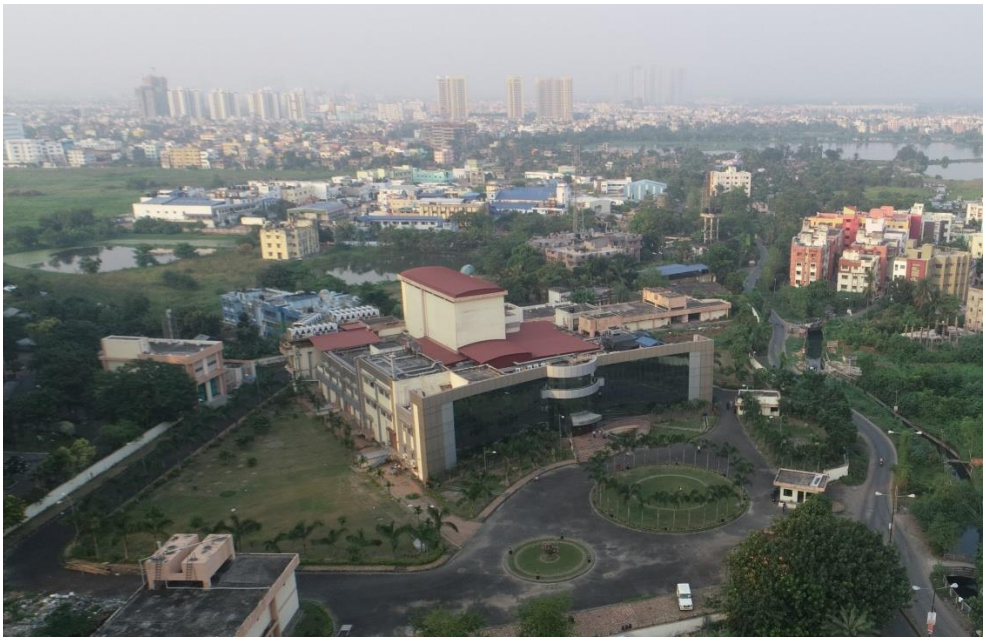
# 30 MeV Medical Cyclotron Facility at VECC, Kolkata

A Medical Cyclotron Facility has been established by Variable Energy Cyclotron Centre at Chalkgaria, Kolkata. The facility has been catering the requirements of medical radioisotopes and radiopharmaceuticals to the medical fraternity in and around Kolkata.

