STATUS OF THE CYCLONE FACILITY

G. Ryckewaert, G. Berger, J.M. Colson, Th. Daras, M. Loiselet, N. Postiau
UCL-CRC, Louvain-la-Neuve, Belgium

Abstract

The CYCLONE facility at the University in Louvain-la-Neuve comprises three cyclotrons. They are used for nuclear physics and astrophysics experiments, mainly with postaccelerated radioactive ion beams; for the study of proton induced fission; for the study of nuclei far from stability. Further uses comprise radiobiology and dosimetry using fast neutrons, PET-isotope production, irradiation of polymer foils for the manufacturing of track-etched membranes and study of radiation effects on electronic components using heavy ions, protons and neutrons.

INTRODUCTION

The CYCLONE facility is used for research in nuclear physics and nuclear astrophysics and for applications in life sciences, materials science and industry. The graph in fig. 1 shows the repartition of the beam time use in 2003. Figure 2 shows the layout of the facility with the different cyclotrons, beam transport lines and experimental areas.

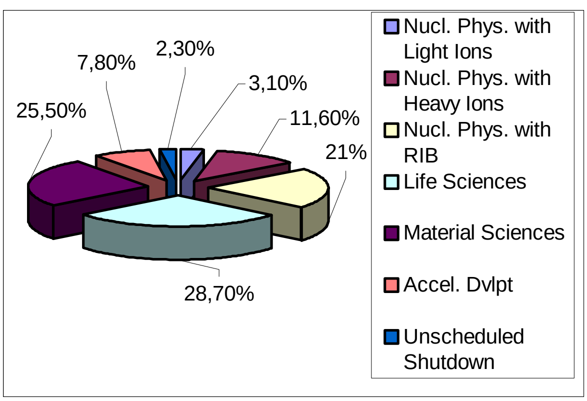

Figure 1 : Operation statistics for 2003.

UPDATE ON RIB PRODUCTION

Postaccelerated Radioactive Ion Beams (RIB) used for experiments include ^{6}Helium, ^{7}Beryllium, ^{10}Carbon, ^{11}Carbon, ^{13}Nitrogen, ^{15}Oxygen, ^{18}Fluorine, ^{18}Neon, and ^{19}Neon. Updated information on available beam intensities and energy ranges are given in the CYCLONE web-site [1].

Most of the radioactive isotopes are produced, ionised and accelerated on-line. CYCLONE30's high intensity 30 MeV proton beam and a few dedicated targets are used for the production. ECR sources are used for ionisation and CYCLONE110 or CYCLONE44 are used for postacceleration and isobaric separation.

LiF is the most fertile target material: it allows the production of ^{6}He,^{15}O, ^{18}Ne and ^{19}Ne with primary 30 MeV proton beam intensities of up to 270 σA. It is worth noting that this beam power of up to 8 kW is totally dissipated in the target material. Carbon isotopes are produced in a Boron Nitride target with primary beam intensities of up to 75 σA. ^{13}N is produced in an enriched ^{13}C target. These targets are described in detail in reference [2].

^{7}Be and ^{18}F beams are produced off-line. The production of the ^{7}Be beams is described in another paper at this conference [3]. ^{18}F is produced in batches using an enriched $H_2{}^{18}O$ target and automated chemistry to synthesize gaseous fluoromethane ($CH_3{}^{18}F$). A description of this production scheme is given in reference [4].

Over the years we have succeeded in delivering reproducible, high purity RIB's to experiments, with good reliability. A few crucial issues in the successive steps related to this mode of operation are discussed in this paragraph.

At the isotope production stage, special targets have to be made and implemented to assure high release efficiency and low outgassing. They have to operate at high temperature, disperse kW's of beam power during hundreds of hours and stand tens of thermal cycles between zero and full power.

At the ionisation stage, ECR source parameters (magnetic field profile, micro-wave power, operational pressure and extraction optics) have to be optimised to obtain the maximal low energy beam intensity in the required charge state. For each element and charge state there is an optimal primary beam intensity: at this point, due to increasing source pressure, the ionisation efficiency decreases faster than the supply from the target increases due to better release and higher production rate. Finally, because the beam formation is strongly dependant on gas pressure and total extracted current, the extraction and beam optics have to be carefully optimised once the source regime has reached it's steady state.

