MEDICAL CYCLOTRON FACILITY AT KOLKATA

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Abstract

A medical cyclotron facility is under development at a new campus of the Centre. This facility will be used, mainly, for the production of radioisotopes and radiopharmaceuticals for diagnostic imaging in Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET), besides front-line research experiments in the fields of material sciences, radiochemistry, liquid metal target development etc. The high-current proton cyclotron system (CYCLONE-30) will be supplied by M/s Ion Beam Application, Belgium. The facility got approval from the regulatory authority to operate the cyclotron with a maximum beam current of 500 μA and the beam energy within 15 to 30 MeV. There will be five external beam lines – one for PET isotope production (mainly, FDG), two for SPECT isotope production (Ga-67 and Tl-201 in the first phase) and two beam lines for research and development. Elaborate infrastructure for the accelerator facility meeting operational as well as regulatory requirements is being developed. The facility is expected to be commissioned around the middle of year 2009. Status of the project and details of the facility will be presented.

INTRODUCTION

In India the reactor produced radiopharmaceuticals have been routinely used by the nuclear medicine centres all over the country. Country's first medical cyclotron dedicated for medical radioisotope production was installed in Mumbai by the Bhabha Atomic Research Centre in 2002. Thereafter, few more cyclotrons are installed in Delhi, Bangalore and Hyderabad. All these are low energy cyclotrons meant for production of PET radioisotopes. In fact they are producing only one product - ^{18}F labeled fluorodeoxy glucose, commonly known as FDG. But there is increasing demand for other useful cyclotron produced radioisotopes namely, ^{201}Tl, ^{123}I, ^{111}In, ^{67}Ga etc. which have unique applications in various diagnostic imaging. All these radioisotopes require higher energy for their production through a specific nuclear reaction. Presently, these isotopes are not available from the indigenous sources. To make the cyclotron produced radiopharmaceuticals available to the common people of our country at an affordable price, Department of Atomic Energy, Government of India, has sanctioned fund to set up a powerful medical cyclotron (30MeV, 500μA) in Kolkata. This facility would be able to cater to the need of cyclotron produced radioisotopes of the entire country, possibly more, for a long period to come. The facility will also produce the most important PET radioisotope i.e. ^{18}F.

CYCLOTRON FACILITY

Table-1 shows the radioisotopes to be produced and concerned nuclear reactions, as well as the beam energy and current required for these reactions. The required proton beam energy to cover all the reactions varies from 18 MeV up to 28 MeV and beam current varies from 40 up to 200 μA.

Table 1

Isotope ($T_{1/2}$ hour)	Nuclear Reaction	Proton Energy (MeV)	Beam Current (μA)
Ga-67 78.3	^{68}Zn(p, 2n) ^{67}Ga	28.5	200 *
Tl-201 73.5	^{203}Tl(p,3n) ^{201}Pb, (9.4h) ^{201}Pb (EC/β+) ^{201}Tl	28.5	200 *
In-111 67.9	^{112}Cd(p,2n) ^{111}In	28.5	200 *
F-18 1.8	^{18}O(p, n) ^{18}F	18	40

So a cyclotron capable of producing proton beam with energy up to 30 MeV and current up to 350 μA is good for our purpose. This will be a negative hydrogen ion cyclotron, but positive proton beam will be extracted. The negative hydrogen ions, produced in an external cusp ion source, will be axially injected into the cyclotron. Two RF cavities will accelerate the negative hydrogen ions. At the extraction radius carbon stripper foils will be used to extract two simultaneous proton beams from the machine. The extracted beam energy will be adjustable from 15 MeV up to 30 MeV and the beam current will be tuneable up to 350μA. High beam quality will be ensured, giving horizontal emittance <10π-mm-mrad, vertical emittance <10π-mm-mrad.

Layout of the Facility

There will be two port-selection magnets installed in two extraction channels, which can guide the extracted beam to different external beam lines. We will have two beam lines on one side and three on the other side, as shown in figure 1. Two beam lines will be used for irradiating solid targets (Ga, Tl), one for PET targets and rest of the two beam lines will be used for various R&D experiments.

