measured quasi-elastic large-angle scattering using thirty 10x10 mm PIN diodes placed 9 cm from the target at 130, 140 and 150 degrees in the laboratory system and two "Rutherford" semiconductor detectors (6 mm diameter) placed at a distance of 27 cm at 35° with respect to the beam. The ^{20}Ne beam of intensity of a few pnA bombarded 100 μg/cm^2 targets of ^{90}Zr and ^{92}Zr (enriched to 98%) on 20 μg/cm^2 C backings. The use of Ni foils as energy degraders and measurements at three angles allowed to determine the excitation function in small effective-energy intervals.

Energy calibration was performed using a precise pulse generator and a ^{241}Am α-particle source. Energy resolution was continuously monitored during the experiment using the energy spectra measured in the forward detectors, and turned out to be about 1.2 MeV (FWHM) for both targets.

From the kinetic-energy spectra, assuming two-body kinematics, Q-value spectra were calculated for the forward and backward detectors. Then, by integration, the number of counts was obtained. The effective energy as well as the corresponding σ_{eq}/σ_R were calculated. The barrier distribution were determined using the finite-difference method.

The results of calculations performed with the code CCQUEL [4] for ^{20}Ne + ^{90}Zr and ^{20}Ne + ^{92}Zr are shown in Fig. 1 (left). They include couplings between the 0^+, 2^+, 4^+, 6^+ states in the ^{20}Ne rotational band. The strong octupole-phonon state of the projectile and the vibrational excitations of the target were also taken into account, though these have little effect. The experimental results differ: for ^{20}Ne + ^{90}Zr, the measured and calculated distributions show similar structures, whereas for ^{20}Ne + ^{92}Zr one can observe the clear difference. While the measured distribution for ^{20}Ne + ^{90}Zr has a well defined structure, the one obtained for ^{20}Ne + ^{92}Zr is virtually structureless and wider. It is surprising, as the ^{20}Ne projectile should completely dominate distributions due to its large deformation, but experimentally we see a clear target isotopic effect. The only possible explanation of these differences seems to be the population of weak direct channels, which should be stronger in the ^{92}Zr case than for the semi-magic ^{90}Zr nucleus. However,

measurements of transfer probabilities in scattering at near-barrier energy, done for both Zr isotopes, have shown that they are very similar [5], thus one should look for other reasons of the D_{qe} differences.

In Fig. 1 (right) we show a comparison of the Q-value spectra for backscattered ^{20}Ne ions for both targets. It is seen that above a few MeV, excitations are much more probable in the ^{92}Zr case. Moreover, they do not correspond to collective excitations in the CC calculations. Apparently, for ^{20}Ne + ^{90}Zr and ^{20}Ne + ^{92}Zr, the strength of single-particle excitations differs significantly, as might be expected, given that ^{90}Zr had a magic neutron number N=50 and a much lower density of excited states. It seems that the partial smoothing of the distribution in ^{90}Zr and complete smoothing in the ^{92}Zr case is due to a large number of these weak single-particle excitations. We are not aware of any similar result reported in the literature.

The detailed analysis [6] showed that the smoothing can be due to absorption in the nucleus surface area during the scattering process. In the studied systems the D_{qe} for ^{92}Zr can be smoothed out because of scattering into a large number of weak (single-particle) excitations.

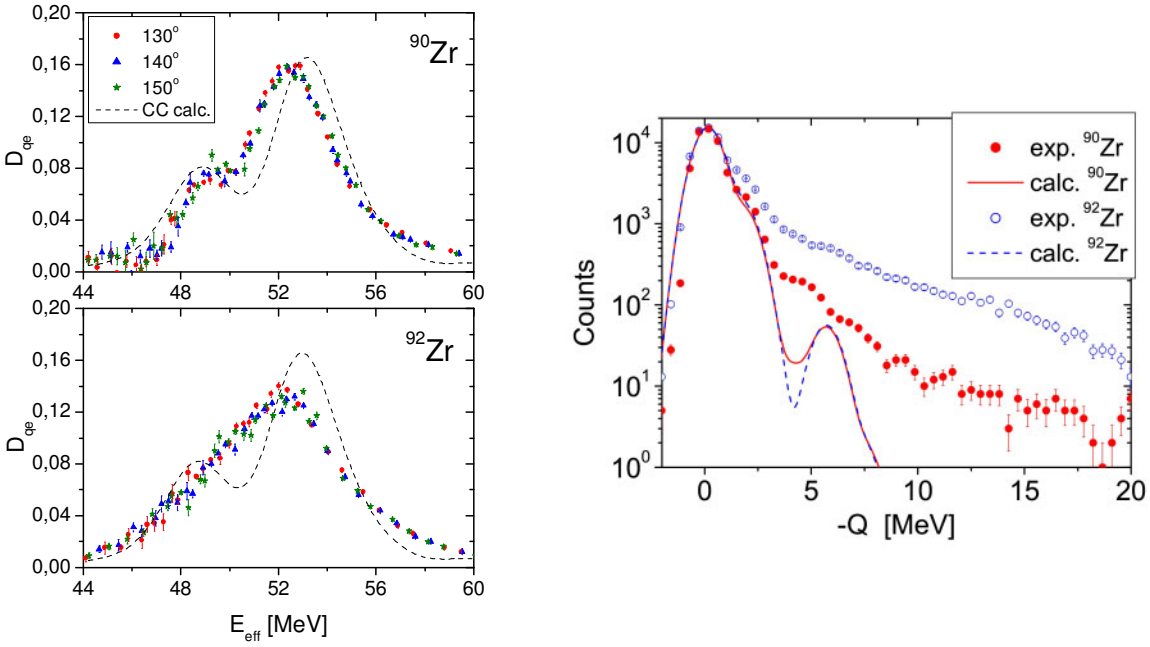

Figure 1: *Left panel:* Barrier distributions for the ^{20}Ne + ^{90}Zr (top) and ^{20}Ne + ^{92}Zr systems (bottom). Different symbols refer to different laboratory angles. The dashed line shows the CC predictions (folded with the experimental resolution). *Right panel:* Non-transfer Q-value spectra for ^{20}Ne + ^{90}Zr and ^{20}Ne + ^{92}Zr from scattering of the ^{20}Ne projectiles at 150 degrees. Lines represent CC calculations after folding with the experimental resolution. All distributions are normalised at the peak.

We thank the target production staff of the LNL, in particular M. Loriggiola. This work was funded in part by Grant No. N202 152 31/ 2796 and supported by the cooperation agreement (03-110) between the IN2P3 (France) and the Polish Laboratories.

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[1] H. Timmers *et al.*, Nucl. Phys. **A584** (1995) 190
[2] L.F. Canto *et al.*, Phys. Rep. **424** (2006) 1
[3] K. Hagino and N. Rowley, Phys. Rev. **C69** (2004) 054610
[4] K. Hagino and N. Rowley (unpublished)
[5] E. Piasecki *et al.*, HIL Annual Report 2008, p. 23
[6] E. Piasecki *et al.*, sent for publication.

3. Gamma-gamma coincidences used in the analysis of the ^{100}Mo Coulomb excitation experiment

K. Hadyńska[1], M. Kisieliński[1,2], M. Kowalczyk[1,3], J. Kownacki[1], P.J. Napiorkowski[1], J. Srebrny[1], K. Wrzosek-Lipska[1,3], M. Zielińska[1]

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Coulomb excitation experiment of ^{100}Mo was performed in December 2007 using the 81 MeV ^{32}S beam from the Warsaw Cyclotron [1]. The measurement was carried out using a dedicated charged particle detection system based on PiN-diodes, coupled to the γ-ray spectrometer OSIRIS II consisting of 12 HPGe equipped with anticompton BGO shields [2].

Two types of measurements were performed. During the first part of the experiment γ rays were registered in coincidence with back-scattered ions using silicon PiN diode detectors. The second part of the experiment was performed in the non-coincidence mode (single γ spectra). Sample spectra collected in coincidence and non-coincidence mode measurements are shown in Fig. 1.

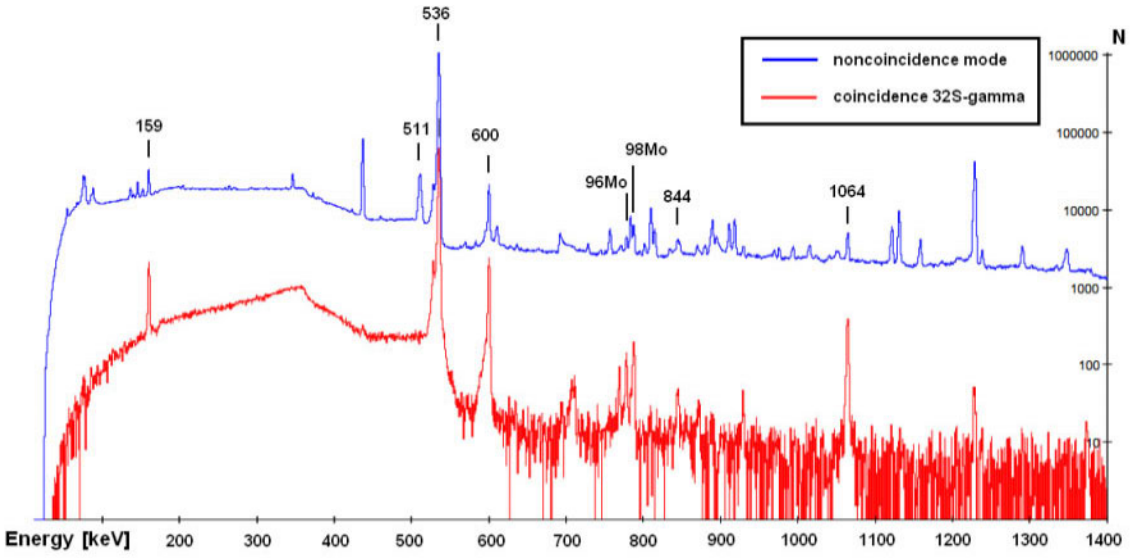

Figure 1: The particle-gamma coincidence spectrum (red) compared to the non-coincidence spectrum (blue) collected by a single HPGe detector.

Since excitation strongly depends on the scattering angle, the excitation patterns obtained in these two types of measurements are different and bring complementary information on matrix elements involved.

Besides ^{100}Mo deexcitation γ lines, many other transitions were observed in the single mode spectra. The analysis of γ-γ coincidence data allowed to identify additional γ lines as a result of nuclear reactions of the ^{32}S beam on the target contaminations: ^{16}O and ^{12}C. Channels of mentioned nuclear reactions are presented in Table 1.

Table 1: Channels of nuclear reactions: $^{32}S+^{16}O \rightarrow {}^{48}Cr^{*}$ and $^{32}S+^{12}C \rightarrow {}^{44}Ti^{*}$. Full list of γ lines observed during the experiment without coincidences with the scattered projectile.

	Reaction channel	Gamma energies observed during the single mode experiment [keV]
Isotopes produced only in $^{16}O+^{32}S$ reaction	^{46}Ti	382, 889, 1121, 1289, 1600
	^{45}Ti	293
	^{46}V	801
Isotopes produced in both $^{16}O+^{32}S$ and $^{12}C+^{32}S$ reactions	^{42}Ca	145, 236, 382, 436, 809, 815, 911, 918, 929, 1023, 1228, 1348, 1527, 1646, 1746, 1925
	^{43}Ti	312
	^{42}Sc	610, 880, 976
	^{43}Sc	136, 151, 728, 1052, 1158, 1186, 1832
Isotopes produced only in $^{12}C+^{32}S$ reaction	^{39}K	346, 757, 1131, 1411, 1776
	^{36}Ar	993, 1973

The strongest identified γ lines are marked in the spectrum shown in Fig. 2. In addition to the lines resulting from nuclear reactions, also background lines from the decay of radioactive elements such as ^{214}Bi, ^{228}Ac, ^{40}K, ^{208}Tl, ^{212}Pb, were identified.

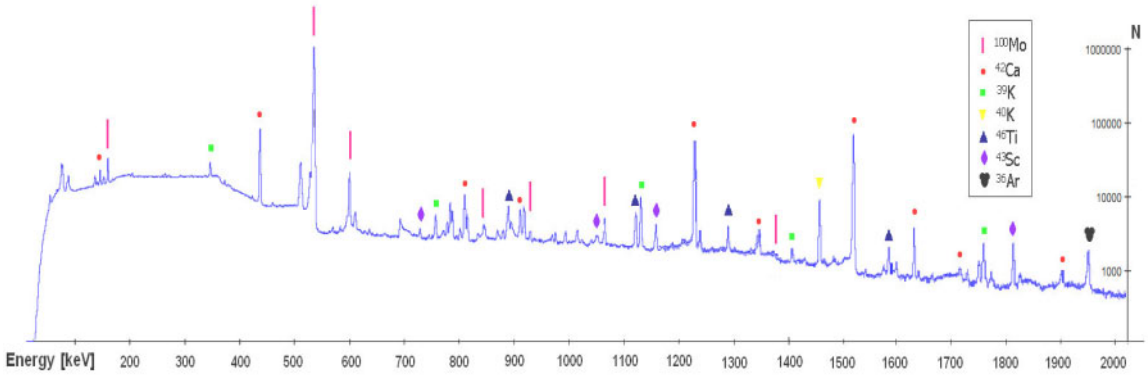

Figure 2: The strongest of identified γ lines in $^{16}O+^{32}S$ and $^{12}C+^{32}S$ reaction channels.

The analysis of γ-γ coincidences allowed also to investigate more carefully the origin of two γ lines, which were initially interpreted as resulting from Coulomb excitation of ^{100}Mo.

The 844 keV line, which is crucial for the 3^{-} state excitation analysis, was in a coincidence only with other ^{100}Mo gamma lines, but the observed yield was too high – the branching ratio 1372 keV / 844 keV known from the literature [3] was not reproduced. It means that there might be a contribution to this line from an unknown long lived state produced during one of reactions of ^{32}S with target contaminations. This contribution could have been determined, if off-beam experimental data had been collected during the experiment, but unfortunately this was not the case.

The 928 keV line in ^{100}Mo seems to be observed during the experiment, but it is obscured by the 929 keV transition in ^{42}Ca. These two lines are very close to each other so it was hard to determine their relative yields. Moreover the calculated 928 keV / 768 keV branching ratio is not consistent with the one given by the literature [3]. As a result, the 928 keV transition was also excluded from the further analysis of the data collected during the inclusive experiment.

The collected data allowed to determine the composition of ^{100}Mo target in a quantitative way. The thickness of ^{12}C and ^{16}O was estimated by comparing intensities of lines from selected nuclear reaction channels: 783 keV and 1130 keV from the decay of ^{39}K produced in $^{12}C(^{32}S, \alpha n)^{39}K$ reaction and 889 keV in case of $^{16}O(^{32}S, 2p)^{46}Ti$ reaction channel. The nuclear reaction cross-sections were calculated using the evapOR code [4], yielding about 400 mb for

^{12}C(^{32}S, αn)^{39}K and about 250 mb for ^{16}O(^{32}S, $2p$)^{46}Ti at the beam energy of 81 MeV. Intensities of the γ lines used for the thickness estimation were normalized to the 536 keV γ transition from the Coulomb excitation of ^{100}Mo first 2^+ excited state. Cross section of the first 2^+ state population was calculated using the GOSIA code [5]. As a result of the estimation based on the cross section analysis, the thickness of ^{12}C layer of 0.16 mg/cm^2, and the thickness of ^{16}O layer of 0.02 mg/cm^2, were obtained.

Further RBS experiment analysis [6], which was performed to more precisely determine the quantity of ^{100}Mo target contaminations, showed that there is a 0.12 mg/cm^2 layer of ^{12}C on the target surface. The analysis of target contaminations showed that there is also an oxidized layer beside the pure ^{100}Mo. Oxygen layer calculated from estimation based on RBS measurement is 0.05 mg/cm^2 thick.

References:

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[3] National Nuclear Data Chart, `http://www.nndc.bnl.gov/`
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[6] K. Wrzosek-Lipska *et al.*, this Report, p. 29

4. Determination of the surface contamination in the ^{100}Mo target using the RBS method

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A Coulomb excitation experiment of ^{100}Mo was carried out in December 2007 using the ^{32}S beam delivered by the Warsaw Cyclotron [1]. Two types of measurements were performed. During the first part of the experiment γ rays were detected in coincidence with back-scattered ions of ^{32}S. In the second part, γ rays were collected in the non-coincidence mode and single γ-ray spectra were collected. The observation of numerous γ lines, which were not related to the Coulomb excitation of ^{100}Mo, prompted the analysis of the γ-γ coincidence data. It allowed to conclude that they result from nuclear reactions of the ^{32}S beam on target contaminations: ^{16}O and ^{12}C [2]. This, in turn, lead to a question about the thickness of ^{12}C and ^{16}O layers and their influence on the effective ^{32}S beam energy which is related to the energy range of ^{32}S ions by which Coulomb excitation of ^{100}Mo is ensued.

It was necessary to perform an additional experiment to investigate the composition of ^{100}Mo target in a quantitative way. The experiment, using the Rutherford Backscattering Spectrometry method (RBS), was carried out at the Ion Beam Center AIM Institute in Dresden, Germany (Forschungszentrum Dresden-Rossendorf). The 1.7 MeV ^{4}He beam was delivered from the 2 MV Van de Graaff accelerator and Rutherford backscattered on the ^{100}Mo target at 170 degrees with respect to the beam direction.

The energy exchange between beam and target atoms during the scattering process is induced by the Coulomb interaction. In an elastic collision, the energy is transferred from the moving

^{4}He ions to the stationary target atoms. The final energy of the scattered ions depends on the masses of incident and target atoms, hence allows identifying the target atoms.

Collected spectra of backscattered ^{4}He ions are shown in Figure 1. Two different regions of the ^{100}Mo target were irradiated: the middle, where a layer of ^{12}C can be observed (green spectrum), and the right side of the target where no ^{12}C contamination was expected (black spectrum).