Post-acceleration and isobaric separation are performed with either CYCLONE110 or CYCLONE44. Isobaric separation is the most important issue of all : most of the accelerated RIB have stable isobaric contaminants with relative charge-to-mass differences in the range of one to a few parts in 10.000 and intensities which can be many orders of magnitude larger than the maximum RIB intensity. Thanks to the cyclotron's inherent high mass resolving power (and, if needed, enhanced by decreasing the acceleration voltage and by detuning the isochronous field) rejection rates of 1 million for a relative mass difference of 1.10^{-4} have been achieved. The cyclotron parameters are first tuned for the required mass resolution and optimum acceleration - extraction efficiency using the stable isobaric beam. Once this has been achieved, either the RF or the magnetic field is shifted to the RIB setting and the production target is connected to the ECR ion source. The extracted beam intensity is measured on a specially designed Faraday cup using in-house built, high gain (10^3 – 10^6), high sensitivity (a few femto-amp), current amplifiers. This measurement - diagnostic device has proven crucial for the development of new RIB and for the final optimisation of all parameters from ion source to cyclotron extraction for each new run using RIB.

PHYSICS USES

As can be seen from fig.1, a majority of physics experiments use RIB. These experiments have either been using various configurations of LEDA [5] (Louvain-Edinburgh Detector Array) in the R-line with CYCLONE110 as the postaccelerator or ARES [6] (Astrophysics REcoil Separator) and CYCLONE44.

The use of DEMON [7] (DEtecteur MOdulaire de Neutrons) has moved towards the study of proton-induced fission of actinide nuclei with protons in the 20 to 65 MeV energy range.

The LISOL [8] (Leuven ISotope separator On-Line) facility on the Z line has been recently refurbished for the production of nuclei far from stability using proton induced fission on a Uranium target and selective ionisation using a LASER-ion source.

USE FOR THE LIFE SCIENCES

After the neutrontherapy programme was stopped at the end of 1999, the well characterised "therapy" neutron beam in the CYCLONE110 W1 line is being used for radiobiology and dosimetry studies.

CYCLONE30 is operated on a daily basis by the University's Positron Tomography (TOPO) - group for the development and the routine production of radiopharmaceuticals for fundamental research and for clinical studies. Radiopharmaceuticals include ^{18}F-FDG, ^{15}O-H_2O, ^{13}N-Ammonia, ^{11}C-MethylIodine, ^{11}C-Methionine and ^{11}C-Acetate. Among others, development and validation work is under way on ^{18}F marked tracers for the quantification of tissular hypoxia and on ^{86}Y marked molecules which are biologically active in oncology.

USE FOR MATERIALS SCIENCE, TECHNOLOGY AND INDUSTRY

The University's Polymer Science Laboratory (POLY) focuses on the study of the interactions between swift heavy ions and polymers. Heavy ion beams ranging from Argon to Xenon are used in the S3 line to irradiate different types of polymer foils in a controlled and reproducible way. A subsequent track etching process creates well-defined pores in the foils. These track etched membranes (TEM) are then used as templates for the synthesis of polymeric or metallic micro- and nanostructures for fundamental and applied research.

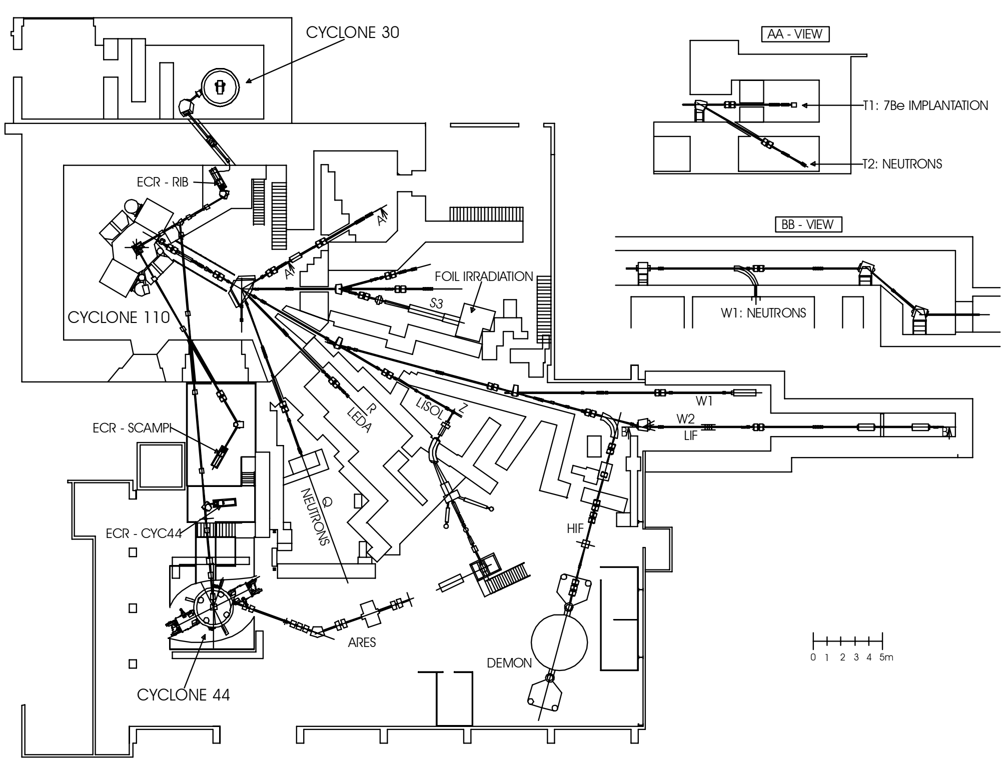

Figure 2 : Layout of the CYCLONE facility.

