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ABSTRACT

The apparatus developped for heavy-ion physics at intermediate energies is presented with some techical details. The basic array consists in 48 identical three-element telescopes (ionization chamber,position sensitive silicon, CsI crystal). Details of the project and the supporting control systems are given.

1 - INTRODUCTION

The detector array here reported has been developped in a program aimed to build experimental tools for the intermediate-energy heavy-ion beams of the tandem + superconducting cyclotron facility of the L.N.S. (Catania), which should provide beams from C to U with energies from 100 to 20 A MeV. In this energy range heavy ion reactions form highly excited nuclear systems. They can decay by emitting intermediate mass fragments (IMF). The origin of the IMF is still an open question and in recent years it has been of large interest for experimental and theoretical investigations. Competing models have been proposed for the decay mechanism and the experiments have not yet clearly identified the appropriate theoretical approach: sequential decay processes in which equilibrium is reached after a sequence of binary decays, or statistical multifragmentation or istantaneous break up of the sysytem. At present the experiments aiming to characterize the multiple emission of IMF (their multiplicity increases with the bombarding energy) are still rather incomplete, although more information has been acquired through exclusive measurements. More exclusive experiments are thus necessary and they should be as complete as possible.

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With this in mind a detection system has been built with low energy threshold, high granularity and large angular coverage for the study of nuclear reactions at intermediate energies using the reverse kinematics technique. This technique has already proven to be efficient and permits, focusing forward the emitted fragments, to reduce the geometrical extension of the detector. The apparatus is designed to have an angular aperture of about ±25° and is suited to study systems with asymmetry up to 0.5, at 50 A MeV. In the following a detailed techical description of the detector array is reported.

2 - THE APPARATUS

The apparatus, schematically shown in fig. 1, is based on 48 identical modules: their front surfaces are tangent to a 50 cm radius sphere, centered in the target.

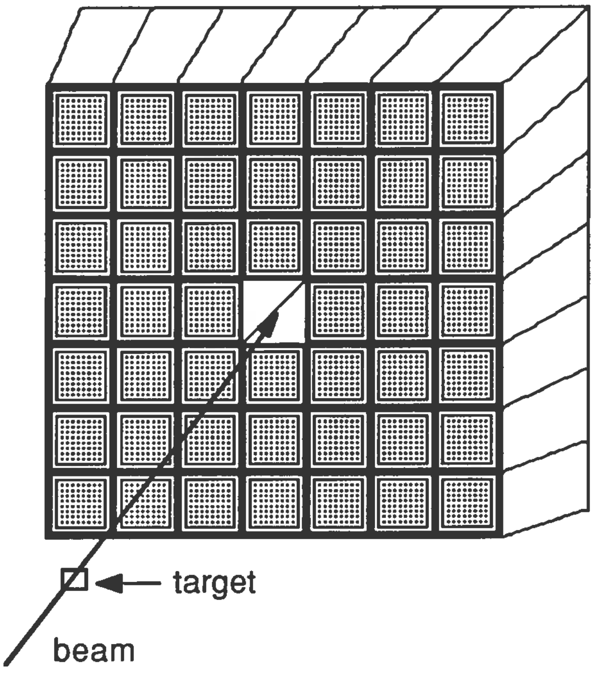


FIG. 1 - Very schematic view of the 48 modules of the apparatus.

Each module, sketched in fig. 2, is shaped as a truncated pyramid (170 mm high) with square base (side length = 70 mm) and contains a three-detector telescope: a ionization chamber, a solid state detector (Si) and a scintillating crystal (CsI).

Each module is closed, on the rear side, by a metallic structure that holds the telescope elements and allocates all the connectors for the detector signals and the gas flow.

