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The First Large Cyclotron in Poland

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FOREWORD

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THE FIRST LARGE CYCLOTRON IN POLAND

[Following is the translation of an article by H. Niewodniczanski and J. Zakrzewski entitled "Pierwszy 'Duzy Cyklotron' w Polsce" (English version above) in Nukleonika (Nucleonics), Supplement I, Vol V, No 1/2, 1960, Warsaw, pages 3-27]

The first "large cyclotron" in Poland was put into operation in the Cracow Center, Institute of Nuclear Research, PAN (Polish Academy of Sciences). This cyclotron with electromagnet pole pieces 120 cm in diameter, which accelerates deuterons to about 13 Mev energy, serves for research in nuclear physics. In this article are given a series of detailed data concerning the design and operation of the cyclotron.

1. INTRODUCTION

One of the basic methods of nuclear physics is the study of nuclear reactions occuring during the bombardment of a nucleus with a beam of high energy particles. Accelerators for charged particles are among the most important tools of experimental research.

As is known, in accordance with the understanding concerning international cooperation for the peaceful uses of atomic energy, the USSR has made available to several people's democracies, among them Poland, complete cyclotron installations.

The cyclotron is a cyclic resonance accelerator, constructed for the first time by E. O. Lawrence in 1932. Ions formed inside a vacuum chamber in a constant magnetic field are accelerated many times by a changing electric field of constant frequency equal to the orbital frequency of the particles expressed by the formula

$$f = \frac{\omega}{2\pi} = \frac{q}{m} \cdot \frac{B}{2\pi}$$

where f is the frequency, ω the pulsatance of the electric field corresponding to the angular velocity of the particle, q the electric charge of the particle, m the particle mass, and B the induction of the electric field.

As is seen from the above resonance condition, the orbital frequency of the particles depends upon their mass and, as in accordance with the laws of relativistic mechanics the mass of the particle increases with increase in energy, the synchronization is disturbed. This can be prevented by such an arrangement of the magnetic field where its induction increases radially -- but this contradicts the condition for magnetic focusing of the ions, which is particularly important, especially for particles along trajectories of large radii. There exists, therefore, a natural limitation of the energy of ions accelerated in the cyclotron. Energies attained in practice in the cyclotron (of constant magnetic field and frequency), for example, do not exceed approximately 25 Mev for deuterons, approximately 13 Mev for protons, etc. The maximum kinetic energy of particles accelerated in a cyclotron is defined by the formula

$$E = \frac{1}{2} mv^2 = \frac{q^2}{2m} B^2 r^2$$

Thus with a magnetic induction B, not exceeding in practice 2.0 Weber per m^2 in view of the saturation of the steel, the energy of a particle of a given mass and charge is proportional to the square of the effective radius r of the pole pieces of the electromagnet.

The new Cracow cyclotron is of medium size (pole pieces 120 cm in diameter) and the name "large cyclotron" is not due to its dimensions, but is used to distinguish it from the old, "small cyclotron" (pole pieces 48 cm in diameter) which was constructed in the Center of Nuclear Physics in Cracow proper, as the first instrument of its kind in Poland and put in operation at the end of 1956.

The large cyclotron was constructed from Soviet plans. The building housing it, however, was slightly modified to suit our needs and conditions. The assembly and operation of the equipment, the basic parts for which were supplied by the USSR, were performed with the cooperation of Soviet experts.

Construction work started in the second quarter of 1956. The general contractor was the Industrial Association of Construction of the Lenin Foundry, Building and

Assembly Administration, and the entirety of the construction was directed, and is still directed, by the Investments Administration of Nuclear Studies.

2. BASIC DATA CHARACTERIZING THE LARGE CRACOW CYCLOTRON Y-120

Diameter of electromagnet pole pieces	120	cm
Height of gap between pole pieces	34.5	cm
Overall mass of iron core of electromagnet	120	t
Winding power of electromagnet at a magnetic field of 15 kOe intensity	100	kw
Stability of magnetic field	0.03	%
Power of high frequency generator	120	kw
Frequency of resonance circuit	9-15	Mcs
Stability of frequency	0.01	%
Amplitude of voltage between dees	150	kv
Internal height of accelerating chamber	17	cm
Effective end-radius	52.5	cm
Deflector voltage	60	kv
Deuteron energy	13	Mev
Energy of α-particles	26	Mev
Ion current on internal target	1	mA

Figure 1 shows the general appearance of the electromagnet with mounted acceleration chamber and resonance lines.

3. DESCRIPTION OF CYCLOTRON SETUP

One can distinguish the following basic technological units of the cyclotron setup: main electromagnet, high frequency generator, accelerator chamber with resonance lines, focusing system for extracted beam, vacuum system, cooling and ventilating system, power system, and control and safety system.

Electromagnet. The core of the electromagnet, in the form of two letters E inverted relative to each other and of a mass of 120 tons and overall dimensions of 4.35 x 2.86 x 1.5 m, is composed of 10 parts. The yoke is made of CT-3 steel laminations and is 40 mm thick. The core is laminated and 100 mm thick. The gap between the electromagnet poles is 345 mm, the eccentricity of poles is 0.9 mm, and the inclination with respect to the ground is 0.15 mm/m.

The pole pieces are the covers of the accelerating chamber made of CT-3 steel, 72.5 mm thick. Between the poles and the chamber covers are two slots for the target "shims" and 8 remotely controlled magnetic blocks about 10 mm thick. On the inside of the chamber, on the other hand, are placed the ring "shims."

The winding of the electromagnet consists of two coils of a mass of 15 tons divided into 14 sections of 48 coils each. It is made from copper tubing 20 mm in diameter through which passes the cooling distilled water (at a rate of approximately 25 liter per minute). The winding is fed from a direct-current generator of 230 volt and 135 kw power, with a stability of the current intensity of 0.03%. In addition, there are two more coils on the electromagnet poles, 50 coils each, fed from 110 v storage batteries with the current reaching 5 amperes. They serve to regulate the position of the central mid plane.

Figure 2 shows the magnetizing characteristic $B = f(I)$, and Fig. 3 the radial fall-off of the magnetic field $\Delta B/B = (B(r) - B(o))/B(o)$ for the magnetic induction $B(o) = 1.42$ Weber/m^2, where $B(o)$ is the induction in the central plane between the pole pieces on their axis, and $B(r)$ the induction on the radius r. Assuming $\Delta B/B = 2.15\%$, an end radius of $r = 525$ mm can be taken. For these values, the maximum azimuthal variation amounts to 0.14%.

<u>High frequency generator</u>. The high frequency generator produces a changing electric field regulated between 8 and 16 Mcs and an amplitude of 150 kv between the accelerating electrodes, the dees. Its high frequenc circuit (Fig. 4) consists of a master generator, an amplifier-follower, a phase shifter, and a five-stage power amplifier. In the last three stages, a grounded-gri system was used which does not require neutralization. The last stage, with a rated power of 120 kw, using two TY-23 A triodes in push-pull, is capacity coupled with the feeder line, i.e., the lines feeding resonant current to the dees. These lines are made of insulated concentric copper tubes, 206 and 75 mm in diameter, 25.3 m in length, and 2 x 60 ohm wave resistance.

The high frequency generator may work: 1) with excitation independent of the master generator with a frequency stabilization of 0.01%; 2) by self-excitation with application of feedback from the dees to the grid of the first-stage tube (by means of an adjustable phase shifter); 3) by mixed excitation, especially effective for impulse action during the training of the accelerator chamber.

To protect the setup in case of a break-down between the dees in the chamber, the high frequency voltage is switched off by means of quick blocking of the tubes of the first and second stages of the amplifier. This is accomplished by means of a so-called manipulator, which serves simultaneously as a pulse modulator with a regulated repetition frequency of 5-300 cycles at a duty cycle variation for 2 to 500, and also for the reception of individual pulses of lengths 0.1 msec - 1 min.