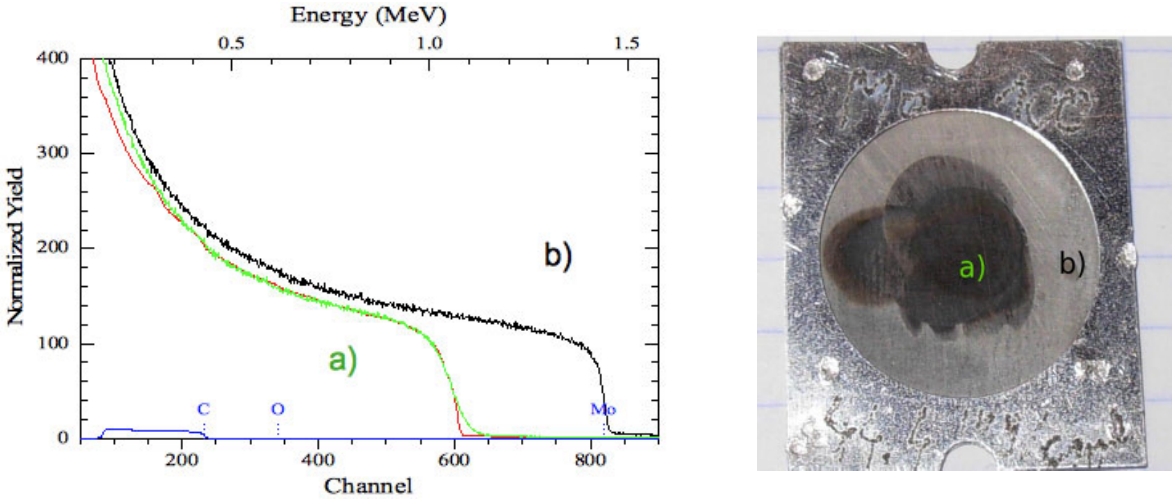

Figure 1: *Left panel*: experimental spectra of ^{4}He ions scattered on the ^{100}Mo target. Green spectrum is related to the scattering of ^{4}He ions, previously slowed down in the ^{12}C layer, on the ^{100}Mo atoms (a). Black spectrum corresponds to the region where no carbon layer is visible (b). Reconstruction of experimental spectrum is marked with the red line. Maximum energies of ^{4}He ions scattered on the ^{12}C, ^{16}O, ^{100}Mo atoms are marked in blue.
Right panel: the ^{100}Mo target under study. Scattering data were collected for two different regions marked on the target.

One can observe that the edge of the spectrum of ^{4}He ions scattered in the region a) covered by ^{12}C (marked in green) is moved to the lower energies as compared to the spectrum corresponding to the region b). This effect is related to the passage of the ^{4}He ions through the ^{12}C layer. The energy loss of ^{4}He due to the penetration of the ^{12}C layer is directly proportional to the thickness of this layer. One can also notice that the edges of both spectra are not sharp and this suggests that the scattering process takes place in the non-uniformly saturated oxidized molybdenum layer.

Experimental spectra were reconstructed (red line in Figure 1.) using the Rutherford Backscattering Spectroscopy analysis package RUMP [3]. The shift of the edge related to the ^{4}He beam energy loss in ^{12}C layer corresponds to the thickness of 0.12 mg/cm^{2} of this material. The shape of the edge was reproduced by introducing twenty oxidized molybdenum layers assuming variable concentration of ^{16}O – the ratio ^{16}O / ^{100}Mo was decreasing with the depth. The total thickness of introduced oxidized layers is equal 0.2 mg/cm^{2}, which corresponds to a 0.05 mg/cm^{2} thick pure ^{16}O layer.

The analysis of the RBS spectra allowed to confirm the presence of ^{12}C and ^{16}O components in the ^{100}Mo target and to extract the thickness of their layers. Our less sophisticated estimation obtained from the reaction cross section analysis gave the same order of magnitude in both cases [2]. Energy loss of the ^{32}S beam in determined ^{12}C layer is equal 2 MeV. Maximum energies of scattered ^{32}S ions, observed during the ^{32}S + ^{100}Mo Coulomb excitation experiment, are in agreement with the decreased value of ^{32}S beam energy. Due to the ^{32}S beam energy loss in the ^{12}C layer and higher stopping power values calculated for ^{32}S ions in oxidized molybdenum layer, as compared to the values obtained for pure ^{100}Mo target, the energy range where Coulomb excitation of ^{100}Mo proceeds is different compared to the case of pure ^{100}Mo target.

The present study of the target composition allows for a proper analysis of the data collected in the earlier Coulomb excitation measurements. The GOSIA code, which is generally used to analyze Coulomb excitation data, solves the excitation equation at a given mean scattering angle and bombarding energy that describe the experiment. As a result, for a given set of electromagnetic matrix elements, the γ yields are calculated. The exact reproduction of the experimentally observed γ yields requires the integration over the finite scattering angle range covered by the particle detectors and over the range of bombarding energies resulting from the projectile energy loss in a target. To compare γ yields collected in the experiment with the yields calculated using the GOSIA code, experimentally observed γ yields need to be corrected for the difference between the yields calculated using the integration and the yields calculated using mean values of the bombarding energy and scattering angle. Such an approach requires precise knowledge of the incident beam energy and energy loss in the target.

References:

[1] K. Wrzosek *et al.,* HIL Annual Report 2007, p. 28
[2] K. Hadyńska *et al.,* this Report 2008, p. 27
[3] `http://www.genplot.com/RUMP/index.htm`

5. Data analysis from electron-gamma coincidence measurements

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Coincidence γ-electron measurements allow determining internal conversion coefficients and, in consequence, transition multipolarities. For these purposes the electron spectrometer designed and constructed at the University of Łódź, coupled to the OSIRIS-II γ-detection array, was used in several successful measurements on beam of the Warsaw Cyclotron. The present work describes a data analysis procedure used to study the decay of the ^{132}Ce isomeric state (results are presented in this Report, [1]). In the measurement:

- The isomeric state in ^{132}Ce was populated in the ^{120}Sn(^{16}O, 4*n*) reaction during cyclotron beam pulses (about 2 ms width). Its decay was investigated during off-beam periods of about 4 ms width, which is comparable with $T_{½}$ = 9.4 ms for the studied isomer;
- Internal conversion coefficients were deduced from the γ-γ and γ-electron coincidence measurements by using electron spectrometer [2,3] coupled to the OSIRIS-II γ-detector array;
- The HPGe detectors in the OSIRIS-II set-up were not identical i.e. they had different registration efficiencies.

The experimental data registered during off-beam periods consist of two groups of events, namely γ-γ and γ-e events. Consequently, during the off-line analysis two types of asymmetric matrices (see text below) were created: one containing γ-γ events and the second one γ-e events.

Assuming that two γ transitions "a" and "b" are in coincidence (in our case it concerns transitions accompanying the decay of the ^{132}Ce isomer) the following formula can be used:

$$\alpha = \frac{I_e(a)}{I_\gamma(a)} = \frac{N_{\gamma b,ea}}{N_{\gamma b,\gamma a}} \cdot \frac{\varepsilon_\gamma(a)}{\varepsilon_e(a)}$$

where:

α - internal conversion coefficient,

$I_e(a)$, $I_\gamma(a)$ – intensities of internal conversion electrons and γ rays, respectively, corresponding to the γ transition "a"

$N_{\gamma b,\,\gamma a}$ – number of γ quanta of energy $E(a)$ being in coincidence with "b" when the gate is set on the γ line of energy $E(b)$.

$N_{\gamma b,ea}$ – number of internal conversion electrons corresponding to γ transition "a" being in coincidence with "b" when the gate is set on the γ line of energy $E(b)$.

$\varepsilon_e(a)$, $\varepsilon_\gamma(a)$ – registration efficiencies of the electron and γ spectrometers for the "a" transition, respectively.

The formula given above was used for:

- Determination of registration efficiency $\varepsilon_e/\varepsilon_\gamma$ based on intensities of conversion electron lines if internal conversion coefficients are well known,
- Determination of conversion coefficients for γ transition of interest if the ratio $\varepsilon_e/\varepsilon_\gamma$ from calibration is known.

To analyse the experimental data, all Ge detectors of the OSIRIS-II array were divided into two groups containing 5 and 6 detectors, respectively. During the off-line analysis the data were sorted into two asymmetric matrices containing the energies of γ rays registered by the first group of Ge detectors on one axis of both matrices. The other axis contained energies of γ rays registered by the second group (in case of the γ-γ matrix) or energies of detected electrons (for the γ-e matrix). In order to make use of all the data, this procedure can be repeated with both groups of Ge detectors interchanged.

In accordance to the procedure described above the efficiency ratio $\varepsilon_e/\varepsilon_\gamma$ depends only on the energy of the "a" transition. It appears that in case of symmetric matrix (events from all γ detectors placed on both axes) the ratio $\varepsilon_e/\varepsilon_\gamma$ depends also on the energy of the gating transition "b", unless all Ge detectors are identical.

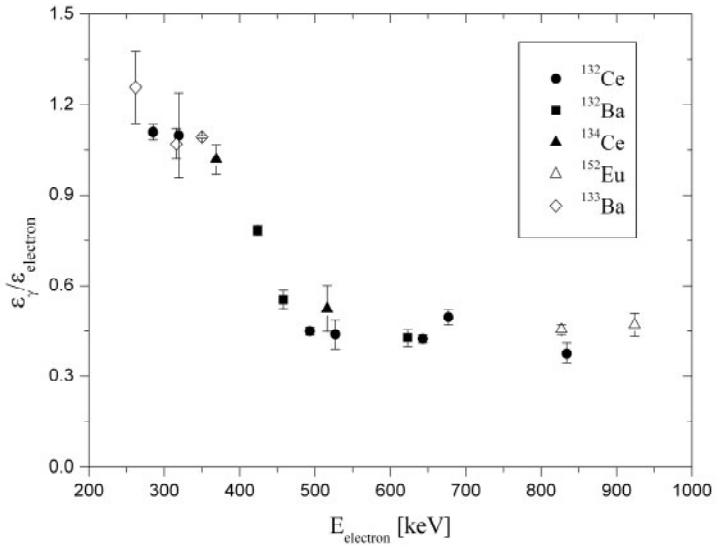

Figure 1: The experimentally determined efficiency curve ($\varepsilon_\gamma/\varepsilon_{electron}$).

The efficiency curve ($\varepsilon_\gamma/\varepsilon_e$) obtained from the present experiment is shown in Fig. 1. It is based mostly on internal calibration points from the ^{132m}Ce → ^{132}Ce and ^{132}La → ^{132}Ba decays (^{132}Ce – 325, 533, 683 and 874 keV; ^{132}Ba – 464 and 663 keV). Additionally the ^{152}Eu source was used (the 867 and 964 keV transitions), as well as some γ transitions from the ^{134}Pr → ^{134}Ce decay following the ^{118}Sn + ^{20}Ne reaction (409, 556 and 763 keV lines). All the transitions used for efficiency calibration had well known multipolarities or internal conversion coefficients.

It is worth noting that the efficiency curve is flat in the region between 400 and 1000 keV, corresponding to the transitions depopulating the 8^- isomer in ^{132}Ce.

The internal conversion electron spectrum (Figure 2) shows that the peak shapes are not gaussian, but asymmetric. To fit all electron lines in the same way, shape parameters have to be determined for the standard apparatus electron line and then used in all other fits. During this experiment the K-internal conversion electron line at energy 424 keV from the 464 keV transition in ^{132}Ba (daughter of ^{132}Ce) was chosen as a standard apparatus line, since it was well separated from other electron lines observed and had the best statistics. The GF3 program from the "RadWare" package [4] was used to fit the spectra. This code is a standard tool to analyse γ-ray spectra, but it provides a peak shape function being general enough to well describe non-gaussian electron peaks. The fitted function is the sum of a gaussian of height H*(1-R/100) and a skew gaussian of height H*R/100. BETA is the decay constant (skewness) of the skew gaussian. STEP is the relative height (in % of the peak height) of a smoothed step function which increases the background below each peak. The shaping parameters used in the present analysis for K-lines were the following: R=34, BETA=4, STEP=4. Since the energy resolution for electron spectra does not allow to distinguish between L and M+… lines, it was necessary to use BETA=2 when fitting L+M+... lines.

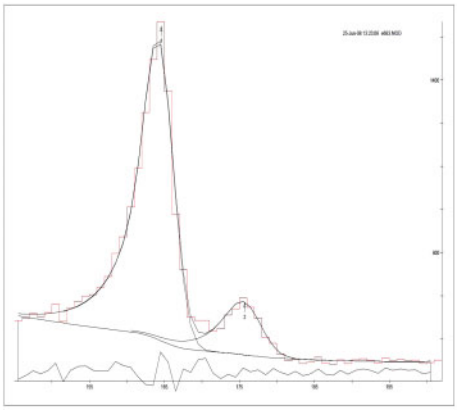

Figure 2: Part of electron spectrum observed in coincidence with the 683 and 798 keV γ-ray transitions, showing K and L+M+… lines corresponding to 533 keV transition in ^{132}Ce. Black line denotes the curve fitted by GF3, with shape parameters R, BETA and STEP fixed as described in the text.

References:

[1] J. Perkowski *et al.,* HIL Annual Report 2008, p. 34
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6. Absolute E3 and M2 transition probabilities for electromagnetic decay of K=8$^-$ isomeric state in ^{132}Ce

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The decay of the $I^\pi = K^\pi = 8^-$ isomer in the ^{132}Ce has been investigated. The measurements were carried out in e-γ and γ-γ coincidence mode, using an electron spectrometer coupled to the OSIRIS II γ array. Experimentally obtained internal conversion coefficients allowed to determine multipolarity of a few transitions in the ^{132}Ce nucleus, providing new information on the phenomenon of K-isomers. The problem of weakening of K-hindrance for K=8$^-$ isomer in ^{132}Ce was studied previously [1] where three decay paths of the isomer were established (see level scheme in Fig. 1).

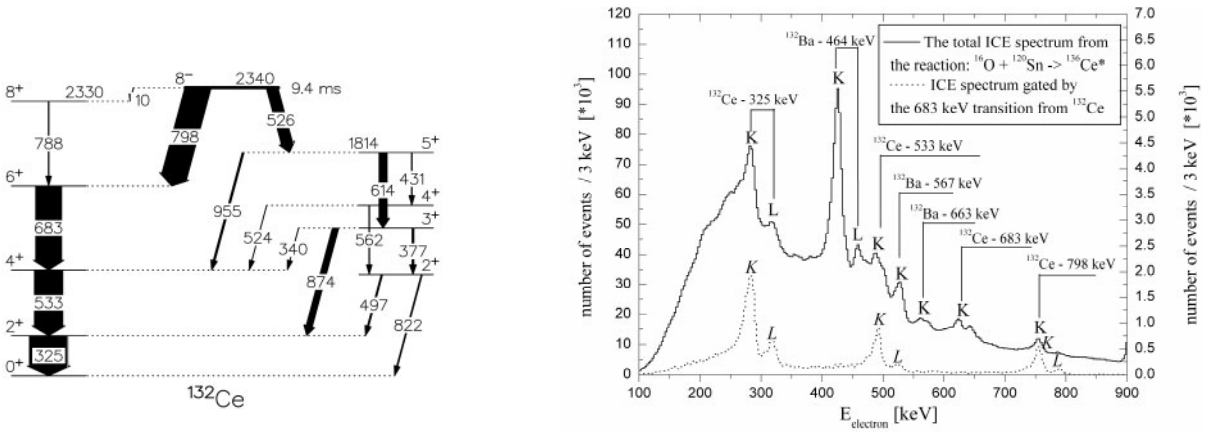

Figure 1: *Left panel*: The decay paths of the $I^\pi = 8^-$, K = 8 isomeric state measured in [1] and extended in this work. *Right panel*: The ICE total spectrum and the spectrum of ICE gated by the 683 keV gamma transition observed below the isomeric state in ^{132}Ce.

The $I^\pi = 8^-$ isomeric state in ^{132}Ce was populated in the ^{120}Sn(^{16}O,4n)^{132}Ce reaction using the 80 MeV ^{16}O beam. The description of experimental set-up can be found in the papers [2-4]. The main goal of this experiment was to determine multipolarities of the 526 and 798 keV transitions. The ICE total spectrum and the spectrum of ICE gated by the 683 keV γ line observed below the isomeric state in ^{132}Ce are shown in Fig. 1 (right panel). The electron spectrum of the 798 keV transition de-exciting the 8$^-$ isomeric state obtained by gating on γ-ray energies of 325, 533 and 683 keV in the gamma-electron matrix, is shown in Fig. 2 (left panel). K and L+M+... electron lines belonging to the 798 keV transition are clearly visible. The multipolarity of this transition was determined by comparing the experimentally obtained

coefficients with the theoretical ones. The measured values of the conversion coefficients for K and L+M+... lines for the 798 keV transition are α_K = 0.0083(6) and $\alpha_{L+M+...}$= 0.0016(4). These correspond to a 65% E3 + 35% M2 mixed transition with mixing parameter δ^2(E3/M2) = 1.9(7). This value was obtained basing on the theoretical conversion coefficients [5]: α_K (M2) = 0.0126, $\alpha_{L+M+...}$(M2) = 0.0020, α_K (E3) = 0.0060, $\alpha_{L+M+...}$(E3) = 0.0013. The electron spectrum for the second transition of interest (526 keV) is shown in Fig. 2 (right panel). The value of conversion coefficients for K and L+M+... lines were determined experimentally as α_K = 0.0198(11) and $\alpha_{L+M+..}$ = 0.0051(5). Both of these are in good agreement with the theoretical values for E3 transitions (α_K(theo.) = 0.0198 and $\alpha_{L+M+...}$(theo.) = 0.0054) and confirm the pure E3 character of the 526 keV transition.

