Design and construction of a target chamber and associated equipments for the BARC Charged Particle Detector Array

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Abstract. A 60 cm diameter spherical high-vacuum target-chamber with side-opening hemispherical-lids, two ancillary-chambers, beam-line-tubes, tees and other high-vacuum components, and chamber-lid handling systems have been designed, constructed and installed for the Charged Particle Detector Array in BARC-TIFR Pelletron-LINAC Facility, Mumbai. This array of several tens of Si-CsI detector modules and other ancillary-detectors will be used for investigations in fusion-fission dynamics, nuclear structure at elevated temperatures and angular momenta, exotic nuclear clusters and related fields. This paper describes the unique features of the system that aid different coincidence experiments, the chamber fabrication experience and the pump-down characteristics with a turbo molecular pump. Unlike many other target chambers in use, this chamber allows multiple overall geometrical configurations to be set to reach experimental goals. For instance, by replacing a hemispherical-lid from one side with a flat-lid, the overall configuration becomes hemispherical. This way, high geometrical efficiency can be provided to an ancillary gamma detector array by allowing it to move close to target from the flat-lid side, although with some sacrifice of geometrical efficiency for charged particles. In experiments where a further improvement of geometrical efficiency for a gamma array is desired, a third compact-cylinder configuration can also be arrived at. Thinned portion of the lids of the chamber also allow neutron coincidence measurements with charged particles and gamma rays.

1. Introduction
A charged particle detector array (CPDA) which can provide Z and energy information of nuclear reaction products is being installed in the recently upgraded BARC-TIFR Pelletron-LINAC Heavy Ion Facility, Mumbai. This array will be used for investigations in fusion-fission dynamics, nuclear structure at elevated temperatures and angular momenta, exotic nuclear clusters, and related fields. These are some of the fields the nuclear physics community has taken special interest since they permit unraveling of complex nuclear structural and dynamic phenomena. This paper describes the unique features of the target chamber of the array that aid different coincidence experiments in the above fields, other facilities in the beam line, the chamber fabrication experience and the pump-down characteristics with a turbo system.

The standard investigative approach in heavy ion reaction physics is the measurement and analysis of the collision effects of a heavy ion beam over a target foil. Depending on the entrance channel parameters, the nuclear collisions produce a number of particles of different mass, charge, energy, and
angle of emission. Some of the studies require only simple measurements with a few detectors, while many other studies require more complete measurements with arrays of different types of detectors. First generation of detector arrays came into existence around 1990 as array of Compton suppressed Ge detectors. With the availability of compact, convenient and reliable charged particle detectors and advances in data acquisition instrumentation, a second generation of such arrays came into existence as in the following examples: INDRA-GANIL (1992), 8πLP-LNL (1997), NIMROD-TAMU (1999), CHIMERA-LNS (2000). With the ever increasing sophistication, reliability and convenience in detector and data acquisition instrumentation, third generation of arrays are also being built in advanced laboratories around the world.

For a comparison of charged particle detector array capabilities, the main characteristics of second generation of such arrays can be classified as: 1) Large 4π arrays for multi fragmentation studies that requiring complete exclusive reconstruction of emitting sources, e.g., INDRA, CHIMERA, NIMROD and FOPI, 2) 4π charged particle detector array as an ancillary detector for gamma spectroscopy, e.g., NORDBALL, GASP, GAMMASPHERE and EUROBALL, 3) Arrays for special purposes, e.g., MEGHA, AMPHORA and ISOLDE Silicon Ball.

The third category–where the present CPDA also belong– in most cases are upgrades of detector systems that cater to various issues in nuclear dynamics and structure, and they are not necessarily (close to)4π systems as arrays in the first two categories. For example, the MEGHA array has 44 three-detector-telescopes (gas-silicon-CsI) mounted suitably for nuclear cluster-breakup studies. In the first two categories, the geometrical configuration of charged particle detectors is more or less singular (being 4π setups) where in the third, multiple configurations can be set to reach experimental goals, provided the scattering chamber is suitably designed to accommodate multiple configurations.