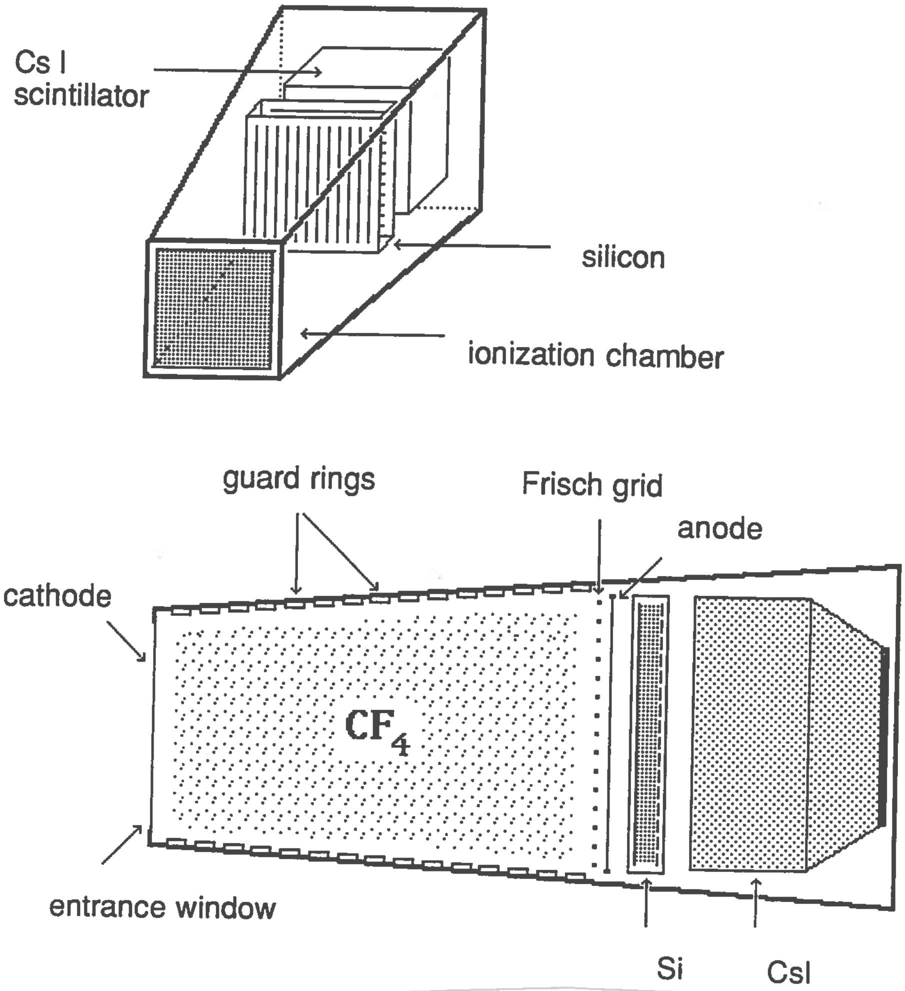


FIG. 2 - Sketch of the three-detector telescope.

The modules, in groups of three or four elements, are inserted on 14 aluminium boxes which contain the preamplifiers (PA)$^{(1)}$, the valves for the gas flow (see fig. 6) and the temperature and pressure transducers.All the aluminium boxes lean on a rectified basement which is supported by a carriage that allows the position adjustement in three dimensions.

Each detail of the modules, of the aluminium boxes and of the whole mechanics required an accurate study and the solution of a variety of problems, some of which are hereafter described.

3 - IONIZATION CHAMBER

The pyramidal envelope of each module is, for a lenght of 85 mm, the ionization chamber (IC). The walls are made of 2 mm epoxidic resin foils (G10), externally coated by a thin and golded copper layer acting as electrostatic shield. The G10 material has been chosen because of its good characteristics as electric insulator and mechanical strength. The walls are assembled using a two-component glue (AW 106 and AW 953, 100:80 mixing ratio) and their rims are shaped to assure a good vacuum sealing.

Furthermore one of the IC walls is obtained overlapping two 1 mm thick G10 sheets. In this way it is possible to obtain a channel where the gas can flow, without any active area loss as it would be if internal tubes were used, and enter the IC very near the front side, assuring a suitable gas replacement in the whole active volume.

