5. Target - Ion sources:

5.1. - Introduction.

In order to describe the status of the target-ion source, in fig.5.1 the target assembly (a), including the transfer tube (b), the ionizing device (source) (c), the target-ion source case (d) and the front end (e) are indicated.

Although developed in close and continuos collaboration, the outer parts (d) and the front-end (e) are not directly developed by the target-ion source group. They will not be described here.

5.2. - The Target Assembly.

In 1997 Referees Meeting, the priority of designing a target assembly able to withstand around 1kW power from the primary beam was pointed out. Some preliminary studies on a new concept graphite target were presented. The final results are now available and show its feasibility. The decision to build and test such a new type of target assembly has been taken. The constructive drawings are ready (fig.5.2) and companies for bids are being contacted. The target assembly will be ready next fall. The following paragraphs will describe the new target concept and its validation.

5.2.1. - Target Requirements.

A new kind of geometry has been studied for graphite targets in order to solve the problem of dissipating the power released by the primary beam in the target itself from its entrance to its complete stop. The characteristics of EXCYT primary beams are:

$A \leq 40$; $I \leq 1$ pμA; $E \leq 100$ MeV/amu. As an average value, 1 kW of power is released by the beam to the target. The way chosen to dissipate the power is by heat radiation, due to its simplicity and reliability compared to the other methods.

In order and to speed up the release process of the products of interest, the temperature must be as high as possible and its distribution in the target must be as homogeneous as possible. On the other hand, to preserve the integrity of the graphite target, a maximum temperature of 2000-2200 °C must not be exceeded.

5.2.2. - Target Concept.

Let's consider the simplest geometry: a cylinder of thickness t_0 equal to the range R of a primary beam particle (fig.5.3-a). The heat radiation and consequent dissipation from the cylinder surface $S_0 = S_{bases} + S_{side}$ does not ensure an efficient cooling. In fact, a beam power well below the foreseen values for EXCYT is enough to exceed the maximum allowed temperature.

The basic idea is to modify the target geometry, by tilting the cylinder as shown in fig.5.3-b. It can be shown by geometric considerations that by increasing the angle α, the volume of the target is unchanged as well as R, the range of each interacting particle. Nevertheless, by increasing the angle α, the thickness t decreases ($t = t_0 \cos \alpha$) and the overall surface increases ($S = (1/\cos \alpha) S_{bases} + S_{side}$).

The main reason why such a geometry modifies the temperature distribution, in particular lowering the maximum temperature, is that the same amount of power Q is released in a target with the same volume but a larger value of S, the surface available for heat dissipation. As the material emissivity ε is unchanged, the result is that a lower temperature T is needed for the irradiation of the same amount of power Q.

($Q = \sigma_0 \varepsilon S T^4$ with σ_0 Plank constant)

It must be noticed that the above mentioned effect greatly increases with increasing α, due to the factor ($1/\cos \alpha$). (fig.5.3-c). In principle, for $\alpha = 90°$ there is no theoretical limit either for the surface value and for the amount of power which can be evacuated. However, from a practical point of view there is a limit to the α value given by the target overall length L (which cannot exceed a reasonable size for the container) and by the thickness t (reduced by increasing α).

5.2.3. - Concept validation by computer simulations.

In order to test the validity of the concept it has been necessary to carry out computer simulations using the Thermal module of the Finite Element Code ANSYS, which is commercially available. For any geometry the ANSYS thermal module implements the tri-dimensional Fourier equations for heat transport in media of known thermal conductivity. It also implements the Stefan-Boltzmann equations for the heat radiation from surfaces of known emissivity, with the evaluation of geometric form factors when required. The code can take into account a value of power generation for each node of the elements in which the geometry is sub-divided.

In this study, a tridimensional model has been created. The thermal-physical properties of the material have been input. The correct radial and axial power distribution originated by the interacting beam in the target volume have been input. The axial power distribution is related to the stopping power, function of the particle energy along its path (see sketch in fig.5.4). The stopping power has been calculated using the code SRIM. Two kinds of radial power distribution of practical interest are simulated. They are due to two kinds of beam profiles: the first is parabolic while the second, generated by a rotating beam, is almost flat.

In order to supply the proper power density values to each ANSYS model node (on the basis of its position in the model, of the stopping power in that point and of the beam profile) the INTERFACE Fortran code has been developed. The way ANSYS, INTERFACE and SRIM are interfaced as schematically shown in fig.5.5. Three different cases have been simulated:

1) (fig.5.6) *Geometry:* α = 10 degrees; cylinder diameter D = 20 mm; overall target length L = 12.7 mm. *Beam:* ^{19}F, 80 Mev/amu, 1 pmicroA, parabolic profile, diameter = D = 20 mm. *Material:* Thermal-physical properties of Graphite UCAR TS 5221, function of temperature (tab. 1). Emissivity ε = 0.9 **.**
2) (fig.5.7) *Geometry:* α = 50 degrees; cylinder diameter D = 20 mm; overall target length L = 33 mm. *Beam:* as # 1. Material: as # 1.
3) (fig.5.8) *Geometry:* as # 2. *Beam:* ^{19}F, 80 Mev/amu, 1 pmicroA, flat profile (rotating beam), diameter =D=20 mm. *Material:* as # 1.

5.2.4. - Simulation results.

The effect of increasing α is clearly shown in case 2) compared to case 1). With all the parameters fixed there is a difference of 257 C° in the maximum temperature, thus reaching the required value of around 2000 C°. By using a flat beam profile (case 3) the maximum target temperature is 1753 C°, with a further reduction of 242 C° compared to case b.

5.2.5. - Validity and advantages of the concept.

The validity of this target concept has been shown by computer simulations. Since the beam interacts with the ***whole*** target, not only is reduced the volume of the latter to the strictly necessary value but also are avoided colder support parts where the diffusion and effusion processes are less efficient. Consequently this geometry allows a more homogenous temperature distribution. The minimum volume also implies the smallest possible total surface of the graphite grains, thus minimizing the sticking problems.