2. Conceptual design of the CPDA

2.1. Charged particle detector module

Having resolved the type of CPDA to be built, the next issue is selection of charged particle detectors. Ion implanted silicon detectors made by BARC at BEL-Bangalore facilities is a natural choice due to qualities silicon possess as a charged particle detection medium and other advantages since the detectors are indigenously produced[1]. Since BARC-BEL detectors have thickness about 300 µm, it will not stop all energetic charged particles of our interest, therefore, it is necessary to have a stop detector in a E–E configuration and, therefore, commercially available CsI detectors were selected as stop detectors. In the mechanical design work for the array, one of the first tasks was to design a detector module mount which will hold the Si and CsI detectors in a transmission and stop detector configuration (see Fig.1(a-b)). The active area of the Si detector is a square of approximately 400 mm² and it is segmented in to four equal squares of 100 mm². The CsI detector is having an active area of approximately 500 mm² square and overall thickness 25 mm with crystal thickness equal to 10 mm. The Si detector is in a precision machined detachable insert which is a foldable structure with a rectangular opening. One side of the insert is made with stainless steel and the other with Derlin. The metal part gives strength and act as a heat sink and the Derlin side protects the conducting tracks in the ceramic substrate from shorting. The detachable design allows one to use CsI detector alone in a module when need arises. It was decided that the detector module should be movable to a desired lab angle but there will not be any movable arms inside the chamber in the first phase. Therefore, graduated rails are provided to fix the detectors at desired angles. A part of such rail is shown in Fig.1(a-b) with arrangement for fixing the module. Since we have option for a large number of detector modules to cover sufficient solid angle, the routine for chamber opening, fixing, closing and then evacuation can be minimized to one or two in an experiment to economize in the machine time. The angular opening of one segment in the detector module will depend on the distance from target at which the module is fixed. It was desired that this opening be around 3° in the array and accordingly the target to first detector distance was selected as 18.5 cm. It followed that the diameter of the spherical chamber required is around 60 cm.
2.2. Target chamber

The main task was to design a versatile high vacuum target chamber made of stainless steel (SS304) which is sufficiently flexible to allow different types of experiments [2] and there are no preceding chambers of this type in our laboratory. The variety of experiments we are interested in can be noted from our recently published works carried out at Pelletron Linac Facility using different simple cylindrical chambers and beam lines. A small cylindrical (20 cm dia., 4 cm height) scattering chamber and a gamma ray multiplicity setup consisting of 14 BGO detectors were used in one of the works. Coincidences between charged particles measured using silicon detectors placed inside the chamber, in particular alpha particles, and gamma rays detected in the BGO array placed outside the chamber were recorded in the experiment. An evaporation residue (ER) detector would have been very useful to improve accuracy of the measurements, however, due to lack of space inside the compact chamber and other reasons, this option was not available in the experiments. The total solid angle subtended by charged particle detectors was only 11 msr, which is rather a low value for this type of work. Another experiment is a first of its kind heavy cluster knockout reaction $^{16}$O+$^{12}$C, $^{22}$C+$^{4}$He where two energetic $^{12}$C ions where detected in coincidence using a pair of silicon telescopes of 4.5 msr solid angle at fixed angles of 41 and 45 degrees. For better event statistics, it would have been better to cover more angles at selected scattering angles ( ) with more detector telescopes. A third kind of experiments is pre-scission charged particle emission where again a large number of charged particle detectors at selectable ‘odd’ angles are required. Details on the physics interests in the above experiments can be obtained from the published articles [3,4]. It is necessary to eliminate above mentioned drawbacks to the extent possible and facilitate several more types of experiments with the new target chamber.

![Fig.1: (a)CAD diagram of the CPDA beam-line part. (b)Expanded view of the target chamber. Full assembly of a single detector module is shown in the inset below. Components of the detector module such as four pad silicon detector, hinged holder for the silicon detector, CsI detector and its holder are shown in an exploded view(bottom). (c) Photograph of the target chamber after fabrication. (d) CAD diagram of hemispherical and (e) compact cylindrical configurations of the CPDA.](image)

There are three distinct configurations possible for the target chamber. One of them, the spherical configuration of diameter 60 cm, is shown in Fig.1(a)-(c). Thin walled hemi-spherical lids and flange cover plates, that are not shown in Fig.1(a), will ensure vacuum. Expanded views of the spherical mount and the detector module are shown in Fig.1(b) to illustrate the design concepts. Detector modules can be held on to circular rails by brackets and the modules can be fixed at any angle within the range provided by the rails. Detector modules can be held similarly inside the central cylindrical part (see Fig.2). As stated earlier, first element of the detector module will be at a distance of 18.5 cm from the center. The range of scattering angles that can be covered is from 10° to 170°. Maximum solid angle that can be covered in this configuration is 1520 msr (12% of $4\pi$). If needed, the total solid angle coverage can be increased by bringing the rails closer by doing a rework on the rails.

By removing a part of the hardware a second configuration namely hemisphere can be arrived at as illustrated in Fig.1(d). In this figure, charged particle detector modules are covered by hemispherical and flat lids. The flat lid has a central thin convex circular area of 25 cm diameter made of 2mm stainless steel. This configuration will have a maximum solid angle coverage of only 930 msr.
for charged particles. Reconfiguring this way has a major advantage that a gamma detector array can be brought closer to target position while still maintaining a reasonable solid angle coverage for charged particle detectors. In experiments where a further improvement of geometrical efficiency for a gamma array is desired, a third configuration can be arrived at as shown in Fig.1(e). Here, charged particle detectors are retained only in the compact-cylindrical portion and the flat lids cover both sides of the chamber. Gamma detector arrays can be brought closer from either sides to double their total geometric efficiency.

