THE IBA PET-DEDICATED CYCLOTRONS MAIN FEATURES AND IMPROVEMENTS

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To meet the requirements of nuclear medicine in Positron Emission Tomography (PET), IBA has developed three PET-dedicated cyclotrons as well as a large range of targets and automated chemistry modules. This paper presents the design and the successive improvements of these cyclotrons, since several units of each model are in operation on a regular basis for clinical and research purposes.

1. The IBA PET-dedicated cyclotrons

IBA (Ion Beam Applications) has developed within five years, a whole range of PET-dedicated cyclotrons. These PET systems are proven machines with several units of each model now in operation: currently, 19 centres use IBA equipment (3 in the United States, 12 in Europe and 2 in Australia, and 2 in Asia) on a regular basis for PET clinical and research purposes.

1.1 Cyclone 18/9

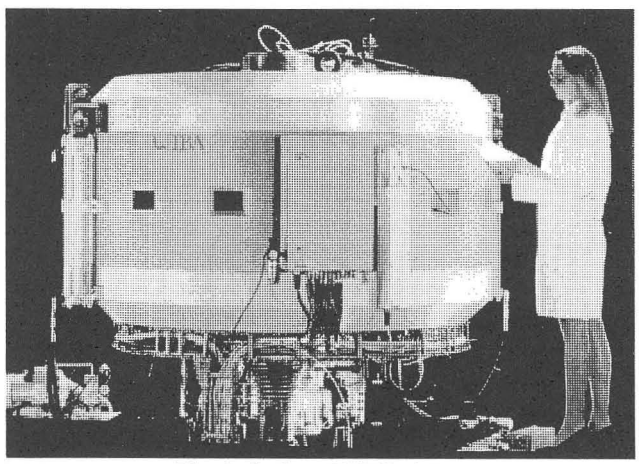

Fig. 1: Cyclone 18/9 Cyclotron

The Cyclone 18/9 is specially intended for large hospitals, medical research centres and centres which distribute FDG.

Its high energy level (18 MeV protons, 9 MeV deuterons) ensures high production yields, e.g. large amounts (more than 2.5 Ci) of F-18 and C-11.
The Cyclone 18/9 is optimized to produce both protons and deuterons: the availability of deuteron beam enables Oxygen 15 to be produced using natural nitrogen as target material (thus avoiding the need for expensive N-15) and to produce F_2 through the ^{20}Ne (d,α) ^{18}F reaction on natural Neon.

1.2 Cyclone 10/5

10 MeV proton, 5 MeV deuteron beams ensure the production of the most common radiopharmaceutical compounds based on F-18, C-11, O-15 and N-13.
The small size of the cyclotron, the low power consumption and the self-shielding make the system suitable for installation and operation in any normal room without special needs for shielding or other particular building requirements.

1.3 Cyclone 3

The Cyclone 3 (3.6 MeV deuterons) is a specialized, compact cyclotron intended for hospital use. It allows to produce Oxygen 15 which is used for neurological studies or can be used in combination with F-18 (obtained from distribution centres) to provide blood-pool subtractions. Its design minimizes the space requirements: compactness, vertical acceleration plane, less than 6 tons weigth, self-shielding minimizing radioactive dose rate around the cyclotron.

1.4 Targetry and Chemistry

A complete range of fully automated PET-targetry has been developed, producing ^{11}C, ^{13}N, ^{15}O, ^{18}F-, $^{18}F2$, as well as a broad range of synthesis units producing the most common labeled compounds are also available : ^{18}F Fluorodesoxyglucose (FDG), ^{11}C cyanide ^{11}C methyliodide / methionine, ^{11}C Acetate, ^{11}C and ^{15}O gases, ^{15}O water. These PET chemistry modules can be installed on any IBA cyclotron but can also be adapted very easily to any existing machine. Besides its in-house expertise, IBA has also built a network of collaborations with PET centers leading to the joint development of new specific PET syntheses (e.g. the Catholic University of Louvain, Belgium).

2. Extensive upgrade program

IBA has continuously up-graded its accelerator systems to improve their reliability and their performance.