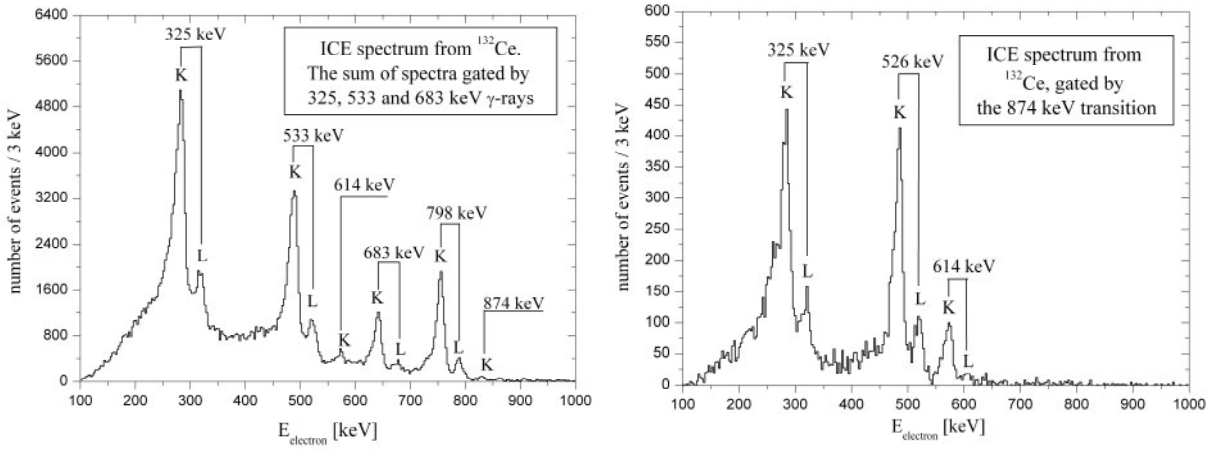

Figure 2: *Left panel*: Summed electron spectrum observed in coincidence with the 325, 533 and 683 keV gamma-ray transitions. *Right panel*: Electron spectrum observed in coincidence with the 874 keV γ-ray transition.

Reduced transition probabilities, hindrance factors and reduced hindrance factors for the 526 and 798 keV transitions have been calculated using the multipolarities measured in the present experiment, the half-life ($T_{1/2}$ = 9.4(3) ms) of the investigated 8^- isomeric state and the relative intensities of the 526 and 798 keV transitions measured in ref. [1]. All achieved results are presented in Table 1. The $8^- \rightarrow 5^+$ E3 transition can be facilitated by K=7 admixture to the 8^- state [6] and K=4 one to the 5^+ and 6^+ levels. The K=4 admixtures were calculated using the Davydov-Filippov triaxial rotor model [7,8] as a function of the triaxiality parameter gamma (see Fig. 3). The experimentally deduced B(E3; $8^- \rightarrow 5^+$) / B(E3; $8^- \rightarrow 6^+$) ratio equal 12 ± 2, interpreted using the D-F model, indicates that the gamma deformation of the 5^+ state is higher by 4° ± 1° degrees than the one of the 6^+ level. The present study has shown that the B(E3; $8^- \rightarrow 5^+$) / B(E3; $8^- \rightarrow 6^+$) ratio for transitions de-exciting K-isomeric states can be a sensitive probe of triaxiality.

Table 1: Results for the 526 keV and 798 keV transitions de-exciting the 8^- isomeric state in ^{132}Ce.

transition energy [keV]	526	798	
intensity I_γ^p	30	68	
α_K	0.0198(11)	0.0083(6)	
$\alpha_{L+M+...}$	0.0051(5)	0.0016(4)	
multipolarity λ	E3	65(9) % E3	35(9) % M2
partial half life $T_{1/2}^p$	31(5) ms	21(4) ms	40(12) ms

transition energy [keV]	526	798	
reduced transition probabilities B(E3) or B(M2)	3.6(5) $e^2(fm)^6$	0.28(6) $e^2(fm)^6$	4.0(1.2) • 10^{-6} $(e\hbar/2Mc)^2\,(fm)^2$
hindrance factor F[a]	290(43)	3800(750)	1.1(0.3) • 10^7
K-forbiddenness ν[b]	3	5	6
reduced hindrance factor f_ν[c]	6.7(3)	5.2(2)	14.9(7)

[a] Hindrance factor F is defined as: $F = T^p_{1/2}/T^W_{1/2}$, where $T^p_{1/2}$ is the partial half-life of the transition and $T^w_{1/2}$ is the corresponding Weisskopf single particle estimate.

[b] K-forbiddenness is calculated using expression: $\nu = |K_f - K_i| - \lambda$

[c] f_ν is defined as: $f_\nu = F^{1/\nu}$

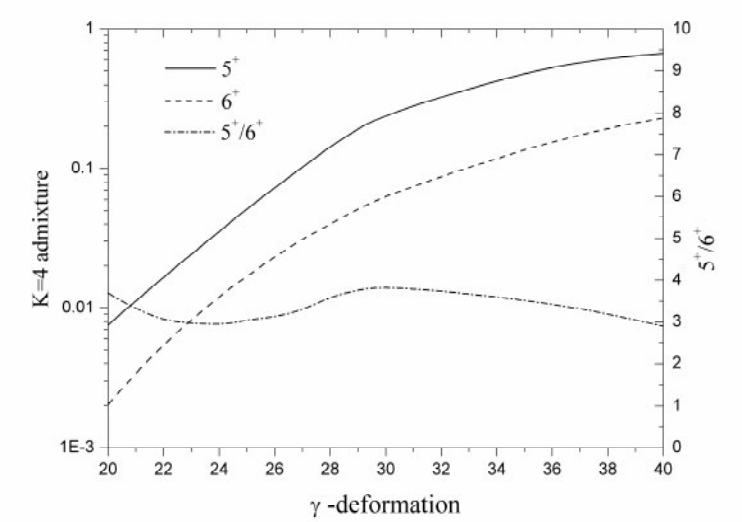

Figure 3. The K=4 admixtures as a function of the triaxiality parameter gamma.

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7. In-beam and off-beam spectroscopy above isomers in ^{148}Ho and ^{149}Ho nuclei

J. Kownacki[1], Ch. Droste[2], E. Ruchowska[3], A. Korman[3], J. Perkowski[4], K. Wrzosek[1,2], M. Zielińska[1], A. Kordyasz[1], M. Kisieliński[1,3], M. Kowalczyk[1,2], T. Morek[2], J. Srebrny[1] J. Andrzejewski[4], A. Król[4], K. Sobczak[4], R. Lieder[5], M. Antczak[1], A. Jakubowski[1], A. Pietrzak[1], R. Pozorek[1]

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The excited states of ^{148}Ho and ^{149}Ho isotopes have been studied with off-beam and in-beam spectroscopy methods following ^{112,114}Sn(^{40}Ar, *xnyp*) reactions. The reactions used lead to nuclei, lying beyond the stability line, which have been already a subject of several investigations, e.g. [1-4]. However, there was no information on the high spin (above the isomers) parts of the level schemes of ^{148}Ho and ^{149}Ho isotopes with the exception of the decay of the 10^+ and $27/2^-$ isomers, respectively.

The experiments were performed using the OSIRIS-II array including 12 HPGe detectors coupled to the dedicated conversion electron spectrometer [5]. Gamma-gamma, electron-γ and E_γ-t coincidences were analyzed. Taking advantage of the unique beam pulse structure of the HIL cyclotron one could measure the γ-γ and e-γ coincidence spectra in the in-beam (1-3 ms) and off-beam (3-8 ms) modes. The decay of the 10^+ isomer in ^{148}Ho was reinvestigated and the half-life of 2.62 ± 0.18 ms was determined, which is in agreement with the earlier result ($T_{1/2}$ = 2.35(4) ms) of R. Broda *et al.* [2].

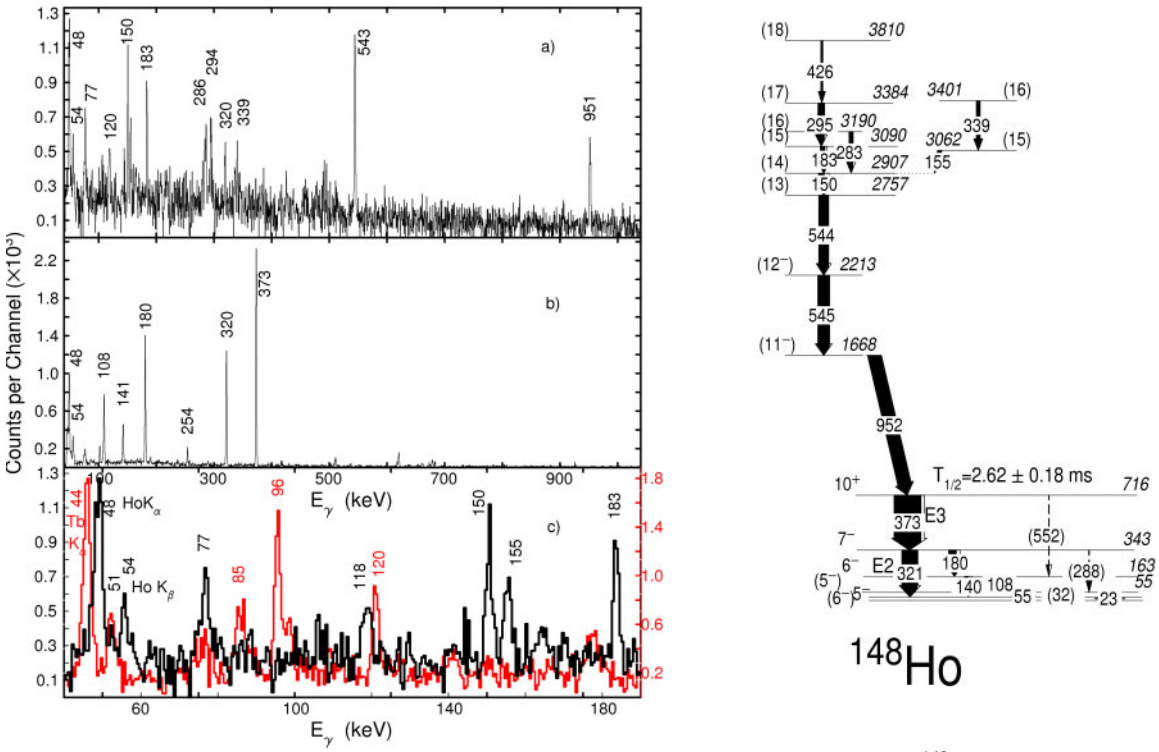


Figure 1: *Left:* a) Preliminarily proposed γ rays feeding the 10^+, 2.62 ms isomer in ^{148}Ho. b) The γ rays deexciting 10^+ isomer. c) X-ray spectra gated by sum of γ rays feeding the 10^+ isomer in ^{148}Ho (black). A similar sum spectrum of γ rays feeding the 10^+ isomer in ^{146}Tb (red) is shown for comparison.
Right: Level scheme of ^{148}Ho extracted in the present work. The existence of additional weak lines 553 and 288 keV is being considered. The 55 keV transition seems to be firmly established in the coincidence spectra of the isomer decay. The levels placed above the 10^+ isomer are preliminarily proposed.

From the electron spectrum collected in the off-beam mode, gated by the sum of the 180 and 320 keV γ rays in ^{148} Ho it was possible to extract the K/L ratio and electron conversion coefficient α_K for the 373 keV line. This allowed for the E3 multipolarity assignement, in accordance with the former assumption based on the α_K value estimated only from the intensity balance [2]. Another new information is that the 321 keV transition is of the E2 nature and most probably feeds the 5^- state.

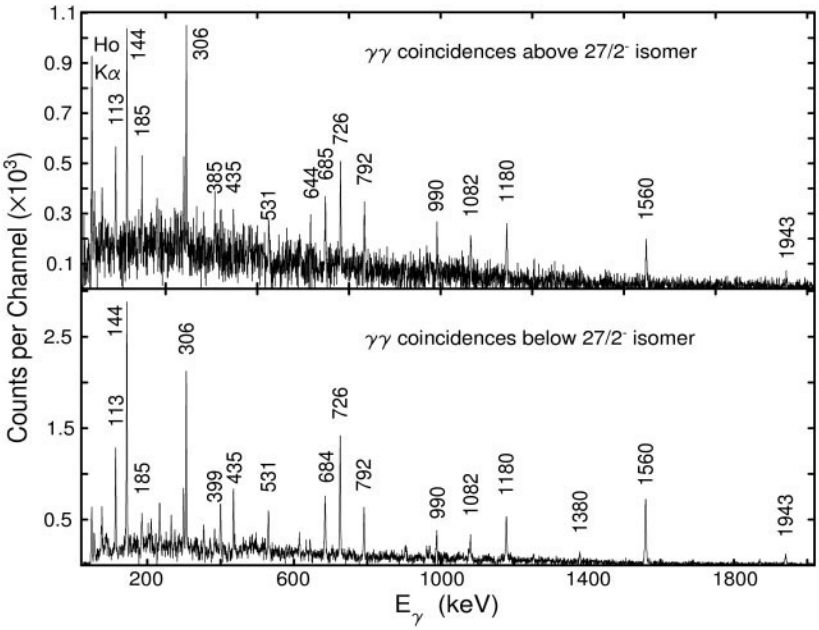
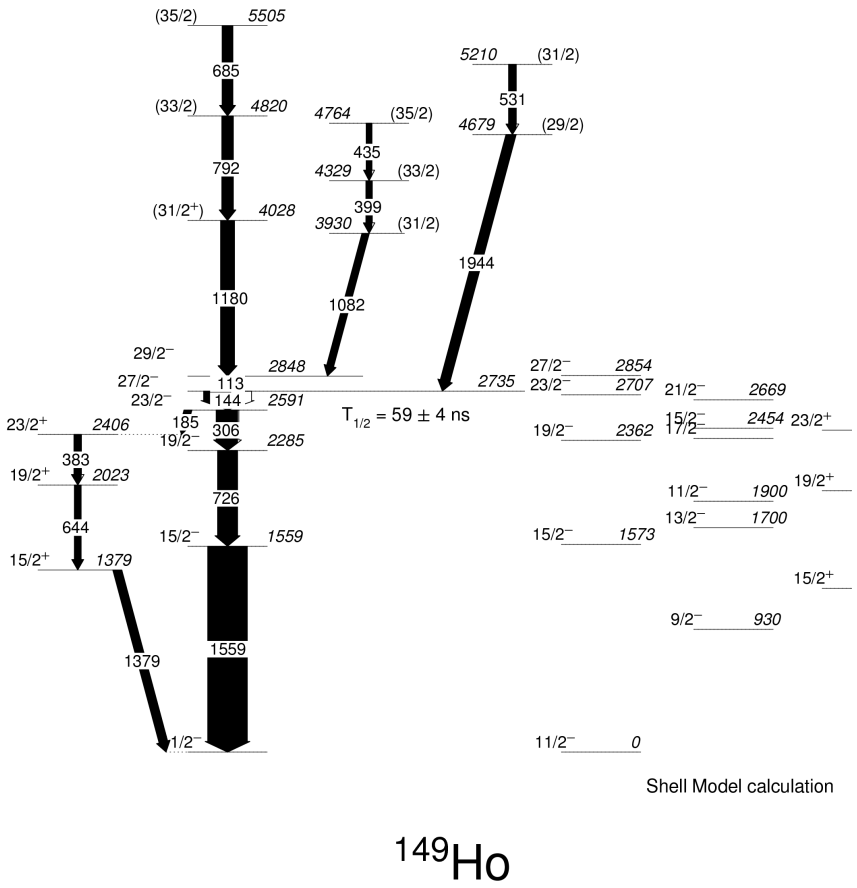


Figure 2: *Bottom*: γ-ray sum spectrum gated by the γ rays deexciting the $27/2^-$, 59 ns isomer in ^{149}Ho showing also the weakened lines deexciting levels above the isomer. *Top:* γ-ray sum spectrum gated by the γ rays feeding the 59 ns isomer showing the weakened lines deexciting levels below the isomer.

The level scheme of ^{148}Ho based on the data obtained from the ^{112,114}Sn(^{40}Ar, *xnyp*) reaction is shown in Fig. 1. A new band like structure above the 10^+ isomer is preliminarily proposed.

Gamma-gamma coincidence spectra for ^{149}Ho are shown in Fig. 2 and the resulting level scheme is presented in Fig. 3.

The γ rays feeding the 59 ns isomer [6] were observed within 200 ns time gate measured in the cyclotron in-beam mode. In addition to the arguments arising from X-ray spectra associated with respective γ rays, and from the in-beam γ-γ coincidence spectra, the ascription of these γ rays to ^{149}Ho was supported by analysis of the prompt-delayed matrix (coincidences of one γ-ray emitted in the prompt time range with respect to the beam pulse, with the second one emitted in the off-beam period). Prompt-delayed matrix that was created in this way includes coincidences of prompt γ lines, feeding isomers of lifetimes in a range comparable with the beam repetition time – with transitions that followed the decay of these isomers. The prompt-delayed coincidences of delayed and prompt γ lines were used to illustrate a mutual correspondence of lines feeding and deexciting 59 ns isomer. The three proton case i.e. ^{149}Ho (^{146}Gd + 3 protons) gives an opportunity to predict the energies of the states using the fractional parentage coefficients approach assuming $(h_{11/2})^3$ configuration and using ^{148}Dy two proton experimental interaction matrix elements. The observed decay energies of $27/2^-$ isomeric state are in a very good agreement with this calculation (see Fig. 3).



^{149}Ho

Figure 3: Level scheme for ^{149}Ho resulting from the present work. The levels placed above the 27/2$^-$ isomer are newly proposed. Shell model predictions of the excited states in ^{149}Ho are also shown (negative parity states assuming $(h_{11/2})^3$ configuration and positive parity states calculated from the $(h_{11/2})^2 s_{1/2}$ and $(h_{11/2})^2 d_{3/2}$ proton excitation).

Summarising, the level schemes of ^{148}Ho and ^{149}Ho have been revised and significantly extended up to about 4 MeV and 6 MeV, respectively. The γ rays feeding the 10$^+$ isomer in ^{148}Ho and 27/2$^-$ isomer in ^{149}Ho nuclei have been preliminarily proposed. A detailed article is in preparation.

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8. First diamonds obtained at HIL using the epitaxial microwave chemical vapour deposition process

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Diamond is the best material to produce detectors of light charged particles, heavy ions and elementary particles. For this reason we have elaborated the reactor based on 2.44 GeV, 700 W magnetron for homo-epitaxial growth of thick MW CVD single crystal diamonds for detector applications [1]. At present we have obtained first results – tiny monocrystal diamonds of about 0.1 - 0.2 mm size, grown on a silicon substrate during 24 h of epitaxial process, see Fig. 1. The conditions of the process were the following: flow of hydrogen 2.17 l/h (at normal pressure), flow of liquid butane 0.33 ml/h, process pressure and temperature about 0.09 bar and 700 ºC, respectively. After improving stability of butane flow, longer epitaxial processes will be possible, which are necessary for production of thick poly-crystal and single-crystal layers for diamond detectors.