The ionization chamber is of the axial type : the entrance window is aluminized on the inner side,acting as cathode; the Frisch grid and the anode define the active volume and are mounted on the rear cover. We have chosen the axial configuration mainly because it requires smaller dead space than the transversal type. Furthermore, if a particular experiment requires this feature, the peculiar possibility (2) of the axial chambers to identify the atomic number of ions stopped in the active volume can be exploited (in this case, as no signal is obtained from the Si detector, the DE-E technique is of no use). Ions of any Z value stop in the IC for energy values anyhow lower than 2.5 A MeV.

The entrance window is a mylar foil (1.5 or 3.0 µm thick) mounted on a 4 mm wide G10 frame and supported by a stainless steel mesh (0.1 mm diameter, 10 mm pitch) held by a frame that defines the entrance area of the telescope (42.4 x 42.4 mm^2).The anode is 1.5 µm aluminized mylar mounted on a thin G10 frame. The electric contact between the anode and the wiring to the preamplifier is obtained throught a thin Cu-Be strip screwed on the anode. The Frish grid (95% transparency) is soldered on a Cu-coated G10 frame and is electrically grounded by means of a spring contact on the wall of the external covering.

From the cathode to the anode there are 36 guard rings obtained with golded Cu strips on the four walls of the chamber : they assure the uniformity of the electric field in the active volume.

The first ring is connected to the cathode by two spring contacts and to the cathodic high voltage through a copper strip in the wall obtained from two G10 sheets, the same for the channel of the gas flow. The copper strip ends in the rear part of the module in such a way that, when the back cover is inserted, a Cu-Be spring assures the contact with the high voltage feedthrough. In a similar way the ground on the back plate is connected to the last guard ring and to the Frisch grid.

The ionization chamber is operated with CF_4. This gas has been chosen for the high density (0.837 mg/cm^3) and the high drift velocity (10 cm/µsec at 1V/cm/torr) , important to reduce the electron collection times and the recombination rate between electrons and positive ions. Typical working pressures are between 200 and 300 mbar. These values correspond to about 27 and 40 µm of silicon respectively.

The vacuum sealing between the pyramidal envelope and the rear flange is obtained using a siliconic rubber foil.

The assembly of all the parts here described demands for high precision and care : many different mechanical masks have been developed to assure the uniformity of the final modules.

4 - SILICON DETECTOR

The silicon detectors, position sensitive in two coordinates, have an active area of 49.5x49.5 mm^2 and a thickness of 500 μm. The range-energy relation for heavy ions in the silicon is shows in fig. 3.

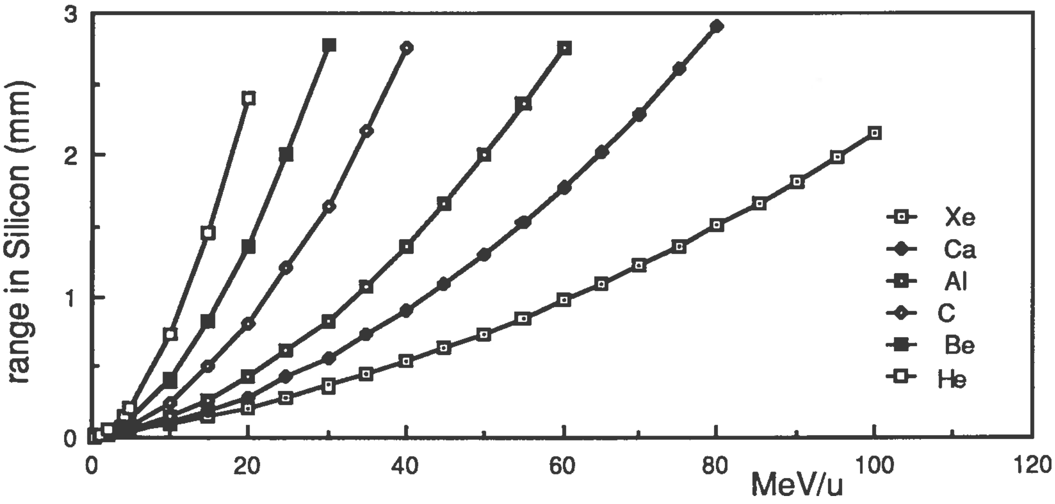
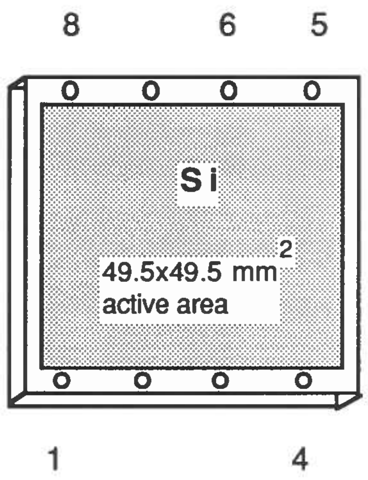