3. Construction

Installation aspects of the fabricated compact cylindrical chamber are described first. This part of the chamber is vertically placed and it defines a vertical ‘reaction’ plane (Fig.2). It is supported from below at three places, at beam inlet and outlet by coupling to sturdy ancillary chambers, and in the middle by a single pillar fixed on the floor. Two stainless steel rings of width 24 mm and thickness 9 mm were welded inside the cylindrical surface so as to provide good reinforcement for the cylindrical structure and they also act as holders for the hemispherical rail structure as well as a place to mount detector modules. This way of chamber alignment can avoid broad stands which usually support horizontally-aligned chambers. Such broad stands may create problems for bringing close bulky gamma detector arrays from the sides.

Fine adjustments for alignment of cylindrical part with respect to beam line could be made by movements on vertical bolts and in horizontal cuts made in the base plates of ancillary chambers. Chamber lids are bought from two sides by two mini-cranes, one for each side, for closing. Detachable semi-circular hooks have been fabricated for lifting the lids by cranes. The motor driving the crane is fixed on top of table-cum crane stand on a linear motion platform. The linear motion provided by these platforms and the vertical motion by the cranes can align the lids to the cylindrical part of the chamber. Use of the guide pins provided at the chamber periphery facilitates the lid alignment to the chamber. Accompanying photograph (Fig.2(a)) shows the vertically aligned compact cylindrical chamber with one lid moved to the foreground for display purpose. Ancillary chambers and the central pillar can also be seen in their aligned positions. One of the lid-handling table-cum-stand with crane attached on top can be seen in the background. The target chamber with both lids closed and the table-cum-stand retracted can be seen in photograph Fig.2(b). The suitably designed table-cum-stands have storage mechanism for storing the hemispherical and flat lids when not in use and have table-tops for users to work on.
Some more details and dimensions of the chamber and associated equipments can be obtained from Fig.3. The multiple target holder contains 6 targets, any one of which may be used without breaking the vacuum. There are total 18 ports on the cylindrical part of which 2 are for 200CF flange fitted with ten numbers of 25-pin D-type electrical feed-throughs. Rest 16 are custom sized ports of OD 70 mm distributed at various angles. These ports are of multi-purpose, including those for insertion of the target ladder, view ports, and electrical feed-throughs. Expanded view of one of the 70 mm port, the one at the bottom, is given in the top right corner inset of Fig.3. A section of the center pillar can also be seen here since the hollow-center-pillar support the main cylinder by surrounding the bottom most port. A thick washer made of Teflon prevents electrical contact between the chamber and the pillar.

As per the design, particles emitted in ±6° most forward and most backward angles will enter in the ancillary chambers placed after and before the target chamber, respectively. These chambers can house detectors for measuring charged particles emitted at these angles, for example, evaporation residue detectors at most forward angles for measuring ERs. Ports are provided at the sides and on top (100 CF and 200 CF size, respectively) of the ancillary chambers for facilitating these works. Construction of these chambers are such that they and the target chamber are electrically insulated from ground. (Suitably designed nylon washers as shown in the left-top inset of Fig.3 help to achieve this insulation.) At the same time the ancillary chamber fixtures provide necessary mechanical support to the target chamber and avoid mechanical stress on beam line insulators. The turbo pumping station (TPU 1201 P with control unit TC 750 from Pfeiffer Vacuum) and high vac gauge(PKR 251) are located upstream and a beam-line insulator and an electrically actuated gate valve isolate the ancillary chamber and the pump station. In the down-stream line also there is a provision for a pump station after a gate-valve, however at present no second pump station is connected. Although the positions of pumps are not at good gas conductance, the same helped in achieving electrical isolation for the chambers. At the end of the beam-line, after a beam-line insulator and a drift tube of length 75 cm, a Faraday cup(FC) is connected for measuring beam current.

Fig.3: Schematic of the CPDA beam-line. Target chamber is in the middle.
The hemispherical mounts (Fig.4) and corresponding lids have also been installed and tested for vacuum and for operations with the lid-handling crane and storage table. The alignment of this part was separately tested using guide blocks and laser pointers. Overall alignment at the target position is better than ±2 mm. For beam collimation there are two provisions, the primary one is an electrically actuated x-y slit at the position indicated in Fig.3. In addition a collimator disc can be placed at the entrance of the cylindrical chamber on a removable retainer ring.

Pump-down characteristics of the compact cylindrical chamber and beam line is shown in Fig.5. Pump-down time from atmospheric pressure to working pressure $2 \times 10^{-6}$ mbar is 2 hours. This was measured with relatively small gas load from detectors, cable etc. Detector response has also been measured[5] in an actual heavy ion reaction experiment for confirmation. The response was satisfactory and detailed analysis of the same will be communicated separately.

4. Summary
Design and construction of a new high vacuum target chamber and associated equipments for nuclear reaction and structure studies at BARC-TIFR Pelletron-LINAC Facility is described. Experimental work with this beam line has been initiated. This facility will house the BARC charged particle detector array that comprising of several tens of Si-CsI detector modules and it got unique features that aid coincidence measurements between the array of charged particle detectors and arrays of neutral particle (gamma, neutron) detectors.

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