STATUS REPORT ON THE CNRS ORLEANS' CYCLOTRON

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Summary : Status report on the CNRS Orléans' cyclotron.

1. Introduction

This status report summarily describes the cyclotron, the beam lines and the irradiation system used, and shows the results obtained in 1984 and 1985.

Previous to this period in 1982, we installed beam plugs on the beam lines. This improvement enabled us to increase the beam production from 1500 h (1981 - 1982) up to 1700 h a year approximatively (1983 - 1984).

In 1985, we had to increase **the beam production** up to **1828 h** and 62,5 % of the total time.

We could obtain these results by drastically limiting the **developing time** which is now only 3,5 % of the total time, and by reducing as much as possible the **preparing time** of the beams. Luckily we had very few break downs during this period of intensive use of the machine : 5 % of the total time as opposed to the usual 7 %. 1985 will certainly be a reference year, as it will be difficult to produce any more beams in the 2 shift-system in use in the laboratory (6 h-14 h, 14h-22h).

Effectively, we will have to increase the developing time in the future, if not, the performances and fiability of the machine will dangerously decrease.

In compensation we may be able to reduce the average preparing time, by developing an automatic control system for the cyclotron parameters.

2. The cyclotron (CGR-MeV 680 type)

Performances and characteristics of the machine can be summarized as follows in table 1 and table 2.

Table 1 : Performances

ENERGY :	
Proton energy range	: 5 - 36 MeV
Deuteron energy range	: 5 - 25 MeV
α particle energy range	: 10 - 50 MeV
$^3He^{++}$ energy range	: 10 - 60 MeV
INTENSITY BEAM :	
Maximum extracted beam intensity for protons and deuterons :	55 μA
Maximum extracted beam intensity for particles and helium 3 :	10 μA

Table 2 : Characteristics

Electromagnet characteristics :	
Weight (metric ton)	110
Pole diameter (m)	1.60
Number of spiralled sectors	4
Gap maximum (cm)	27
Gap minimum (cm)	13
Maximum average induction at the extraction radius 67,5 cm (kG)	15
Number of ampere turns in the main coils	250.000
Number of trim coils (pair)	8
Number of harmonic coils (pair)	4
Radiofrequency : Range from 20 to 40 MHz	
Number of dees	2
Number of cavities	2
Dee angle	60°
Maximum dee voltage (kV)	40
RF power available (kW)	2 x 50
Frequency stability	10^{-6}
Dee voltage stability	5×10^{-3}
Phase stability	$\pm$ 0.2°
Extraction :	
Electrostatic deflector :	
Maximum field (kV/cm	110
Angular span	65°
Magnetic channel	passive
Gradient corrector	
Ion source : Type Livingstone	
Location : internal, vertically introduced	
Maximum arc power (W)	800
The center region is designed for 2, 3, 4 harmonic operations with a single orbit for all energies particles.	

3. The beams lines and the irradiation systems (Fig1)

From the switching magnet Mo, the beam can be bent in four directions:

3.1. Line 1 (27°30 right) : This line built and installed in 1982, is used for short-lived radioisotopes production. A horizontal 27°30 bending magnet located in shielded room 1 allows us to have two different gaseous targets at our disposal. They are connected to the NUCLEAR MEDICINE unit where short-lived radioisotopes are used.

3.2. Line 2 (0º) : This beam line is mainly used for activation experiments. The end of the line located in shielded room 2, can be equipped with different irradiation devices :

An irradiation system within vacuum. The target is cooled by thermal contact with a water-cooled copper target holder. The maximum irradiated area is 7 cm².

Two beryllium targets : for fast neutron production. The first one, thickness 10 mm to be used with a 34 MeV proton beam - Be(p,n) nuclear reaction -.The second one, thickness 3 mm to be used with a 25 MeV deuton beam - Be(d,n) nuclear reaction -.

An irradiation system for archaeometry purpose allowing the automatic irradiation of a batch of old coins. The beam-line is closed by a 25 µm titanium foil, the irradiation is carried out at atmospheric pressure.