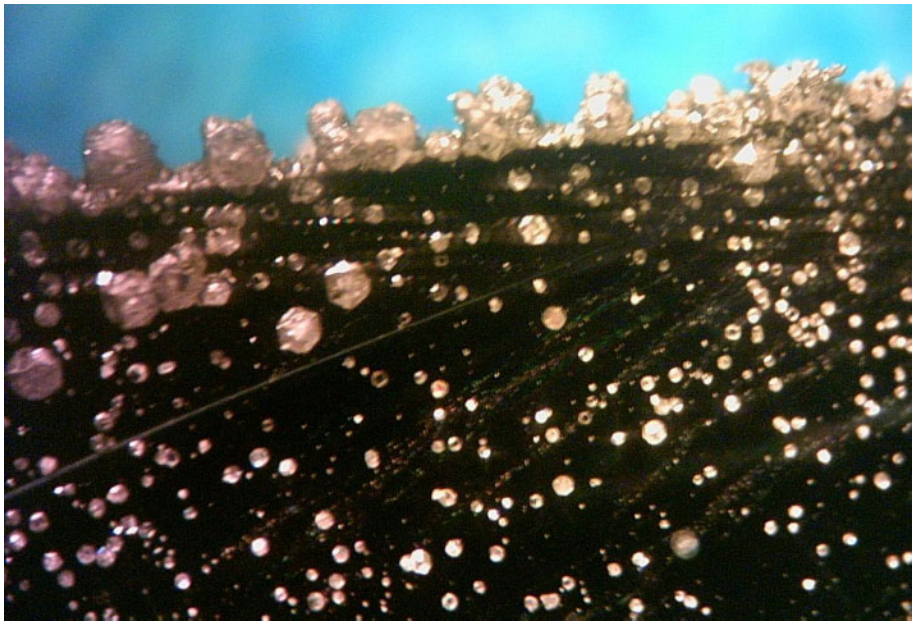

Figure 1: Diamonds grown by MW CVD epitaxial process on a silicon substrate.

References:

[1] A. J. Kordyasz *et al.*, HIL Annual Report 2007, p. 47

9. Correction of silicon resistivity by selective neutron transmutation doping

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Uniform resistivity of silicon material for detectors is very important for light charged particle and heavy ion identification by Digital Pulse Shape Analysis (DPSA). To obtain wafers of uniform resistivity, the method of Selective neutron Transmutation Doping (SnTD) of n-type silicon wafers was proposed [1]. It allows to correct the resistivity by capture of thermal neutrons followed by phosphor donor doping, using the reaction $^{30}Si(n, \gamma)^{31}Si \rightarrow {}^{31}P + \beta^-$ in selected regions of the silicon wafer. In the first step we have elaborated a non-destructive procedure to determine silicon wafer resistivity distribution by the C-V method [2,3]. As an example, Figure 1 presents the resistivity distribution of a four inch Topsil high resistivity wafer.

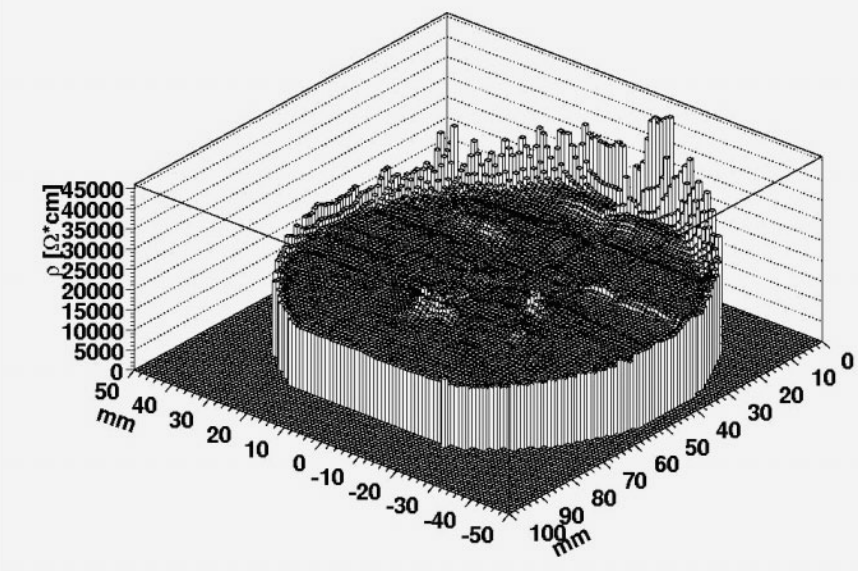

Figure 1: Four inch wafer resistivity as a function of position.

The SnTD process of correcting resistivity of silicon wafers will be performed in high thermal (or cold) neutron flux through Cd filters [4] of thickness distributions dependent on the neutron flux and silicon wafer resistivity distributions. First irradiations will be performed in the virtual vertical neutron flux channel of reactor Maria at Świerk. The virtual neutron channel V1 was proposed, designed and built by one of the authors (K.P.). Figure 2 illustrates the design of the device, which is currently in the test phase (neutron flux distribution measurements). The name "virtual" follows from the mode of operation of this channel. During irradiation the device is inserted in water close to the nuclear reactor Maria core to obtain the maximal thermal neutron flux. After having finished these tests, we will start to modify silicon wafer resistivity distribution using the SnTD method.

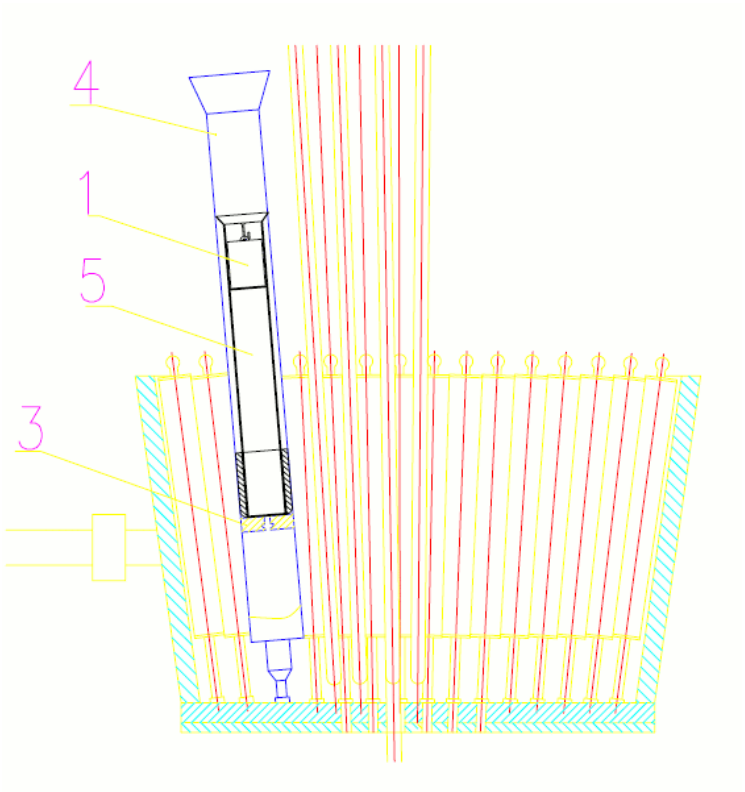

Figure 2: "Virtual" V1 vertical channel of reactor Maria with thermal neutron flux intensity about 10^{12} neutrons/s/cm^2. 1 – container for silicon wafers, 3 – graphite block, 4 – basket surrounding the channel, 5 – V1 channel

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[4] V. Nesvizhevsky, *private comm.*

10. Search for α-decaying isomers in trans-lead isotopes using the IGISOL device

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After identification of an α-decaying (9^-) isomer in ^{216}Fr in the earlier experiments on the IGISOL device [1,2], in 2008 we have concentrated on the search for isomers in ^{220}Ac using the same experimental method and technique.

To produce ^{220}Ac and ^{224}Pa activities, we applied the ^{209}Bi(^{14}N,p2n) and ^{209}Bi(^{18}O,3n) reactions, respectively. Bismuth target was placed inside the helium gas cell of the IGISOL system [3]. The cell of a volume of 400 cm^3, for which the gas flow simulations were performed using the FLUENT and GAMBIT program package [4], was off-line tested with an α-decay recoil source ^{223}Ra. An average extraction time of about 6 ms was obtained for singly charged ^{215}Po ions. An efficiency of approximately 6% was determined for stopping, guiding and extracting singly charged ^{213}Rn ions produced by a 5.6-5.9 MeV/u ^{14}N on the ^{209}Bi target. Investigations of the α-decay chain ^{224}Pa→^{220}Ac→^{216}Fr→^{212}At→^{208}Bi have allowed us to determine an isomer ratio of 0.09(2) for the (9^-) isomer of ^{212}At, which is different from the value of 0.28(1) obtained in [1] from the analysis of the ^{220}Ac α chain. The results suggest the existence of an isomeric (9^-) state in ^{220}Ac fed by the (5^-) ground state α decay of ^{224}Pa. Experimental details and preliminary results were presented at the ENAM'08 conference [5].

Technical improvements in the IGISOL device have pursued in 2008, and a new beam energy degrader was constructed and installed in front of the target inside the target chamber.

These works were partially performed in the frame of the University of Warsaw – IN2P3 (France) collaboration (No. 04-112) and have been supported in part by the Polish Ministry of Science and Higher Education (Grant No. N202017032/0696) and the Interdisciplinary Center for Mathematical and Computational Modelling of the University of Warsaw (Grant No. G26-4).

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[4] `http://www.fluent.com`
[5] J. Kurcewicz *et al.*, "Search for an α-decaying isomer in ^{220}Ac", ENAM'08, Book of abstracts, p. 158

11. Evaluation of biological effectiveness of ^{12}C and ^{20}Ne ions with high LET using the micronucleus test

J. Czub[1], D. Banaś[1,2], J. Braziewicz[1,2], I. Buraczewska[3], J. Choiński[4], U. Górak[5], M. Jaskóła[6], A. Korman[6], A. Lankoff[7], H. Lisowska[7], Z. Szefliński[5], A. Wójcik[3,7]

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The micronucleus test is a standard method for evaluation of irradiation damage in cells [1]. The lesions arising from irradiation are observed as micronuclei (MN) in binucleated cells (BNC). Micronuclei are formed from acentric fragments of chromosomes or from whole chromosomes, which are not incorporated into the main nucleus after nuclear division. In this test one can also study the level of nucleoplasmic bridges (NPB's), which are seen in BNC as a result of dicentrics (kind of chromosomal aberration). Examples of a micronucleus and a nucleoplasmic bridge observed in our study are shown in Figure 1.

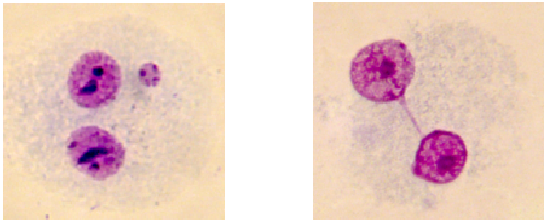

Figure 1: Example of a micronucleus arising in binucleated cell (left photo) and a nucleoplasmic bridge observed in CHO-K1 cell (right photo) following ion irradiation.

The irradiations were performed using the dedicated experimental set-up [2] at the Heavy Ion Laboratory. As a biological system, Chinese hamster ovary cells (CHO-K1) were used. Number of micronuclei in binucleated cells was studied for different doses for ^{12}C and ^{20}Ne irradiations (see Fig. 2). As shown in Fig. 2, the dependence of the ratio MN/BNC on the dose level can be well described by a second order polynomial: $MN/BNC = \alpha D + \beta D^2$, where α, β are fit parameters and D is a dose value.

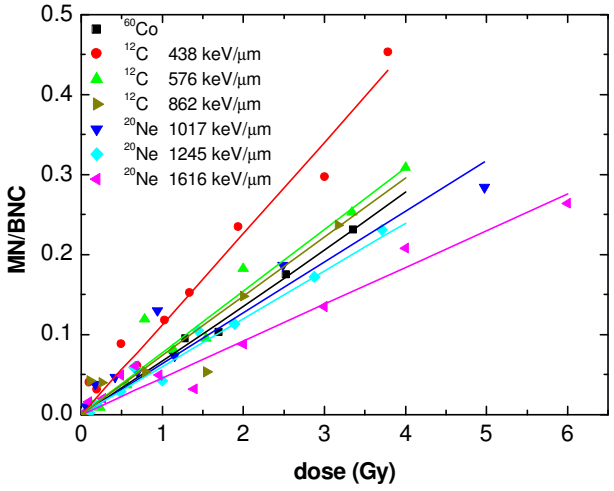

Figure 2: The ratio of MN/BNC as a function of dose for ^{12}C and ^{20}Ne ions with various LET (linear energy transfer) values. Solid lines present second order polynomial fits to the experimental data.

Additionally, for calculation of the relative biological effectiveness (RBE) the micronuclei were counted in binucleated cells after γ-ray irradiations (from a therapeutic ^{60}Co source). These irradiations were performed at the Holycross Cancer Center in Kielce. The RBE_M values as a function of LET are shown in Fig. 3. RBE_M corresponds to the maximum RBE and is obtained as the ratio of α terms for particle and ^{60}Co irradiation.

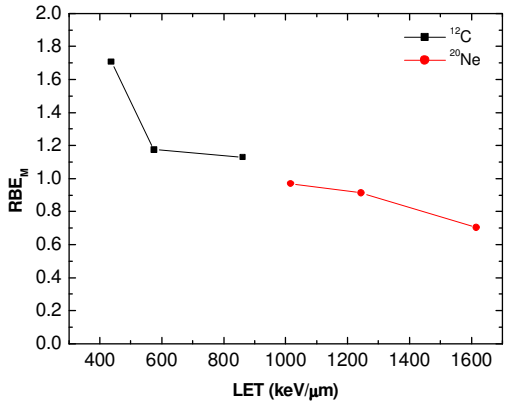

Figure 3: RBE_M as a function of LET for ^{12}C and ^{20}Ne ions.

Our results show that for high LET values the RBE_M does not depend on the ion species, which is an important and new information for this correlation. For lower LET values, RBE_M=f(LET) differs for various ions. The same conclusions were drawn from our previous study [3], where a different biological test (clonogenic) was used. The magnitudes of RBE obtained in our present and previous evaluation differ, since they depend on method which is used to study irradiation damage in cells.

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12. Calibration of the PM-355 nuclear track detector: track diameter and track depth characterisation

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3) *Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland*

Systematic investigations of the CR-39 detector and its modern versions such as PM-355, PM-500, and PM-600 have been performed at the Andrzej Sołtan Institute for many years. These investigations resulted in calibration data presenting mainly track diameters as a function of projectile parameters (e.g. atomic number Z, ion energy E, energy per nucleon E/M etc.) and etching time [1]. Recently, using a scanning electron microscopy technique (SEM), we have also studied etch pitch depth of tracks produced by heavier ions in the PM-355 detector material [2].

Latent tracks in the polymeric detectors were chemically etched under standard conditions during different periods of time to develop the tracks. To make possible the observation of longitudinal track profiles the detector sample was broken perpendicularly to its surfaces. Using electron microscope we were able to observe detector surface morphology and measure diameters and depths of the tracks.

Small samples of the PM-355 detector (~1 x 3 cm) with a thickness of 500 µm were irradiated with C ions of energy 70 MeV (5.8 MeV/amu), 80 MeV (6.7 MeV/amu) and 90 MeV (7.5 MeV/amu). The ion beams were provided by the U-200P heavy ion cyclotron at the Heavy Ion Laboratory, University of Warsaw. The collimated (Ø = 2mm) carbon beams of intensities between 5-15 enA were scattered on a self-supporting thin Au-foil (~100 µg/cm^2) and hit the detectors perpendicularly to the sample surface. The scattered ions were monitored by a surface barrier Si detector to determine fluxes and energy spectra of the projectiles. The irradiated detectors were etched in a 6.25 N NaOH water solution at a temperature of 70 ^{o}C ± 1^o. The etching process was interrupted every 15 minutes for track observation. A Scanning Electron Microscope of DSM 942 type (Zeiss, Germany) was used for determining track diameters and to measure track depths [2].

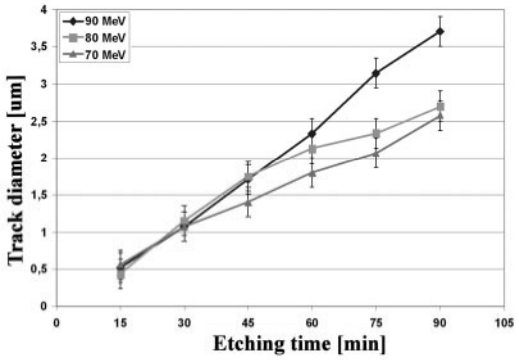

Figure 1: Diameters of tracks resulting from irradiation by C-ions of energy 70, 80 and 90 MeV as a function of etching time.

In Fig. 1 the measured track diameters are presented as a function of etching time. Figure 2 shows sample photos of craters induced in the PM-355 detector samples, which were irradiated by C ions of energy 70 and 90 MeV, respectively, and etched only for 1 hour. In Fig. 3 photos of the shape evolution of tracks produced by the C ions in the PM-355 detector samples are presented. The tracks are clearly visible and the depths of the tracks can be easily measured on the detector fracture.

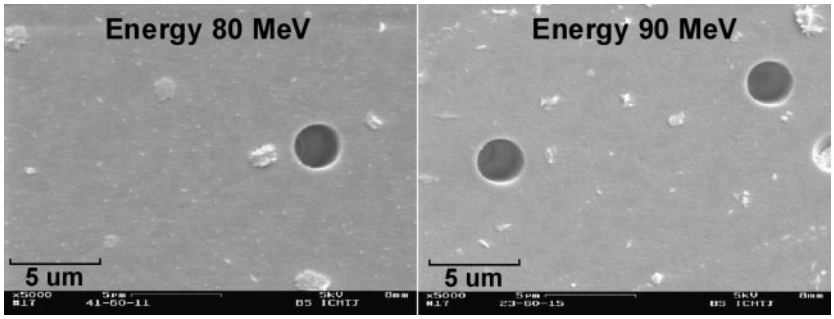

Figure 2: Exemplary photos of the craters induced in the PM-355 detector samples irradiated by C-ions of different energies. The samples were etched for one hour.