The last three stages of the amplifier of the high frequency power regulator are cooled with distilled water (about 300 liter per minute). When the temperature of the cooling water rises to 60°C there appears a warning signal and above 65°C the voltage is cut off automatically.

Accelerating chamber and resonance lines. The accelerating chamber is composed of non-magnetic plates, with the exception of the covers which are simultaneously the pole pieces. The individual joints have rubber vacuum gaskets. On the inside, the chamber, 170 mm in height, is covered with an electroplated layer of copper 0.05 mm thick, and at the joints it has contact springs in order to improve conductivity at high frequency. In the side walls of the chamber are Plexiglas peep-holes, openings for the introduction of the ion source, the tuners' lead, electrodes for measuring the voltage on the dees, and probes. During assembly the chamber is placed between the poles of the electromagnet on four rollers and then secured by means of appropriate wedges. For convenience in dismantling, one wall of the chamber can be removed by unscrewing together with the dees and resonance lines, which are mounted for this purpose on a dilly which can be moved on rails.

The dees (Fig. 5) are two electrodes with a copper coating of 1.5 mm thick on a portable aluminum frame. The inside height of the dees is 86 mm, and the gap between them averages 50 mm. Inside the dees are removable plates the so-called fillers, which, by causing the proper electrical field, contribute to a more intensified pulling of ions from the source. In the left dee (looking from the side of the line) is a deflecting plate, mounted on insulators, the so-called deflector of a hyperbolic shape (in the direction of the chamber axis).

The dees, cooled by distilled water and having appropriate graphite shields, are mounted on bars running along the resonance lines, and inside one of them passes the wire feeding the deflector.

The resonance lines (Fig. 6) are quarter-wave vacuum lines connected with the accelerating chamber by means of a choke, and are pumped together by means of two diffusion pumps.

The coil coupling the lines feeding the high frequency generator with the resonance lines is bolted to a capacitive vacuum bushing (of 10 kv working voltage) which can be placed in four different openings, depending on the tuning of the circuit (input resistance of coupling loops 88 ohms, inductance $L = 0.4\ \mu H$). Shorting plates located inside the resonance lines are used to change the frequency of the self-oscillations of the circuit and can be removed without breaking the "vacuum" inside the accelerating chamber.

The frequency of the resonance circuit varies from 9.5 - 15.2 Mcs, the unloaded circuit has a $Q = 2000$, average dee--ground capacitance -- 450 micromicrofarad, coupling capacitance (between dees) -- 15 micromicrofarad. Two remote-control tuners serve to tune the circuit within 1 - 2%. The resonance lines, like the dees and deflector, are cooled by means of distilled water.

The ion source is introduced on the side from which the ion beams emerge, i.e., on the opposite side of the resonance lines. At present, there are two types of ion source in use: open-bell suitable mostly for initial work, and slit, which are more efficient (Fig. 7). The cathode, made of tungsten or tantalum wire 2 - 3 mm in diameter can be made incandescent with a direct or alternating current of 200 - 400 A. The arc formed in the ion source has an intensity on the order of 100 v at a current of about 2 A. Regulation and change of the cathode (after operation for 10 - 20 hours) is accomplished without breaking the "vacuum" inside the accelerating chamber.

The ion source is connected with the electrolyzer (Fig. 8) by means of copper tubing through a remotely-controlled needle valve. The ion source is also cooled with distilled water. On the side of the ion source are also introduced into the chamber so-called "probes" of ion beams.

Focusing system of emerging beam. The ion beam is transferred from the accelerating chamber to the neighboring target chamber in a vacuum "ion duct". This "ion duct" is about 11 m long, 16 cm in diameter, and has two telescopic joints. It is mounted on the central surface-plane of the acceleration chamber (at a height of 120 cm from the floor) and pumped by means of two smaller diffusion pumps. To focus the ion beam use is made of two four-pole hyperbolic magnetic lenses (Fig. 9) with a field gradient of 350 Oe/cm.

The overall mass of each lens is 400 kg. The yoke and four poles are made of CT-3 steel. Winding consists of four coils each of which has two secontion of 60 windings made of copper tubing 5 mm in diameter and cooled with distilled water (3.3 liter/minute). The rated current in the winding of each lens amounts to 60 A with a stability of 0.5%.

In order to decrease the neutron background in the space of the target chamber, an electromagnet (Fig. 10) deflecting the beam by a 13° angle is placed on the "ion duct" behind the lenses. The overall mass of this electromagnet is 7.5 t, the intensity of the magnetic field 4500 Oe in a slot 10 cm high, rated magnetic current 21 A with a stability of 0.5%.

A cylindrical target chamber (Fig. 11), with an internal diameter of 150 cm and height of 80 cm, is connected to the end of the "ion duct" through a vacuum is equipped on th valve. It has Plexiglas peep-holes and inside with special remote-control turning handles. This chamber is pumped with an additional diffusion pump.

Vacuum system. The vacuum system of the cyclotro installation can be divided into: a) high vacuum part (10^{-6} -- 10^{-5} mm Hg) comprising the accelerating chamber with the resonance lines and the ion duct with the target chamber -- pumped with five diffusion pumps and b) fore-vacuum parts, comprising the pipelines from the diffusion pumps to the rotary fore-vacuum pumps. In this part we include also the so-called "pre-fore-vacuum" pipeline, serving for the preliminary pumping of the chambers and ion duct.

The fore-vacuum pipeline, 21.3 m in length and 136 liters in capacity, is composed of stainless steel pipes 102 mm in diameter and connected by means of special collarless joints. The "pre-fore-vacuum" pipeline is composed similarly and is 27.3 m long and has a 175 lit capacity. They are pumped by means of two indentical (one as a reserve) two-stage rotary water cooled (200 ℓ/h) pumps (Fig. 12) with a yield of 40 lit/sec and driven by two induction motors of 7 kw power. After assembling the fore-vacuum system and pumping it down to 3 x 10^{-4} mmHg, a permissible leakage of 0.002 cm-h per liter volume has been established.

The high vacuum system is pumped by means of water-cooled oil diffusion pumps: two for the accelerating chamber of an effective yield of 1250 lit/sec at 10^{-5} mmHg (power of heater 2 kw, intensity of distillate flow 2 lit/min) and one for the target chamber with a yield of 500 lit/sec (power of heater 1.5 kw, intensity of distillate flow 5 lit/min).

The high vacuum units have freezing traps cooled with liquid nitrogen, total use of which amounts to 8 lit/hr. Each unit has a valve closing by hand and from a distance. The high vacuum units, on their own, gave a vacuum of 2 x 10^{-6} mmHg, and with freezing with liquid nitrogen of 5 x 10^{-7} mmHg. The vacuum obtained for the whole system amounted to about 10^{-6} mmHg with a leakage not exceeding 10^{-3} mmHg/h for the entire evacuated volume (on the order of 4 m^3). Working with a beam (while feeding molecular hydrogen in quantities of 2 - 3 cm^3h) the vacuum was on the order of 10^{-5} mmHg.

The vacuum is measured in three places in the acceleration chamber, ion duct, and the target chamber. The manometer block has three tubes: ionization, magneto-electric, and thermocouple. In addition, the vacuum can be measured directly from the diffusion pumps and collector of the rotary pumps.

Cooling and ventilation. The main parts of the apparatus such as the acceleration chamber, winding of the electromagnets (main and four-pole lenses), high frequency generator, and the diffusion pumps are cooled by means of distilled water with a combined flow on the order of 500 lit/min. This water circles in a closed circuit

(Fig. 13) through a tank of 5 m^3 capacity and a 4 sectional heat exchanger with a cooling surface of 18.12 m^2. The distilled water is re-drawn by means of one of the two-stage pumps with a deliver Q = 70 m^3/hr and drawing height of 60 m of water, driven by an induction motor of 28 kw power.