FIG. 3 - Range-Energy relation in silicon for different ions.

Presently we can use two different types. The first one$^{(3)}$ is a strip detector, with 16 orizonthal strips on one side and 16 vertical strips on the other side. The strips on each side are connected through 100 ohm resistors to forme resistive chains, at the ends of which the signals containing the position information are obtained. The energy lost in the detector is given by the sum of the two signals of any of the two chains. The main advantage of this type of silicon detector is that the position information, reflecting the strip structure, is discrete. Thus no calibration is required$^{(4)}$.

The second type of silicon detector has a resistive cathode: the charge flowing to this electrode is divided by the resistive layer, as a non-linear function of the position, in four signals available at the corners of the detector. The energy loss information is given directly by the anodic signal. This fact and the small reverse current, lower than in the previous type, give eventually a better energy resolution. This is obviously an advantage as the energy resolution is also important for the Z resolving power.

The silicon detectors are mounted on G10 frames designed and produced in our laboratory to minimize the dead area (total dimensions 55x57mm^2), following the experience acquired in the project of the experimental apparatus for the Bevalac facility $^{(6)}$. Three frames are used : the upper and the lower ones hold the detector in place and allocate the contacts while the intermediate frame has the function of avoiding any pressure to the silicon wafer.



external dimensions :

55x57 mm

Pins :

1,4,5,8 front side, position signals

6 rear side, energy signal, positive bias

FIG. 4 - Sketch of the assembly for the Si detector.

Eight pins (fig. 4) are present on the silicon frame. Some are used by the silicon itself while others are for the anodic signal and to mechanically support the anode-Frisch grid block. All the pins find their appropriate connections on the frame supporting the CsI crystal.

5. - CsI SCINTILLATOR

This crystal has been chosen because of the advantages (7) that it presents with respect to other possible candidates. Even if the light yield is only 45% of the NaI, the CsI crystal does not require any particular covering because it is only slightly igroscopic, it can hold fairly well mechanical shocks and can be easily machined. A fairly high (4.51 gr/cm^3) density makes this scintillator suitable to stop in a few centimeters ions in the energy range we are interested in. The light emission spectrum, with a maximum around 550 nm, fits with the response curve of the silicon photodiodes : the quantic efficiency is around 65% at 550 nm.

Furthermore, no saturation (8) of the light yield as a function of the deposited energy has been found up to now and the recent literature shows that the CsI response function is reasonably linear as a function of the energy for highy ionizing ions (9).

The crystals are 4.1 cm high and for about 2 cm are shaped as truncated pyramids that acts as light guides. The larger base is 51x51 mm^2 while the smaller one (25x25 mm^2) is apt to be coupled to the photodiode.

As about 50% of the scintillation light may be lost through the lateral walls, particular care has been devoted to the treatment of these surfaces, with the aim to optimize the light collection. The best solution we found requires:

- To polish the crystal surfaces as smooth and transparent as possible. Different kinds of felts have been used, with alumina powder (0.05 and 0.3 μm diameter)in pure alcohol, with the essential cunning of drying frequently the crystal with a buckskin.

