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# SEVEN DECADES OF SCIENCE WITH ACCELERATORS AT IPHC

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*Abstract*

The Institut Pluridisciplinaire Hubert Curien (IPHC) is a laboratory with solid foundations and perspectives to overcome future challenges. It is a component of the Centre National de Recherche Scientifique (CNRS) and the University of Strasbourg. It has been founded in 2006 after fusion of three local laboratories leading research in the field of analytical chemistry, ecology/environment and subatomic physics. The activities related with subatomic physics present a rich history which goes back to the 40's and is now evolving towards new challenges at the frontier of the knowledge with the contribution of other sciences as biology, chemistry, medicine and radiobiology. The paper will cover a number of past and current activities with emphasis on the link between research and technology.

## INTRODUCTION

Before being a well-established laboratory in the French and European landscape IPHC went through several periods marked by continuous evolution, contrasting activities and remarkable results. Among the various fields of research explored today such as chemistry, ecology, ethology, physiology, radiobiology and subatomic physics, this article focuses on the activities developed with accelerators. The history of the Institute will be covered through six periods: origin, growth, confirmation, maturation, change in trend and metamorphosis.

## THE ORIGIN

Activities related with nuclear physics applied to medicine have started in 1941 during second war, German occupation and evacuation of Strasbourg's university in Clermont-Ferrand and Dordogne. The "Medizinisches Forschungs Institut" is built inside the hospital and near the faculty of medicine with four departments in biology, chemistry, medicine and physics, see Fig. 1.

Figure 1: First accelerator building with Cockcroft Walton neutron generator at the civil hospices in Strasbourg DC, 1944.

First beam was produced after the liberation of the city in 1944 and the ensuing turbulences in 1948 with a neutron generator based on a 1.5 MV Cockcroft Walton accelerator, see Fig. 2. The goal was to produce isotopes for radiotracers ($^{32}P$) with $^{2}H$ beam induced neutrons on Be target and to perform radiobiology on cells, one of the first facility in Europe at the time. Research is driven by recent discoveries: neutron as a new particle, induced radioactivity, fission, etc. Activities are stimulated by competition with Heidelberg and two French laboratories, that of F. Joliot located in Ivry and the Collège de France.

Figure 2: Cockcroft Walton 1.5 MV electrostatic accelerator stands on the putting green nowadays of IPHC on the Strasbourg campus.

These investments were supplemented by a new X-rays generator, an electron microscope and a cyclotron purchased in 1942. It should be noted that the first lecture in the field of nuclear physics was given in 1947 by Pr S. Gorodetsky, a friend of F. Joliot-Curie. From the beginning, the research has been characterized by the support of leading scientists, a strong interaction between theory and experiment, and the sustainability of the program in the field of nuclear physics (structure of the nucleus, spectroscopy, EM transition, interactions and life time measurements), and nuclear chemistry (chemical effects of nuclear reactions and ionizing radiations). These developments appear after the first works started in the 1930s on X-rays at 100 keV, the sources of natural radioactivity (gamma at 2 MeV with $^{226}$Ra source) and the need to study deeper effects with more energetic light ions [1-6].

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Figure 3: New nuclear physics research center built in the western part of Strasbourg in 1959.

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## THE GROWTH

The Institute experienced a period of significant growth between 1950 and 1970. The "Institut de Recherches Nucléaires" was created in 1951, transformed into a "Centre de Recherches Nucléaires" in 1955 and finally moved to a spacious and dedicated place in the West part of the city in 1958, see Fig. 3. The first $^4He^{2+}$ beam was produced at 5.5 MeV in 1959 with a brand new Van de Graaff accelerator installed in a new building, see Fig. 4 (the 6th CN in the world). The research is dedicated to the spin study of excited states of the light nucleus, to the measurement of the cross-section of nuclear reactions (with$^1$H - $^4$He ions), to the angular distribution of the $\gamma$ emission and to the measurement of $\beta$ decay measurement (with time scale of $10^{-10}$ s). Other VDG accelerators were commissioned between 1960 and 1965: a 2 MV (HVEC), 2 units at 3 MV (HVEC), and a 4 MV (HVEC). Considerable progress is being made in the field of technology: new beam lines, $\gamma$ spectroscopy, spectrometers, electronics and semiconductor detectors. During the 1960s, new contributions from local groups to high-energy experiments at CERN (ISOLDE) and Saclay (properties of the antiproton, positron and muon), and international collaborations with Heidelberg, Krakow, Yale, Stanford, BNL and other labs are launched. Diversification is on the way. To mention, a local study of a new linear proton accelerator in 1968 and the dawn of heavy ions physics with larger accelerators e.g. the creation of GANIL in Caen and the project to install a new electrostatic tandem accelerator in Strasbourg in order to cross the Coulomb barrier for heavier nucleus (MP10).