To insure uninterrupted cooling in case one of the pumps breaks down, the high frequency generator can be cooled by gravity with distilled water from an emergency tank placed under the roof. Distilled water is obtained from two distillers 50 kw in power and 60 lit/hr yield installed on the premises. It is cooled with a heat exchanger with industrial water (100 m^3/hr) circulating in another closed circuit by 4 pumps (14 kw power each) and a spray pond (about 520 m^3 capacity).

Intake and exhaust ventilation is provided in specific spots by means of appropriate fans, and in the main areas a 6-fold change of air per hour is possible.

Power system. The cyclotron building is provided with a three-phase network of 6 kv and 380 v. An underground distribution system feeds from the 6 kv network, the 380 kw induction motor driving the unit for the high frequency generator and a transformer (180 kvA) giving a voltage of 3 x 220/127v. In addition, a 110 v storage battery of 360 Ah capacity and two 24 v batteries of 500 Ah capacity are on hand.

All the above currents and voltages (with the exception of the high voltage) are distributed to the various loads through an 18-panel switchboard (Fig. 14).

From the three-phase 3 x 380/220 v network are fed the induction motors, distillers, and lighting; whereas the heaters of the large diffusion pumps, the small rectifiers and filaments of the high frequency generator tubes, as well as the emergency lighting which is automatically thrown over to the 110 v dc from the storage battery when the alternating current fails -- are fed from the 3 x 220/127 v network. From the 100 v and 24 dc network are fed the blocking and signalling system. The total power drawn during the operation of the cyclotron is on the order of 0.5 mw.

Control and Safety. The individual units and the rotary pump motors are essentially started locally. but after the start they are controlled remotely from a central control panel (Fig. 15). A system of blocking and signalling was established for the high frequency generator, electromagnet vacuum, and the entrance doors.

The generator has a blocking system, which, besides protecting its operation, insures the proper sequence of connections (first cooling, then filaments, followed by a gradual increase in the anode voltage). In view of the high anode voltage (10 kv), a double blocking was introduced: mechanical and electric.

Blocking of the vacuum setups makes the connection of the rotary and diffusion pumps depend on their own cooling; the opening of their valves, however -- on the starting of the pumps. When cooling is insufficient or power is lacking, valves close automatically. When vacuum deteriorates to 10^{-4} mmHg a signal is produced, the high voltage is disconnected from the dees, and in the case of further deterioration of the vacuum -- the valves are automatically closed.

In signalling one can distinguish: a) signals for the location of contacts, valves, and doors by means of red or green lights, b) warning signals, appearing when vacuum goes above 10^{-4} mmHg by lighting and a sound signal (bell), c) emergency signals, which act when there is insufficient cooling or power of vacuum pumps by a lighting and sound signal (siren). In addition, to insure contacts, a loudspeaker system and interoffice telephones have been installed.

4. CYCLOTRON BUILDING

Figure 16 shows the building in which the new cyclotron is located. This building, oblong in outline, has three floors. Arrangement of the main floor is shown on Fig. 17. The basement contains: 6 kw distributor, kenotron rectifier for the deflector, fore-vacuum pumps, and pumps for the distiller, ventilation chambers, laboratories, photographic darkroom, and storage rooms. On the first floor are located the laboratory facilities: microscope room, radio-chemical, stable sources, electronics, general laboratory and rooms: conference, director's, offices, etc.

5. PROTECTION AGAINST RADIATION

During its operation, the cyclotron constitutes a strong source of γ and neutron radiations. For example, a beam of deuterons of 13 Mev energy and intensity of 1 mA falling on an internal beryllium target causes a reaction $Be^{9}(d, n) B^{10}$ releasing a stream of fast neutrons on the order of 10^{13}n/sec.

For the protection of personnel from direct radiation, both the main hall containing the cyclotron, as well as the location of the experimental target chamber have concrete walls and ceiling 2.6 m thick, and entrances are protected with sliding and rotating doors of steel containers (1.6 m thick) filled with saturated aqueous solution of borax. In these areas are installed the dosimetry apparatus (ionization chambers), which permits a constant control of the γ ray radiation level. Dosimetric service is equipped further with inspection and control apparatus for the measuring of neutron streams as well as α, β, and γ radiation of various surfaces of the various parts of the cyclotron installation, as well as floors, chairs, clothing, etc.

In addition, each worker is equipped with individual dosimetric apparatus in the form of pocket size capacity chambers and test-films.

6 ENERGY CHANGE OF ACCELERATED PARTICLES

The proper focusing of the ion beam is a basic condition for the stable operation of the cyclotron. On the initial paths the ion beam is focused as a result of the inhomogeneity of the electric field in the gap between the dees. As the kinetic energy of the particle increases, i.e., on paths of larger radii (above 1/3 of the end radius), the electric field becomes less significant and the ion beam is maintained in the vicinity of the mean central plane between the dees and the magnetic field. For this purpose is essential a proper radial fall of the magnetic field amounting to about 2% on the end radius.

On the basis of the characteristics of the fall of the magnetic field for the various "shims" and currents feeding the electromagnet, corresponding to a magnetic induction in the center of about 1.4 Weber/m^2 (14,000 Gauss), the effective end radius r_k = 525 mm was selected. For this radius we obtain, for the resonance condition $B = 6.56 \times 10^{-2}\ A/Zf$, a formula for the energy of the accelerated particles

$$E = 5.68 \cdot 10^{-2} Af$$

where B is the magnetic induction in Weber/m^2, A the mass number, Z the atomic number, f the frequency in Mcs, and E the energy in Mev.

Figure 18 shows these dependencies for deuterons (A/Z = 2/1) in the straight line and for protons (A/Z =1/1) in the broken line.

Possible energy changes of accelerated particles for a given end radius are limited by the maximal magnetic induction B_{max} = 1.5 Weber/m^2 and by the scope of frequenc change of the resonance system 9 - 15 Mcs. Orientationally then, the scope of energies for protons is 4.5 - 12.5 Mev, and for deuterons 9 - 15 Mev. In practice, however, the energy attained by the particles depends also on the voltage between the dees ($U_{dd\ max} \approx 65$ kv) and the deflector voltage ($U_{df\ max} \approx 65$ kv). Practically speaking, the amplitude of the voltage between the dees should be 1.5--2 times larger than the minimal value of $U_{dd\ min} = 200(B/Z)((E/E_0 + (\Delta B/B))$, where $E_0 = m_0c^2$ is the energy at rest of the particle (of rest mass m_0) in Mev. This minimum voltage needed to bring the ion beam to the end radius is dependent on the fall of the magnetic field, which at a fixed frequency of the oscillator, causes deviation from synchronism. Since the fall of the magnetic field changes nonlinearly with change in the magnetic current (increasing for large magnetic induction), the maximum energies factually obtained by the accelerated ions are smaller than called for by the above outline for the given limiting conditions.

7 WORK CONNECTED WITH CYCLOTRON APPARATUS

Magnetic measurements and the shimming of the main electromagnetic field for the acceleration of deuterons to nominal energies were conducted during the first quarter of 1958. After assembling and control of the entirety of the cyclotron, preliminary running of the apparatus was done in the fourth quarter of 1958. In pulse work with a small duty cycle amounting to 0.01 (i.e., with a length of pulse of 1 msec and repetition frequency of 10 Cps), using and open-bell ion source on a probe inside the accelerating chamber, an ion beam was obtained from molecular hydrogen with a maximum intensity reaching up to 1 mA. Next, after applying a deflector with a negative voltage on the order of 60 kv, the beam was guided outside the acceleration chamber; in this the remotely controlled wedge shims proved very helpful. On the target placed in the target chamber located at a distance of about 11 m from the accelerating chamber, we obtained in pulse work with a duty cycle of 0.025, an ion beam with an average intensity of 2.5 μA, and the diameter of the track of the collimated beam did not exceed 25 mm. An attempt was also made to accelerate deuterons by directing a beam with an energy of 13 Mev and average current on the order of 1 μA in air outside the target chamber through a thin aluminum foil (Fig. 19).