An irradiation system for wear experiments with accurate control of the beam position on the target.

3.3. Line 3 (27º30 left). This line is used for radioisotope production, mainly for iodine 123 production[1] . Its end is located in shielded room 3.

In this room irradiation is carried out at atmospheric pressure and the beam line is closed by a 25 µm titanium foil. Ahead of this foil, an automatic irradiation system allows the irradiation of solid targets with high intensity beams.

A pneumatic transfer system connects this irradiation system with a hot cell located in a high activity laboratory. A control unit in the hot laboratory enables all the irradiations and handling operations. When the rabbit in which the target is, has reached its irradiation position, two jacks automatically connect it with a water circuit : 8 b, 4 l/min, and the back surface of the target is water-cooled while the front surface of the target and the titanium foil are cooled by air or helium gas : the irradiated area on the target is about 5 cm².

3.4. Line 4 (45º left). This line was added in March and April 1980 and is used for NEUTRONTHERAPY [2].

After a horizontal 45º (M_1) bending and a vertical 90º (M_2) bending, the beam impinges a 5 mm thick beryllium target [3,4] . It is composed of a Be disc 5 mm thick and of a carbon stopper disc 2,5 mm thick with water under pressure (8b) in-between the two so as to ensure an efficient cooling.

(During the running period, the target is hit by a 34 MeV proton beam with 40 µA intensity). This cooling water comes from a circuit different from the others (water activation). The target is continued by a movable mechanical system which allows to interpose polyethylene filters in the neutrons beam (low energies filtration) or a lead sheet 6 cm thick (protection during patient positioning). After the latter system come the ionisation chambers for monitoring the treatment, and the vertical neutrons collimating system located in the treatment room in the basement of the NEUTRONTHERAPY unit. It is composed of a fixed part built in heavy concrete, in which are introduced the inserts which determine irradiation fields. The patient is treated 1.35 m from the target.

4. Results achieved so far

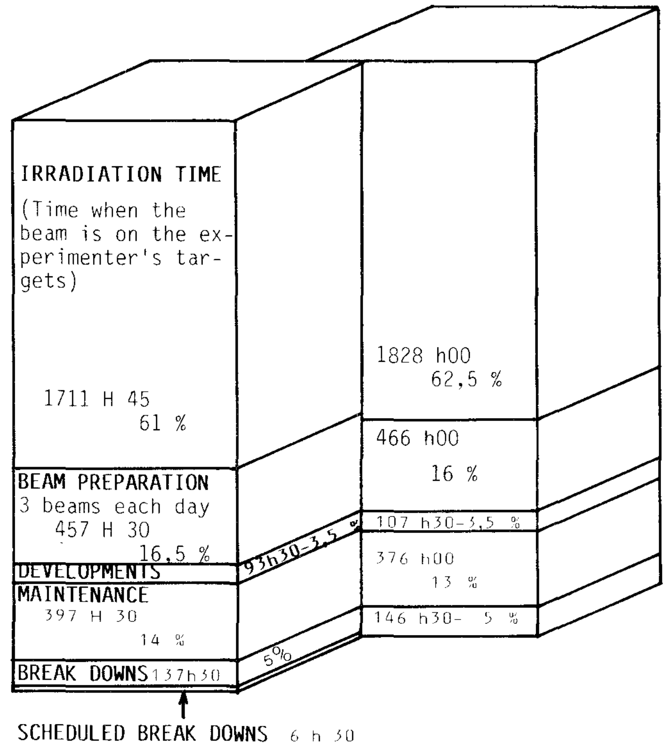
The total time, 2.804 h 15 for 1984 and 2.918 h for 1985 was divided as follows (table 3).

Table 3 shows :

- the regular running of the cyclotron in 1984, as opposed to 1985.