The results obtained were analysed on the basis of the well known model of two etch rates: the track etch rate V_T, which is directed along the particle trajectory and the undamaged material bulk rate V_B. Profiles of tracks which are visible in Fig. 3 seem to be very similar to cone

intersections. From the track depth measurement results as well as from the V_B values which were determined in this paper, the V_T values were calculated. The track etching rate (V_T) values obtained are between 1.5 and 2. One notes that the V_T/V_B values are between 2.5÷3.5 and are about the same for three incident carbon projectile energies used. Comparing these values with $V_T/V_B \approx 1.5$ obtained for 6.7 MeV protons by Sartowska *et al.* [3] one may note that the V_T/V_B values for carbon are about two times higher as compared to the proton data. A similar conclusion can also be drawn for track diameters for 1÷2 hours of etching time.

A comparison of the stopping power values in PM-355 material for similar proton and C-ion velocities (~ 6.5 MeV/amu) shows that the values measured for carbon ions are about 36 times higher than for the protons.

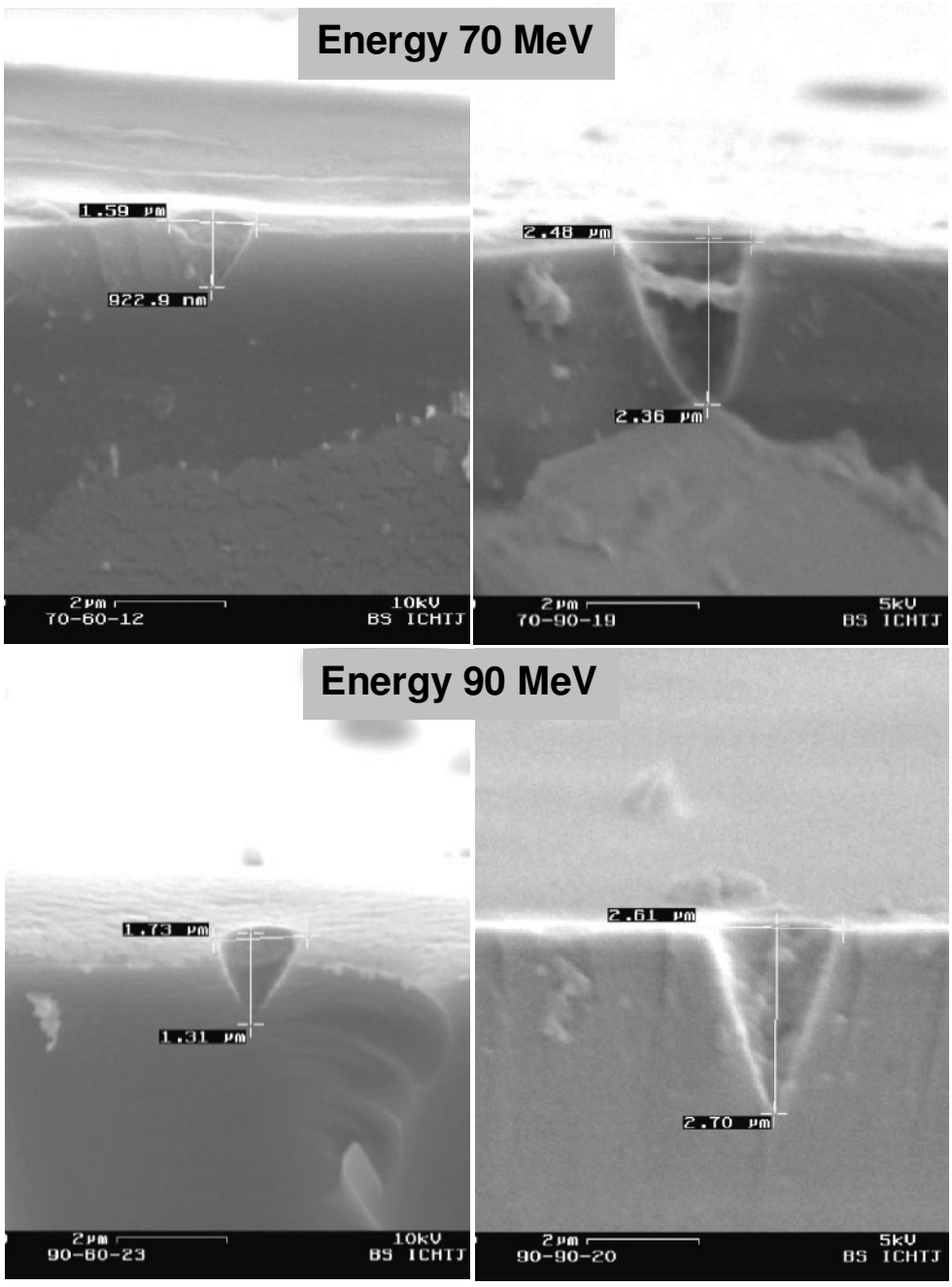

Figure 3: Shape evolution of tracks produced by C ions of two different energies in the PM-355 detector, as a function of etching time. The tracks on the left side were etched for one hour and the ones on the right for 1.5 h.

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Part C:
Experiments using outside facilities

1. New Neutron Detector Array for SPIRAL2

M. Palacz[1], G. Jaworski[1,2] for the NEDA collaboration

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2) *Faculty of Physics, Warsaw University of Technology, Warsaw, Poland*

One of the tasks of the SPIRAL2 Preparatory Phase project is to design a new neutron detector system, with the primary aim to improve neutron multiplicity filtering in γ-ray spectroscopy fusion-evaporation experiments, especially when neutron emission is very rare. The main difficulty in such studies is that one neutron may scatter between two or more detectors in a multi detector system and this can lead to the apparent increase of the number of detected neutrons. As the most exotic, most interesting nuclei are often produced with the emission of two or more neutrons, with very low cross sections, γ-ray spectra gated by multiple neutrons are usually dominated by events in which neutron multiplicity larger than one was spuriously deduced from interactions of one particle.

Within this project, for which the name NEDA (NEutron Detector Array) has recently been adopted, the Warsaw group has concentrated so far on the evaluation of the validity of neutron interactions in the Geant4 code. Geant4 is a package of choice as a simulation tool for the project, due to its widespread use for the evaluation of other detector systems, which are often simultaneously employed in the experiments, including the AGATA array [1] and the existing Neutron Wall array [2]. Very significant deficiency of the Geant4 formalism of neutron interactions has however been previously reported, which would make the code unsuitable for the evaluation of the properties of the new array. In December 2008 a new version of Geant4 (4.9.2) was released, in which the known defects of the neutron interactions were presumably fixed [3].

The material, which is almost exclusively used in so far functioning detectors of neutrons, is liquid organic scintillator BC501A, with the chemical composition very closely resembling xylene $C_6H_4(CH_3)_2$. Neutrons are detected mainly as a result of (multiple) elastic scattering on protons, with some contributions of other processes, including inelastic scattering on protons and carbon, as well as elastic scattering on carbon. Note that for the light production in the scintillator, processes which involve carbon have little significance, due to small energy transfer to the medium in the scattering on carbon and significantly lower light production per energy unit for carbon particles than for protons. Scattering on carbon does however influence the angular distribution of interacting neutrons and this affects probability to register interactions in more than one detector.

Material, which is considered as an alternative to BC501A, is the deuterated scintillator BC537, with the chemical composition C_6D_6. Thus interactions of neutrons with deuterium will also have to be validated, and a reliable procedure of comparing light output of protons and deuteriums will have to be established.

We have already been able to identify some inconsistencies of the Geant4.9.2 results. One example is that the linear momentum is not properly preserved in the process $^{12}C(n, \alpha)^{9}Be$. It is not clear yet if faults in treatment of such rather rare events indicate a more general problem, and if they matter for the design of the new array. Work on validation of the Geant4 formalism is in progress.

References:

[1] AGATA, Technical Proposal, ed. J. Gerl, W. Korten, 2001
AGATA Technical Design Report, ed. J. Simpson, J. Nyberg, W. Korten
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2. Monte Carlo simulations of lifetime measurements with GASP or AGATA and the Recoil Filter Detector

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One important limitation in in-beam γ-ray studies of light or medium mass nuclei produced in fusion evaporation experiments is significant Doppler broadening of fast γ-ray lines, associated with the spread of the recoiling residuum velocity and its angular distribution. This spread is due to the fact that emission of each n, p and α particle gives a significant kinematic boost to the emitting nucleus, and this is especially important for reaction channels in which two α particles are emitted. A smaller alteration of the recoil trajectory originates from the straggling in the target material. The Recoil Filter Detector [1] can be employed in the experiments, enabling precise event-by-event Doppler correction based on the velocity vector measured for each evaporation residuum, resulting in a very significant reduction of the widths of the γ-ray peaks.

In addition to obvious importance of the improved energy resolution for identification of transitions belonging to a specific nucleus, and for establishing schemes of excited states, shapes and broadening of γ-ray lines can as well be used to determine life times of the nuclear states, employing DSAM methods. Sensitivity of such a measurement is also directly related to the quality of the Doppler correction, and thus application of the RFD detector is desired [2].

The feasibility of determining lifetimes of excited states in the ^{64}Ge nucleus was evaluated using the Geant4 model of RFD [3] in connection to the GASP [4] and AGATA [5] spectrometers. Fusion-evaporation events induced by the 110 MeV ^{32}S beam hitting the 0.7 mg/cm^2 ^{40}Ca target, leading to the residual nucleus ^{64}Ge via the emission of 2α particles, were generated using the COMPA code [6]. For each event, a 1.3 MeV γ ray, isotropically emitted with the lifetime distribution $e^{-\lambda t}$ was appended to the kinematic data of emitted particles and of the recoiling nucleus. Such events were used as input to the GASP-RFD and AGATA-RFD Geant4 models. In case of AGATA, γ-ray tracking procedures were applied to simulated interactions, to recover energies of γ rays. For both detector systems, γ-ray energies were Doppler corrected using RFD data, and spectra corresponding to selected detection angles were created. The results are presented in Fig. 1. The same number of input events was used to generate GASP and AGATA data. For comparison, the following line shapes are also shown: corresponding to emission immediately after the residual nucleus was created (prompt), and to emission in-flight (after the recoils left the target) - obtained with RFD and with the average Doppler correction (without RFD), as well as for the emission from a stopped source.

We can conclude that some sensitivity to the lifetime of the emitting state can be seen in the GASP data, while the effects are much more pronounced with AGATA. This is due to the fact that individual GASP detectors have the opening angle of 14^o while AGATA provides precise information on position of the first interaction (5 mm spatial resolution) corresponding to about 1^o angle. It can also be noticed that application of RFD is essential for the full exploitation of the AGATA angular resolution capabilities.

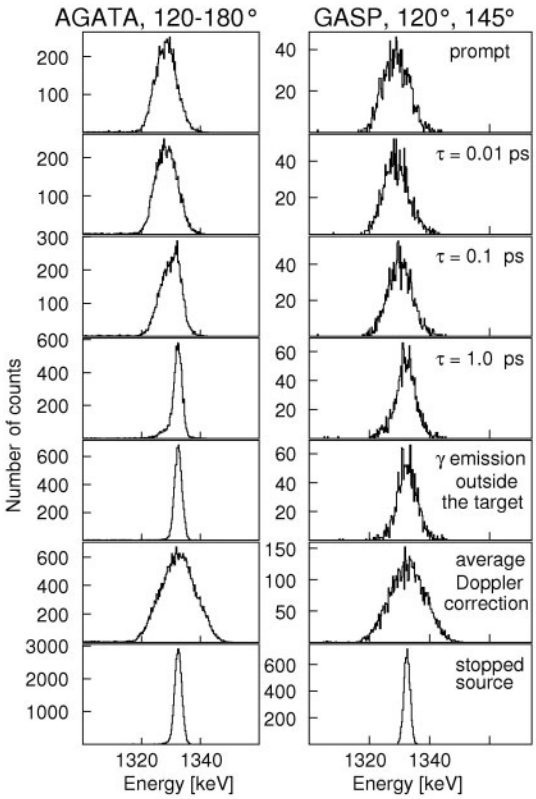

Figure 1: Simulated shapes of transitions registered in AGATA and GASP, for different life times of the state emitting a 1.3 MeV γ ray.

References:

[1] W. Męczyński *et al.*, Nucl. Instr. and Meth., **A580** (2007) 1310
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and G. Jaworski, M. Palacz, W. Męczyński, HIL Annual Report 2006, p. 48
[4] C. Rossi Alvarez, Nucl. Phys. News **3** (1993)
[5] AGATA Technical Proposal, ed. J. Gerl, W. Korten, 2001
[6] E. Grodner *et al.*, Eur. Phys. J. **A27** (2006) 325

3. Direct Z measurements of heavy elements using high energy synchrotron radiation

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If super heavy elements (SHE) exist in nature, they are extremely dispersed in minerals of known elements or can form small inclusions in them. Recently a big progress has been achieved in search for SHE in natural materials via the synchrotron radiation approach, since the high-energy and high-intensity beams available at many facilities can be used for atomic Z identification of SHE.

High energy synchrotron bremsstrahlung beams from Advanced Photon Source in Argonne National Laboratory were used to excite L-X and K-X fluorescence radiation of heavy and super heavy elements. Samples were preliminary selected at HIL using a Si(Li) detector for X-ray detection and a 200 mCi Am-241 source for the excitation.

Three different experimental methods were tested at ANL:

- Beam of 50 keV (10^{10} ph/s) was used for the L-X ray excitation of elements with Z ranging from 110 to 130 and energies of 20.2-29.2 keV, respectively. An Si(Li) detector was used to measure the characteristic radiation. Difficulties were encountered due to the fact that if a sample contained Th, U or Rh, Pd, Ag, In elements, quite intense lines were present in the measured spectra in the same energy region as the one where the SHE lines were expected. Thus, in some cases the information from the Si(Li) detector is not sufficient. It is necessary to measure observed lines with higher energy resolution. The estimated sensitivity for the element 120 was about 1E15 atoms.

- A crystal spectrometer built at APS, including a curved Si crystal, a goniometer, a 2m long copper tube as a collimator and a Ge detector to measure photon energies, was used for a higher energy resolution measurement. A 50 keV beam (1E12 ph/s) was used for the excitation and the characteristic radiation was measured using the crystal spectrometer and the Si(Li) detector. Several measurements were performed, in case of one sample the U L-X lines (γ_1, γ_2 , γ_8, γ_3, γ_6, γ_{11}, γ_4) were observed. This method required very long measurement times. The estimated sensitivity was about 1E13 atoms.

- To excite K-X ray in SHE the following beam energies were chosen: 300 keV ($3 \cdot 10^8$ ph/s), 276 keV ($3 \cdot 10^9$ ph/s) and 205 keV ($3 \cdot 10^{10}$ ph/s). The K edges calculated for SHE are equal 182.03 keV for element 110 and 297.48 keV for element 130. In this case a 10-element intrinsic Ge detector was used for the characteristic radiation measurement. A few 10^4 second long measurements were performed. The background from the scattered X-rays was quite high and no lines were observed. The estimated sensitivity was more than 1E17 atoms.

The optimal approach seems to be the one emploing the crystal spectrometer and Si(Li) detectors**.**

4. Scintillation Ionization Detector (SID) for heavy and superheavy elements detection

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4) Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland

In order to minimize the background effect we proposed to equip the detection system dedicated for superheavy element search at GANIL with an additional scintillation-ionization detector located just before the implantation detector [1]. The detector consists of two main parts: photo-tube with focusing mirror (scintillation part) and two planes of proportional counters (PPC). Both parts of SID detector are working in the same gas. Scintillation pulses are characterised by a very short rise time and could be used in ToF (time of filght) measurements as well as in pileup rejection

systems. PPC detectors have high efficiency for light charged particles (LPC) detection thus can strongly reduce the LPC background.

Figure 1: Ionization part (left side) and the scintillation part (right side) of the SID detector.

The SID chamber was recently used in the complete fusion SHE experiment (E533) at GANIL. At the Warsaw cyclotron facility (HIL) we plan to make further tests of the SID detector by using low-energy Ar beam.

References:

[1] Z. Sosin *et al.*, Acta Phys. Pol. **B40** (2009) 741

5. Coulomb excitation of light Hg nuclei

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In light, even mass Hg isotopes, a weakly deformed oblate ground state band is found to coexist with a more deformed prolate band. To investigate the origin and evolution of shape coexistence in the N = 102-108 mid shell region Coulomb excitation measurements of ^{182,184,186,188}Hg were performed at REX-ISOLDE using the MINIBALL detector array. Beams of ^{182,184,186,188}Hg isotopes were provided by ISOLDE and post accelerated by REX, for the first time, to an energy of 2.85 MeV/u and delivered to the target position of MINIBALL.

Using the Coulomb excitation analysis code GOSIA matrix elements can be obtained for the observed low-lying states in the measured nuclei which will enable the magnitude and sign

of the diagonal matrix element to be determined, giving an accurate measure of deformation and mixing. The evolution of band mixing and deformation will enhance our understanding of shape coexistence in this part of the nuclear landscape.

The Warsaw group played a vital role in the analysis of this data. This involved helping produce and debug the GOSIA input files and explaning the proceses of each stage of the analysis. The technique of 'cross-normalisation' – normalising to the target excitation in the Coulomb excitation reaction – enabled us to be independent of the B(E2) values obtained from lifetime measurements for the Hg nuclei in our analysis. Results are being obtained and matrix elements derived.

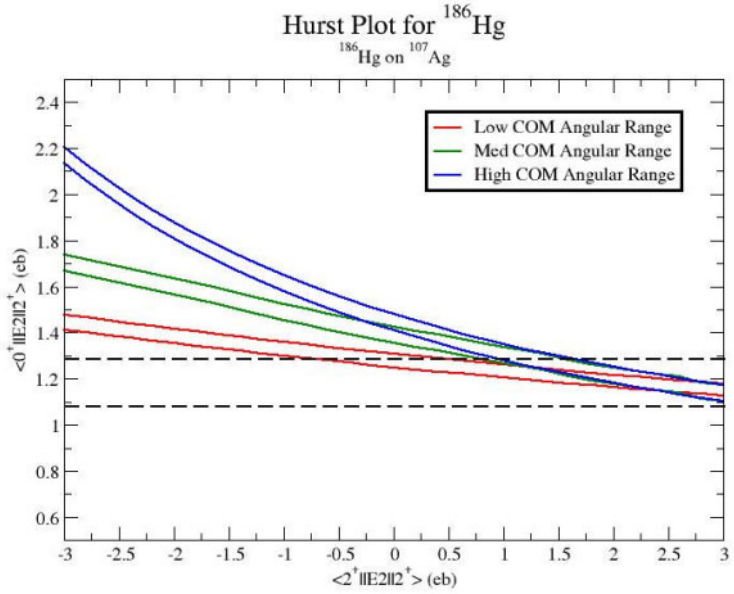

Figure 1: The graphical process used to derive the diagonal matrix element for the first 2^+ state in ^{186}Hg using GOSIA. A positive value indicating oblate structure is found.