There will be two automated solid target irradiation systems, for the production of ^{67}Ga, ^{201}Tl (optionally ^{123}I, ^{111}In) and one automated gas/liquid target irradiation system for the production of [^{18}F] fluoride, [^{18}F]F_2, [^{11}C]CO_2, [^{15}O]O_2 etc. After irradiation, the solid targets will be transported to the receiving hot-cell via pneumatic transfer system. A fully automated radiochemistry system will be used for the remote production of labelled molecules from the irradiated target materials.

Radiopharmaceuticals

In the first phase of production, following products would be available: (1) SPECT products [^{201}Tl]Thallous

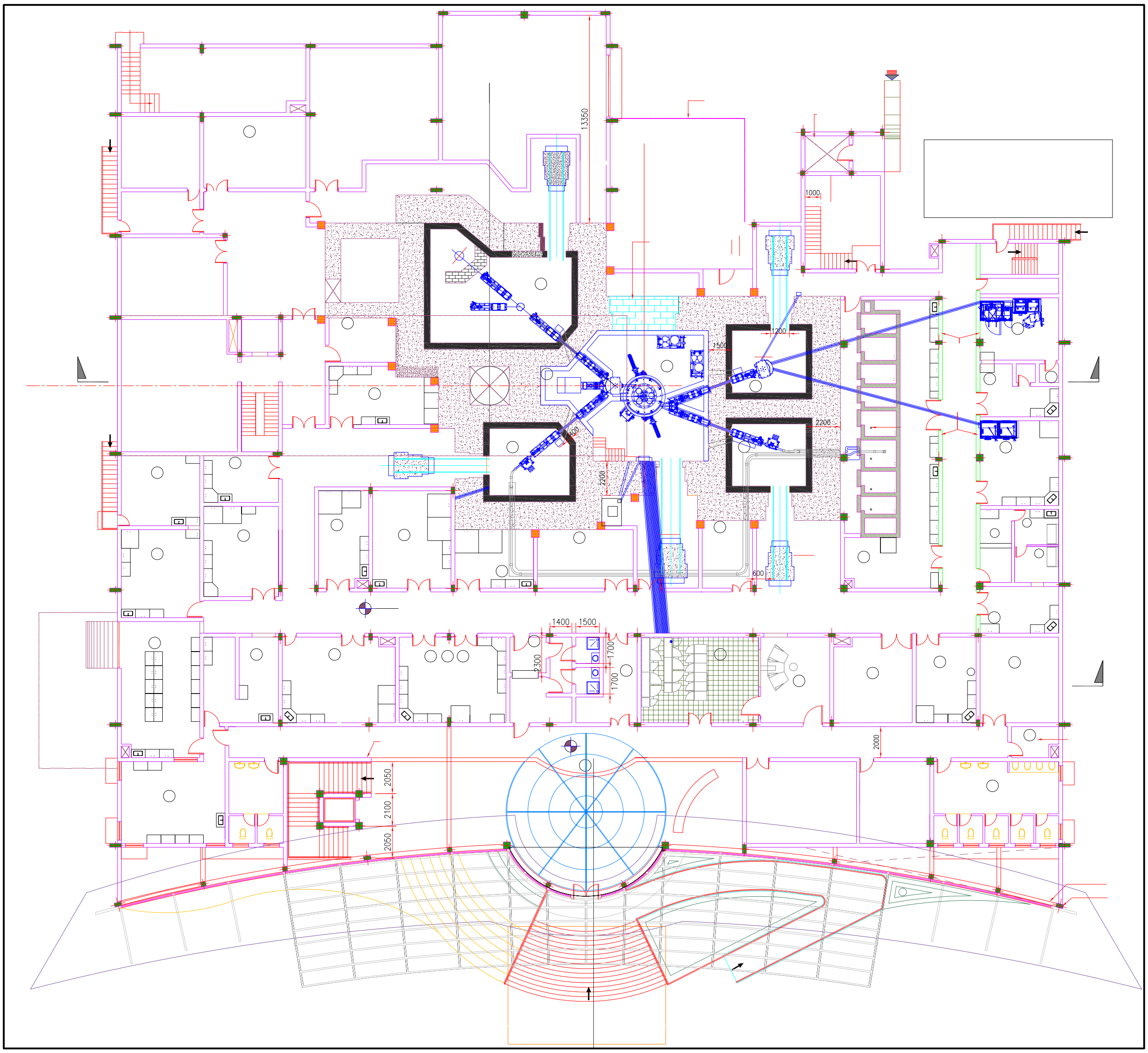

Figure 1: Layout of the medical cyclotron facility.