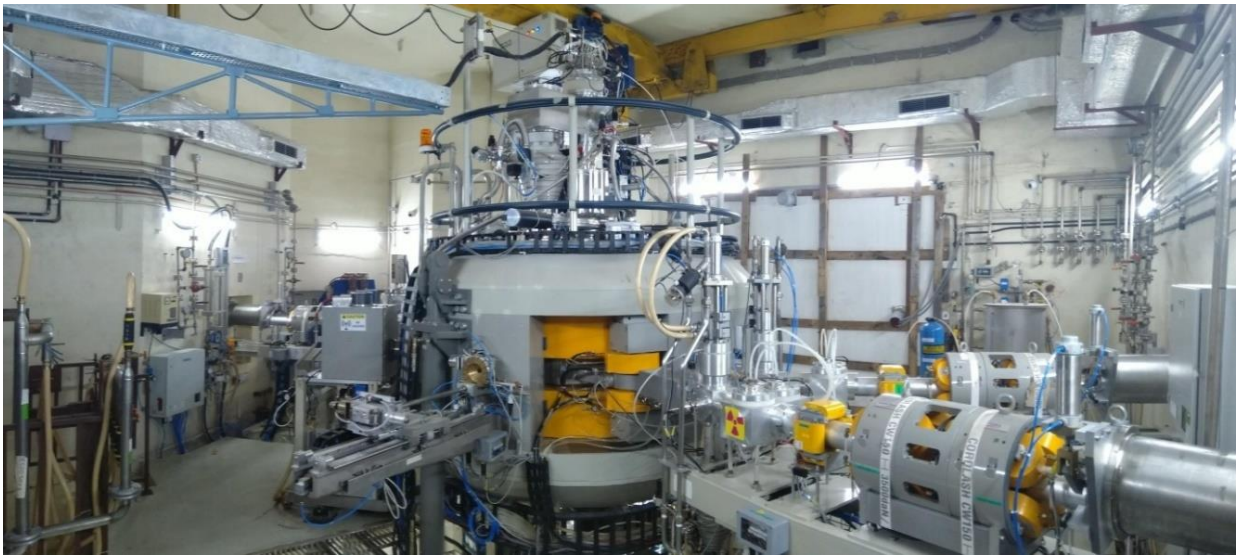


VECC Medical Cyclotron Facility at Chakgaria, Kolkata

**Cyclotron and Beam lines:**

The heart of this facility is a 30 MeV H-cyclotron called CYCLONE-30. This cyclotron is a negative hydrogen ion accelerator. This cyclotron is a fixed magnetic field, fixed RF frequency, variable energy and dual-beam cyclotron. There are two RF cavities, called dee, to accelerate the negative hydrogen ions. At the extraction radius two carbon stripper foils placed at diametrically opposite ports. These strippers are used to extract two simultaneous proton beams from the machine with extraction efficiency more than 99%. While passing through the carbon stripper foils the circulating negative hydrogen ion is converted into proton, which bends in the opposite direction to come out of the machine. The extracted beam energy is adjustable from 15 MeV up to 30 MeV by properly adjusting the radial position of carbon foils and beam current is also tuneable up to 350 μA.

**Figure 1:***30 MeV Medical Cyclotron at Chalkgaria campus of VECC Kolkata.*



This cyclotron is used to produce positron emitting radioisotope $^{18}F$, which in turn is used to produce FDG (Fluorodeoxyglocose) radiopharmaceutical. FDG is used in Positron Emission Tomography (PET) for medical diagnostics. The cyclotron is also used for the production of gamma emitting radioisotopes such as Ga-67, Tl-201, I-123, etc. and related radiopharmaceuticals, that will be used with a gamma camera for Single Photon Emission Computed Tomography (SPECT).

There are five extraction beam lines in this cyclotron facility – one beam line is dedicated for production of PET radioisotopes, two beam lines are dedicated for production of SPECT radioisotopes and two other beam lines are used for R&D activities related to material science and liquid-metal target study.

In this cyclotron facility, an external multi-cusp ion source is used, which can produce about 5 mA of negative hydrogen ion beam having maximum energy about 35 keV. The H- beam is then injected axially into the cyclotron and bent into the median plane by an electrostatic spiral inflector. The axial injection beam line consists of an electrostatic Einzel lens, a set of steering magnets, RF buncher and a Glaser lens giving a high-quality beam and high injection efficiency. The use of external ion source reduces the neutral gas pressure inside the cyclotron. Consequently, stripping of the H- ions during the acceleration process is also reduced. This reduces the beam loss and residual activation of the cyclotron.

The parameters of 30 MeV Medical cyclotron is given in Table 1:

**Table 1:** *Parameters of the 30 MeV Medical cyclotron.*

| | |
|---|---|
| Particle Type | Proton |
| Beam Energy | 15–30 MeV at extraction |
| Beam Current | 350 μA for normal operation and 500 μA (max) |
| Accelerator type | CYCLOTRON (negative ion; dual beam) |
| Energy Spread | 2% |
| Average Magnetic Field | 10kG |
| RF frequency | 65.5MHz |
| No. of Dees | 2 |
| RF Harmonic | 4 |
| Dee Voltage | 50 |
| Dee angular width | 30° |
| RF power | 15kW |
| Ion Source | H- multicusp |
| Source current | 5mA |
| Operating Vacuum | $3\times10^{-6}$ mbar |
| Vacuum system | CRP+DP |
| Type of extraction | Stripper foil |

The main magnet of the medical cyclotron has four-sectors, each consisting of a small pole gap region called “Hill” and a large pole gap region called “Valley” alternatively. The magnetic field in the Hill regions is about 1.7 Tesla and in the Valley region is about 0.1 Tesla. The average field is about 1.07 Tesla. The magnet is compact with small Hill gap (30 mm)and large Valley gap (1100 mm), providing strong vertical focusing to the beam due to high flutter amplitude. The cyclotron has fixed magnetic field and fixed RF frequency and no trim coils. The isochronous condition required for beam acceleration is achieved by appropriate pole shaping during the design-manufacturing stage by keeping the pole gap constant and adjusting the sector angle radially to get the desired magnetic field values along the radius.