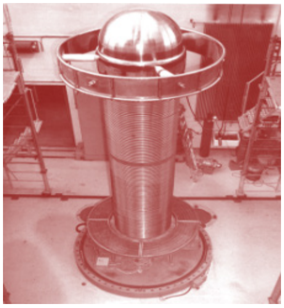

Figure 4: CN Van de Graaff accelerator operated at 5.5 MeV at IRN in 1959. Coaxial ring electrodes installed along acceleration column with terminal at the top.

## THE CONFIRMATION

The 1970s were marked by the commissioning of a HEVC Tandem referenced MP10 (1972), started at 9 MV and upgraded to 18 MV, see Fig. 5. The acceleration of new ions over a wide mass range is now possible: $^1$H – $^{197}$Au [7]. Specific research is carried out in the field of nuclear $\gamma$ spectroscopy, high-spin nuclear shape (a field of excellence ever since), neutron capture and measurement of fusion cross-section (e.g. $^{40}$Ca/$^{16}$O), interaction of heavy ions (e.g. $^{12}$C/$^{32}$S), $\gamma$ and particle emission for different nuclear reactions. On the other hand, new fields of research are confirmed with the expansion of high-energy physics activities, the contribution to CERN/SPS experiments, the search for weak interactions (measurement of the mass of particles, questioning of the SM), and collaboration on detectors for LEP. More complex reactions are carried out in the form of linked and cascade reactions of fusion-fission, fusion-evaporation, inelastic collision, interaction between heavy-ions, etc. At that time, a nuclear reactor was in operation on campus, producing targets and sources of $^{241}$Am, $^{210}$Po, $^{56}$Co, neutron activation and performing 1400 irradiations per year. The reactor was stopped in 1997. High-energy and neutrino physics are progressing with participation in the DELPHI, ISR and NA36 experiments at CERN. Post-acceleration with a K500-60 MeV/A cyclotron was planned in 1978.

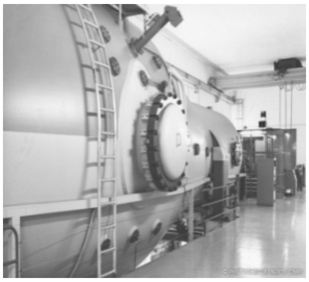

Figure 5: The new MP VDG tandem accelerator commissioned at 9 MV in 1972 and upgraded at 18 MV.

## THE MATURATION

During the 1980-1990 decade, most research programs in physics were intensified due to favorable economic conditions. Nuclear physics detectors achieve unparalleled performance (see the "Château de cristal"). The number of experiments at CERN increased and numerous collaborations were established during this period: with G. Charpak, GANIL, GSI, LBNL, BNL, RIKEN, etc. The nuclear chemistry department is also developing in many fields with expertise in beam-matter interaction (ions, neutrons, $\gamma$), ion implantation at high current (at 4 MV), modification of surface properties, thin film deposition, surface analysis (Si, GaAs, PIXE), nuclear waste management, radiotracers production (with accelerators), research on CMOS circuits, solar cells, liquid crystals, positron annihilation (B-field influence), and dating of samples. It should be noted that the interest in fundamental research, multi-disciplinary activities, and education through science already grew in 1981. Industrial applications were developed such as high performance laser and pico-second camera, and spin-off companies were founded in 1984 (VIVIRAD) and in 1985 (AERIAL).

Each coin has two sides. Mega-science projects appear with increased size, duration, manpower and energy consumption (LHC R&D is launched), fixed-target experiments decrease at CERN and interest in applications to society becomes a must. For example, research on boron-neutron therapy (BNT) was launched with $^{10}$B fixed in the tumour, activated by neutrons and production of alpha particles at 2.8 MeV with $^7$Li in 1990.

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## CHANGE IN TREND

The years 1990 to 2005 were a boiling time in the research center with much energy expended to build, commission and operate a new large electrostatic accelerator, see Fig. 6. The first beam was produced in 1994 but the installation was dismantled ten years later. In the meantime many low-energy nuclear physics experiments have been carried out, for example with a $^{28}Si^{8+}$ beam of 250 nAe at 145 MeV [8, 9]. These experiments allowed research on exotic nuclear structures and the observation of extremely deformed high-spin nuclei (e.g. hyper-deformation observed in 1996 with $10^{20}$ rotation/s), unstable nuclei (on the time scale $10^{-12}$-$10^{-15}$ s), SHE synthesis (A 252, N much larger than Z), and symmetry breaking (e.g. pear shape with aspect ratio 3:1). Significant progress is being made in the field of nuclear spectrometry, reaction mechanisms and the study of fragments (fusion-fission, elastic scattering, evaporation). To cite only the field of excellence developed at the time at CRN: germanium multi-detectors called Eurogam and Euroball (nucleus excitation and de-excitation) with a precision unequalled in the world.