chloride and [^{67}Ga]Gallium citrate, because of fairly long half life of ^{201}Tl and ^{67}Ga, radiopharmaceuticals formulated from these radioisotopes can be supplied to any hospital in India, (2) PET Products: [^{18}F]FDG. The hospitals in and around Kolkata, for the first time would be able to use this unique radiopharmaceutical for use in oncology, neurology and cardiology. Other useful radiopharmaceuticals of ^{123}I and ^{111}In would be introduced in the second phase of the project. Depending on the need, radioisotopes like ^{57}Co, ^{124}I, ^{90}Y, ^{64}Cu, ^{186}Re, ^{103}Pd etc. could also be produced.

EXPERIMENTAL BEAM LINES

Two dedicated beam lines will be used for research and developmental experiments.

Materials Science R&D

High intensity proton beams from the medical cyclotron provide a unique facility for radiation damage studies on reactor materials, as energetic charged particles are useful for simulating the bulk damage induced by fast neutrons. For example, 20 MeV protons with 350 μA current will produce, in stainless steel, a damage of 2×10^{-5} dpa/sec over a sample thickness of about 0.7 mm. This is higher than the damage rate produced in fast reactors ($\sim 10^{-6}$ dpa/sec). With this energy, thick samples of the order of 0.5 to 1 mm can be irradiated. This makes the post irradiation investigation of the samples feasible by a variety of bulk techniques like XRD, positron lifetime, mechanical property measurements. The main interest will be in studying the irradiation effects in structural materials like D9, D9I and ferritic steels. Some of the important studies that will be carried out are: ductile to brittle transition in ferritic steels, development of void swelling resistant steels, phase stability under irradiation in advanced austenitic steels etc. Apart from the above utilization for structural materials, studies on basic damage mechanisms are of importance for better understanding of radiation effects in materials. In the ordered intermetallics, the evolution of disorder and amorphization during irradiation is of fundamental interest. Another class of materials in which defect accumulation and consequent amorphization is of interest is ceramics used for nuclear waste disposal. The availability of high-energy beam will facilitate the study of the damage phenomena in these materials using a wide variety of bulk techniques such as XRD and positron lifetime.

Apart from radiation damage studies, other areas of experiments in the material science beam line include induced radioactivity studies, thin layer activation analysis of nano-coatings, production of special isotopes for use as sources in various experiments like PAS, PACS etc., study of mass, charge and angular momentum distribution of fission products in proton induced fission of actinides etc.

The experiments to be carried out will require different energies and currents. Taking into consideration the radiological safety, the material science and related activities will be carried out in two different chambers depending on the energies and currents to be utilized for irradiation. One chamber on the undeflected beam line in the material science cave will be used for high dose experiments where the currents will be of the order of 200µA. The low dose experiments up to about 50µA beam current will be carried out in another chamber to be installed at the end of a small branch-off beam line in the same cave. Special shielding wall has been provided to enclose the high dose chamber.

Beam characteristics in material science beam line are as follows:

Beam Energy	15- 30 MeV
Beam current on target	50 µA chamber 2, 200 µA chamber 1
Beam spot at target	10 to 12 mm FWHM
Scanning device	Uniform, XY rectangular
Beam dimension at target location	to reach 30 x 30 mm, uniform
Scanner Frequency	200 Hz / 20 Hz orthogonal
Target collimator	Four drums collimators

There will be another beam line to use full beam power (15 kW) on the target. This beam line will bend down to an underground (10 m) cave.

Following experiments are planned in this beam line.

a) Window thermal-cycling studies in LBE target flow conditions.

b) Active gas handling techniques.

c) Remote handling of irradiated target.

d) Radiation damage studies in the candidate materials for target window and other subsystems.

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