**Applications**

The cyclotron-produced radioisotopes will be used in nuclear imaging. The radioisotopes utilized for functional imaging of different organs provide information which cannot be obtained from other imaging modalities like X-ray, Ultrasonography, CT scan, etc. Thus, it gives vital information for

better understanding of human physiology and pathology. A few important uses of the cyclotron-produced radioisotopes and their half-lives are given in Table 2.

Besides producing radioisotopes for medical uses, the cyclotron is used for various research and developmental applications. A few topics to name are as follows:

1. Radiation damage studies
2. Production of $^{68}$Ge for preparation of $^{68}$Ge/ $^{68}$Ga generator, $^{64}$Cu, $^{22}$Na for Positron Annihilation Studies and $^{57}$Co sources, which is used in calibration of isotope dose calibrators, gamma cameras and Mossbauer sources which will be done in future for which separate clearance will be taken.
3. Wear and tear studies.
4. Target window study for Pb-Bi target assembly.

**Table 2:** *List of radioisotopes produced in the cyclotron along with their half-lives and their uses.*

| Radio-isotopes | Nuclear Reaction | Half-life(h) | Use |
|---|---|---|---|
| $^{67}$Ga | $^{68}$Zn(p, 2n) $^{67}$Ga | 78.3 | Soft tissue tumor imaging (abscess and infection imaging) |
| $^{201}$Tl | $^{203}$Tl(p, 3n) $^{201}$Pb EC/β+ $^{201}$Pb → $^{201}$Tl | 73.5 | Myocardial perfusion imaging |
| $^{123}$I | $^{124}$Xe(p,2n)$^{123}$Cs →$^{123}$Xe →$^{123}$I & $^{124}$Xe(p, pn)$^{123}$Xe →$^{123}$I | 13.3 | Thyroid uptake & imaging, myocardial imaging, tumor imaging |
| $^{18}$F | $^{18}$O(p, n) $^{18}$F | 1.8 | Regional glucose metabolism in brain, heart and tumor |
| $^{68}$Ga | $^{68}$Zn(p, n) $^{68}$Ga | 1.1 | localization of somatostatin receptor positive neuroendocrine tumors (NETs) in adult and pediatric patients |

***Target:***

The most important irradiation parameters determining the formation of a radioactive product are the beam flux, energy and irradiation time as well as number of target nuclei, nuclear reaction cross section and half-life of the produced radioisotope. There are three types of targets for radio-isotope production –solid target, liquid target and gas target. Standard radionuclides are mostly produced in either gas or liquid targets due to their easy use and no manual handling for routine production activities.

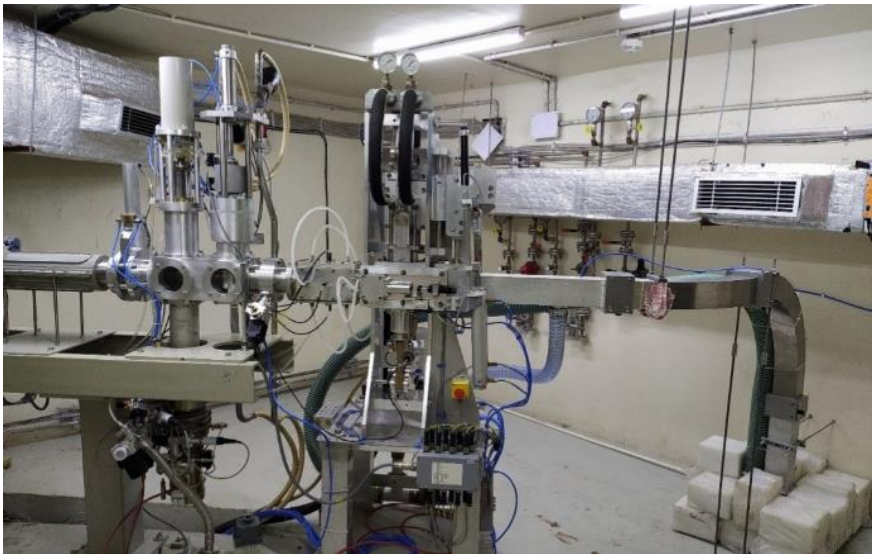


**Figure 2:** *Solid target irradiation system and pneumatic transfer system.*

***Solid Target:***

Generally, enriched target materials of a few hundred μm thickness are layered on a back plate made of highly conductive metal. This solid target preparation process requires isotropic material deposition in a pure form, such as, electroplating.Gallium-67-citrate &Gallium-68 isotope have been successfully produced from enriched Zinc-68 target on Copper base plate. The beam is incident on the target surface in a small angle so that the beam power is dissipated on a large surface area, to avoid melting of the target. To avoid the associated high radiation hazards, the target is transported in between the irradiation station and hot-cell by remote controlled pneumatic transfer system, as shown in Figure 2.