2.1 Cyclone 18/9

Since the two first installations in Montreal, Canada and Shreveport LA, USA, the Cyclone 18/9 has undergone an extensive upgrade program including:

- Redesign of the central region, the dee/cavity structure and the sources to maximize beam current stability and output.

The Cyclone 18/9 has a "deep valley" magnet design.
The sources, one producing H^- ions the other producing D^- ions, are located in two opposite valleys. Their insertion mode is radial. The dees are located in the valleys that do not contain a source. The dees are connected at the center and supported on one side by vertical copper stems.
Previously, these stems were fixed to the upper part of the yoke. Therefore, central region and source adjustments had to be done after each closing of the cyclotron, by means of radial and azimutal external movements.
From the third machine, the stems are fixed to the lower part of the yoke and then, the sources and the central region can be adjusted cyclotron opened. The source movements have been suppressed and the sources are now stably set in their optimal position. This redesign avoids any tuning or uncertainty about the source position.
The central region and the chimney designs have had successive improvements (such as optimization of chimney and puller slot dimensions) in order to improve internal beam extraction yield.

Recent measurements on Cyclone 18/9 installed at the Herzzentrum Nordrhein-Westfalen in Bad Oeynhausen and at the Klinikum der Universität Ulm, Germany, have already shown the effectiveness of these modifications.

- The Cyclone 18/9 has become a complete fully automatic system.

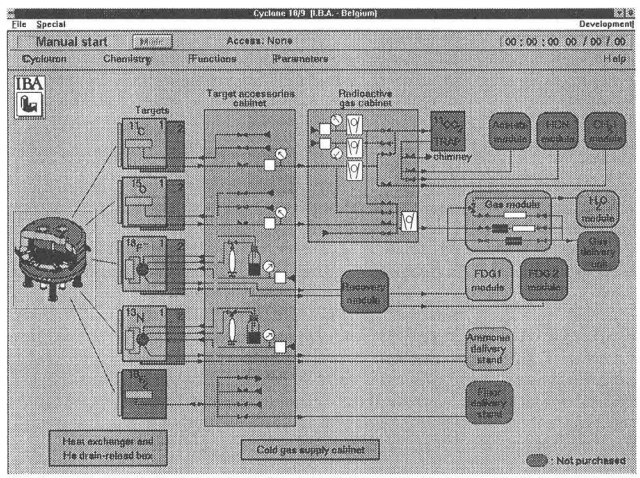

Fig. 2 : Central Flowchart for the Control of the PET System

The overall design, (e.g. fixed position of the two ion sources, same frequency for both proton and deuteron beams, negative ion extraction method...) have been optimized to allow for the highest level of computer control. Preset combinations of beam, target operations and chemical synthesis are included in the control system. The operator simply selects the target, bombardment time and beam current on target, and the computer automatically monitors, optimizes and regulates such parameters as dee voltage, magnetic field or ion source voltage. The user has access to these preset combinations and can modify them.

- The ongoing development of the software.

Automation of the Cyclone 18/9 has been carefully designed to be user-friendly, flexible and reliable.
The user interface consists of multi-window applications software with a mouse used to move between displays and to select commands. The system is menu-driven through self explanatory, color graphic displays representing essential aspects of the cyclotron and the chemistry processes.
The multi-window applications software is compatible with Windows™ -utilities. A logbook of cyclotron operation is available as well as a data log which records the main data of the system. These records can be easily transferred to a spreadsheet table for analysis. For example, the integrated beam current of each particle (protons or deuterons) is recorded to keep track of the lifetime of the cathodes of the

ion sources. The same measurement is done for each stripper foil. These records are very useful for planning maintenance. The Programmable Logic Controller can accomodate signals coming from other equipment, such as flags from the stack monitors or area radiation monitors to be used as safety interlocks.