After the opening ceremony of the cyclotron on 22 November 1958, further experiments to increase the current intensity of the ion beam were performed with the cooperation of Soviet experts. The slit type of ion source was applied with which the loss of accelerated ions along the path to the end radius was decreased to one third.

Accelerating deuterons in pulse work with a duty cycle of 0.5 (pulse 10 msec, frequency 50 Cps) an ion beam of 13 Mev energy and average current reaching to 60 μA was obtained on the outside target.

Experiments are further being conducted to improve the various parameters and to go over to continuous operation. Construction of a gas chamber to slow down the ions together with a magnetic selector of currents is foreseen.

Foreseen are also such experiments on the proper formation of the magnetic field in the cyclotron, which would permit to accelerate in it -- at a constant frequency of the oscillator -- protons to an energy above 30 Mev.

8 RESEARCH WORK WITH THE USE OF THE CYCLOTRON

The cyclotron was used to start research work in nuclear physics already while it was being put in operation.

Preparatory work in constructing proper measuring apparatus and auxiliary instruments for research with the cyclotron were being conducted even before that and are being continued at present.

The program of research work using the cyclotron, foreseen and systematically prepared, concerns first of all problems connected with stripping phenomena, especially polarization effects connected with this phenomenon. Work has commenced and is continuing on confirmation and eventual better definition of polarization of neutrons arising from stripping of deuterons on C^{12} nuclei. For this purpose apparatus is being used which was constructed in Institute II IBJ and which is composed of an inert gas pressure proportional counter (about 10 atmos) and corresponding electrical apparatus ending with a ten-channel amplitude analyzer working coincidentally with the scintillation counters on neutrons (Horniak type) for registering the asymetric scattering to the left and to the right, defining the degree of polarization of the neutrons Preliminary results have already been obtained, confirming the polarization of neutrons in the reaction $C^{12}(d, n)N^{13}$ for a reaction angle of 15° in the laboratory system. For further research work on these problems, there is being prepared in the Institute the construction of a magnetic analyzer of the energy of protons obtained from the stripping reaction and emerging under different angles with respect to the direction of the deuteron beam.

Research work with the cyclotron is already being conducted now and is being planned for the coming years; several advanced scientists of the Institute are now serving as scientific workers in foremost foreign laboratories specializing in these problems. Among others, two of our scientific workers have studied for over a year and a half the polarization effects in stripping with the cyclotron at the Nuclear Physics Research Laboratory of the University of Liverpool. As is known, this center has been and continues to be the most important world center of research on the stripping phenomenon.

Manuscript submitted to the editor in May 1959.

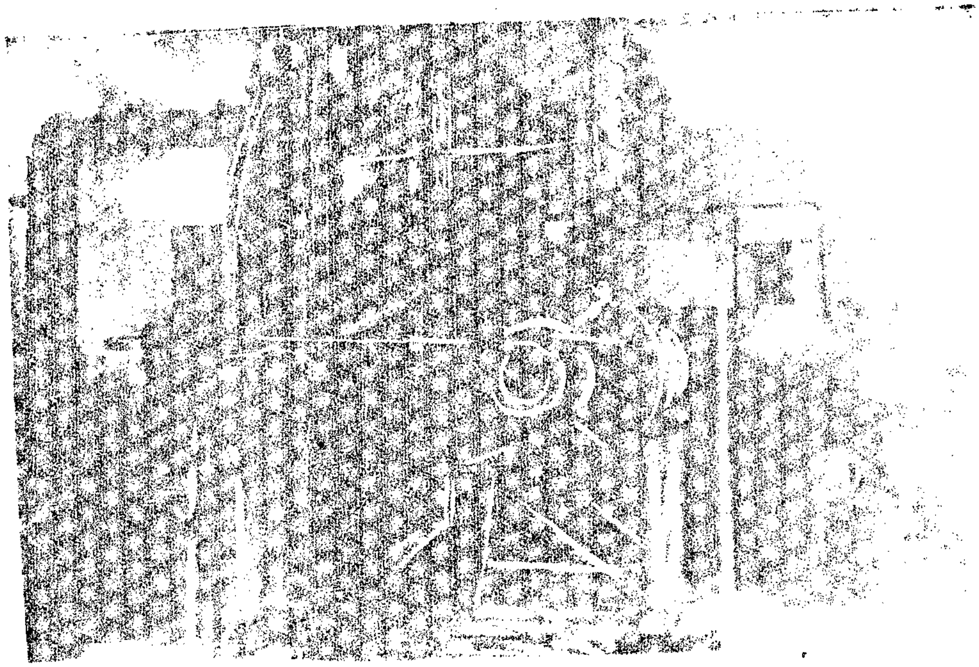

Figure 1. General view of cyclotron from the side of the resonance lines

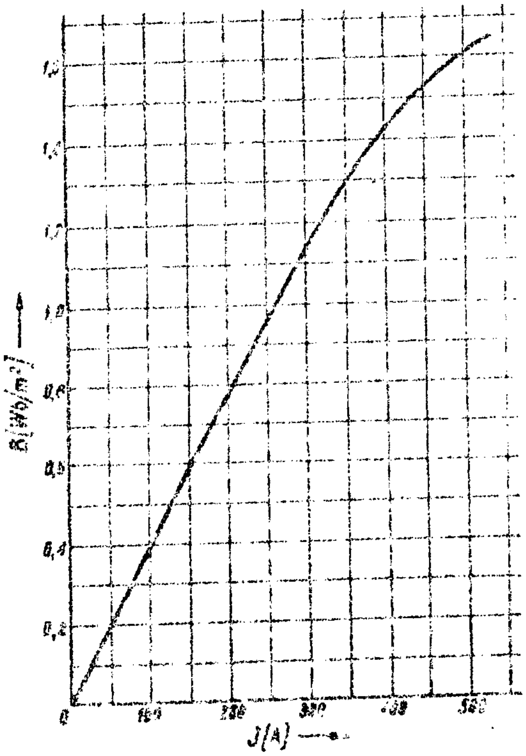

Figure 2. Magnetizing characteristics of the main electromagnet

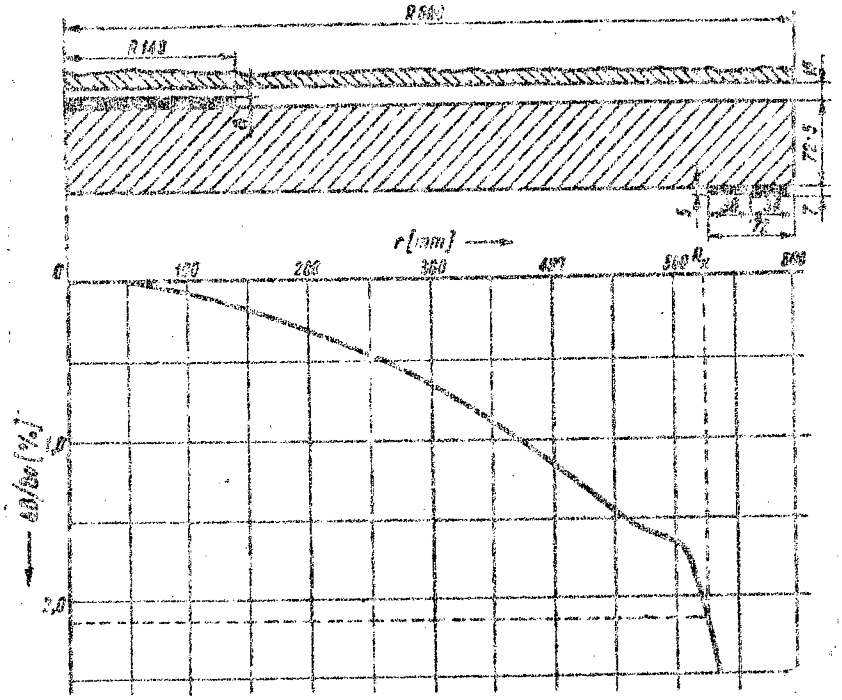

Figure 3. Characteristic of the fall-off of the magnetic field along the radius. In the upper part of the picture are noted the location and dimensions of the "shims."