***Liquid Target:***

The production of radio-metals involves the use of solution targets, where the target material is dissolved in an aqueous solution in the form of salts. This method is very useful due to simple handling, on demand availability, a faster production process without dissolution and adjustable use of enriched material depending on the needs for a single production, which greatly reduces the cost. For $^{18}F$ production, $^{18}O$ enriched water is used as target. We have successfully produced and delivered $^{18}F$-FDG to nearby hospitals for diagnostics purpose of cancer patients.

***Hotcells:***

The Radiopharmaceuticals Laboratory of BRIT in the Medical Cyclotron Facility would contain total of ten hotcells (HC). Seven hotcells are required for SPECT radioisotopes ($^{201}Tl$, $^{67}Ga$ etc.) and three are required for handling PET radioisotope, $^{18}F$.Table-III explains the functional use of various SPECT hotcells. Irradiated solid targets will be transferred to the receiving hotcell through a lead shielded pneumatic transfer system. Transfer of radioactive/inactive material from one hotcell to other will be affected by a trolley which can move along a lead shielded conveyor system running below the hotcells. All the SPECT hotcells will be shielded with 100mm thick lead. Radioactive solid and liquid wastes generated in the radiochemical processing will be stored in containers kept in the basement.

Irradiate [$^{18}O$] water containing [$^{18}F$] fluoride will be transferred to the PET hot cell through the lead shielded narrow plastic tubes for subsequent synthesis of FDG. Small amount of radioactive waste generated would be stored in the hot cell itself and this could be discarded next day (as the waste would contain only [18F] fluoride having 110 min. half-life. Table-IV explains the functional use of PET hotcells. All the PET hotcells would be shielded with 75mm thick lead.

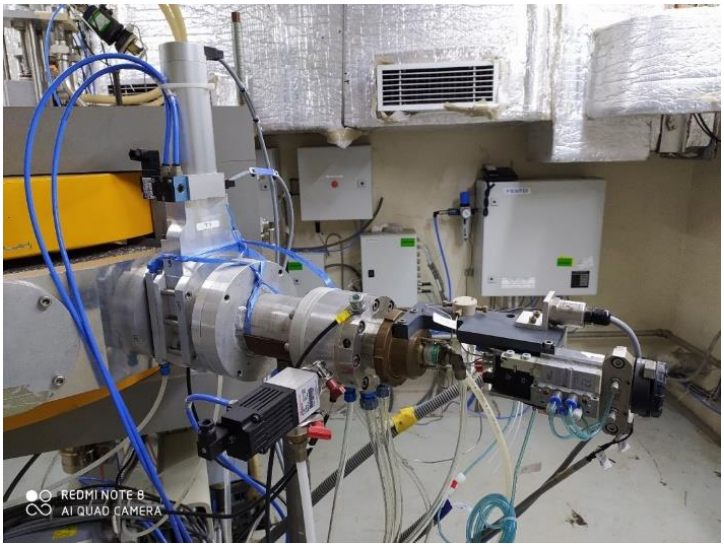



**Figure 3:** *Liquid target – $^{18}O$ enriched water target is used for $^{18}F$ production.*

**Table 3:functional use of various SPECT hotcells**

| Si No. | Hotcell Name | Activities to be carried out |
|---|---|---|
| 1 | Receiving HC | Solid target to be mounted on the target carrier and sent to the irradiation station and also irradiated targets to be removed from the carrier remotely with the help of master slave manipulator. |
| 2 | Tl-1 Chemistry HC | $^{201}Pb$ produced in the irradiated target shall be chemically separated from active and inactive Tl isotopes and allowed to decay to $^{201}Tl$. |
| 3 | Tl-2 Chemistry HC | $^{201}Tl$ produced from $^{201}Pb$ decay shall be chemically separated from residual $^{201}Pb$ here. |
| 4 | Ga- Chemistry HC | Ga radioisotopes shall be separated from inactive $^{68}Zn$ and other coproduced impurity radioisotopes using wet chemistry. |
| 5 | Recovery HC | Waste liquid generated in chemistry hotcells shall be processed here to recover enriched $^{203}Tl$ and $^{68}Zn$ isotope. |
| 6 | Dispensing HC | Finished Radiopharmaceuticals shall be dispensed in vials using automatic dispensing equipment. |
| 7 | R & D Hot cell | Targets irradiated for any developmental work shall be handled in this hot cell. |

