HEAVY ION LABORATORY, UNIVERSITY OF WARSAW – A UNIQUE RESEARCH CENTER IN POLAND

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Abstract

On behalf of the staff of the Heavy Ion Laboratory of the University of Warsaw (HIL) we present the current state of development of the laboratory. HIL is a user facility operating a K_{max}=160 isochronous heavy ion cyclotron, unique in central Europe. Two ECR ion sources, a homemade 10 GHz and a commercial (Supernanogan Pantechnik) 14.5 GHz, supply ions to the machine. In the center of the machine a "spiral" type inflector bends the ion beams into the median plane. The current system allows ions from He up to Xe to be accelerated with energies up to 10 A MeV. The research program of HIL includes nuclear physics, solid state physics, medical radioisotope production, biology and detector testing. In 2012 HIL launched a new facility - the Radiopharmaceuticals Production and Research Center (RPRC). This is a fully GMP compliant production facility of radiopharmaceuticals for PET. It operates a General Electric PETtrace 840 cyclotron and a complete production line of FDG. An external beam line with target station, designed and constructed by the Laboratory, allows metallic and powdered samples to be irradiated, extending medical isotope research by using proton and deuteron beams.

THE HEAVY ION LABORATORY OF THE UNIVERSITY OF WARSAW

The Heavy Ion Laboratory [1] is situated in the centre of the University of Warsaw and the Polish Academy of Sciences Scientific Campus Ochota, 500 m from the Public Central Teaching Hospital affiliated to the Medical University of Warsaw (MUW) - see Figure 1.

Figure 1: Scientific Campus Ochota.

HIL was founded in 1979 by an agreement between three state institutions: the Ministry of Science and Higher Education, the Polish Academy of Sciences and the National Atomic Energy Agency. The Laboratory plays the role of a user facility and is an inter–faculty unit of the University of Warsaw. Currently, HIL operates two cyclotrons: a U-200P heavy ion cyclotron and a compact cyclotron accelerating protons and deuterons. In order to host both accelerators the HIL building was divided into two parts. The main part is assigned to the heavy ion cyclotron with its research infrastructure. The second part is dedicated to the compact cyclotron and is located in the underground part of the HIL building, see Figure 2.

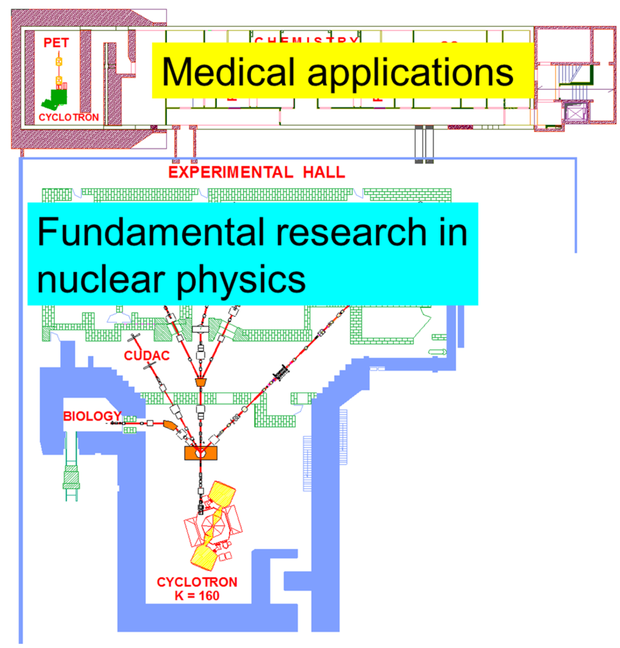

Figure 2: A scheme of the building.

With two cyclotrons HIL is the perfect place to carry out fundamental research in nuclear physics, solid state physics, medical radioisotope production, biology and detector testing. All the above mentioned activities are based on the heavy ion cyclotron with a K value varying from 120 to 160. This is an isochronous cyclotron with four straight sectors. The stripper foil system allows ions with energies from 2 to 10 MeV/A to be extracted.

Two ECR ion sources supply ions to the machine. The older ECRIS, homemade, operates at 10 GHz and delivers beams of light elements from He to Ar. The second ion source, a commercial Supernanogan from Pantechnik, bought a few years ago, operates at 14.5 GHz and delivers beams up to Xe. It is equipped with a high temperature oven and a "Sputtering" system. With this source not only gaseous but also metallic ions are available for acceleration. The sources are mounted in the basement of the cyclotron cave and connected to the machine via an

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injection line. The beams from the ion sources and injection line are transferred to the first cyclotron orbit through a spiral inflector. As a result of recent crucial improvements, i.e. adding the commercial ECRIS and implementation of the spiral inflector, the accelerator has been able to deliver an average of 3300 h/y of beam time for almost 100 users/y during recent years. The new inflector was developed in collaboration with the cyclotron team from Dubna (Russia).