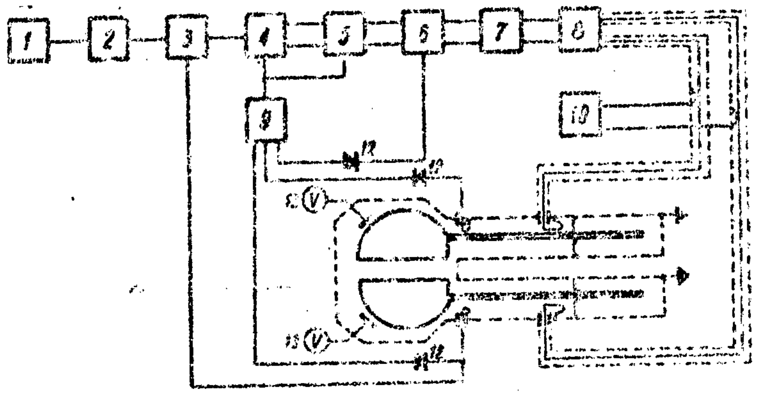

Figure 4. Block diagram of the high frequency generator.
1 -- master generator
2 -- amplifier-follower
3 -- phase shifter
4 -- I stage high frequency generator
5 -- II " " " "
6 -- III " " " "
7 -- IV " " " "
8 -- V " " " "
9 -- modulator
10 -- setup for measuring power and standing wave ratio
11 -- resonance lines with dees
12 -- safety detectors
13 -- high voltage voltmeters