Reels of foil are also irradiated routinely for industry : these TEM are used in a variety of applications such as haemodialysis modules, biosensors, diagnostics and virus removal equipment.

In the T1 line of CYCLONE110, a vacuum chamber has been equipped to develop and perform implantations of ^{7}Be in non metallic surfaces, for wear measurements. This application is described at this conference in ref. [3].

Radiation effects studies and testing of electronic devices with heavy ions, protons and neutrons from CYCLONE110 have become an important share in beam time use. Several experimental areas have specific equipment for these purposes.

The Heavy ion Irradiation Facility (HIF) consists of a vacuum chamber equipped with a device positioning system, calibration and monitoring detectors, upstream diffusion foil, collimator and laser alignment diode and a user interface for irradiation control and reporting. The sensitivity of electronic devices to radiation is characterised in function of the LET of the impinging ions. Therefore, each component has to be irradiated with a sequence of different ions of increasing mass (and thus increasing LET), a so-called "ion cocktail". An ion cocktail consists of a set of different accelerated ions with similar A/Q ratios and equal magnetic rigidity. The latest ion cocktail developed for this purpose with the ECR source SCAMPI and CYCLONE110 is given in Table 1.

Table 1 : Heavy Ion cocktail for SEE studies

Ion	Energy at DUT (MeV)	LET (Si) $MeV/mg/cm^2$	Range (Si) (σm)
$^{13}C^{4+}$	131	1,2	266
$^{22}Ne^{7+}$	235	3,3	199
$^{28}Si^{8+}$	236	6,8	106
$^{40}Ar^{12+}$	372	10,1	119
$^{58}Ni^{18+}$	567	20,6	98
$^{83}Kr^{25+}$	756	32,4	92

To allow fast switching from one ion to the other, all these ions have to be present after the ion source at the same time. For this mode of operation, SCAMPI runs with a series of calibrated leaks (^{13}CO, ^{22}Ne, Silane, Argon and ^{83}Kr) and the heated oven with Nickel.

The Light ion Irradiation Facility (LIF), installed on the W2 line, consists of a diffuser to obtain a uniform spot of 10 cm diameter at the test position, collimators, energy degraders, monitoring detector and device support frame. Protons of up to 75 MeV are used.

Two positions are equipped to perform testing with neutrons. A thick Beryllium target has been installed in the T2 line. It is bombarded with up to 10 σA of 50 MeV Deuterons and mainly used for testing and qualification of the CMS Tracker detectors and other equipment to be used at the LHC. The Q-line, built for neutron physics experiments, allows the production of quasi mono-energetic neutron beams at variable energies between 20 and 60 MeV. This line is now also used to determine device sensitivity to atmospheric neutrons.

NEW CONTROL SYSTEM FOR CYCLONE44

The CYCLONE44 controls have been transferred from COROS to WinCC and, remaining manual controls of some subsystems have been integrated. The existing S5 PLC programme has been entirely rewritten to obtain a complete separation between control/safety functions and the operator interface which has been transferred to the WinCC level. Simplified but still realistic representations of the different machine parts and beam lines have been adopted allowing the representation of a maximum of process information for diagnostic and interaction. Navigation between pages is possible either from the external branching system generated by WinCC or from buttons in the different views. The commands and adjustments are directly accessed from windows which appear by clicking on the elements shown. Synoptic views have been created in parallel to allow access to a large number of parameters in a swift and direct way. The control system covers now all subsystems required for RIB tuning.

FUTURE DEVELOPMENTS

RIB development has started on the production of an ^{14}O beam. ^{14}O will be produced by the $^{12}C(^{3}He,n)$ reaction using a 35 MeV $^{3}He^{1+}$ beam from CYCLONE110. This will be the first beam to be produced with CYCLONE110 and postaccelerated by CYCLONE44.

To allow ECR ion source development work without interfering with "routine" operation of SCAMPI, the construction of a new ECR source, similar to SCAMPI, has been started.

Development work is also going on with CYCLONE44 to improve acceleration efficiency and isobaric separation. New approaches to enhance isobaric separation are being explored.

ACKNOWLEDGMENTS

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