The target will be placed inside an external cylindrical heater. For the future target the value of α will be chosen large enough to lower the maximum temperature well below the allowed upper limit. The heater will be used while the beam is on. The electrical power will raise the temperature to the foreseen value, with the advantage of having a more homogenous target temperature. The value of the electrical power will be adjusted to compensate for possible changes in beam intensities, by leaving the angle of the target unchanged.

Finally, it is worth mentioning the easy manufacturing of this kind of target.

5.3. - The source.

Three kinds of sources will be used, based on the drawings of already existing CERN-Isolde models,:

- Plasma discharge ionization source (fig.5.9).
- Positive surface ionization source (fig.5.10).
- Negative surface ionization source(fig.5.11).

Three complete sets of parts for each type of source have been machined by an external company (Plansee, Isolde supplier) and by the LNS workshop. All the three sources are therefore ready for use. A fourth type of source, MIDAS (microwave discharge ion source), for the production of 1+ ions is under development. After the promising results of a first series of tests, an improved prototype is being built. (MIDAS is not developed by the target-ion source group: details are not given here).

5.4. - Ongoing activities.

a) Further studies concerning diffusion and effusion in target and target assemblies are being carried out. In particular, a Fortran code implementing the algorithms of diffusion in different geometries and effusion has been developed.

b) Before commissioning the facility, it is important to have a greater knowledge and gain some practical experience about the chemical interactions between the species of interest, released under atomic and molecular form from the target materials, and parts of the target assembly (the transfer tube in particular). The interaction between volatile forms of the products of interest which are expected to leave the target (for example: F_2 , CF_4, CF_6 …), and various materials at high temperatures under vacuum will be studied. A controlled flow of the above gases will flow through electrically heated pipes, having the same inner diameter and lenght of transfer tubes and made of different candidates materials (tantalum, carbon, molibdenum, rhenium). The gases leaving the heated pipe will be analysed on-line by a gas-spectrometer. Other chemical analyses will be carried out on samples of the pipe after gas flowing. In collaboration with LNS target laboratory, the experimental set-up is beeing built and measurements will start in September.

5.5. - Future Studies and developments.

The high temperature chemistry of Fluorine and Carbon and of Lithium and Carbon will be studied. The results in terms of negative ionization efficiency for fluorine obtained at HRIBF in Oak Ridge using some specially developed cesium-negative surface ion sorces and the results obtained at CERN-Isolde (Tamburella et al.) in the same field are very interesting for our purposes. We plan to develop a negative ion source for fluorine, based on drawings and information from both Laboratories.

5.6. - *Conclusions*

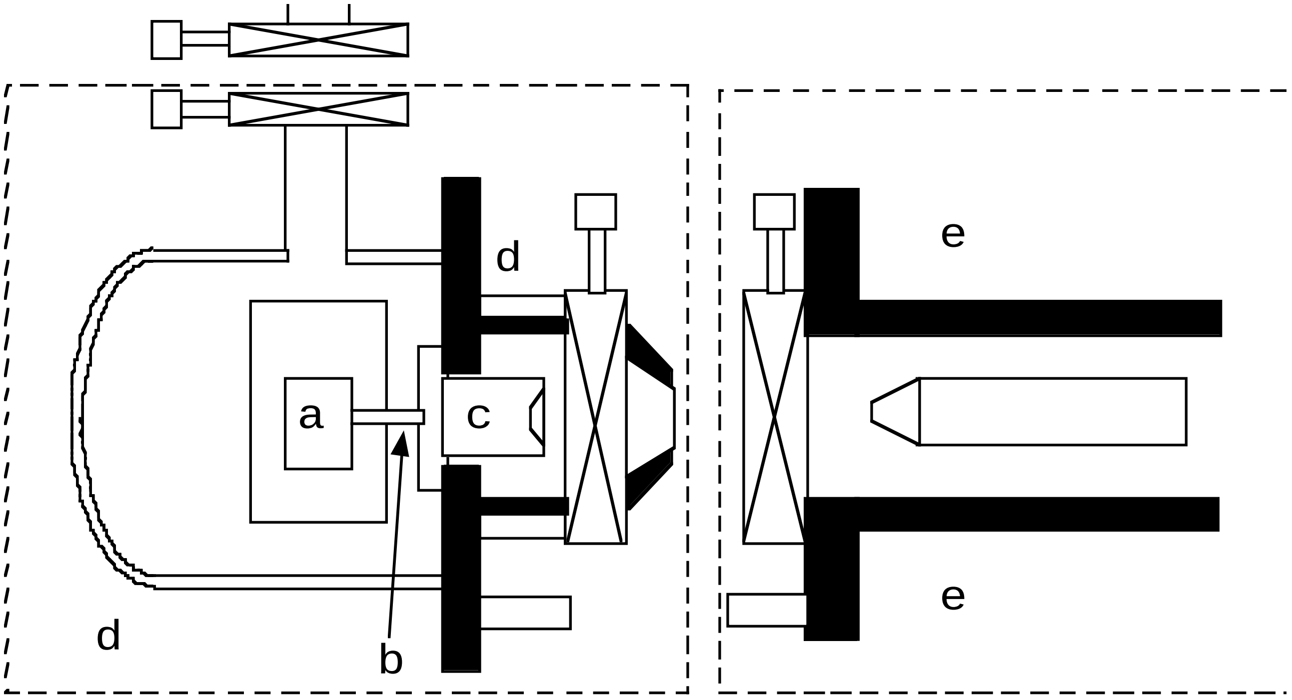
The goal of designing and building a new concept target assembly and a set of sources will be fully reached next fall. Although various theoretical studies will be carried out, experimental activities, before commissioning the facility, would be extremely useful. Among them, temperature measurements and reliability tests for a prototype of the new concept target assembly, using electrical heating and a full power beam, would have a high priority. More in general, the availability of a test-bench for ion sources has become crucial to allow further tests and developments of the various configurations of target assemblies and sources.