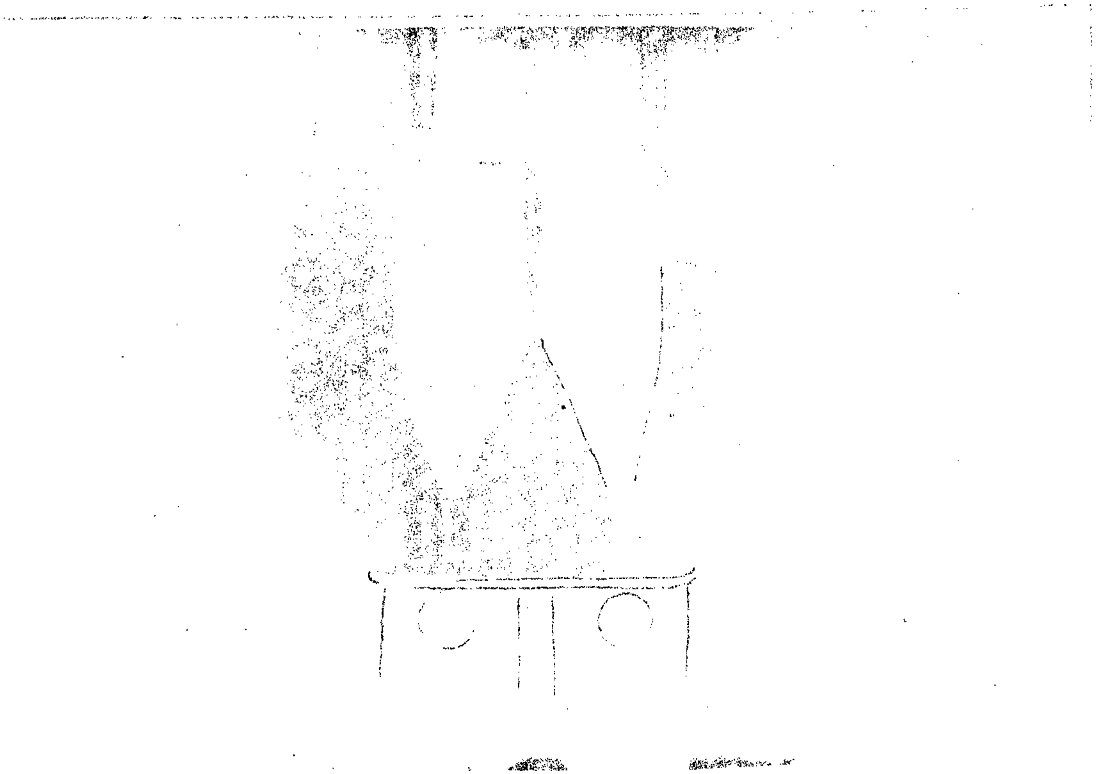

Figure 5. General view of the dees

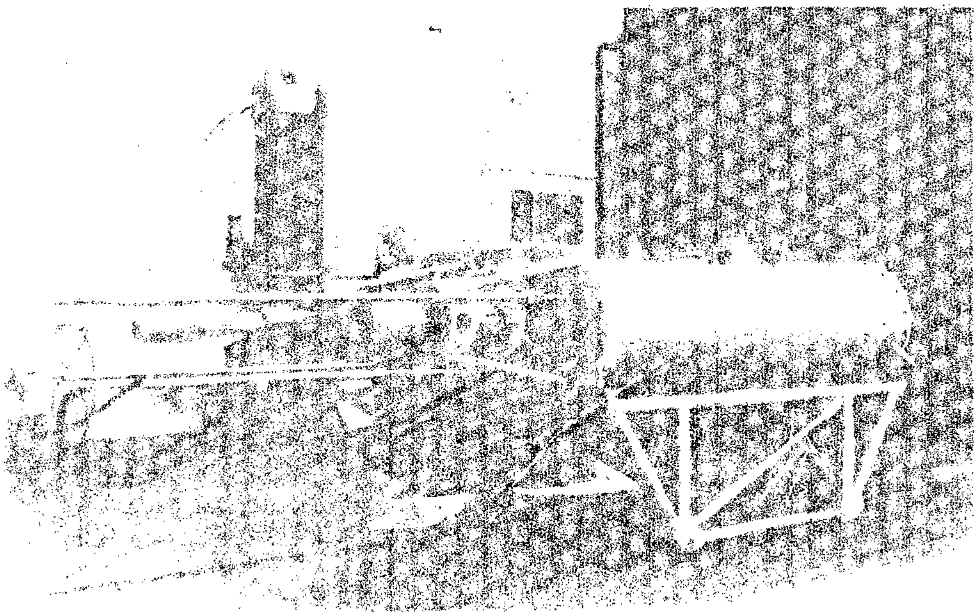

Figure 6. Resonance lines

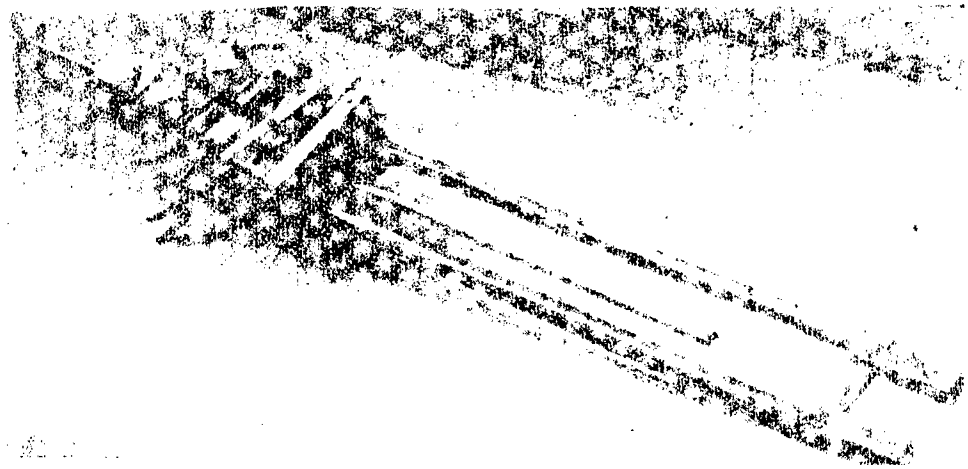

Figure 7. Slit type ion source with so-called internal probe

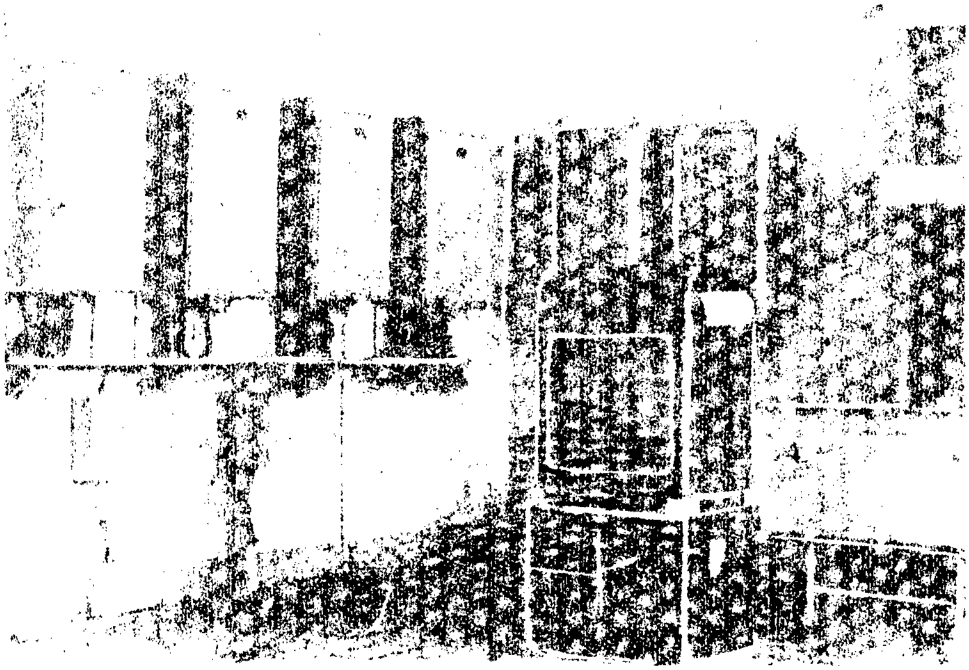

Figure 8. Electrolyzer

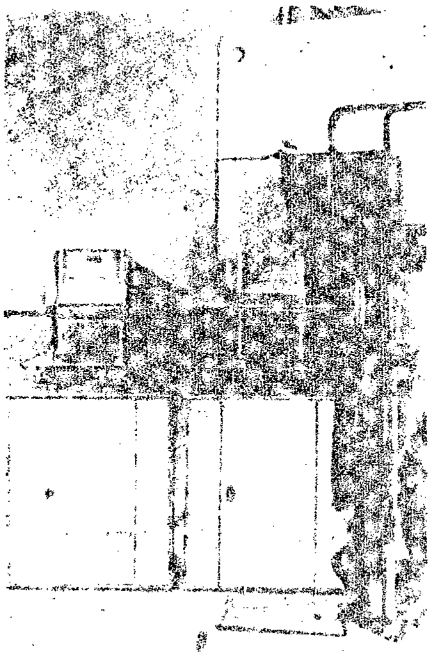

Figure 9. Four-pole magnetic lenses

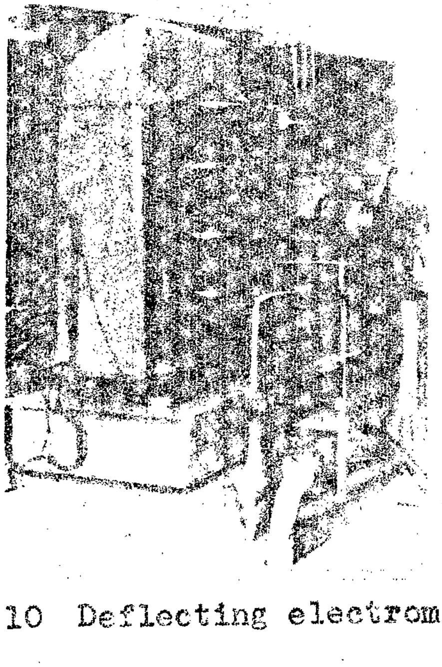

Figure 10 Deflecting electromagnet

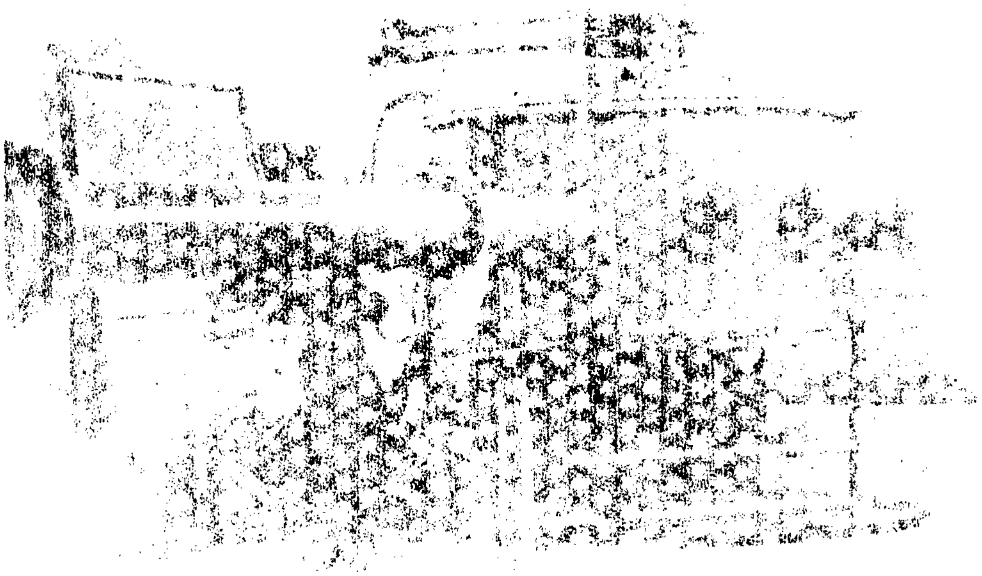

