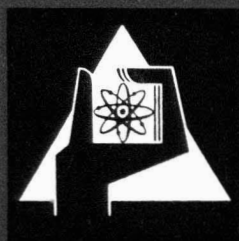# KERNFORSCHUNGSZENTRUM

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Two Compact, High-Intensity Pulsed Neutron Sources

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1. Introduction

For advanced neutron decay measurements and for time-of-flight applica-
tion higher neutron intensities are required than can be achieved with the
conventional present-day Cockroft-Walton type neutron generators. Electron
linear accelerators are extremely strong pulsed neutron sources, however,
they are very expensive and their flexibility is limited. In order to have
a flexible device easily transportable to any experimental set-up, two types
of small powerful neutron generators have been developed in our laboratory.
To meet the urgent needs, an accelerator with stationary high voltage power
supply operating with a pulsed duoplasmatron ion source /1/, /2/, /3/ was
built. For long range applications a more ambitious "neutron flash tube" has
been developed which is based on a pulsed rf-discharge combined with a pulsed
acceleration voltage. Both accelerators produce 14 MeV neutrons from the
$H^3(d,n)He^4$ reaction and use tritium targets.

2. A High-Power Neutron Pulse Generator with Duoplasmatron Source (W.Eyrich)

The basic disadvantage of the conventional accelerators is the large
distance between the ion source and the target. Space charge and lens aber-
ration limit the beam current, and the highest value we could achieve with
accelerators built in our laboratory was 26 mA /4/. To avoid these difficul-
ties, in the design described below the focusing device was deleted and the
target was set close enough to the extraction channel to get the total ion
current from a duoplasmatron ion source on to the target in spite of space

charge effects. The position was chosen in order to achieve a complete and uniform target loading. A second unusual design principle was to connect the target with the high voltage and to have the ion source at ground potential. This greatly facilitates the power supply since all the auxiliary equipment is now on ground potential and does not have to be powered via insulating transformers.

On this basis the construction was made to meet the following requirements as well:

1. The background between the neutron bursts should be zero.

2. The target should be positioned as close to the surface of the accelerator as possible to keep the efficient solid angle of source neutrons high.

3. The overall dimensions should not be larger than about $1m^3$.

4. The accelerator should be reliable enough to run continuously for days.

The following specifications were obtained:

Burst length: 5 - 50 μsec
Repetition rate: up to 400/sec
Acceleration voltage: 120 kV
Max. ion current: 500 mA on target.

The instantaneous neutron production rate amounts to about $2 \cdot 10^{13}$/sec. The average current is limited by the target cooling to 2 mA.

2.1   Description of the accelerator

Fig. 1 shows a sectional drawing of the neutron generator and Fig. 2 gives a photographic view from the side with the ion source removed. In the sectional drawing, Fig. 1, the accelerator is cut perpendicular to the view of the photograph so that here the ion source is located on the top (parts 1 - 6, Fig. 1). Below the source is the hollow accelerating electrode connected to negative high voltage (parts 9 and 10) with the ion inlet opening on its top (8) and the exchangeable neutron generating target is at the bottom (10).

In addition, the electrode contains channels (11) to extract the neutral gas; these channels are so designed that no electric lines of force are able to deflect the ion beam within the electrode. In the lower part the electrode contains a ring channel (22) for the oil cooling of the target. The electrode is supported by two porcelain insulators (13 and 14)[1]. Both insulators are cone-shaped and have a boring in the axial direction. The negative high voltage is fed to the accelerating electrode through the insulator (13) by a high-voltage cable (18). Insulator (14) contains the target cooling supply. For that purpose, boring 17 is separated in the axial direction by a partition wall of teflon, and the two halves thus generated serve as the inlet and outlet of the annular cooling oil channel. The extraction electrode is contained in a steel housing (12) kept under an internal pressure of about $8 \cdot 10^{-5}$ torr during operation, or $5 \cdot 10^{-7}$ torr, if no gas is introduced. This vacuum is generated by an oil diffusion pump flanged onto the housing. Two tube adapter (15, 16) securing the support insulators, are flanged onto the housing. One adapter (16) is equipped with a metal bellows to take up the differences in length of the supporting insulators. The porcelain parts are each supported by screw collar flanges (23, 24) screwed onto the flanges of the adapters and pressing a bead of the insulator against a rubber seal. On one side of the high-voltage input the screw collar flange (23) has a groove, housing a current transformer coil for measuring the pulse currents flowing to the extraction electrode. At the top the steel housing is closed by the ion source, and at the bottom by a thin-walled top lid (21).