2. Table 5.1.

UCAR Specialties
Graphite properties Grade TS 5221 49 B

Apparent density	1.74 g/cm^3
Average particle size	< 0.005 mm
Resistivity	15.0 microhm metro
Flexural strength	31 Mpa
Tensile strength	29.0 Mpa
Compressive strength	62 Mpa
Young modulus	11.0 Gpa
Coeff. Thermal Expansion	4.5 E-6 mm/mm/C°
Thermal Conductivity	82 W/mK
Permeability	<0.002 Darcy’s
Porosity	17%
Hardness	45 Rockwell “H”
Ash Content	35 ppm

Not garanteed typical properties, measured at room temperature.



Target-ion source comp

FRONT-END

Fig. 5.1

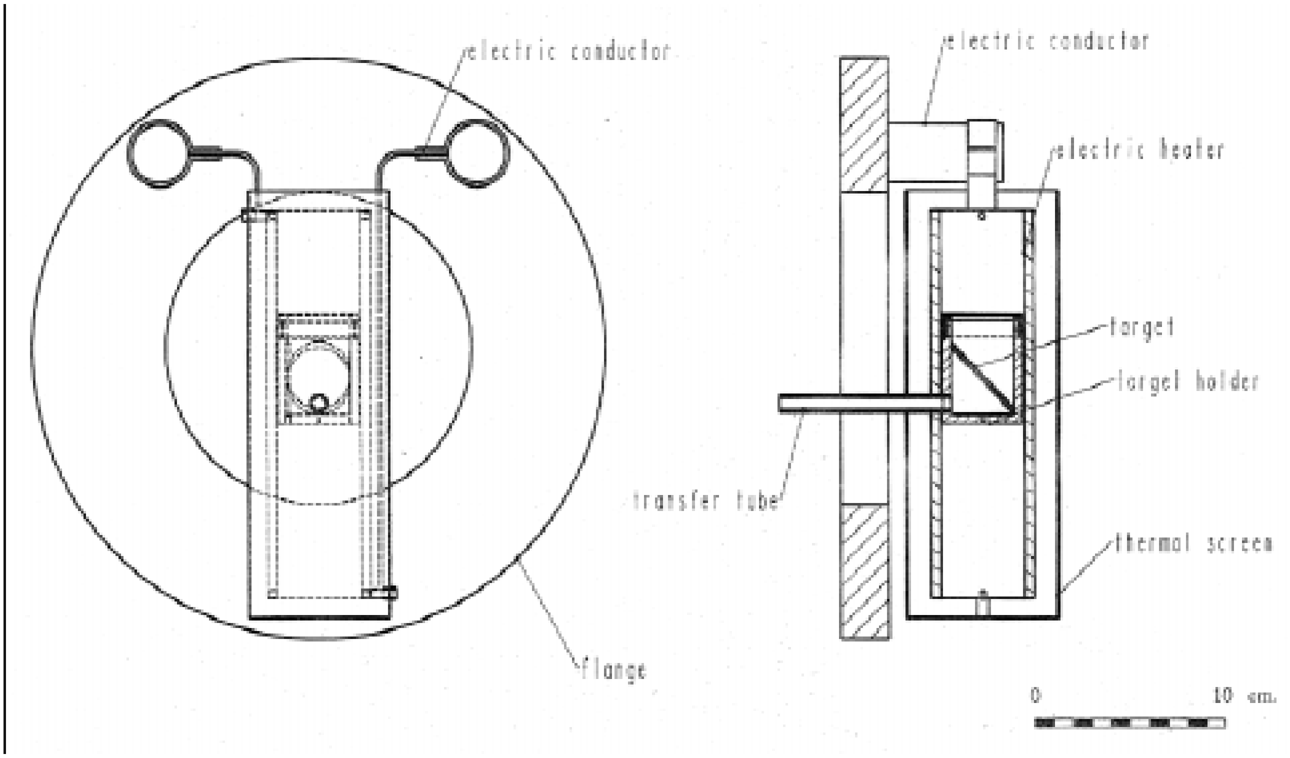


Fig. 5.2

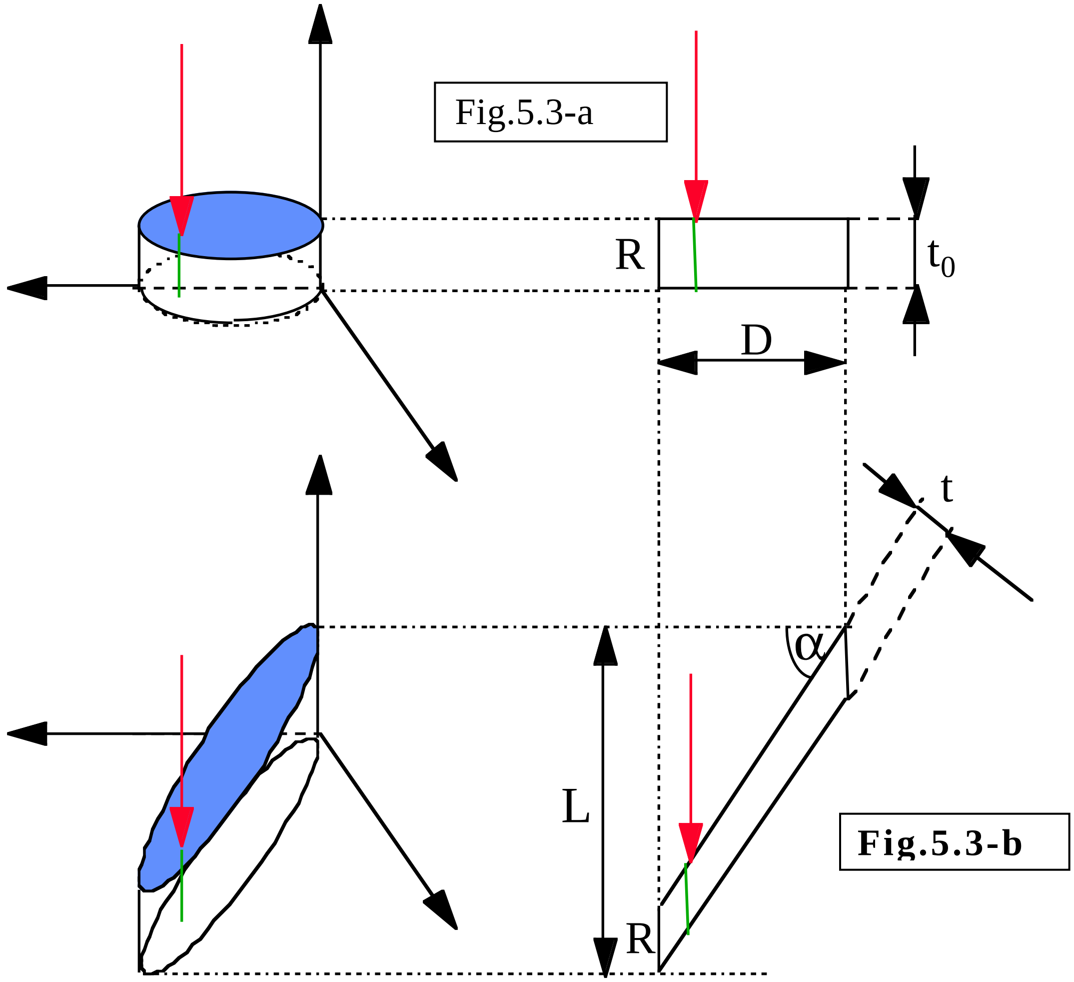


Fig.5.3-a

Fig.5.3-b

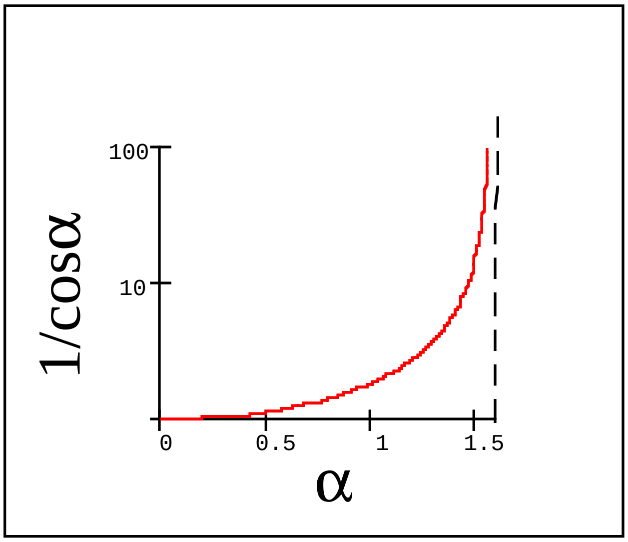


Fig.5.3-c

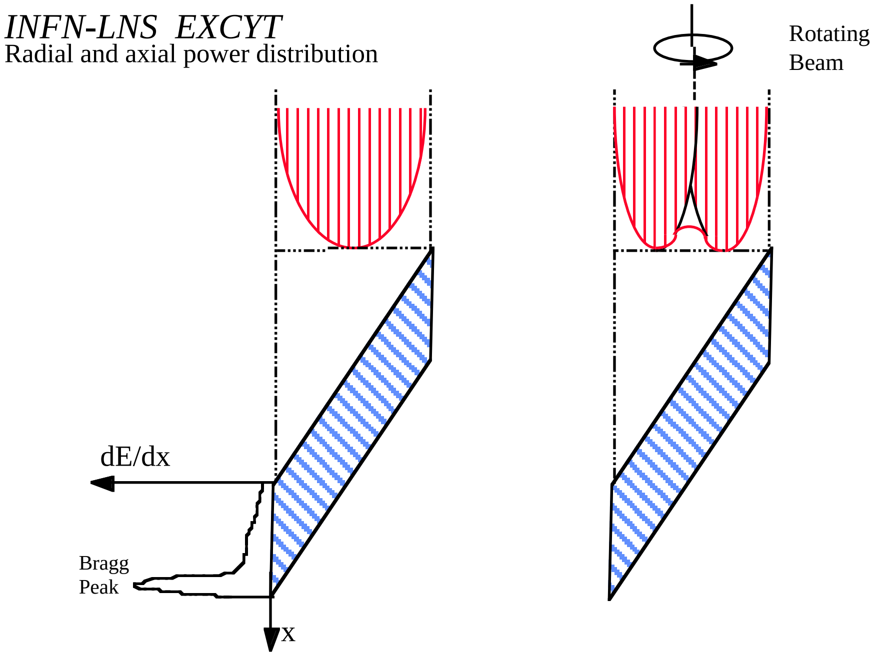

INFN-LNS EXCYT
Radial and axial power distribution
Rotating
Beam
dE/dx
Bragg
Peak
x