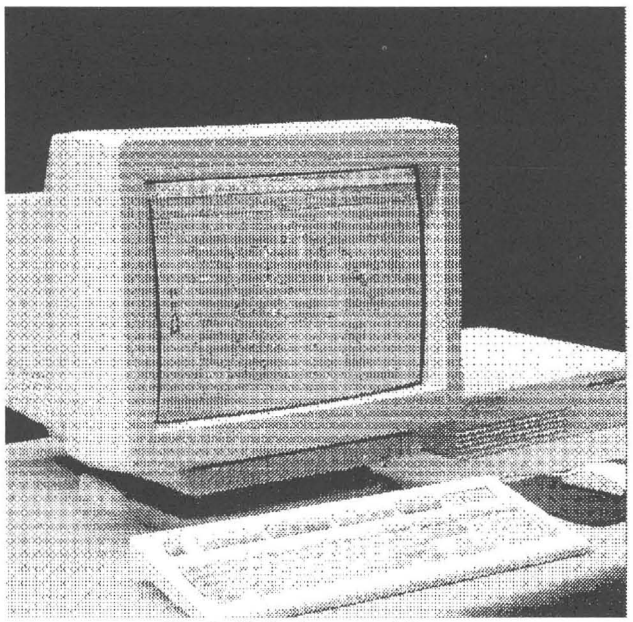

Fig. 3 : Fully Automated System

- Beam diagnostics.

Beam intensity measurements are performed at four different places along the beam path and transmitted to the control system: on a new internal beam probe, at the stripper foil, on the target collimator (used by the controller to optimize the beam position on target) and on the target itself.
The internal beam probe is a water-cooled copper finger, fixed at 10 cm radius on a lateral edge of a sector. The probe can be inserted or not in the median plane to intercept the internal beam path.

- A relocalisation of the targets, improving beam transmission and target shielding.

Targets are now directly mounted on the vacuum chamber, rather than on short external beam lines. Access to the targets is always possible without lifting the upper yoke.
This new location improves the beam extraction yield of more than 20%: the proton beam transmission increases from 60% to 80-100%, through a collimator of 10 mm in diameter.
The eight targets are located in the mid-plane all around the vacuum chamber and are partially shielded by the yoke. An operator working on any target is thus always at far distance from other possibly activated targets.

Optional shielded doors can also be mounted in front of each target in order to rather reduce the radioactivity level. As an illustration, on the Cyclone 18/9 machine installed at the Herzzentrum Nordrhein-Westfalen in Bad Oeynhausen, each target is self-shielded with a steel door, 10 cm thick, reducing the radioactive dose rate by a factor 4.

- Pneumatic gate valve on target.

Pneumatic gate valves have been installed between the vacuum chamber and each target. Maintenance on target, window holder and collimator can be performed without interrupting the vacuum in the cyclotron.

- Pressure transducer inside the target.

The Cyclone 18/9 from Geneva is mounted with pressure transducers inside the targets, allowing to measure the internal pressure and thus preventing window foil rupture.

- Maintenance.

For a more efficient maintenance, a special effort has been made on quick connections for water, electrical and gas tubing to allow an easy and rapid dismount of each part of the cyclotron.

- Cost Reduction Program.

A cost reduction program is in progress without any compromise on the quality of the equipment. As an illustration, the machine is now shipped completely wired, assembled and tested allowing to reduce installation time and costs (the last installation time has been reduced by 25%).

2.2 Cyclone 10/5

There have been two installations of the Cyclone 10/5 cyclotron, (one at the KUL - AZ Gasthuisberg in Leuven, Belgium and the other one at the Austin Hospital in Melbourne, Australia). The new proposed Cyclone 10/5 is the same unit as previous but with substantial improvements that incorporate the advantages and technical expertise developed on the 18/9 Cyclotron:

- adaptation of the Cyclone 18/9 proven central region, dee/cavity structure, sources;
- the addition of the internal beam probe;
- the operating software is totally different from previous and adapted from the Cyclone 18/9 control system. Operating under windows the "In Touch ™" IBA-developed control software allows for intuitive, mouse driven operation, even by personnel without long cyclotron experience. All routine operation is taken care of by the software, including source, R.F., vacuum, targets and chemistry modules. The system is extremely user friendly with an integrated logbook and many other advantages;

- two hydraulic jacks (instead of the previous screw system) to lift the upper yoke and open the Cyclotron;
- a new self shielding design adapted from the Cyclone 3 consisting of two shells. The shielding opens in two parts in the same plane. The composition and the design of the shell has been optimized to reduce the total weight and overall dimensions.

