THE NRCAM CYCLOTRON FACILITIES

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The NRCAM Cyclotron started operation at the end of 1994 with a mission to produce SPECT and in the second stage PET radioisotopes for Iran . This cyclotron is the first Cyclone-30 with the negative ion source which can accelerate both protons and deuterons . Beams of H^- and d^- generated in a multicusp ion source are injected to the inflector at the center of the cyclotron with especial design and accelerated in two 30° dees powered by the RF system on its fourth harmonic modes . Beams can be extracted by two carbon stripper systems at opposite sides of the cyclotron and transported to 4 target rooms by 4 beam lines . This paper will describe the cyclotron facility and the status of the machine during the first year of its operation.

1 Introduction

The application of nuclear medicine is now well established in many hospitals and nuclear medical centers and there are increasing demands for SPECT and in future PET radioisotopes in Iran . To meet these rising demands , the NRCAM multipurpose cyclotron project was approved as a national project with high priority in 1989 .

After 2 years of intensive planning and study on different aspects of the project , the contract was finally signed with IBA , Belgium in 1992 .

The cyclotron building and its associated laboratories construction began in 1993 and lasted for 18 months . Machine was installed and tested in 1994 and officially started operation in Jan. 1995 .

In parallel to the cyclotron installation , the radioisotope production laboratories and hot-labs were equiped and since June 1995 the weekly production of ^{201}Tl and ^{67}Ga have began.

2 Layout of the Cyclotron Facilities

The cyclotron and beam rooms' arrangements are illustrated in Fig 1. The whole area of the cyclotron facility is about 5000 sq.m. The building is divided into four different sections as follows:

2.1 Cyclotron Vault and Target Rooms

The cyclotron vault and it's four surrounding target rooms occupied an area of about 600 sq.m. of the building with concrete walls and ceilings of about two meters thick , and to prevent any contamination of active gases can be kept under the negative pressure . The cyclotron body was guided into the vault through the hole on the roof . Four target rooms which are devoted for different activities , named as solid target room , gas target room , PET target room and R & D target room , are connected to the cyclotron by four identical beam lines .

At the present the solid target station has installed and is connected to the reception hot cell in chemistry section by a rabbit system .

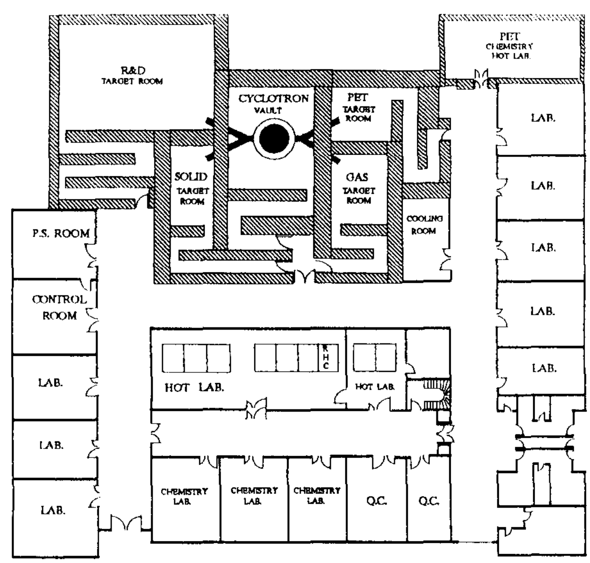

Fig 1. Layout of the Cyclotron facilities

2.2 Chemistry Section

This section consists of Reception Hot Cell (RHC) , in which the solid targets can be send to and received from the solid target station , and three different hot labs as well as 5 supporting chemistry and quality control labs .

The whole section can be put under different levels of negative pressure according to the safety standards .

2.3 Technical Supporting Section

In this section all supporting laboratories , counting rooms and electronic and mechanical workshops are situated .

2.4 PET Section

In this section , rooms for PET chemistry , PET camera , and other related labs were built and in future will be equiped for PET programm.

3 Cyclotron Description and Parameters

3.1 Ion Source

The H^- (and d^-) source is of multicusp design based on the method first used by Leung et.al (1) for producing negative ions .