- To wrap the lateral surfaces with 10 layers of 0.1μm teflon foils. Teflon (PTFE) has an index of refraction (n=1.6) similar to the value of the CsI (n=1.8). The wrapping has to be as adherent as possible to prevent the trapping of air bubbles that would cause losses in the light collection. On the front surface, where the ions enter the scintillator, the use of a reflector that causes very small energy losses is mandatory. Satisfactory results have been obtained using 1.5 μm thick mylar, aluminized on both sides.

Laboratory tests on the energy resolution with radiactive sources gave, using a phototube sensitive to the blue wave-lenght region, results very similar to what can be found in literature. Anyhow we have choosen to use photodiodes as read-out elements because of the obvious advantages as far as the space occupation and the handyness are concerned. We mounted the Hamamatsu S-3204-04 photodiodes (80 pF, 18*18 mm^2 active area) selected to have a dark current lower than 15 nA.

The optical coupling is obtained using a two-component siliconic glue (Silgel RTV 612 A+B by Wacker), that has a good trasmission in the wave-lenght of interest and gives a stable contact even if it can be easily removed without any damage to the crystal or to the photodiode. The Silgel glue has a refraction index of 1.465 and has to be degased in vacuum before the use, to avoid the building up of bubbles during the polymerization of the thin layer that makes the optical contact.

Eventually the performances are tested and the wrapped crystall is placed in the crystal holder where two plexiglass wedges keep it in place. We stress that the preamplifier for the PD signal is located inside the detector module, very near the crystal. The minimization of the distance between the PD and the PA is in fact very important to have good performances.

6. - GAS FLOW AND CONTROL SYSTEMS

The gas supplying system is based on two CF_4 bottles (fig. 5), connected to a system of valves which allows the substitution of one of the bottles without stopping the gas flow to the detectors. A nitrogen bottle is also available, to be used in the initial stages of operation and when going back to atmospheric pressure. Throught stainless steel piping the gas flows from the bottles, placed outside the scattering chamber hall, to a panel very near the reaction chamber where it continues to the total flow gauge and to the two-fold filtering system (Matheson 6406). The gas exits from this system with oxigen and water vapour contents reduced to a few p.p.m.. The gas enters the refrigerating cylinder and , through a remote-controlled safety valve (S1), reaches the scattering chamber on a special flange designed to have the gas inlet tube (teflon, 6mm dia.) running inside the 40 KF bellow used for the gas outlet (fig.6). In this way the high pressure piping (≈2 bar) is never in contact with the vacuum of the scattering chamber. The gas flow is then divided, by a radially shaped distributor, between 14 teflon tubes. Each of these supplies one of the 14 aluminium boxes, reaching the gas-flow control valves (MKS 248A 5000) (10) running inside the 16KF bellows for the gas output. The gas enters eventually the ionization chambers after on/off valves (SIRAI 401, modified) which control the use of any individual detector.

The gas exits from each module, filling the aluminium box volume, through a group of two on/off valves. The first one, normally closed (SIRAI 301), is used only in the pre-vacuum stage while the second one is normally open and can be closed in case that particular detector has to be isolated. This valve holds a special "window breakage" sensor, essentially made by a golded Cu-Be strip that is forced to touch the electrically grounded body of the sensor whenever the window breakage redirects the gas flow from the aluminium box to the detector. A signal is thus generated which informs the gas control system. This system reacts closing the input and output valves related to this detector. This sensor has been designed and built in our laboratory as no commercial device is available in the pressure range here of interest (30-300 mbar).

From the aluminium boxes the gas flows in the outlet bellows and, through the on/off safety valve S2 (MKS 153) and the total flow valve F1 (MKS 258BY), to the dry root pump (Edwards DP40). Two KNF dry compressors and a filtering system (Saes Getters) allow eventually to reuse the gas. A suitable control system will mix this gas with the one from the bottles, in case of necessity.