Currently two new R.F. generators are under construction. Their commissioning is expected at the beginning of 2016.

The ECR ion source team is also involved in work associated with the international project 'EMILIE' [2]. As can be seen in Figure 2, beams from the U-200P are transferred to an experimental hall equipped with a number of stationary experimental set-ups.

THE RESEARCH PROGRAM OF HIL

The research program is defined by each experimental set-up. Short description is provided below.

EAGLE (Figure 3)

The acronym EAGLE denotes the central European Array for Gamma Levels Evaluation. This is our newest multi-detector gamma ray spectrometer [3]. It started operation in 2009. Its frame is able to host up to 30 HPGe detectors with Anti-Compton Shielding. This measuring system can be modified by adding existing auxiliary detectors such as a 4π Si-ball, an electron spectrometer (ULESE) [4], the so-called 'Munich chamber' equipped with 48 PiN diodes (max. 110) or the 'Bucharest' plunger [5]. The latter device is available within the framework of our collaboration with IFIN-HH, Romania.

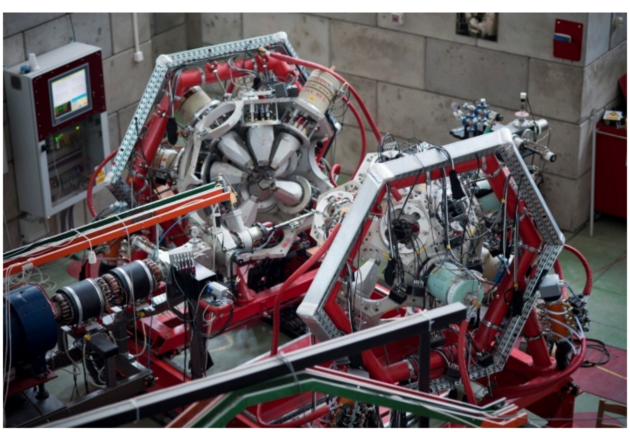

Figure 3: EAGLE set-up.

This modern experimental set-up allows us to conduct research on nuclear structure by γ-spectroscopy techniques such as: γ-γ angular correlations with the EAGLE HPGe array, e-γ spectroscopy with the ULESE spectrometer, lifetime measurements using tools such as the Doppler Shift Attenuation Method [6] and the Recoil Distance Doppler Shift technique, and complex Coulomb excitation experiments relevant for nuclear structure physics [7] but also complementary to RIB experiments by providing additional experimental data derived from independent experiments, crucial when going towards more exotic nuclei. During the last few months the effort of the research groups was focused on the search for chiral symmetry breaking in atomic nuclei by Doppler-shift measurements of picosecond lifetimes, a study of the violation of K-selection rules by measurements of internal conversion coefficients for transitions deexciting K isomers, studies of non-spherical and non-axial shapes of nuclei by direct measurements of electromagnetic matrix elements using the Coulomb excitation method (GOSIA code) and a study of the reaction mechanism for complete and incomplete fusion by measurements of gamma radiation in coincidence with emitted charged particles (protons, alphas).

CUDAC

This experimental set-up is a small scattering chamber, equipped with an array of backward hemisphere semiconductor detectors (PiN diode type) and forward hemisphere monitoring Si counters. It is mostly used for Coulomb excitation studies and measurements of fusion barrier level distributions. A new version of the scattering chamber is currently under construction.

ICARE (Figure 4)

The acronym ICARE denotes 'Identificateur de Charges A Rendement Eleve'. ICARE is a particle spectroscopy chamber from IReS Strasburg (France), present at HIL since 2007. Its huge size (Φ1.0m x 0.7m) allows the use of up to 48 telescopes for charged particle detection, identification and energy measurements.

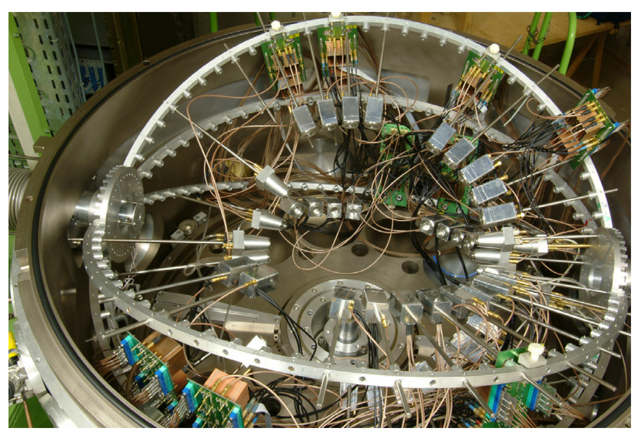

Figure 4: ICARE set-up.