The source is operated with a filament power of 1.0 kW , an arc voltage of 150 volts and an arc current of 30 amps . Typically , the gas flow is less than 10 std cm^3 min^{-1}. Under these conditions , with 9 mm diameter extraction hole and source biased at 30 kV extracted H^- beam is greater than 2.5 mA inside a normalized emittance of 0.65 π mm mrad . The cyclone-30 deuteron capability is based on its innovative region developed at IBA . Because of these special design beams of d^- injected at 14.5 KeV , can be accelerated on the same harmonic of their orbital frequency as H^-, using the same inflector and centeral region geometry and R.F. system as normally used for H^- ions . Due to the lower injection energy of d^- , the extracted current is lower .

The source power supplies are located in the power supplies room .

3.2 Axial Injection

The H^- and d^- ions generated in multicusp source leaving it with an energy of 28-30 KeV for H^- and about 14.5 KeV for d^- are guided by axial injection transport system to the inflector at the center of the cyclotron . The axial injection system is made up of the following elements :

- solenoid Glazer Lens (Strong Lens) with a 1000 Gauss magnetic field serves to focus the beam .
- Electrostatic Einzell Lens (Weak Lens) , which permits a weak focusing of low energy beams .
- Bunchers used in the axial injection line to group the particles in order to prepare and to optimize the amount of the beam that can be accelerated .

It consists of a double gap grid structure formed by two single grounded grids and a double grid oscillating at the cyclotron frequency and driven from pick-up capacitor located in the final stage RF amplifier . The distance between the two gaps , center to center , is the distance travelled by particles (at the injection energy around 30 KeV) during half of RF Period .

- Faraday cup , with a water-cooled copper plate allowing to stop the beam and measure the current .

The appropriate power supplies are situated in the power supplies room .

3.3 Magnetic System

The cyclone 30 magnetic structure consists of :

- Two plates - The upper and lower yokes , symmetrical with respect to the median plane .
- Four wedge - shaped sectors rigidly fixed onto each plate , reffered to as the hills .
- Four wedge shaped spacing between the hills known as the valleys .
- Four flux returns to complete the assembly.
- Two coils and their power supplies

3.4 RF System

The accelerating electrodes , the "dees" are supported from above and below by stems inserted in the valleys . When the yoke is lifted , the dees split into a lower and upper part .

The dees are made of solid copper and are conduction cooled .

The two 30°dees operated on the 4^{th} harmonic mode with respect to the particle revolution frequency for H^- , and the same harmonic mode for d^- .

To compensate for the different relativistic mass increases between H^- and d^- at larger radii , movable steel shims actuated by pneumatic cylinders located outside the cyclotron and installed in opposite valleys are used .

The R.F. power needed to obtain 50 kV of dee voltage is approximately 5.5 kW per cavity . In addition , up to 15 kW of R.F. power are used for beam acceleration . A single R.F amplifier delivering 25 kW of R.F power at 65.9 MHz and 32.86 MHz for protons and deuterons respectively

The final 25 kW amplifier which is a tetrode type , is situated in cyclotron vault (directly attached to the cyclotron), other R.F. amplifying stages and power supplies are situated in power supplies room and in the basement under the solid target room .

3.5 Extraction System

The extraction of the beam is based on H^- and d^- ions stripping , when they are crossing a thin carbon foil , with more than 99% efficiency .

The stripping foils are mounted on two stripping probes . The strippers are made of carbon foils or carbon fibers to allow partial interception of the beam and extraction of two beams at different energy levels or different current at the same time .

The extraction of the d^- beams is totally identical to the extraction of H^- and uses the same stripper system as for H^- .

3.6 Control System

The Cyclone-30 and related equipment such as beam transport lines and solid target systems are controlled by SIMATIC programmable logic controller (PLC) from Siemens .

3.7 Beam Transport System

Four identical beam transport systems are guiding the beams to four different target rooms . Each beam transport system comprises : Q-triplet and its power supplies , pumping station , beam line , neutron shutter (50 cm) , rotary twin-drum collimator , beam diagnostic (consisting of : one aluminium cube , one water-cooled faraday cup , one pneumatically actuated beam viewer and windows) and beam entrance facility (consisting of : one aluminium cube and one water cooled faraday cup) .

3.8 Solid Target System

The IBA Mark II solid target system including Irradiation Station in target room , Reception Station in hot lab. , Pneumatic Transport System through the basement and Control Unit in the control room , was installed , and is utilized in the process of radioisotope production and R&D activities , Fig 2 .