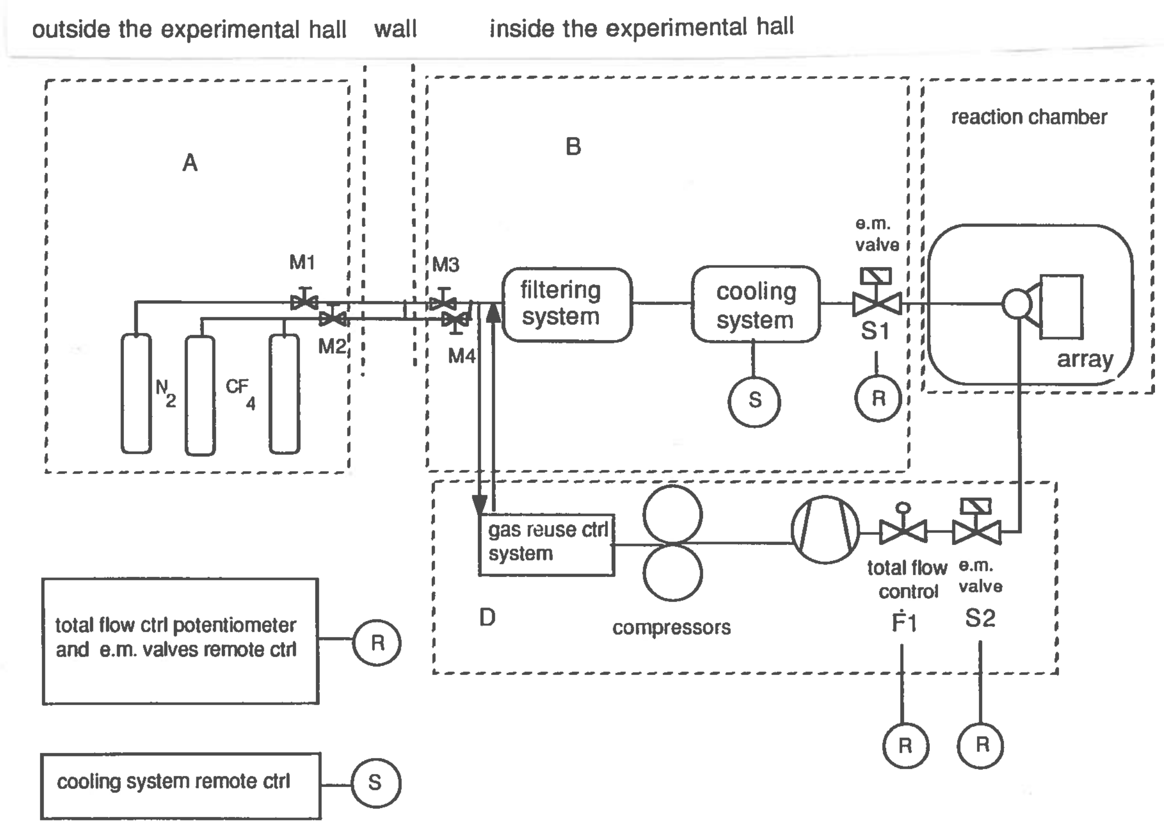


FIG. 5 - Overwiew digram of the gas-flow system

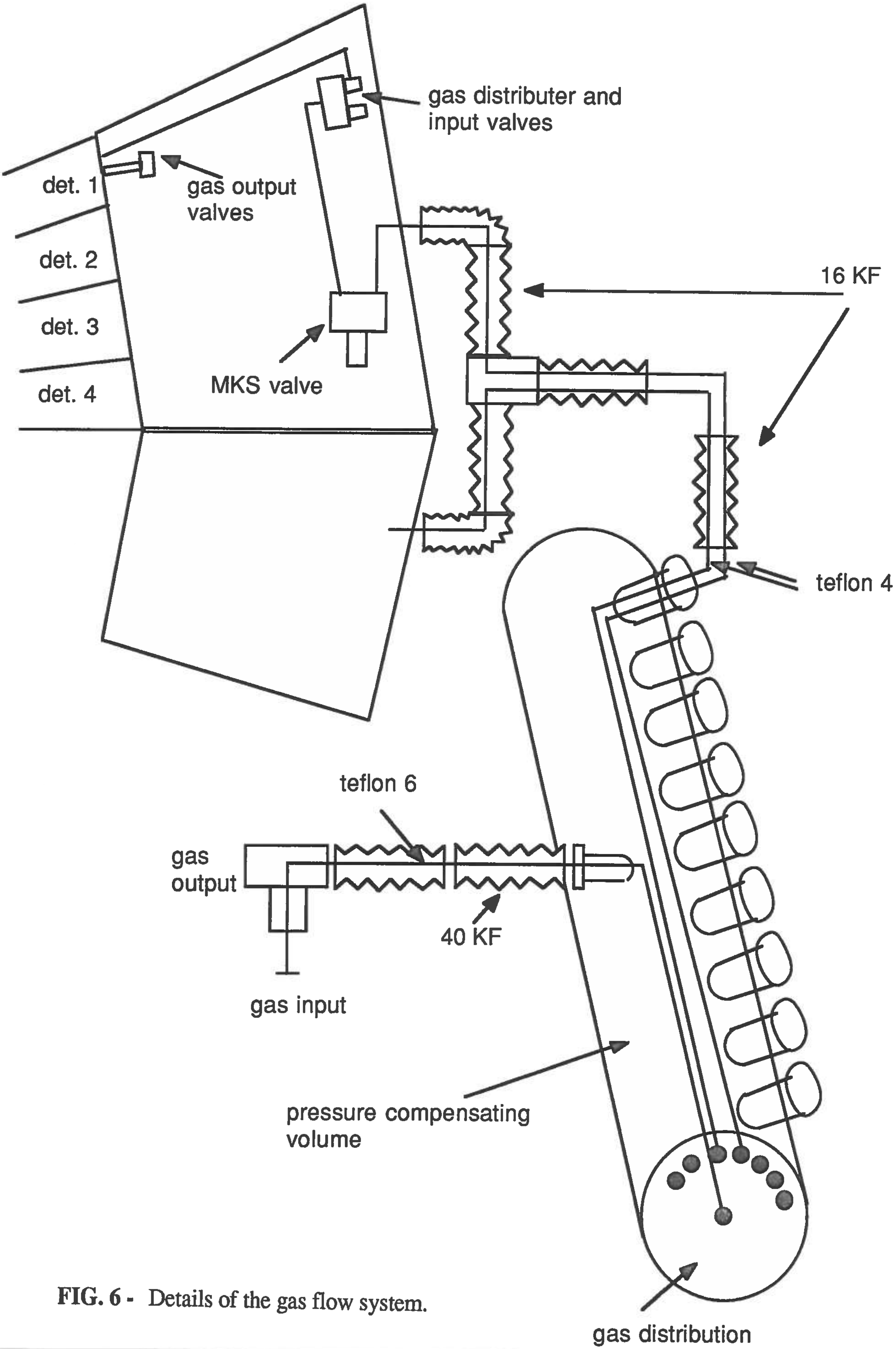


FIG. 6 - Details of the gas flow system.

As laboratory tests have shown that the temperature inside the aluminium boxes, even with the refrigerated gas flow, reaches high values, due to the power dissipated by the PA and all the valves, the aluminium boxes themselves are refrigerated. One of their walls has a vacuum sealed channel where the refrigerated liquid can flow. To avoid contamination problems to the scattering chamber in case of leakages of the refrigerating system, pure alchool is used. The temperatures of the gas at the entrance of the ionization chambers and on the PA boards are remotely monitored.

CONCLUSIONS

Many satisfactory tests of the apparatus have shown that it performs as required, beeing able to discriminate the atomic number also at low energies and having a position resolution apt to measure angular correlations.

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