The direction of the CRN was changed in 1996 and the laboratory became the “Institut de Recherches Subatomiques” in 1997 (IReS). As if to announce the next period of upheaval, major developments are looming on the horizon. Recruitment is decreasing at IReS as well as the number of disciplines, publications and groups, but a greater specialization of the activities can be noticed. The LHC R&D program is expended to CMS, ALICE and Atlas detectors. European programs are becoming more and more attractive, physics research shows an aggregation of ever larger accelerators in Europe like CERN, GSI, GANIL, due to the worldwide trend towards higher energies, international collaborations (Japan, USA, JINR, INFN, etc.) and industrial applications leaving less space for more modest installations.

Figure 6: The Vivitron, a 20 MV large tandem. View on the terminal, longitudinal structure and intermediate polarized porticos distributed radially.

## THE METAMORPHOSIS

The evolution of nuclear physics, the applications, the need to consider interactions between different disciplines to produce cutting-edge research, and the availability of new instruments at a reasonable price have contributed to the metamorphosis of the Institute and led to the creation of the “Institut Pluridisciplinaire Hubert Curien” (IPHC) in 2006. A new 24 MeV cyclotron is purchased, see Figs. 7-8, and activities start in 2012 with the production of radionuclides applied to medical imaging.

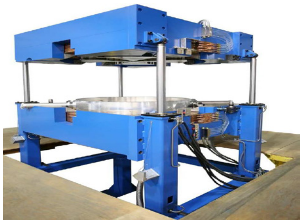

Figure 7 : TR24 cyclotron with open structure. Coils, magnet and vacuum chamber are removed.

Figure 8 Global view with yoke of magnet and beam line inside cave in controlled area.

The so called CYRCé facility is a hub for conducting research and experimentation in three main areas. The first concerns imaging and diagnostic techniques as PET, SPECT, the evolution of in-vivo tumours and the development of new detectors (time of flight, multimode, etc.), see Fig. 9. The second field is hadron therapy such as tomography with protons, cross-section measurement, in-vivo and in-vitro radiobiology, the interaction between the proton and the cell (radiochemistry) and the development of simulation code (G4-DNA). The last area is dosimetry with neutron, X-rays and proton detection techniques, and radiation dose control. $^{18}F$ and $^{64}Cu$ are the main radionuclides produced by accelerated protons and the external target (mainly $^{18}O$ in the electroplated substrate). The first is used as a radiotracer to study hypoxia and cell death in oncology. It should be noticed that this latest development involves the participation of several laboratory teams and therefore requires the collaboration of different experts in different fields: nuclear physicists, physiologists, analytical chemists, molecular engineering, electronics, mechanics and accelerator physicists.

Figure 9: Hot cell of CYRCé facility used for radiobiology, hadron therapy and medical imaging research at IPHC. Equipment is adapted to the manipulation of cells, samples, hot targets, radionuclides and other components.

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Alongside these activities, other significant research programs are carried out by several IPHC teams through collaborations with CERN, in particular high-energy physics at the LHC with the rewarding discovery of the Higgs boson in 2012 and more discoveries to come [10]. Some scientific drivers are the search for exotic nuclei and rare isotopes, nuclear synthesis, nuclear astrophysics, the origin of elements and star formation, the search for the maximum number of nucleons (with the heaviest nucleus and proton/neutron distribution), identification of hidden mass and new interactions (dark matter, dark energy). The IPHC is now firmly anchored in the national landscape, see Fig. 10, and on the world map, see Fig. 11.

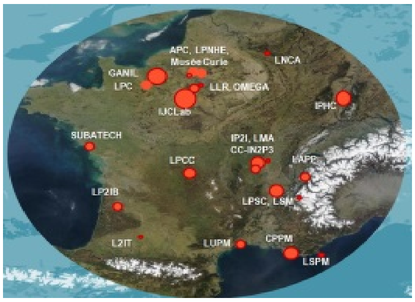

Figure 10: National landscape of CNRS/IN2P3 laboratories, and IPHC located on the East part.

Figure 11: Map of the international collaborations with IPHC.

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