Fig. 5.4

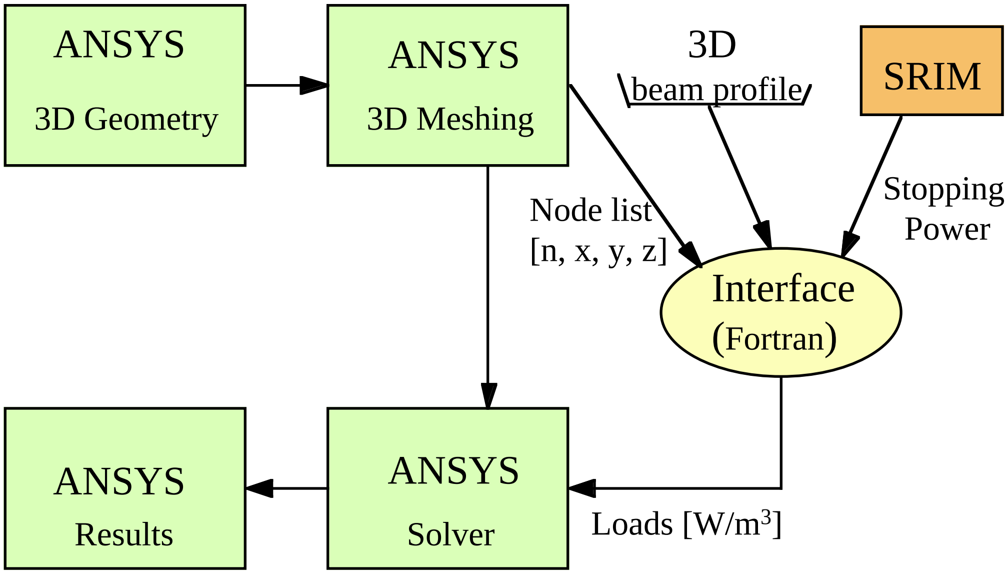
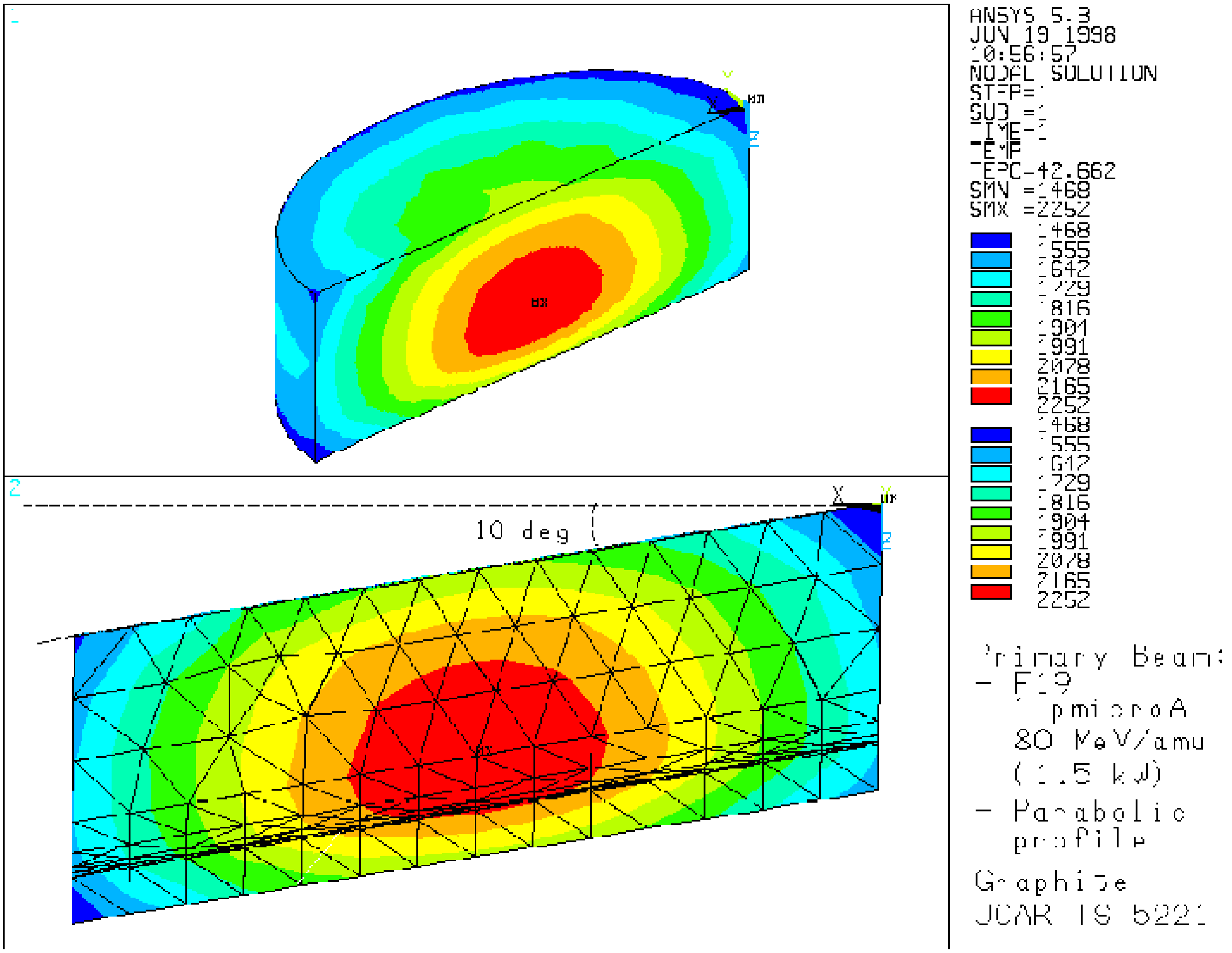

ANSYS
3D Geometry
ANSYS
3D Meshing
3D
beam profile
SRIM
Node list
[n, x, y, z]
Stopping
Power
Interface
(Fortran)
ANSYS
Results
ANSYS
Solver
Loads [W/m^3]