6. The Eurisol database

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The EURISOL database containing experimental and calculated cross-sections [1], and estimate of ISOL efficiencies, based on ISOLDE SC yield database [2], was upgraded by several theoretical calculations.

The prediction of production cross-sections was added for reactions in which experimental cross-section data do not exist, extending database prediction range.

Much effort was devoted to reproduce existing experimental data with results of simulation codes. An example of comparison between experimental data and computer code calculations (ABRABLA code) is shown in Fig. 1, for ^{238}U + Pb reaction at 1 GeV/nucleon.

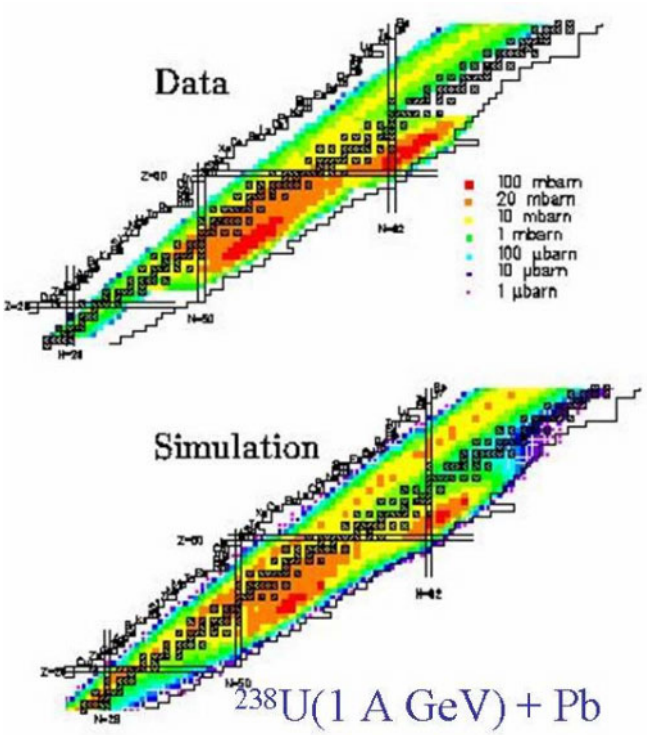

Figure 1: Experimental and calculated (ABRABLA code) nuclide production cross-sections.

The comparison between measured and calculated production-section will result in an improvement of model predictions, what is expected as one of the goals of EURISOL project.

The database is currently running at the HIL server:

`http://www.slcj.uw.edu.pl/~wojtek/eurisol_database_HIL.php`

and at the GSI server :

`http://www-win.gsi.de/eurisol%2Dt11/database.htm`

This work was supported by the European Community under the FP6 "Research Infrastructure Action – Structuring the European Research Area" EURISOL DS Project; Contract No. 515768 RIDS.

References:

[1] `http://www-win.gsi.de/charms/Publications/publica.htm`
[2] H.-J. Kluge, *ISOLDE user's guide*, CERN Geneva, 1986,
`http://isolde.web.cern.ch/ISOLDE/`

7. Research on activation of TiO_2 nanoparticles

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Scientists world-wide continue to discover unique properties of everyday materials at the sub-micrometer scale, better known as the nanometer domain. These novel properties of common materials, observable only at the nano-scale, have already found their first commercial applications. For example, TiO_2 nanoparticles are present in some sunscreens to absorb UV light and therefore to protect skin against sunburn or genetic damage. While benefits of nanotechnology are widely publicised, the discussion of potential effects of their widespread use in consumer and industrial products is just beginning to emerge. Both pioneers of nanotechnology and its opponents find it extremely hard to argue their case as only limited information is available. It has been shown that nanoparticles can enter the human body through several ports. Accidental or involuntary contact during production or use is most likely to happen via lungs from where a rapid translocation through the blood stream is possible to other vital organs.

Titanium dioxide, also known as titanium (IV) oxide or Titania, is the naturally occurring oxide of titanium, chemical formula TiO_2. When used as a pigment, it is called titanium white, Pigment White 6, or CI 77891. It is manufactured worldwide in large quantities for use in a wide range of applications, from paint to sunscreen to food coloring. The target used for this study consisted of 12 mg titanium dioxide powder of 99.6% purity enclosed in an aluminum capsule of 10 mm diameter and 0.3 mm thickness. The irradiations were performed on the Scanditronix MC 40 cyclotron model of the Institute for Health and Consumer Protection (IHCP) of the European Commission, Joint Research Centre (Ispra, Italy), which allows to accelerate positive ions such as protons, deuterons, alphas and $^3He^{2+}$ at variable energies.

The method for ^{48}V (half-life $T_{1/2}$ = 15.97 d) production is based on proton irradiation of titanium powder through ^{48}Ti (p, n) ^{48}V nuclear reaction. The irradiation was carried out with a proton beam of 25 MeV energy and intensity of 10 μA for 45 minutes. This proton beam energy was selected to maximize the production yield of ^{48}V. The activity of ^{48}V obtained in such conditions was 848 kBq. During the irradiation, the Al capsule containing the TiO_2 target was directly cooled by a closed loop cooling-water system of the cyclotron. To reduce the dose exposure during the handling of the activated sample, the target was left for radioactive decay for about 1 day after the irradiation.

The analysis of activities of the main product ^{48}V from proton irradiation of titanium was performed by means of γ-ray spectrometry. Several high purity germanium detectors, energy and efficiency calibrated by using certified radioactive standard sources, were used to measure γ-ray spectra for each of the irradiated samples of titanium dioxide. The spectra were analysed with Genie 2000 software (CANBERRA, USA). Gamma-ray spectra of the proton activated samples of titanium are shown in Figures 1 and 2. Figure 1 shows the spectrum of the activated TiO_2 contained in an Al capsule (a) compared to the one of the TiO_2 sample removed from its capsule (b). Radioisotopes such as ^{65}Zn and ^{56}Co result from activation of metal impurities of the Al capsule. Figure 2 presents two γ-ray spectra. Spectrum (a) refers to the TiO_2 pellet while the spectrum (b) to the suspension solution.

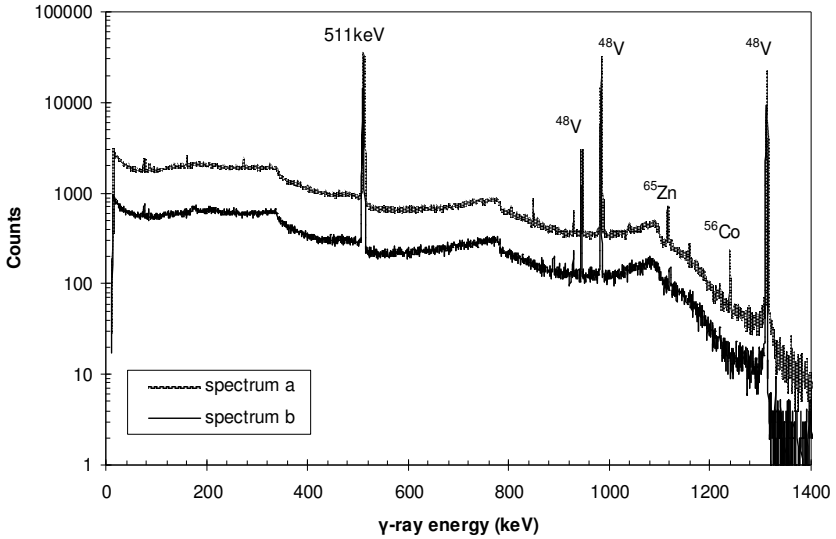

Figure 1: Gamma-ray spectra of the proton-irradiated TiO_2 powder. Spectrum (a) refers to the irradiated TiO_2 powder contained in an Al capsule while spectrum (b) corresponds to the TiO_2 powder removed from its capsule. The γ-ray peaks of ^{48}V are well resolved in both spectra. The γ-ray peaks of ^{56}Co, ^{65}Zn are due to the impurities of the Al capsule (spectrum a) which were activated.

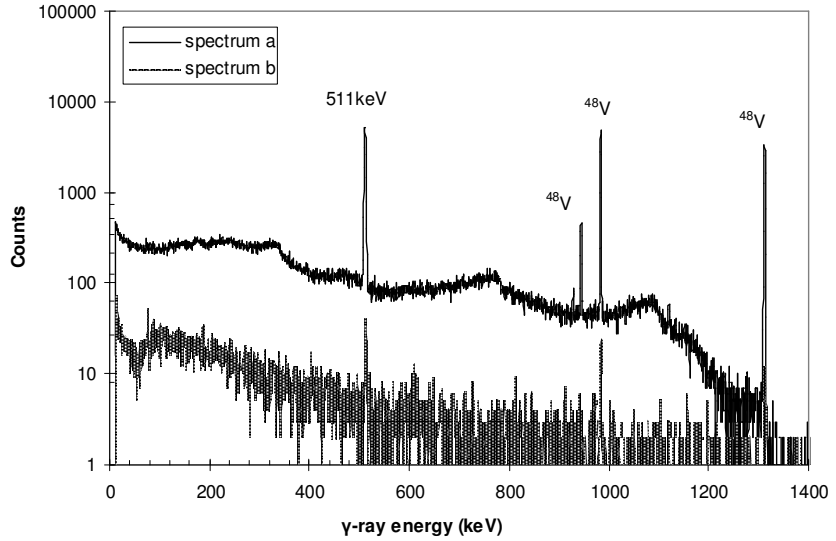

Figure 2: Gamma-ray spectra (spectra a and b) collected after centrifugation of the colloidal TiO_2 solution. Spectrum (a) corresponds to the TiO_2 pellet while the spectrum (b) to the suspension solution, which shows much lower activity of ^{48}V with respect to spectrum (a).

The activated titanium dioxide powder was diluted by water to recover all amount of irradiated sample. The sample of colloidal solution, containing 12 mg of TiO_2 powder and 2ml of water, was closed in an Eppendorf vial and put in to the ultracentrifuge. The parameters of the ultracentrifugation process were: speed 41000 rpm, temperature 4 ºC, time of centrifugation 1 h and volume of sample 2 ml. Industrially fabricated TiO_2 nanoparticles can successfully be radiolabelled with ^{48}V by proton irradiation. Essentially all radioactivity is retained in the nanoparticles and the proton bombardment of a sufficiently thin and well cooled volume of nanoparticles does not introduce a significant damage to them.

8. Neutron activation of nanoparticles using a cyclotron

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Research on methods of production of different types of radionuclides for nuclear medicine applications is currently under way at the Scanditronix MC40 Cyclotron of the Joint Research Centre (JRC, Ispra). One goal is the testing and the optimization of an ion-beam driven neutron activator for the production of radioactive nanoparticles such as those based on Re (^{186g}Re, $T_{1/2}$ = 89.25 h, ^{188g}Re, $T_{1/2}$ = 16.98 h) or Ho (^{166}Ho, $T_{1/2}$ = 26.80 h) radioisotopes for brachytherapy applications. Another goal is the production of radioactive nanoparticles for risk assessment of possible toxicity of such particles (nanotoxicity). In this paper the activator facility is described and experimental results on production yields of various radionuclides are presented and discussed. The results obtained are in reasonable agreement with those calculated with MCNPX and FLUKA codes. The promising activation yields obtained in this work open interesting perspectives for applications of radioactive nanoparticles. If transferred to a high intensity cyclotron facility, the technique may constitute an attractive alternative to nuclear reactors for production of certain radionuclides for medical or other applications.

Monte Carlo calculations (MCNPX and FLUKA) have been used to design a neutron activator driven by a cyclotron ion beam. The activator is based on the concept of Adiabatic Resonance Crossing (ARC) which was introduced for the first time by Nobel Laureate Carlo Rubbia. Neutrons are generated by accelerated charge particles such as proton or deuteron beams, bombarding a target such as beryllium. The fast neutrons generated are slowed down with an appropriate moderator made of lead and graphite, after which they are captured in selected materials to be transmuted. An activator prototype has been constructed and installed, and is being tested at the JRC cyclotron.

The neutron activator prototype has been installed on a dedicated beamline of the MC40 cyclotron. Figure 1 (left) shows a sketch of the activator in which the main components – the Be target, the water cooling system (acting as a moderator), the lead buffer, the graphite reflector and the sample activation positions – are presented. Right panel of Fig. 1 shows a picture of the activator as installed in the beam line, in which the sample insertion rods are also visible.

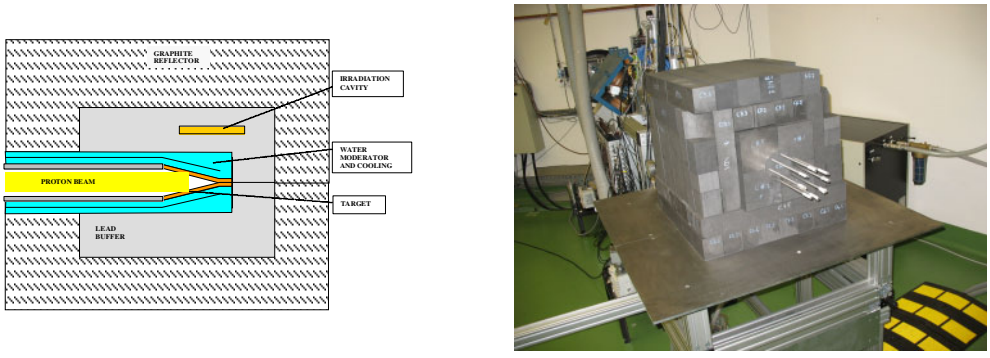

Figure 1: *Left:* Sketch of the neutron activator. *Right:* Photograph of the neutron activator installed in a beam line of the JRC cyclotron.

Various types of samples were activated in the neutron activator – pure metal foils, disks, solutions and powders. Most irradiation runs were performed at 36 MeV proton beam energy. Preliminary irradiations were carried out at low beam currents for testing of the cooling system and sensors of the activator facility, after which the current was increased step by step up to 40 μA in the last runs. Figure 2 shows γ-ray spectra of activated Au, Re and Ho foils.

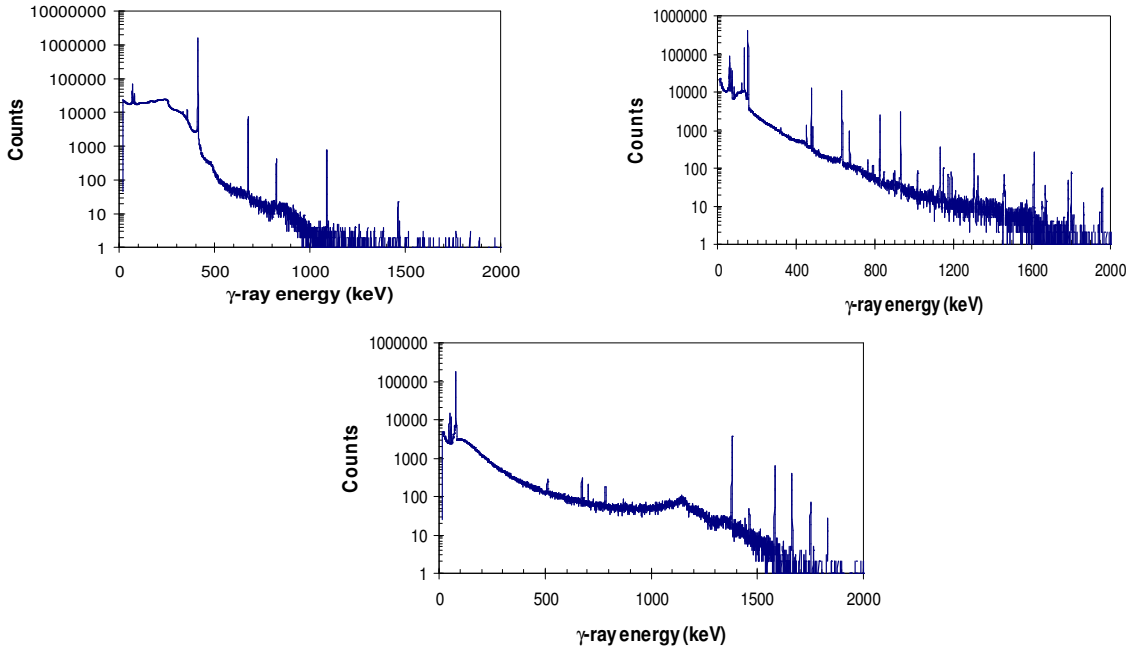

Figure 2: Gamma-ray spectra of activated pure Au, Re and Ho foils irradiated in the neutron activator. The γ-ray peaks of ^{198g}Au (top left), ^{198g}Re / ^{196g}Re (top right) and ^{166g}Ho (bottom panel) are all well resolved.

The measured production yields of ^{198g}Au, ^{188g}Re and ^{166g}Ho by irradiating foils of Au, Re and Ho are 972, 385 and 2520 kBq/(μA·h·g) respectively, which are of the same order of magnitude as those calculated, as shown in Table 1. Due to the lack of nuclear data (nuclear cross sections for reactions to the different isomeric states), the MCNPX calculated yields refer to the sums of the yields of the isomeric states (ground and isomeric) of the radioisotopes produced.

Table 1: Measured and MCNPX-calculated production yields (in kBq·g^{-1}·μA^{-1}·h^{-1}) for ^{198g}Au, ^{188g}Re and ^{166g}Ho via irradiation of Au, Re and Ho foils, respectively.