Table 3 :

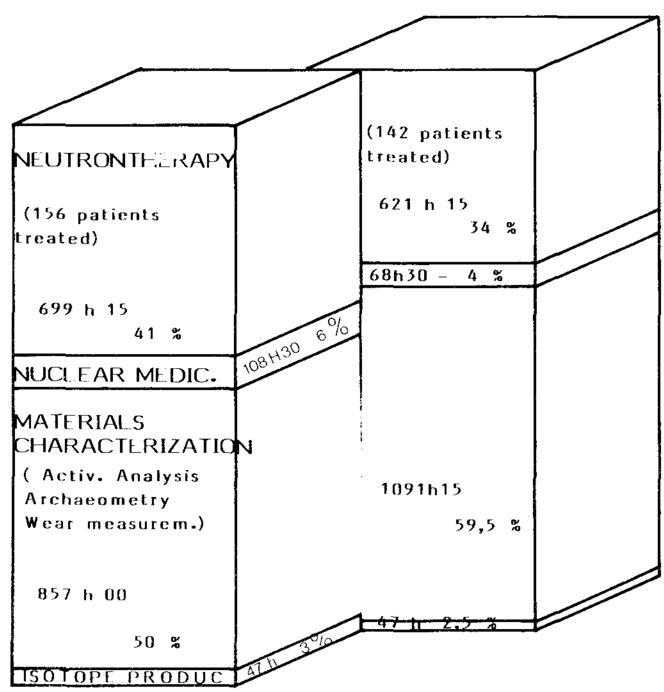
1984	1985
Total time : 2804 h 15	Total time : 2918 h 00



4.1. Irradiation time : This time can be divided as follows according to the type of experiments (table 4).

Table 4 :

1984	1985
Irradiation time : 1711 h 45	Irradiation time : 1828 h 00



The distribution of the irradiation time according to the type of ions can be divided as follows :

Table 5 :

Particles	1984		1985	
	Irradiation time	%	Irradiation time	%
Protons	1.378 h 30	80,5	1.407 h 15	77
Deuterons	275 h 00	16	399 h 45	22
$^{++}_{3}He$	50 h 15	3	6 h 00	< 1
α	8 h 00	0,5	15 h 00	< 1

4.2. Beam preparation :

Table 6 :

	1982	1983	1984	1985
Nbr of beams days	186	199	181	182
Total preparating time	578 h 45	514 h 15	457 h 30	466 h 00
Nbr of beams prepared in the year	559	582	615	662
Nbr of beams prepared during a day	3,01	2,92	3,4	3,64
Average preparating time	1 h 04	0 h 88	0 h 74	0h 70

Table 6 shows the average preparating time evolution during the last four years.

In 1985 we prepared 3,6 beams a day as opposed to 3 beams a day in 1982 and the average preparating time was 0,7 h as compared to approximately 1 h in 1982.

This important decrease of the beam preparing time (30 %) is halfly due to the use of beam plugs on the beam lines since 1983 and to a higher technical skill of the operating staff.

4.3. Machine developments :

- 4.3.1. with the cyclotron running

The developing time has decreased in 1984 and 1985. It now lies around 3,5 % of the total time, and approximatively 100 hours a year. It is the consequence of an important request of irradiation time by experimenters. The developing time was used mainly for :

. Adjusting the accelerating parameters of the various beams routinely used after the replacing of the electrostatic channel (February 1985).

. Formating deflector electrodes and R.F. cavities after the various interventions required by the tuning up of the electrostatic channel (1985).

. Improving the characteristics of the ions sources mainly for the production of alpha and helion particules.

4.3.2. Without the cyclotron running.

New electrostatic channel

The angular span of the new device has been increased from 58° to 65°. Thus, for a given energy, the electric field is now much lower.

This change is an improvement for the 34 MeV proton beam required for NEUTRONTHERAPY, and which is extracted from the cyclotron with a deflector voltage of 46 kV instead of 56 kV previously needed.