Fig. 5.5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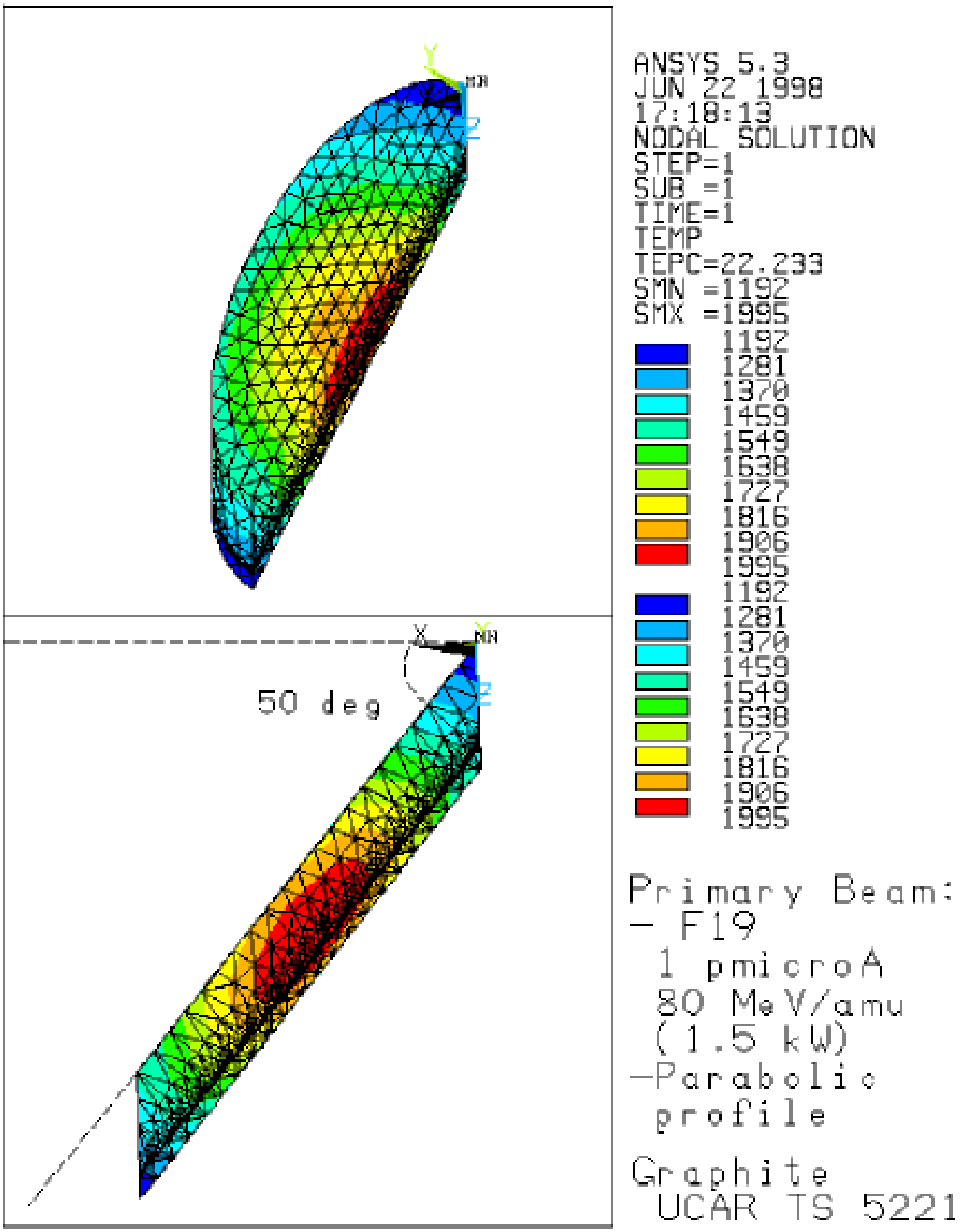
1555
1642
1729
1816
1904
1991
2078
2165
2252
1468
1555
1642
1729
1816
1904
1991
2078
2165
2252
10 deg
X
Y
Z
MX
MN
Primary Beam:
- F19
pmicroA
80 MeV/amu
(1.5 kW)
- Parabolic
profile
Graphite
UCAR IS 5221

Fig. 5.6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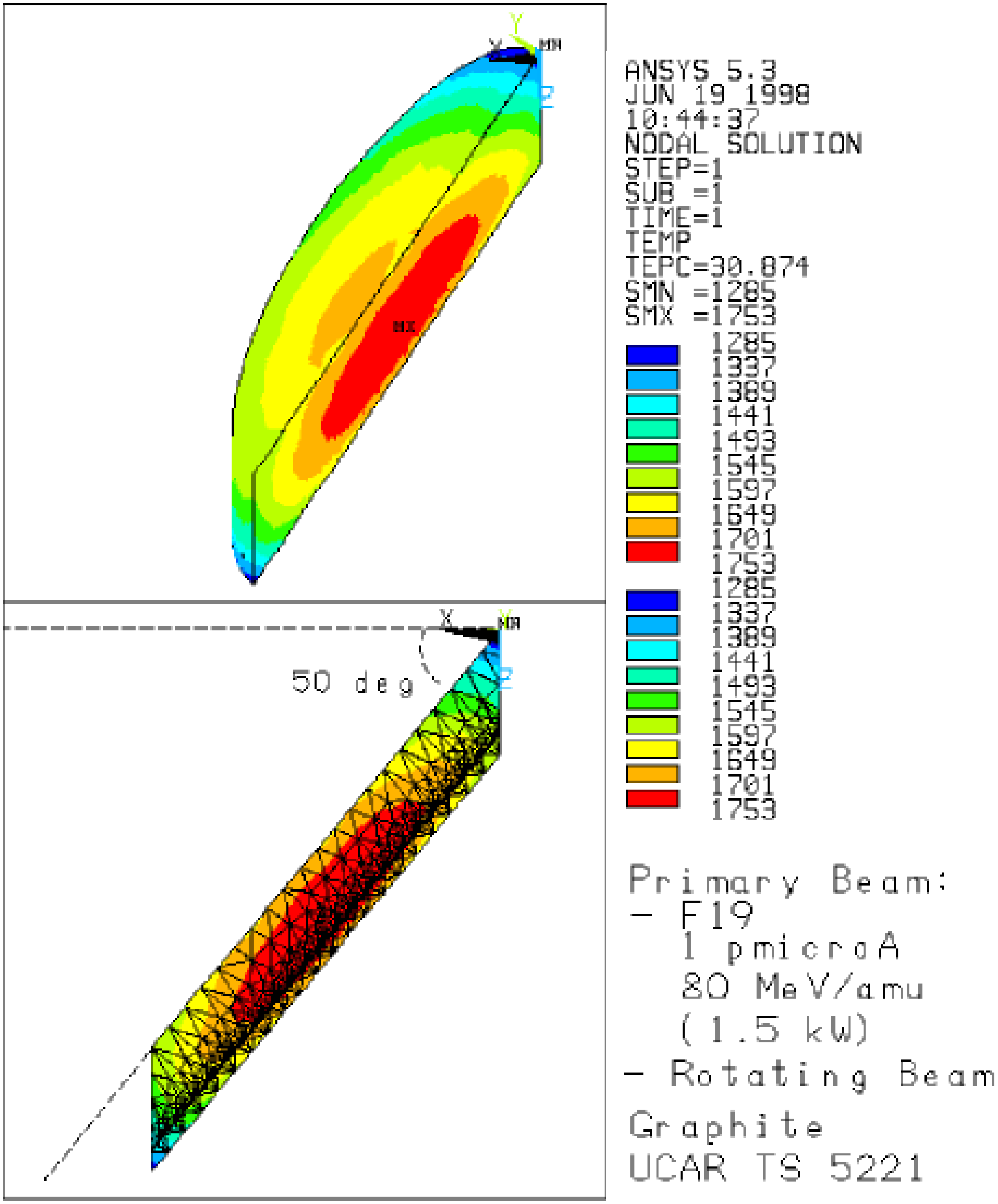
1906
1995
1192
1281
1370
1459
1549
1638
1727
1816
1906
1995
Y
Z
X
MN
MX
50 deg
Primary Beam:
- F19
1 pmicroA
80 MeV/amu
(1.5 kW)
-Parabolic
profile
Graphite
UCAR TS 5221