**Table 4: Functional use of PET hotcells**

| Hot cell Name | Activities to be carried out |
|---|---|
| FDG Synthesis HC-1 | Synthesis of $^{18}F$-FDG using 18F |
| FDG Synthesis HC-2 | ~do~ Enroute to cell is selected by PLC Controller |
| FDG Dispensing HC | $^{18}F$-FDG dispensing using a semiautomatic dispenser. |

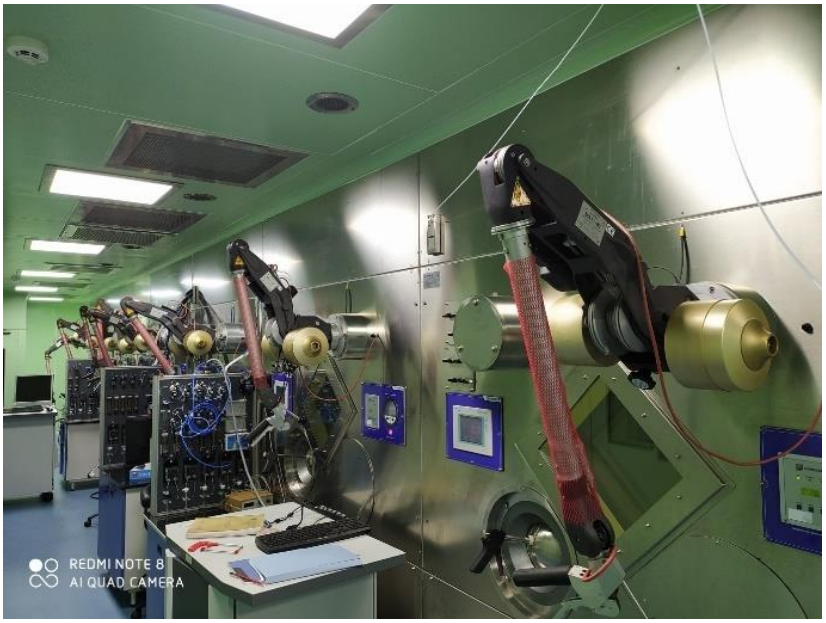



**Figure 4:** *SPECT hot cells.*

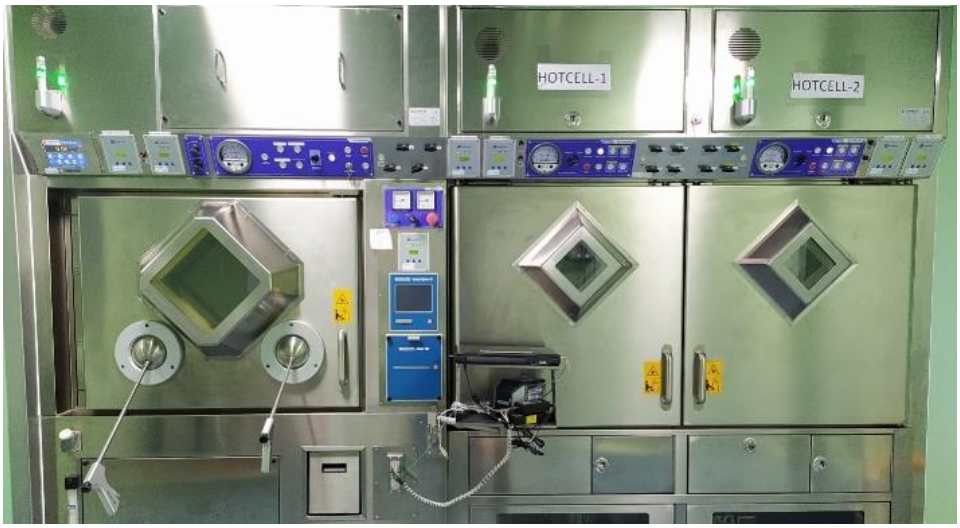



**Figure 5:** *PET hot cells.*

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