Figure 11 Target chamber with "ion duct" leading to it

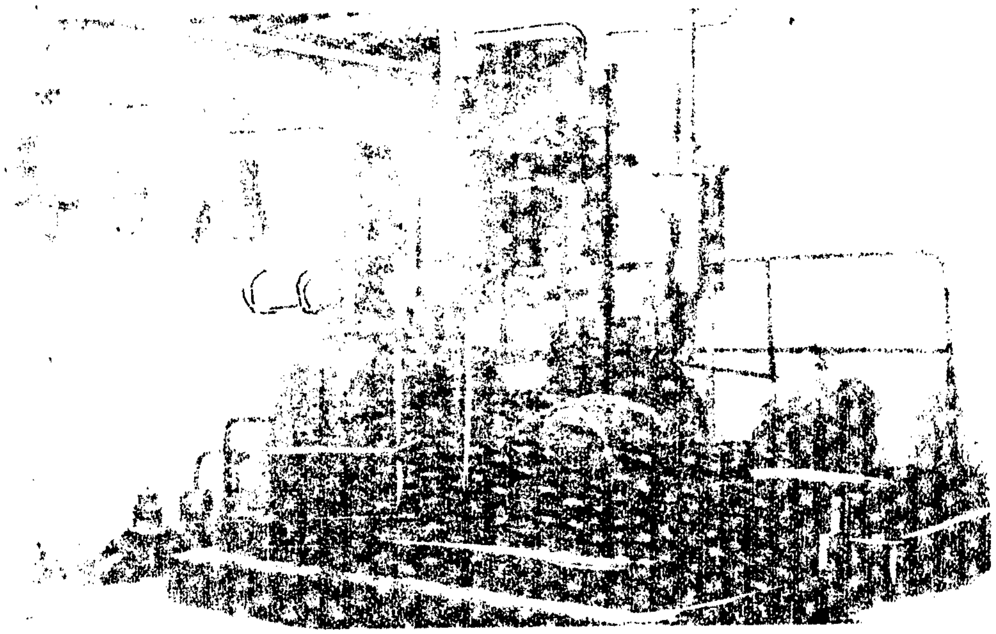

Figure 12 Rotary pumps for fore-vacuum

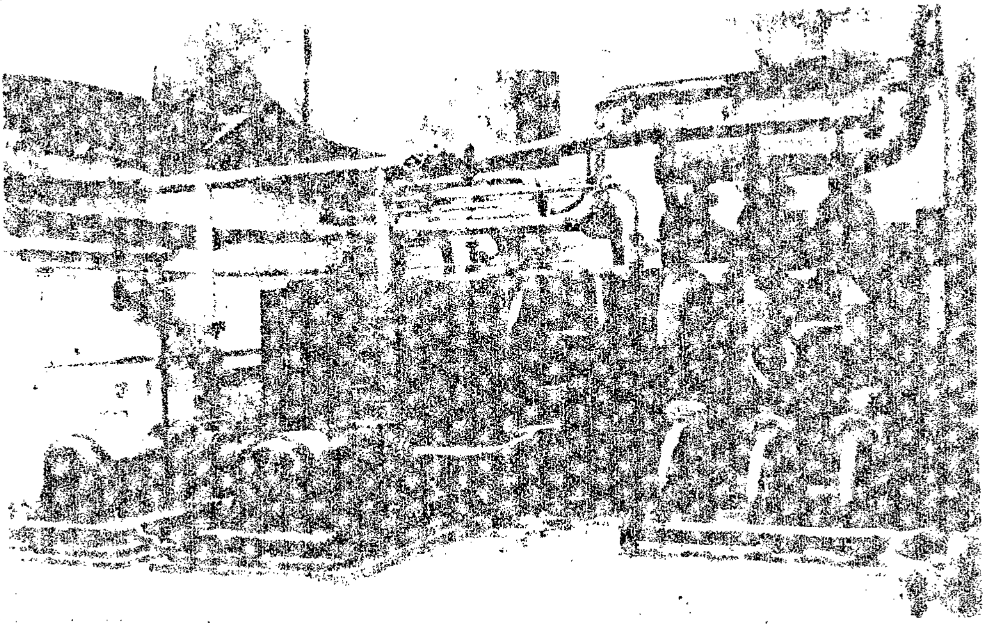

Figure 13 . View of part of the distillation room

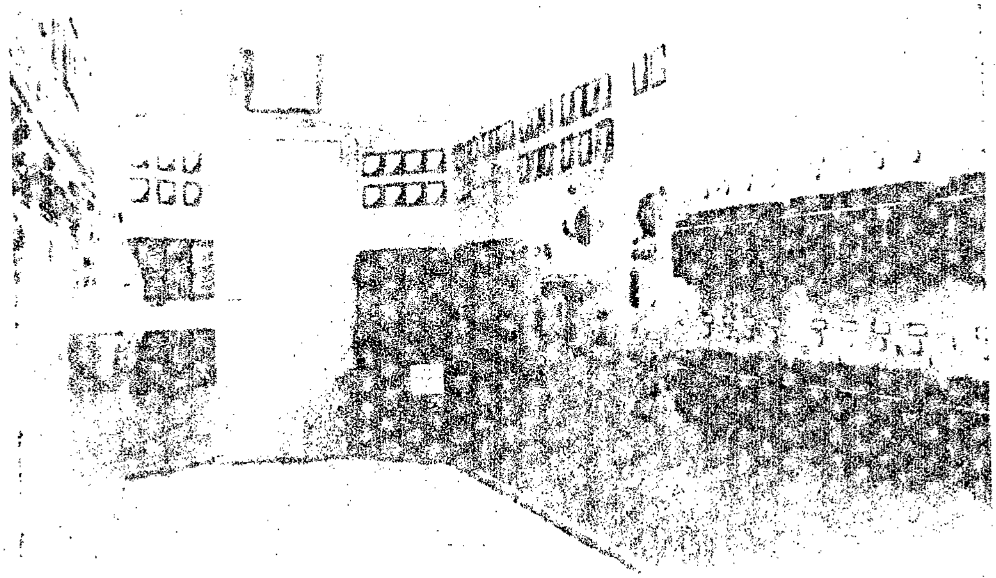

Figure 14. View of part of the 18-panel switchboard

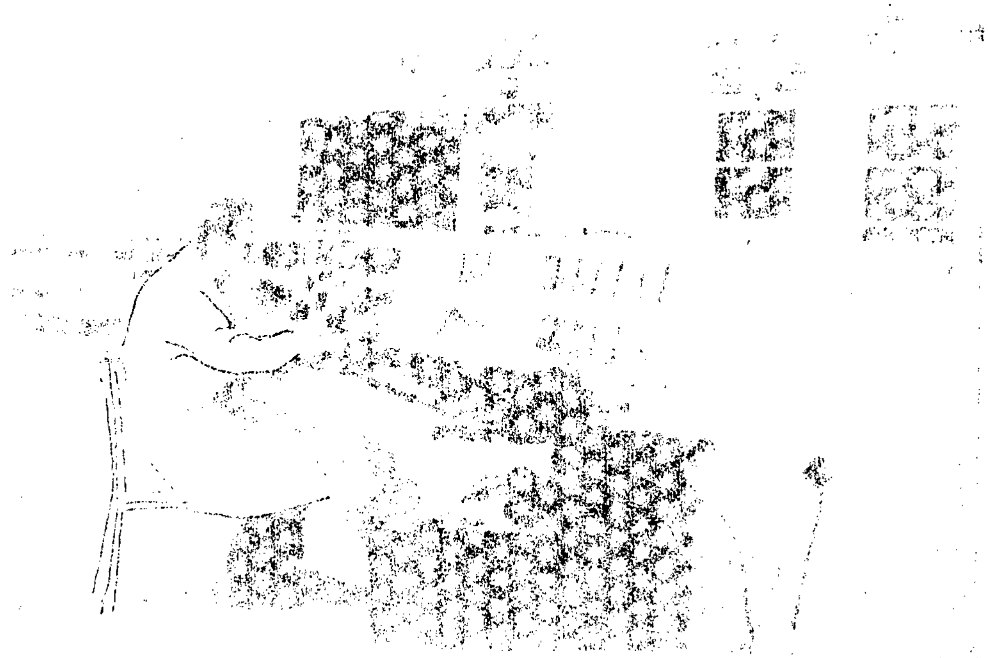

Figure 15. Central control board

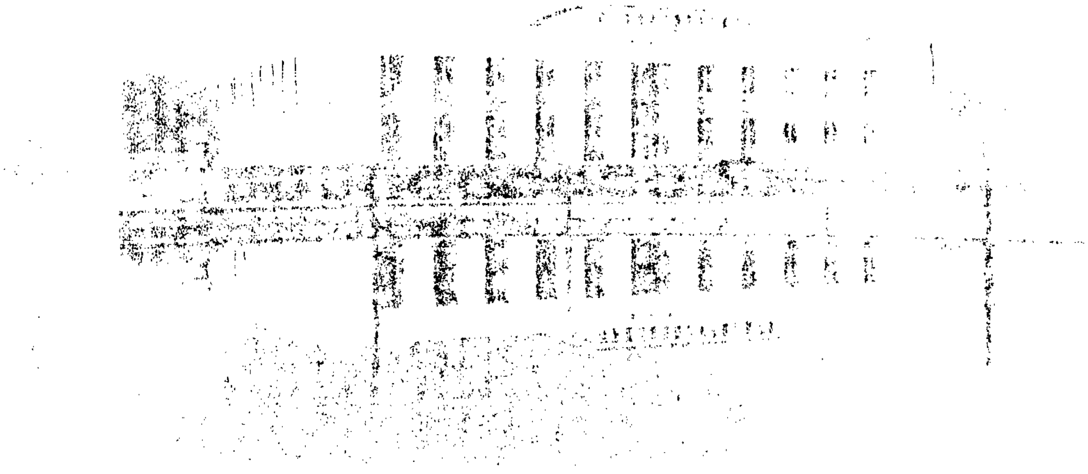

Figure 16. General view of cyclotron building. On the first plane the spray pond of the secondary cooling circuit