Fig. 5.7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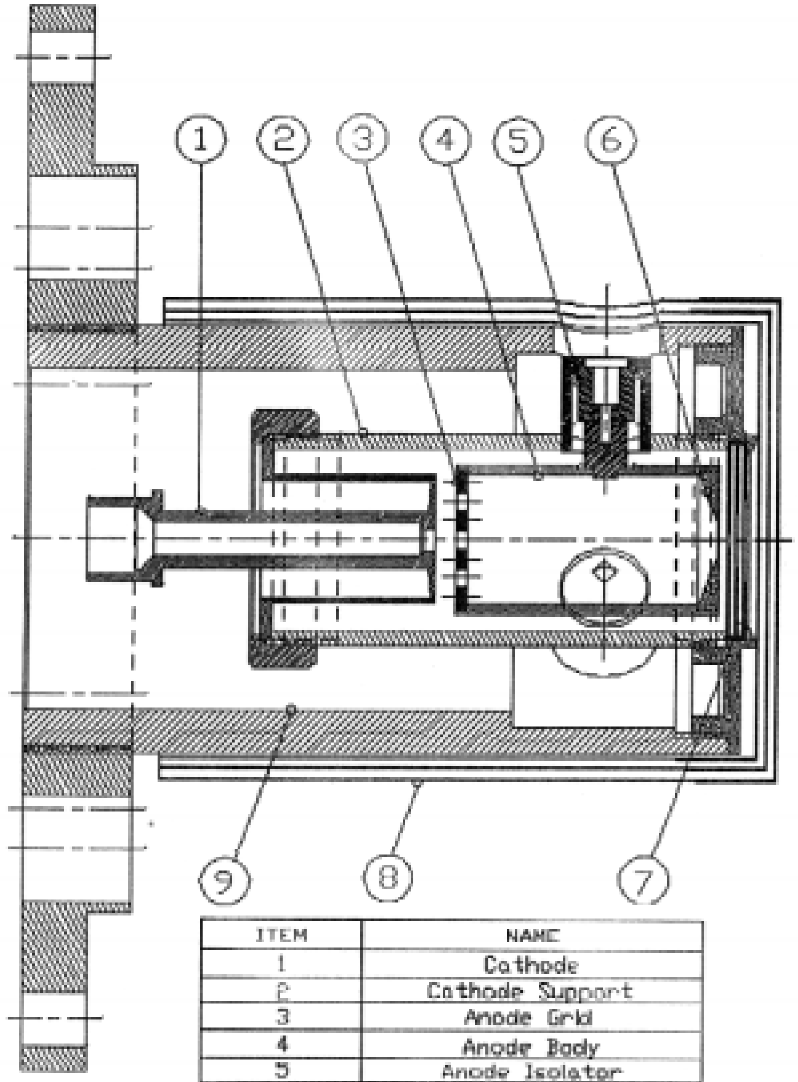
1493
1545
1597
1649
1701
1753
1285
1337
1389
1441
1493
1545
1597
1649
1701
1753
Y
X
Z
MN
MX
50 deg
Primary Beam:
- F19
1 pmicroA
80 MeV/amu
(1.5 kW)
- Rotating Beam
Graphite
UCAR TS 5221

Fig. 5.8



ITEM	NAME
1	Cathode
2	Cathode Support
3	Anode Grid
4	Anode Body
5	Anode Isolator
6	Outlet
7	Thermal Screen
8	External Thermal Screen
9	Support Assembly