The Mark II system uses a target tilted at 6° with respect to the beam axis . The focused beam exhibits a gaussian profile of 6 mm FWHM . It is then rotated with a radius of 3 mm at the frequency of 50 Hz , resulting in an apparent flat beam profile after a 10 mm diameter collimator . This flat beam profile , with no hot spots , allows for a much higher beam power on target without target material evaporation in an area of target bombardment of 950 mm^2 .

The beam rotation is obtained by a cylindrical steering magnet fixed around the beam tube .

The target is flat and racetrack shaped with dimensions of 120 mm (length) x 25 mm (width) x 12 mm (thickness) . Target material is electrodeposited on an elliptical shaped area measuring 10 mm x 100 mm . It has a typical thickness of 170 μm which yields a total of 900 to 1000 milligrams of material .

The present target backing material has made of copper and its back is finned to increase the water to copper heat exchange . This target was tested with 350 μA of proton beam .

All system logic is handled by the same PLC which controls the cyclotron .

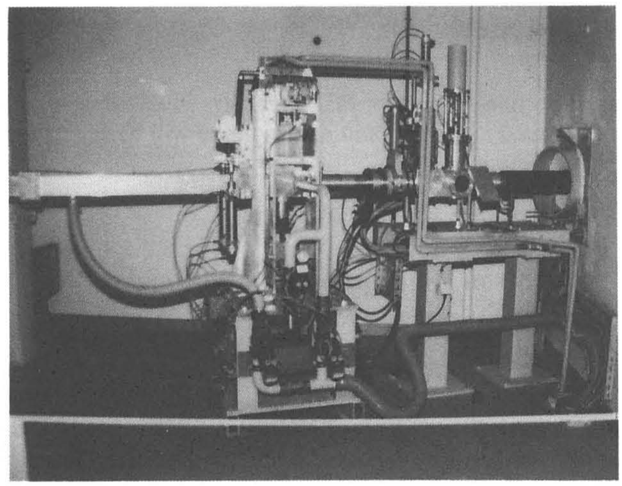

Fig 2. Solid Target Station installed in Solid Target Room

3.9 The Cyclotron Parameters :

Beam

- Type of particles extracted	p , d
- Energy	p: 15 - 30 MeV d: 7 - 15 MeV
- Maximum intensity	p: 500 μA d: 180 μA
- Number of exit ports	4
- Number of simultaneous extracted beams	2
- Extracted beam emittance :	
horizontally	< 10 π. mm. mrad
vertically	< 5 π. mm. mrad.
Energy spread	< 600 keV

Magnetic Structure

- Number of sectors	4
- Sector angle (radially varying)	54 - 58 degrees
- Hill field	1.7 Tesla
- Valley field	0.12 Tesla
- Dc power in the coil	7.2 kW
- Iron weight	45 tons
- Copper weight	4 tons

RF System

- Number of dees (connected at the center)	2
- Dee angle	30 degrees
- Harmonic mode	4
- Frequency for p	65.90 MHz
for d	32.86 MHz
- Dee voltage (nominal)	50 kV
- Dissipated R.F. power :	
per beam	5.5 kW
beam extraction	15 kW

4 Radiation Monitoring Systems

The radiation monitoring system at NRCAM cyclotron facility has been structured into four sections :

- Cyclotron vault and it's four target rooms , monitoring , with ion chamber gamma counters and BF_3 neutron detector.
- Control room monitoring , with an ion chamber gamma counter and BF_3 neutron detector.
- Chemistry area monitoring , with GMT counter .
- Ventilation room and stack monitoring , with GMT counter.

Data from all monitoring systems are transferred to the main cyclotron control computer and an independent PC in which the ventilation systems also can be monitored and controlled in the control room .

5 Facilities Performances

The performance of the NRCAM cyclotron has been improved during the first year operation of the cyclotron . Personnel have now been fully trained in the operation and some aspects of the machine maintenance .

Regular weekly production of ^{201}Tl and ^{67}Ga radioisotopes made confidence for further activities with respect to the production of other radioisotopes .

In this regard research on targetary for ^{111}In production was carried on and studies for ^{123}I radioisotope and $Kr\text{-}m_{81}$ generator productions were done . In the mean time planning for future activities in PET , has started .

References :

1. Leung . K . N. , Ehlers . K .W. and Bacal . M. ReV. Sci. Instrum , 54 , 56 (1983) .

2. IBA's Cyclone - 30 Brochure (unpublished)