Radioisotope	Half Life	MCNPX Yield	Measured Yield
^{198}Au		553	
^{198g}Au	2.69 d		972
^{186}Re		693	
^{188}Re		1150	
^{186g}Re	3.7 d		385
^{188g}Re	0.71 d		2100
^{166}Ho		1650	
^{166g}Ho	26.8 h		2520

To summarize, a relatively compact accelerator driven neutron activator has been developed, based on the ARC principle. Preliminary results on activations of foils of various materials were

found to be in good agreement with the theory. This work opens interesting perspectives for production of radioisotopes by neutron activation using cyclotron facilities.

Further irradiation tests are being carried out to investigate ways of increasing radioisotope yields by, for example, changing the beam particles (e.g. deuterons), considering other target materials for neutron generation (e.g. Ta), modifying the activator geometry, or using beams of high current in the range of mA, which can be achieved in modern cyclotrons. The results obtained with the developed activator are already promising and some of the activated nanoparticle samples are under study for medical imaging.

9. Application of the polyimide foils

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Since introduction to the market in late 1960s, the polyimide materials have been applied in many fields due to their superior properties such as excellent mechanical strength, high thermal, chemical and long-term stability, inertness to the most common solvents, resistance to radiation, and low dielectric constant [1,2]. Their applications range from aerospace to microelectronics.

It was noticed very early that polyimide foils could be as well an excellent backing support for thin targets required for measurements in nuclear physics, replacing other plastic or carbon foils. In cases when heat produced by the beam is not in an excess amount they can be superior to thin metal foils often used as backings for target preparation (see Table 1). However, the relatively high thickness of commercially available foils, known under various trade names, strongly limited such applications as usually they are not thinner than 1 mg/cm^2 (around 7-8 microns). This order of thickness may cause high energy losses of particles passing through and thinner foils are needed to avoid this problem.

The method of in situ polymerisation developed at the end of 1970 [3] and modified later [4] allowed preparation of thin self-supporting foils down to 10 μg/cm^2 with diameters of up to 25 cm.

Foils of such areal density satisfy most of the nuclear physics requirements for backings and for entrance windows to gas chambers. The foils have been used with big success as protective barrier preventing contamination from self-sputtering source in high-accuracy fission counting [3]. They have been foreseen as well to be applied as backings of the optical filters for x-ray telescopes [4] (Fig. 1).

Table 1: Comparison of various types of foils.

	Polyimide $(C_{22}H_{10}N_2O_4)_n$	Mylar $(C_{10}H_8O_4)_n$	Aluminium Al
Density	1.41 g/cm^3	1.39 g/cm^3	2.7 g/cm^3
Temperature resistance	450 - 500 ºC	250 ºC	660 ºC
Min. thickness routinely used	0.21 μm (30 μg/cm^2)	1.5 μm (200 μg/cm^2)	2 μm (540 μg/cm^2)
Min. thickness available	0.07 μm (10 μg/cm^2)	as above	depends on available technique
resistance to radiation	see text	unknown	

Mechanical strength of the modified foils was examined by dropping test and by exposing to the differential pressure [4]. The dropping test showed that the foil of 37 μg/cm^2 dropped from the height of 3 m remained unchanged, neither broken nor deformed.

The test of the resistance to the differential pressure of foils with areal density of about 40 and 70 μg/cm^2 was performed with use of an accurate pressure gauge (Wallace and Tiernan), and pressure was registered at the moment of foil rupture. Foils of 40 μg/cm^2 broke in the range of 15 - 39 mbar and foils of 70 μg/cm^2 broke in the range of 19.5 - 65 mbar. It occasionally happened that the samples of thicker foil resisted pressure much higher then 60 mbar before breaking.

The range of breaking differential pressure suggests that presence of weak (thinner) spots in a foil limits the pressure that foil of given thickness can withstand. Weak spots could be caused by glass surface imperfections or inhomogeneous distribution of the polycondensate layer on the glass surface (step of the foil preparation procedure [2,4], or could be the consequence of damage to the foil during the floating process.

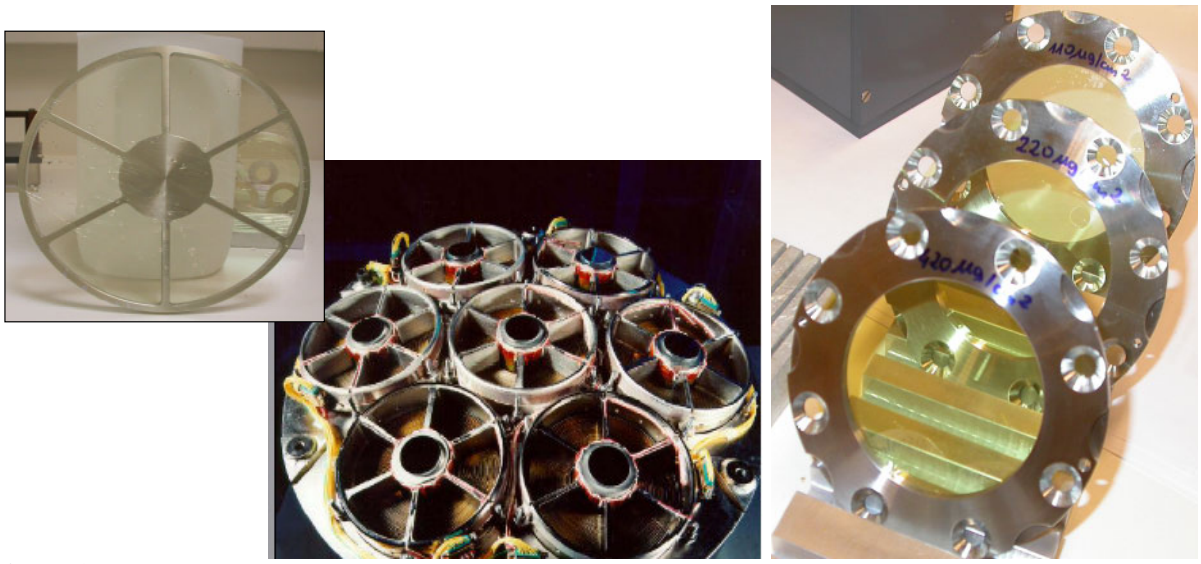

Figure 1: Polyimide foils mounted on the 'spider' support before covering with aluminum layer (on the left) to be used as filter for x-ray telescopes (middle). On the right, foils of different thickness mounted on the entrance window flanges.

The resistance to the radiation: some data are available from Du Pont for Kapton. From this data we can learn that foils exposed to the flux of neutrons of 5 x10^{12} n/cm·s and γ radiation darken at the dose of 5x10^7 Gy and start to harden at 10^8 Gy.

Studies of the life-time of thin polyimide foils in beams of helium ions and protons (Table 2) have been performed by irradiating the foils with beams of different intensities from the Van de Graaff accelerator at SINS in Warsaw, Poland [6].

Table 2: Life-time of the polyimide foils irradiated by ^{4}He ions and protons.

Beam	2.0 MeV $^4He^{+1}$ ions			1.5 MeV protons				
beam intensity I [nA]	50	100	160	150	300	500	1000	5000
deposited beam power ΔE x I [W]	4.3×10^{-3}	8.5×10^{-3}	1.4×10^{-2}	1.4×10^{-3}	2.9×10^{-3}	4.8×10^{-3}	1.0×10^{-2}	4.8×10^{-2}
foil status	foils remained unbroken after few hours of irradiation		foil ruptured after 5×10^{-4} C	foils remained unbroken after few hours of irradiation				foil ruptured after ~10^{-2} C

Permeability: Gas targets in the past were realised either by gas flow through the target container or by implantation of the gas into a solid matrix. Polyimide foils, with their characteristics and low density are frequently considered as appropriate for entrance windows to gas chambers used as detectors or target container in astro- and nuclear physics studies. In addition to the features listed earlier, the material used as entrance window should be characterised by low gas permeability to contain the gas within the container throughout the experiment.

The measurements of the gas flow rate through the membrane needed for permeability coefficient calculations can be based on monitoring of changes of the gas volume at constant pressure or changes of the permeate pressure in a stable volume. The latter method was chosen in these studies. Details of the experiment can be found in [7].

The permeability of 4 μm (~ 570 μg/cm^2) foils produced by *in-situ* polymerisation has been measured at room temperature for He and Ar. For He, the measurements were performed in the pressure range of 4-70 mbar and for Ar in the range of 20-140 mbar. The permeability was found to be in good agreement with the values published for thicker (~8.5 μm ≈ 1.2 mg/cm^2) commercial foils.

References:

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[4] A. Stolarz, J. Van Gestel, Nucl. Instr. and Meth. **A 561** (2006) 115

[5] D.M. Gilliam, A. Yue, M.S. Dewey, Nucl. Instr. and Meth. **A 590** (2008) 181

[6] M. Jaskóła, A. Korman, A. Stolarz, Nucl. Instr. and Meth. **A 590** (2008) 176

[7] A. Stolarz, M. Varlam, R. Wellum, Nucl. Instr. and Meth. **A 590** (2008) 185

Part D:
General information on HIL activities

1. PhD and MSc theses

1.1 PhD theses of students affiliated at HIL and of HIL staff members

Jan Mierzejewski
Supervisor: prof. dr hab. T. Matulewicz. Expected completion time: 2009

Katarzyna Wrzosek
Supervisor: dr hab. L. Pieńkowski. Expected completion time: 2009

Grzegorz Jaworski, Faculty of Physics, Warsaw University of Technology
Supervisor: prof. dr hab. J. Kownacki. Expected completion time: 2011

Katarzyna Hadyńska
Supervisor: prof. dr hab. M. Kicińska-Habior. Expected completion time: 2012

Daniel Piętak, Institute of Radioelectronics, Warsaw University of Technology
Supervisor: prof. dr hab. J. Wojciechowski. Expected completion time: 2012

1.2 PhD theses based on the experiments at the Warsaw Cyclotron, completed in 2008 or in progress

Iwona Sankowska, Faculty of Physics, University of Warsaw
Badanie pikosekundowych czasów życia stanów wzbudzonych izotopów cezu
Study of picosecond lifetimes of excited states in Cs isotopes
Supervisor: dr hab. T. Morek. Defended on 16 May 2008

Andrii A. Rudchik, Institute for Nuclear Research, Ukrainian Academy of Sciences
Scattering and transfer reactions in the collisions of ^{7}Li+^{11}B, ^{12}C+^{11}B, ^{7}Li+^{16,18}O nuclei
Supervisor: dr O.A. Ponkratenko. Defended on 16 May 2008

Adam Król, University of Łódź
Spektrometr elektronów konwersji wewnętrznej do badań na wiązce jonów cyklotronu Środowiskowego Laboratorium Ciężkich Jonów UW
Internal conversion electron spectrometer for in-beam studies at the HIL cyclotron
Supervisor: prof. dr hab. J. Andrzejewski. Defended on 2 July 2008

Volodymyr O. Romanyshyn, Institute for Nuclear Research, Ukrainian Academy of Sciences
Isotopic and isobaric effects in ^{6,7}Li+^{10}B reactions
Supervisor: prof. A.T. Rudchik. Expected completion time: 2009

Joanna Czub, Faculty of Physics, Świętokrzyska Academy
Biologiczne działanie promieniowania o wysokim LET
Biological effects of radiation with high LET value
Supervisor: prof. dr hab. J. Braziewicz. Expected completion time: 2009

Izabela Strojek, The Andrzej Sołtan Institute for Nuclear Studies, Świerk/Otwock
Supervisor: prof. dr hab. K. Rusek. Expected completion time: 2010

1.3 MSc theses supervised by HIL staff members, completed in 2008 or in progress

Daniel Piętak, Department of Electronics and Information Technology,
Warsaw University of Technology
Implementacja algorytmu genetycznego do analizy danych z pomiarów wzbudzeń kulombowskich
Implementation of the genetic algorithm to Coulomb excitation data analysis
Supervisors: dr A. Pająk, dr P. Napiorkowski. Defended on 27 May 2008

Katarzyna Hadyńska, Department of Physics,
Wzbudzenia kulombowskie jądra ^{100}Mo
Coulomb excitation of ^{100}Mo
Adam Mickiewicz University, Poznań
Supervisors: prof. dr hab. W. Nawrocik, dr P. Napiorkowski. Defended on 8 July 2008

Łukasz Czernik, Faculty of Physics, Warsaw University of Technology
Kalibracje spektrometru scyntylacyjnego promieniowania γ z wykorzystaniem krótkożyciowych produktów reakcji jądrowych
Calibration of a scintillator γ-ray spectrometer using short-lived nuclear reaction products
Supervisor: dr J. Srebrny. Expected completion time: 2009

Alicja Staudt, Department of Physics, University of Silesia
Badanie własności zespołu detektorów układu ICARE
Characteristics of the ICARE detection set-up
Supervisors: prof. dr hab. W. Zipper, dr hab. E. Piasecki. Expected completion time: 2009

Anna Piórkowska, Department of Physics, University of Silesia
Zastosowanie wielodetektorowego układu ICARE do pomiaru rozkładu kątowego rozpraszania ^{20}Ne + ^{208}Pb przy energiach 105 MeV i 115 MeV
Angular distributions of ^{20}Ne + ^{208}Pb scattering at 105 and 115 MeV beam energy measured with the ICARE multidetector set-up
Supervisors: prof. dr hab. W. Zipper, dr hab. E. Piasecki. Expected completion time: 2009

Grzegorz Mentrak, Faculty of Physics, Warsaw University of Technology
Opracowanie układu cyfrowo-analogowego sterowania zasilaczami prądu stałego do magnesów odchylających w Warszawskim Cyklotronie
A digital/analog control system for DC power supplies for bending magnets of the Warsaw Cyclotron
Supervisor: dr J. Choiński. Expected completion time: 2010

1.4 Other MSc theses based on the experiments at the Warsaw Cyclotron, completed in 2008 or in progress

Miron Sadziak, Faculty of Physics, University of Warsaw
Kalibracja detektora scyntylacyjnego BaF_2 oraz stosowane metody numeryczne
Calibration of the BaF_2 scintillator and applied numerical solutions
Supervisor: prof. dr hab. T. Matulewicz. Defended in 2008

Agnieszka Żywno, Faculty of Physics, University of Warsaw
Nowe technologie w budowie skanerów dla diagnostyki medycznej
New technologies for construction of medical diagnostics scanners
Supervisor: dr hab. Z. Szefliński. Defended in 2008

Jan Dyczewski, Faculty of Physics, University of Warsaw
Opracowanie metodyki uzyskania jednorodnej wiązki jonów z Cyklotronu Warszawskiego
A method to obtain homogeneous beams from the Warsaw Cyclotron
Supervisor: dr hab. Z. Szefliński. Expected completion time: 2009

Urszula Górak, Faculty of Physics, University of Warsaw
Współczynniki skuteczności biologicznej dla komórek CHO-K1, naświetlanych jonami węgla ^{12}C
Relative biological effectiveness for CHO-K1 cells irradiated with ^{12}C ions
Supervisor: dr hab. Z. Szefliński. Expected completion time: 2009

Łukasz Kaźmierczak, Faculty of Physics, University of Warsaw
Badanie krzywych przeżywalności dla komórek CHO-K1
Survival curves of CHO-K1 cells
Supervisor: dr hab. Z. Szefliński. Expected completion time: 2009

Damian Karpiński, Faculty of Physics, University of Warsaw
Badanie korelacji kątowych kwantów gamma na wiązce ciężkich jonów jako źródło informacji spektroskopowych
Angular correlations of gamma rays measured in beam of heavy ions: a source of spectroscopic information
Supervisor: dr E. Grodner. Expected completion time: 2009.

Łukasz Janiak, University of Łódź,
Wyznaczenie multipolowości przejść elektromagnetycznych na podstawie pomiarówkoincydencyjnych elektron-gamma
Determination of multipolarities of electromagnetic transitions from electron-gamma coincidence measurements
Supervisor: dr J. Perkowski. Expected completion time: 2010.