Fig. 5.9

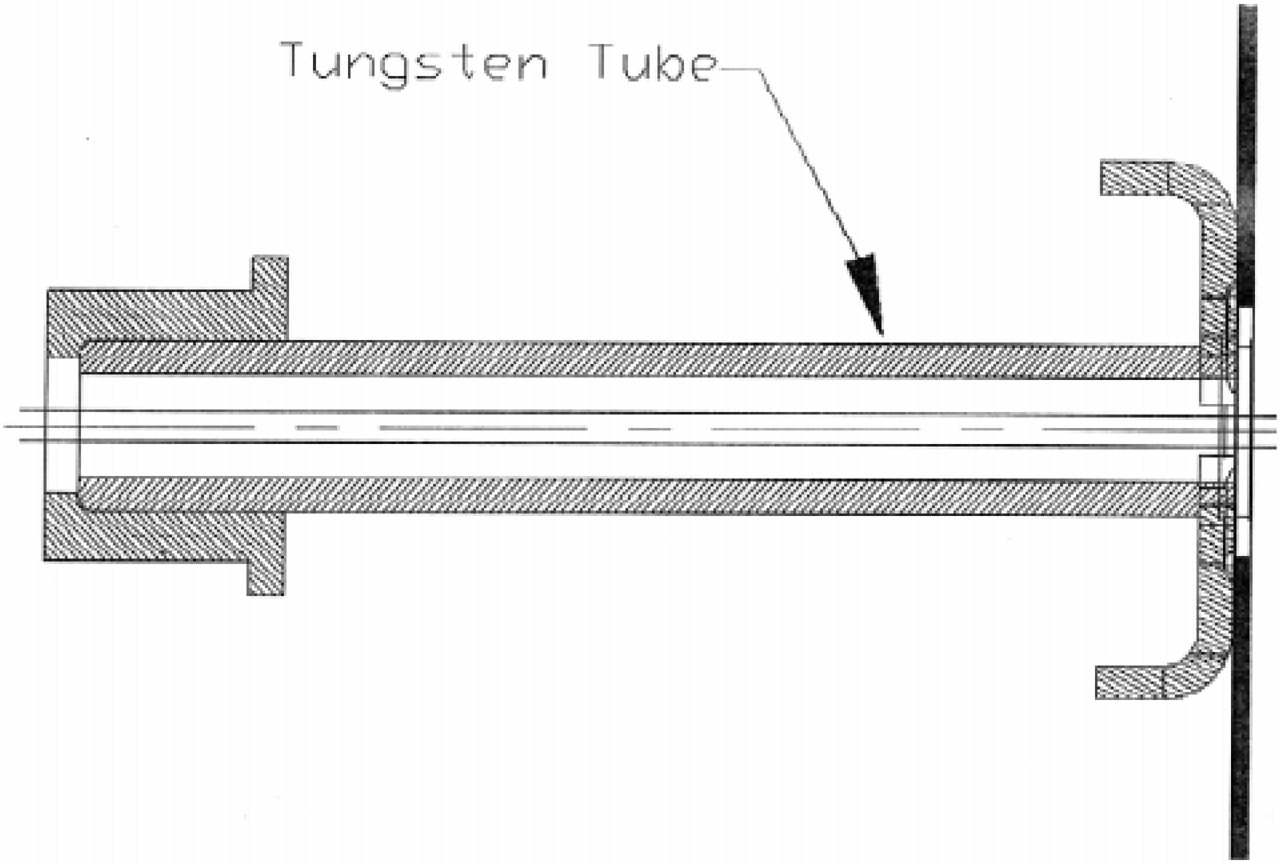
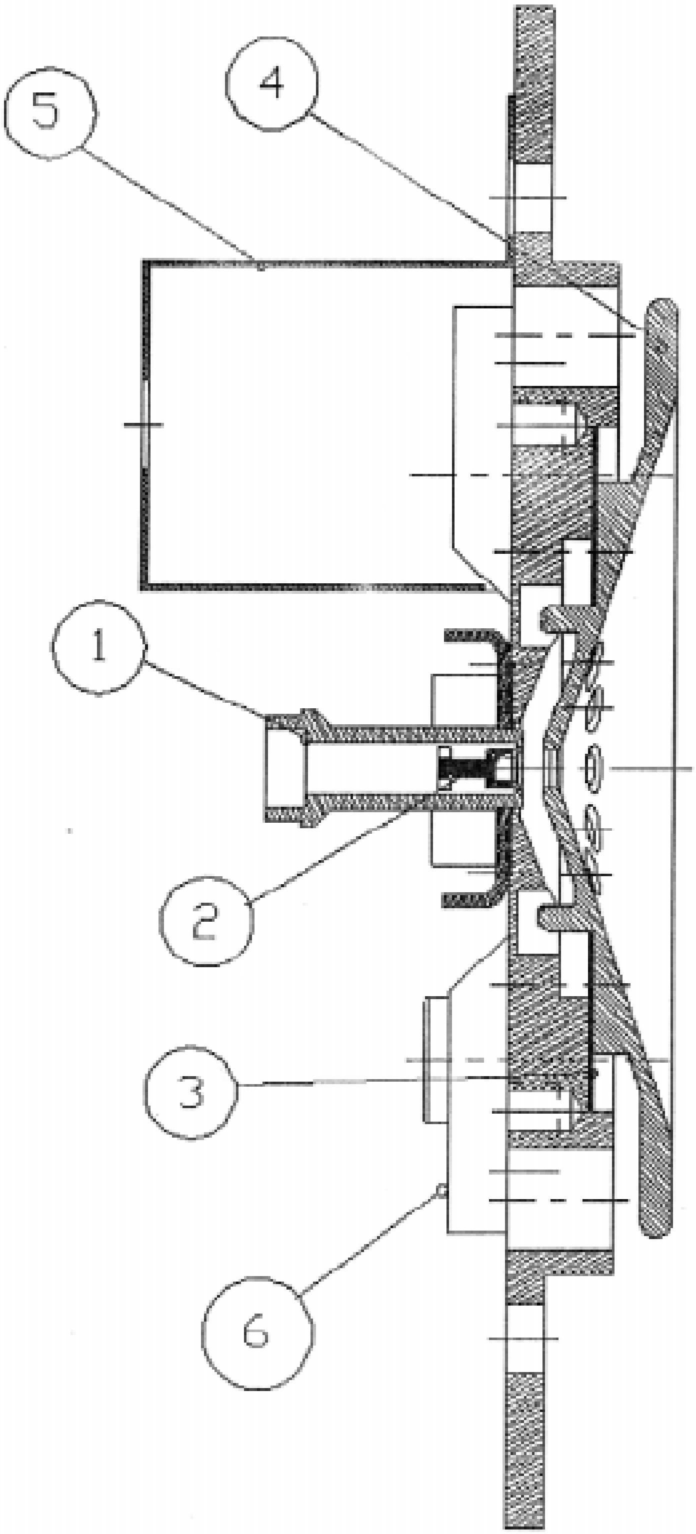


Fig. 5.10



ITEM	NAME
1	LAB6 HOLDER
2	IONIZER
3	ISOLATOR DISK
4	SCREENING ELECTRODE
5	MAGNET SHIELDING
6	POLAR PIECE

Fig. 5.11