The scientific program assigned to this set-up includes barrier distribution measurements, reaction mechanism studies and novel detector tests [8,9]. Recent experiments were devoted to:

- barrier level distribution studies – *CUDAC & ICARE;*
- a series of experiments using ^{11,10}B, ^{18}O, ^{14,15} N beams on light targets: ^{6,7}Li, ^{9}Be, ^{12,13}C – energies 4-6 MeV/c;
- backward angle structure in the ^{20}Ne+^{28}Si quasi-elastic scattering at near-barrier energies – a study of the reactions of α-clustering nuclei;

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- measurements of elastic scattering cross sections for ^{16}O and ^{13}C on light nuclei (^{12}C, ^{9}Be) at energies of 2–3 MeV/n – optical model parameters of the nucleus-nucleus interaction and cluster transfer studies;
- an indirect study of the astrophysical $^{16}O+^{16}O$ fusion reaction by the Trojan Horse Method;
- a search for heavy ion molecular resonances with an Ar beam using the Thick Target Inverse Kinematics method.

Applications of Heavy Ions

In recent years one of the research groups from HIL has been actively engaged in an investigation of the production capabilities of ^{211}At, ^{43}Sc, ^{44}Sc, $^{72}Se/^{72}As$ radioisotopes and their potential medical applications. For this purpose a consortium of HIL, the Inst. of Nucl. Chemistry and Technology and Polatom – National Centre for Nuclear Research was established. The radioisotopes are produced by alpha beam reactions using the internal target station of the heavy ion cyclotron [10].

Supplementary Services

In addition to the research infrastructure described above HIL also has an on-line mass separator IGISOL, a detector laboratory, a target laboratory, a set-up for biological sample irradiation experiments [11] and a laboratory for medical imaging equipped with a DST-XL Gamma camera. The latter laboratory is mainly dedicated for use by students specializing in 'Medical Physics'.

THE RADIOPHARMACEUTICALS PRODUCTION AND RESEARCH CENTER

RPRC (Figure 5) was constructed for radiopharmaceuticals production for PET [12–14]. This is a fully GMP compliant production centre certified by the Polish authorities which has been operating since May, 2012.

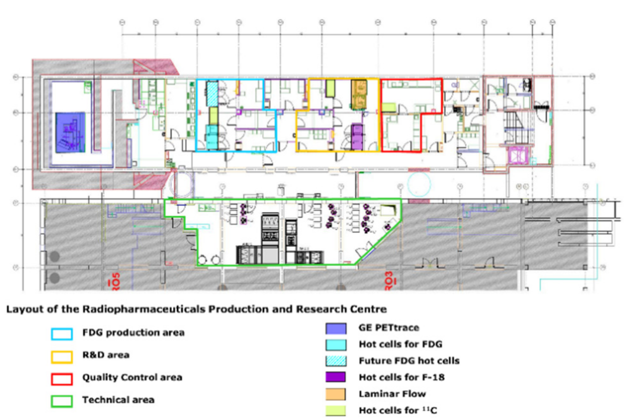

Figure 5: The layout of RPRC.

The facility consists of the cyclotron vault, two "hot chemistry" production laboratories, a quality control department, administration rooms, technical rooms and different kinds of store rooms including the archives. RPRC operates a GE PETtrace 840 cyclotron and a complete production line of 18F-fluorodeoxyglucose. The second production lab is dedicated to R&D and is equipped with several synthesizers and dispenser units. The apparatus collected in this lab allows the production of radiopharmaceuticals containing ^{18}F, ^{15}O and ^{11}C radio-isotopes. Besides ^{18}F, ^{15}O and ^{11}C targets the cyclo-tron is additionally equipped with an external short beam line with a target station. This latter is the outcome of the ALTECH project. The station allows the irradiation of metallic and powdered samples. Currently the ^{99m}Tc isotope is produced from a ^{100}Mo target. After a small modification the device will also be used to carry out the PET-SKAND project, focused on the production and utilization of Sc isotopes.

CONCLUSION

HIL is a one-of-its-kind Polish nuclear physics center, a place for research, education and medical applications studies. It is also a member of the European Transnational Access Facility. This national nuclear physics laboratory is open for external researchers and it also serves as an educational center for local and foreign students [15].

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