2.3 Cyclone 3

The new developments on the Cyclone 3 include:
- improvement of the central region and source to increase beam reliability.

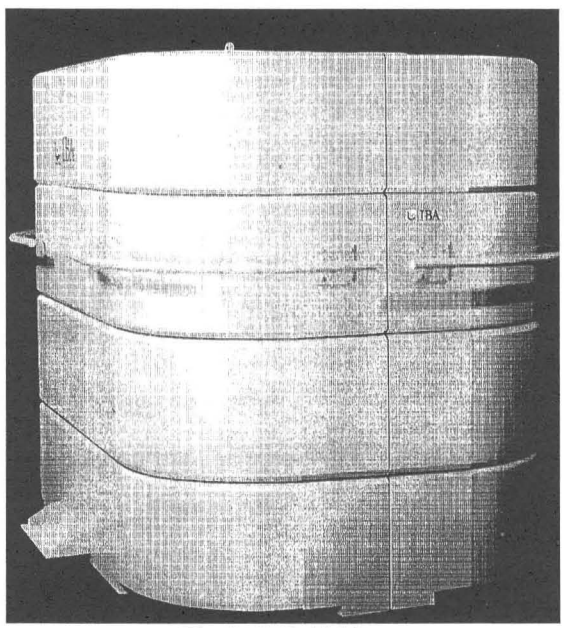

Fig. 4 : Self-shielding

- a new self shielding design dedicated to the project for the Universitätsklinikum Rudolf-Virchow in Berlin. The self-shielding consisting of two shells, moving on air-cushions. The shielding opens in two parts in the same plane. The composition and the design of the shell has been optimized to reduce the total weight and overall dimensions. Measurements have shown that radioactive dose rate at one meter from the self-shielding is less than 1 µSv/h.

3. Customized system

An external beam transport line has been specially designed on the Cyclone 18/9 for the Forschungszentrum Rossendorf, for target developments and education purposes. The transmission yields are higher than 50% through a collimator of 12 mm diameter. The beam spot diameter is approximatively 15 mm, without hot spot. Beam current instabilities are less than 5% [1].

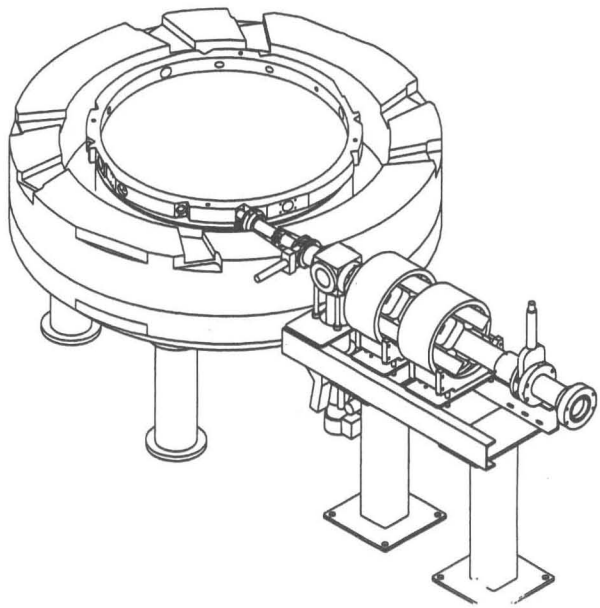

Fig. 5 : External transport beam line

Moreover, fulfilling the Hôpital Cantonal Universitaire of Geneva requirements, the Cyclone 18/9 has been adapted to offer the possibility of installing an axial source in a future stage in order to increase beam current until 300µA.
A screen display of the building safety system, customized to Shreveport project, has been integrated in the control system of the cyclotron.

References

[1] "The New Cyclotron of the Forschungszentrum Rossendorf PET center", Dr. St. Preusche *et al*, presented at the Cyclotron'95, Cape Town, Oct 1995.