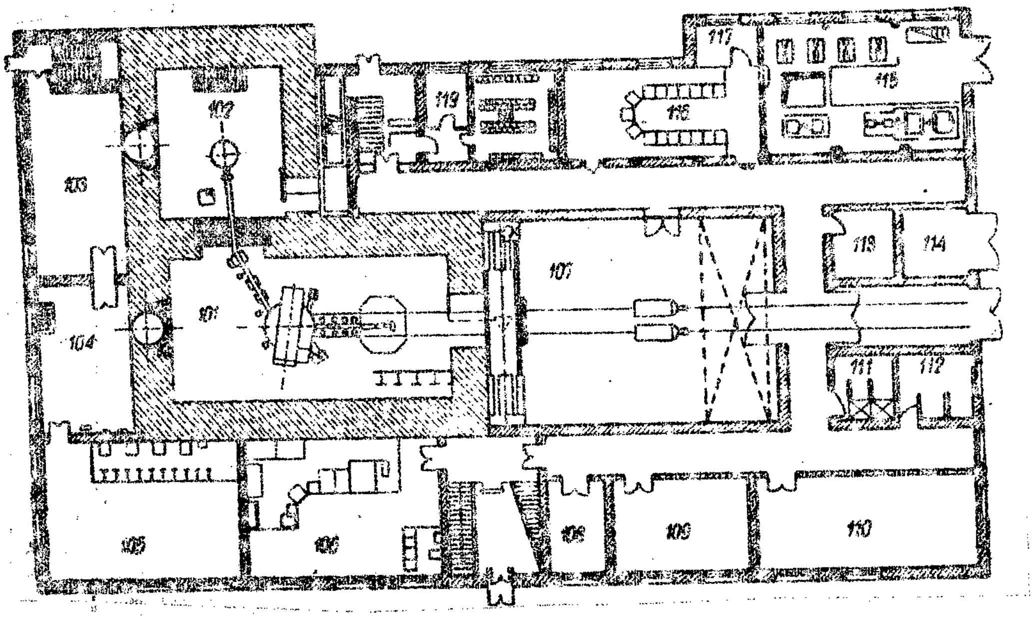

Figure 17. Plan of the ground floor of the cyclotron building.

101 -- main cyclotron room
102 -- experimental room for target chamber
103 -- measurements room
104 -- electrolysis room
105 -- central adjusting panel
106 -- high frequency generator
107 -- large preparation room
110 -- experimental shop
115 -- machinery room
116 -- main distribution room
118 -- battery room

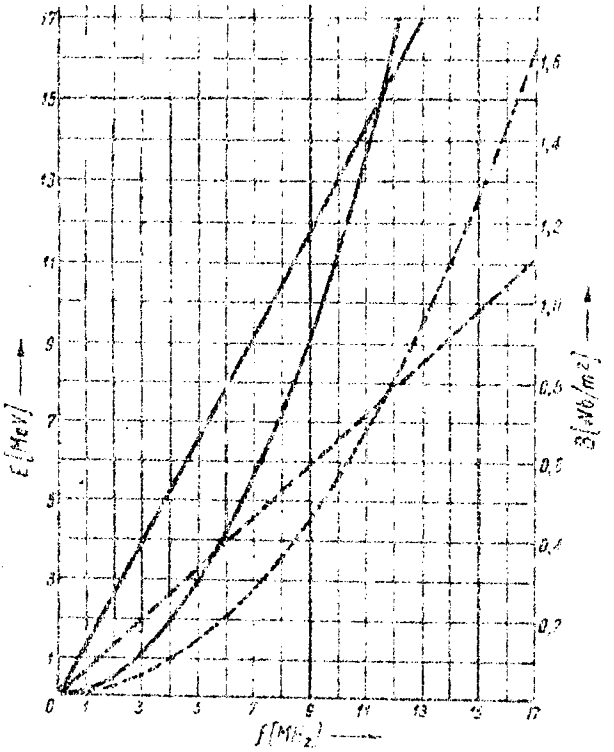

Figure 18. Dependence of the deuteron energy E_d and proton energy E_p on the end radius r_k = 525 mm, and the magnetic field inductions B_d and B_p corresponding to them, on the oscillator frequency

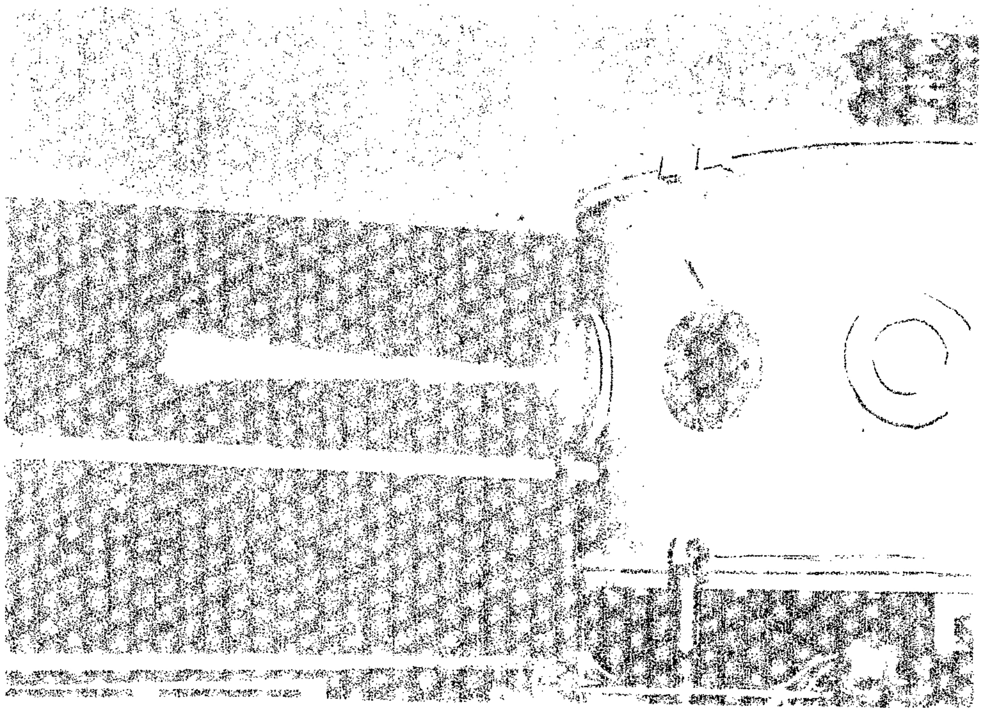

Figure 19. Photograph of beam of ions accelerated in the new Cracow cyclotron emanating from one of the small windows of the target chamber: the longer beam represents lighting of air under the influence of bombardment with deuterons accelerated to about 13 Mev, the shorter -- lighting of air under the influence of bombardment with protons of 6.5 Mev energy emanating from molecular ions of light H_2 hydrogen accelerated in the cyclotron together with the deuterons.

END

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