2. Seminars

2.1. Seminars at HIL

M. Dehnel 14 February
D-Pace: Provider of Custom Designed & TRIUMF Licensed Equipment for Industrial/Academic Particle Accelerators

J. Jastrzębski, W. Kurcewicz, J. Kownacki, E. Piasecki, Z. Szefliński 11 March
Prezentacje eksperymentów przewidzianych do wykonania od kwietnia do czerwca 2008
Open PAC meeting – presentation of experiments planned for April – June 2008

J. Jastrzębski 17 April
Sprawozdanie z działalności Laboratorium (1.01.2007-31.03.2008)
Report from the HIL director (1.01.2007-31.03.2008)

J. Jastrzębski, Z. Szefliński, W. Kurcewicz, A. Kordyasz, K. Hadyńska, J. Srebrny, M. Scheck, K. Wrzosek, E. Grodner, J. Mierzejewski, E. Piasecki, I. Strojek — 4 November

Prezentacje eksperymentów przewidzianych do wykonania od listopada 2008 do czerwca 2009

Open PAC meeting – presentation of experiments planned for November 2008 – June 2009

J. Srebrny — 11 December

Spotkanie Komitetu Użytkowników U200P – harmonogram prac przy układzie EAGLE

Open Users' Committee Meeting – time schedule for the EAGLE spectrometer

2.2. External seminars given by HIL staff

M. Palacz — 11 January

Szósty tydzień AGATY

6th AGATA Week

Seminar of the Nuclear Physics Division, Faculty of Physics, University of Warsaw, Warsaw, Poland

L. Pieńkowski — 11 January

Nuclear-coal synergy for emission-free liquid fuel production

Meeting at HIL organized by HIL and AGH University of Science and Technology, Warsaw, Poland

M. Zielińska — 25 January

Wzbudzenie kulombowskie egzotycznej wiązki ^{44}Ar w GANIL

Coulomb excitation of the exotic ^{44}Ar beam at GANIL

Seminar of the Nuclear Physics Division, Faculty of Physics, University of Warsaw, Warsaw, Poland

A. Stolarz — 14 February

Polyimide foils as backing support for target preparation

EFNUDAT Collaboration and Users Meeting, Dresden, Germany

J. Kownacki — 19 March

Poszukiwanie izomerów w obszarze mili- i mikro- i nano- sekundowym w obszarze mas A~ 120-150 w eksperymentach "na wiązce" jonów z cyklotronu U200 w Warszawie

Nuclear structure studies of ms-, micro- and nano- second isomers in A=120-150 mass region performed at the Warsaw Cyclotron U200

Seminar of the Department of Nuclear Physics and Radiation Safety, Faculty of Physics and Applied Informatics, University of Łódź, Łódź, Poland

L. Pieńkowski — 31 March

Milcząca i zapomniana ofiara Czarnobyla

Silent and forgotten victim of Chernobyl

Jerzy Pniewski Colloquium of the Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland

J. Srebrny 8 April
Sum Rules and triaxiality
GOSIA Workshop, HIL, Warsaw, Poland

J. Iwanicki 8 April
Introduction to GOSIA simulations
GOSIA Workshop, HIL, Warsaw, Poland

K. Wrzosek 8 April
Accuracy of matrix elements resulting from various divisions of the data
GOSIA Workshop, HIL, Warsaw, Poland

M. Zielińska 8 April
Complicated particle detection geometry and normalization to target excitation
GOSIA Workshop, HIL, Warsaw, Poland

D. Piętak 10 April
Implementation of a genetic algorithm for COULEX data analysis
GOSIA Workshop, HIL, Warsaw, Poland

K. Hadyńska 16 May
Wzbudzenie kulombowskie ^{100}Mo: badanie własności najniżej leżących stanów wzbudzonych
Coulomb excitation of ^{100}Mo: properties of the lowest excited states
Seminar of the Nuclear Physics Division,
Faculty of Physics, University of Warsaw, Warsaw, Poland

J. Srebrny 29 May
Scientific program of the EAGLE campaign on beams of the Warsaw Cyclotron at HIL UW
European Gammapool Workshop, Paris, France

A. Stolarz 9 June
Activity of the target preparation group
IRMM, Geel, Belgium

P.J. Napiorkowski 12 June
Summary of the GOSIA workshop
INTAG meeting, CERN, Geneva

G. Jaworski 24 June
Symulacje reakcji fuzji-ewaporacji i detektorów dodatkowych spektrometru AGATA
Simulations of fusion-evaporation reactions and ancillary detectors of the AGATA spectrometer
Doctoral seminar at the Faculty of Physics,
Warsaw University of Technology, Warsaw, Poland

G. Jaworski 9 July
Simulations of lifetime measurements with RFD, AGATA and GASP
7th AGATA Week, Uppsala, Sweden

J. Srebrny 14 July
Quadrupole collectivity in ^{104}Ru – COULEX experiments and comparison to microscopic calculations
Seminar of the Laboratori Nazionali di Legnaro, Legnaro, Italy

J. Jastrzębski 6 September
Nuclear Physics at the Warsaw Cyclotron
Zakopane Conference on Nuclear Physics, Zakopane, Poland

A. Trzcińska 6 September
Are the weak reaction channels really weak?
Zakopane Conference on Nuclear Physics, Zakopane, Poland

M. Zielińska 11 September
Determination of nuclear static moments using post-accelerated exotic beams:
Coulomb excitation of neutron-rich ^{44}Ar at SPIRAL
ENAM '08, Ryn, Poland

A. Stolarz 15 September
Actinide targets preparation at IRMM – then and now
24th World Conference of the INTDS, Caen, France

J. Jastrzębski 18 September
Presentation of the Report "Nuclear Physics in Poland 1996 - 2006"
EURONS Town Meeting, Rhodes, Greece

A. Trzcińska 19 September
Nuclear periphery studied with antiprotonic atoms
LEAP '08, Vienna, Austria

M. Zielińska 19 September
Determination of nuclear moments using post-accelerated exotic beams: Coulomb excitation of neutron-rich ^{44}Ar at SPIRAL
EURONS Town Meeting, Rhodes, Greece

L. Pieńkowski 1 October
Nuclear-coal synergy
Conference “Clean Coal Technologies”, Sosnowiec, Poland

E. Piasecki 24 October
Rozkład wysokości barier: nowe pomiary i nowe niespodzianki
Fusion barrier distributions: new measurements, new suprises
Seminar of the Nuclear Physics Division,
Faculty of Physics, University of Warsaw, Warsaw, Poland

L. Pieńkowski 6 November
Nuclear-coal synergy
Conference STPIChem, Ustroń-Jaszowiec, Poland

K. Kilian 21 November
Radiofarmaceutyki do pozytronowej tomografii emisyjnej (PET). Nowe możliwości dla nauki, ochrony zdrowia i przemysłu
Radiopharmaceutics for Positron Emission Tomography (PET). New possibilities for science, health care and industry
Seminar of the Biophysics Division,
Faculty of Physics, University of Warsaw, Warsaw, Poland

M. Palacz 27 November
In beam gamma-ray spectroscopy investigations of nuclei in the vicinity of ^{100}Sn – perspectives at GANIL
COPIGAL Workshop, Paris, France

P. Napiorkowski 27 November
Nuclear deformation in excited states – past, present and future
COPIGAL Workshop, Paris, France

M. Zielińska 27 November
Nuclear deformation studied by Coulomb excitation – recent experiments at GANIL
COPIGAL Workshop, Paris, France

A. Kordyasz 27 November
Towards correction of silicon wafer uniformity resistivity distribution by selective transmutation doping
FAZIA days, Huelva, Spain

I. Cydzik 4 December
Overview and activities of the Heavy Ion Laboratory
CYCLEUR WORKSHOP, JRC European Commission, Ispra, Italy

E. Piasecki 18 December
New results in fusion barrier distributions
Workshop "SHE Research - Prospects for the Next Decade", Kraków, Poland

2.3 Poster presentations

J. Mierzejewski
EAGLE (central European Array for Gamma Levels Evaluation) with EUROBALL Phase-I detectors
European Gammapool Workshop, Paris, France, 27-30 May 2008

M. Zielińska
Coulomb excitation of neutron-rich ^{44}Ar at SPIRAL
EURORIB '08, Giens, France, 9-13 June 2008

G. Jaworski
Impact of ancillary detectors on the AGATA performance
Euroschool on Exotic Beams, Piaski, Poland, 1-7 September 2008

K. Hadyńska
Coulomb Excitation of ^{100}Mo – recent results from Heavy Ion Laboratory, University of Warsaw
Zakopane Conference on Nuclear Physics, Zakopane, Poland, 1-7 September 2008

M. Zielińska
Determination of nuclear moments using post-accelerated exotic beams: Coulomb excitation of neutron-rich ^{44}Ar at SPIRAL
ENAM '08, Ryn, Poland, 7-13 September 2008

D. Piętak
Graphical User Interface for Coulex analysis tool – input generator for the GOSIA code
EURONS Town Meeting, Rhodes, Greece, 17-19 September 2008

A. Kordyasz
Resistivity distribution of Si wafer by C-V measurement with gravitationally pressed mercury drop
EURONS Town Meeting, Rhodes, Greece, 17-19 September 2008

2.4 Involvement of HIL staff in organization of conferences and workshops

Polish Workshop on Acceleration and Applications of Heavy Ions,
31 March – 5 April 2008, HIL, Warsaw
Local Organizing Committee: P. Napiorkowski, A. Trzcińska

GOSIA Workshop '08, 8-10 March 2008, HIL, Warsaw
Local Organizing Committee: P. Napiorkowski, M. Zielińska, J. Srebrny, K. Hadyńska

Euroschool on Exotic Beams, 1-7 September 2008, Piaski
Members of the Local Organizing Committee: M. Wolińska-Cichocka, M. Zielińska

ENAM '08, 7-13 September 2008, Ryn
Members of the Local Organizing Committee: M. Palacz, M. Wolińska-Cichocka

Science Festival and Researchers' Night, 19-28 September 2008, Warsaw
Local Coordinator: K. Wrzosek

3. ISI listed publications, other publications

3.1. Publications in journals listed by ISI

3.1.1 Publications resulting from work performed with HIL facilities

J. Andrzejewski, A. Król, J. Perkowski, K. Sobczak, R. Wojtkiewicz, M. Kisieliński, M. Kowalczyk, J. Kownacki, A. Korman,
"Electron spectrometer for „in-beam" spectroscopy",
Nucl. Inst. and Meth. in Phys. Res. **A 585** (2008) 155.

M. Jaskóła, A. Korman, A. Stolarz,
"Estimation of the impurity levels in polyimide foils and the life-time of the foils irradiated by charged projectiles"
Nucl. Inst. and Meth. in Phys. Res. **A 590** (2008) 176.

A.J. Kordyasz, E. Kulczycka,
"Double sided strip monolithic silicon E-ΔE telescope produced by Quasi-Selective Epitaxy",
Nucl. Inst. and Meth. in Phys. Res. **A 596** (2008) 131.

J. Czub, D. Banaś, A. Błaszczyk, J. Braziewicz, I. Buraczewska, J. Choiński, U. Górak, M. Jaskóła, A. Korman, A. Lankoff, H. Lisowska, A. Łukaszek, Z. Szefliński, A. Wójcik,
"Biological effectiveness of ^{12}C and ^{20}Ne ions with very high LET",
Int. J. of Radiation Biology **84** (2008) 821.

I. Sankowska, C. Droste, E. Grodner, T. Morek, J. Srebrny, A.A. Pasternak, J. Kownacki, P. Napiorkowski, S.G. Rohoziński, M. Kowalczyk, M. Kisieliński, R. Kaczarowski, E. Ruchowska,
"E2 transition probabilities in the decoupled band of the ^{129}La nucleus",
Eur. Phys. J. **A 37** (2008) 169**.**

I. Fijał-Kirejczyk, M. Jaskóła, A. Korman, D. Banaś, J. Braziewicz, J. Choiński, U. Majewska, M. Pajek, W. Kretchmer, G. Łapicki, T. Mukoyama, D. Trautmann,
"L-subshell ionization of heavy elements by S ions with energy of 0.4-3.8 MeV/amu",
Nucl. Inst. and Meth. in Phys. Res. **B 266** (2008) 2255.

J. Kownacki, M. Kisieliński, M. Kowalczyk, Ch. Droste, T. Morek, E. Ruchowska, J. Srebrny, M. Wolińska-Cichocka, M. Palacz, A. Korman, J. Andrzejewski, A. Król, J. Perkowski, R. Lieder, J. Mierzejewski, I. Sankowska,
"Observation of a new $(25/2^+)$ isomer in ^{121}Sb",
Acta Phys. Pol. **B39** (2008) 489.

A. Król, J. Andrzejewski, J. Perkowski, K. Sobczak, R. Wojtkiewicz, M. Kisieliński, M. Kowalczyk, J. Kownacki, A. Korman,
"The internal conversion electron and gamma spectroscopy in the ^{14}N + ^{197}Au reaction measurements",
Acta Phys. Pol. **B39** (2008) 495.

K. Wrzosek, M. Zielińska, T. Czosnyka, J. Choiński, K. Hadyńska, J. Iwanicki, M. Kisieliński, M. Kowalczyk, J. Kownacki, P. Napiorkowski, D. Piętak, J. Srebrny, K. Zając,
"New γ-particle detection set-up for Coulomb excitation experiments – towards determination of triaxiality of ^{100}Mo",
Acta Phys. Pol. **B39** (2008) 513.

E. Grodner,
"Quest for the chiral symmetry breaking in atomic nuclei",
Acta Phys. Pol. **B39** (2008) 531.

J. Czub, D. Banaś, A. Błaszczyk, J. Braziewicz, I. Buraczewska, J. Choiński, U. Górak, M. Jaskóła, A. Korman, A. Lankoff, H. Lisowska, A. Łukaszek, Z. Szefliński, A. Wójcik,
"Cell survival and chromosomal aberrations in CHO-K1 cells irradiated by carbon ions",
Applied Radiation and Isotopes 67 (2009) 447.

J. Jastrzębski,
"Nuclear physics at the Warsaw Cyclotron",
Acta Phys. Pol. **B40** (2009) 839.

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3.3 Internal reports

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6. Program Advisory Committee

Brunon Sikora, Chairman (Faculty of Physics, University of Warsaw)

Bogdan Fornal (Henryk Niewodniczański Institute of Nuclear Physics,
Polish Academy of Sciences, Kraków)

Jerzy Jastrzębski (HIL, University of Warsaw)

Reinhard Kulessa (Marian Smoluchowski Institute of Physics, Jagiellonian University, Kraków)

Andrzej Marcinkowski (Andrzej Sołtan Institute for Nuclear Studies, Warszawa/Świerk)

Adam Sobiczewski (Andrzej Sołtan Institute for Nuclear Studies, Warszawa/Świerk)

Władysław Trzaska (University of Jyväskylä, Finland)

Andrzej Turos (Andrzej Sołtan Institute for Nuclear Studies, Warszawa/Świerk;
Institute of Electronic Materials Technology, Warszawa)

Teresa Rząca-Urban (Faculty of Physics, University of Warsaw)

Jan Żylicz (Faculty of Physics, University of Warsaw)

The **Users Committee**, serving as a link between the cyclotron users and the Laboratory is chaired by Julian Srebrny (HIL UW).

The international Program Advisory Committee of Heavy Ion Laboratory meets usually twice a year, in spring and in autumn. Deadline for submitting proposals is two weeks before a PAC meeting.

In 2008, PAC meetings took place on 11 March and 4 November. Fourteen research projects have been approved and 421 shifts allocated in total.

7. Events at HIL

7.1 GOSIA Workshop

A meeting on Coulomb excitation data analysis, GOSIA Workshop '08, was held at HIL on 8-10 April 2008.

Coulomb Excitation method is presently used by many scientific collaborations all over the world. Recently new interest in COULEX is drawn by commissioning of radioactive beam facilities opening perspectives to investigate structure of unstable nuclei. Complexity of experimental set-ups used to study new regions of nuclide chart brings earlier unknown problems in data analysis. The available tool for data analysis – the semiclassical coupled-channel Coulomb excitation least-squares search code GOSIA has been used extensively for Coulomb excitation work internationally by many users leading to significant advances in nuclear science.

The aim of the workshop was to bring together the community of present and potential GOSIA users. The meeting provided experienced users with an opportunity to present recent achievements in COULEX measurement analysis, allowing newcomers to the field to get some handy hints.

During the first day of the workshop presentations were concentrated on on-going research projects and recent sophisticated solutions in Coulex analysis. On the second day a GOSIA hands-on training was organised, while the last day provided an opportunity to discuss future plans and possible developments of the Coulex analysis software. The detailed programme of the workshop can be found at its Web page:
`http://www.slcj.uw.edu.pl/gosia_workshop`

Following the discussions at the workshop, the GOSIA Users Group has been established to promote, prioritise and facilitate development of GOSIA and related codes. GOSIA Steering Committee was formed to coordinate the actions of the GOSIA Users Group.

The meeting was organised as a part of INTAG activity in the framework of the FP6 I3-Eurons Project.

7.2 Workshop on HTR technology in Poland

The workshop with participation of professor Jerzy Buzek, Member of European Parliament and of senator Zbigniew Romaszewski, Deputy Speaker of Senat RP was organised at the Heavy Ion Laboratory on 11 January 2008. The deputy rectors of University of Science and Technology in Kraków (AGH), University of Warsaw and Warsaw University of Technology were present during this event. It was concluded that HTR technology development is an attractive and important option for Poland.

7.3 Final Workshop of the HTR Working Group of SNE-TP

Heavy Ion Laboratory participated in the HTR working group under Sustainable Nuclear Energy Technology Platform (SNE-TP). The final workshop was organized at HIL on 19 September 2008. The strategic plan for HTR development in Europe is now included in the final SNE-TP report (see `http://www.snetp.eu`).

7.4 Heavy Ion Laboratory Prize founded by Prof. T. Inamura – edition 2008

The prize was established by Professor T.T. Inamura who had worked in the Heavy Ion Laboratory in years 1998-2002 and made a great contribution to HIL development.

Award in the amount of 5.000 USD is presented every second year to recognise and support young researchers having outstanding experimental or technical achievements in the field of nuclear and atomic physics or related subjects. The results should be obtained by using the Warsaw Cyclotron or other HIL apparatus.

Candidates must be scientists or PhD students below the age of 36 on the day of application.

The most important selection criterion is the candidate's academic achievement demonstrated by publications in the international journals and presentations on international conferences. Achievements in the field of interdisciplinary applications of the HIL cyclotron are highly valued.

In the third edition, in 2008, the Heavy Ion Laboratory Prize has been awarded to Dr. Jarosław Perkowski from the Faculty of Physics and Applied Informatics of the University of Łódź, for his contribution to the design, construction and installation at HIL of the conversion electron spectrometer and nuclear structure studies done with this set-up in beam of the Warsaw Cyclotron.

8. Laboratory Guests

Participants of HIL experiments from outside-Warsaw laboratories:

J. Andrzejewski	University of Łódź, Poland
D. Banaś	Holycross Cancer Centre, Kielce, Poland
A. Błaszczyk	Nicolaus Copernicus University, Toruń, Poland
J. Braziewicz	Jan Kochanowski University, Kielce, Poland
A. Bruce	University of Brighton, UK
H. Bzyl	IPN Orsay, France
J. Czub	Jan Kochanowski University, Kielce, Poland
M. Kasztelan	The Andrzej Sołtan Institute for Nuclear Studies, Łódź, Poland
S. Khlebnikov	Khoplin Radium Institute, St. Petersburg, Russia
S. Kliczewski	The H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
T. Krogulski	Faculty of Physics, University of Białystok, Poland
A. Król	University of Łódź, Poland
E. Koshchiy	Kharkiv University, Ukraine
T. Lotkiev	Joint Institute for Nuclear Research, Dubna, Russia
J. Marganiec	University of Łódź, Poland
M. Mutterer	Technische Universitat, Darmstadt, Germany
J. Perkowski	University of Łódź, Poland
A. Piórkowska	Institute of Physics, University of Silesia, Katowice, Poland
S. Smirnov	Joint Institute for Nuclear Research, Dubna, Russia
K. Sobczak	University of Łódź, Poland
A. Staudt	Institute of Physics, University of Silesia, Katowice, Poland
P. Szaflik	Institute of Physics, University of Silesia, Katowice, Poland
W. Trzaska	University of Jyvaskyla, Finland
A. Wilczek	Institute of Physics, University of Silesia, Katowice, Poland

Other short-time visitors:

G. de France	GANIL, Caen, France
A. Pakou	University of Ioannina, Greece
A. Pasternak	Ioffe Physical Technical Institute, St. Petersburg, Russia
A. Petts	University of Liverpool, UK
M. Scheck	University of Liverpool, UK