The average leakage current is less important, and particularly the sparking rate is not so high as with the former device : there are fewer interruptions during the treatments. Thus after an intervention in the accelerating chamber the formating period is much shorter. When the intervention takes place on the maintenance day : Monday, the 34 MeV proton beam can be used on Tuesday evening as opposed to Wednesday evening with the former device.

4.4. Break downs : They were mainly due to the failures in :

- **high voltage power supply** (10 kV - 20 A) : In February 1984, a water leak in the tank which contains high voltage transformers caused many electrical insulation troubles.

The repair couldn't have been possible but for the kindness of our collegues of Louvain-la Neuve in Belgium, who lent us a spare tank at short notice.

- **Power supplies of the :**
  . trimming coils : C_1, C_2, C_3, C_6, H_2H_4.
  . switching magnet M_o
  . bending magnet M_{41}.

- **Radio frequency system**

. Replacing in the resonant cavities, the copper sheet allowing the evacuation of RF currents to the earth (Dec. 1984 - May 1985).

. Replacing the power tubes 800 W and 50 kW on preamplifiers and amplifiers.

- **Beam pipe** : Vacuum leakage on the beam pipe located at the exit of accelerating chamber.

- **Ion sources.**

- **Water cooling circuits, etc...**

5. Future developments

5.1. Cyclotron

Improvement of the cyclotron fiability

Replacing :
- the power supply of the main coils (1000 A - 100 v)
- the power supplies of the correcting coils (250 A 25 v).

Construction of an electronic rack allowing the automatic setting of the magnetic parameters of the cyclotron and the beam lines.

Improvement of the cyclotron performances

- Replacing the low level stages (phase discriminators modulators...) on the RF system with new devices reacting less to frequency and to amplitude.

- Replacing the center slit by a new one with a remote control of the slit width ;

5.2.Beam lines

Construction of a second beam line for NEUTRONTHERAPY. A new beam line for Neutrontherapy has been studied. This beam line would allow the use of horizontal neutron beams for treatments. The vertical 90° bending magnet would be mechanically rotating and drive the Be target in its motion.

Thus a horizontal neutron beam would be free for use in a 2nd treatment room. A beam plug could allow the patient's positionning in a treatment room, while a 2nd patient would be under treatment in the 2nd room.

Construction of a new irradiation system associated to a pneumatic transfer for isotope production installed in a shielded room n° 1.

5.3. Applications

Radioactivation analysis

The current trend is to obtain improved sensitivities in order to study the metallurgy of ultra pure semiconductors (GaAs, InP,...) and to establish correlations betwen impurities and physical properties. Improved sensitivities are obtained on the one hand by using higher energies and higher intensities, and on the other hand by developing fast and reliable radiochemical separations.

Neutrontherapy[5]

The New horizontal neutron beam foreseen would allow a better use of the beam time, with an improvement on the treatment quality.

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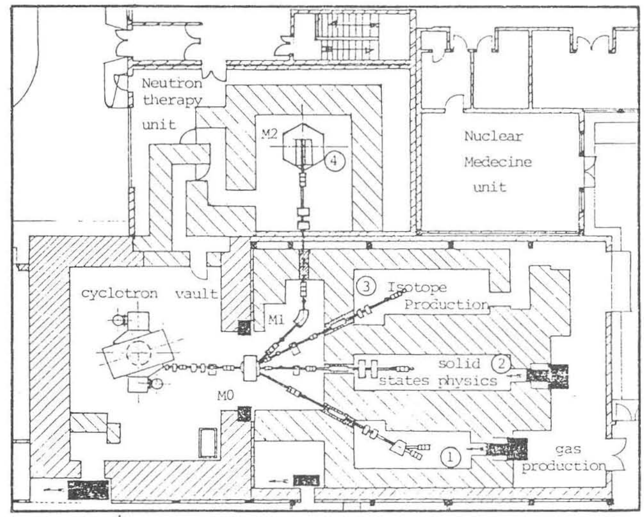

Figure 1 : shows the general lay out of the machine, the experimental area and beam transport lines.