2.2   The ion source

The duoplasmatron ion source [1], [2], [3] is composed of a cathode (1,2) an intermediate electrode (3) and an anode (4). The cathode consists of a helically wound tape, 12 mm wide, 130 mm long of three times folded nickel screen (mesh size 0.04 mm, thickness of wire 0.03 mm). For activation it is thinly coated with a mixture of 50 % strontium carbonate and 50 % barium carbonate dissolved in amyl acetate. This type of cathode supplies currents up to 40 A at 900°C and has a very long life at this operating temperature, and when the cathode is cold, air can be admitted without any disadvantage. The cathode tape is mounted on a flange by two rods. One rod acts at the

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[1] Another accelerator was built having one insulator only.

same time as the current input. The cathode flange (1) is placed upon a porcelain spacer ring which is attached to the intermediate electrode (3) and screwed onto the intermediate electrode flange through an insulation. The intermediate electrode (3) surrounds the cathode and, in its cone-shaped section, has a channel 4 mm in diameter for the plasma to flow to the anode. The intermediate electrode is made of steel and is mounted in a steel flange with copper disks brazed to it for better heat removal.

The anode serves as the end flange of the ion source. It consists of a steel plate containing a molybdenum insert (5) in its centre with a hole of 1.2 mm diameter and 0.5 mm length drilled in its top, which then widens up to 8 mm in the downward direction. Again, copper inserts are brazed onto the steel plate for good heat removal; these inserts contain the channels through which the coolant is pumped. However, these channels are not required for our pulsed operation because the average power of the ion source is very low. It is sufficient to use a strong blower to remove the heat from the electrode flanges, shaped like cooling fins. The anode has a wide groove (6) to contain the excitation coil generating the magnetic field between anode and intermediate electrode. The groove is closed by the intermediate electrode flange. A pertinax disc and a vacuum seal of silicone rubber insulate the two electrodes from each other. The anode is secured to the intermediate electrode by plactic screws. The palladium gas inlet valve is screwed onto the cathode flange.

2.3   Operation of the generator

The ignition of the discharge is initiated by a square wave pulse of about 300 V amplitude applied to the cathode, the anode remaining on ground potential. The arc current then increases to 40 A, the arc voltage being 90 V. The current is limited by a total resistance of 10Ω (R$_3$, R$_4$ of Fig.3). The intermediate electrode is fed by a voltage divider. In order to facilitate ignition the intermediate electrode is connected to the anode by a capacitor of 0.1 μF (C$_f$, Fig. 3). Immediately after ignition the current of the intermediate electrode drops to nearly zero, and the electrode reaches a steady state potential of +40 V with respect to the cathode. At the end of the pulse a short circuit caused by the triggering of thyratron T$_2$ removes the arc voltage. To excite the gas discharge in the ion source a pressure of about 0.12 torr is required. The cathode saturation current has to exceed 20 A. If the emission of the cathode is less, ignition of

the plasma will occur either not at all, or only after *some* delay. If the pressure is too low, the discharge, if occurring at all, will break down before the end of the pulse, or plasma oscillations will appear. The latter happens when the high ion current decreases the pressure in the source below the value necessary for discharge. Between intermediate electrode and anode an axial inhomogeneous magnetic field is used to focus the plasma onto the 1.2 mm diameter hole in the anode. In this way, it is possible to compress to 1/10 the cross section of the plasma filament emitted from the 4 mm diameter channel of the intermediate electrode, thus causing an increase in plasma current through the opening in the anode of more than ten times the original value.

The plasma passing the anode opening of 1.2 mm diameter diverges in the widening bore, there forming a plasma boundary from which the ions are emitted. By means of the extraction electrode the acceleration voltage is applied. The ions leaving the plasma boundary thus are forced to form a space charge limited beam and are accelerated to pass the extraction electrode channel. Behind the channel the beam diverges due to space charge, reaching a diameter of 30 mm at the target distance of 80 mm.

The extracted ion current is roughly determined by the parallel beam space charge formula

$$I_{deuteron} = 3.84 \cdot 10^{-8} \frac{F}{d^2} \times U^{3/2}$$

where

U = extraction voltage in volts

d = distance in cm between extraction electrode and anode of the duoplasmatron ion source = 0.8 cm

F = emission area in cm^2. This is the area of the boring of 0.5 cm^2 in the anode.

At an extraction voltage of 60 kV this gives I = 0.28 A and at 120 kV, I = 1.38 A.

At an accelerator voltage of 120 kV the ion current was measured, and the neutron source strength was determined by means of foil activation. The pulse current from direct measurement was 0.5 A, while the current deduced from activation via neutron yield was 0.31 A. Under these conditions an

instantaneous source strength of $1.9 \cdot 10^{13}$ neutrons/sec was obtained; that means $1.5 \cdot 10^8$ or $9.5 \cdot 10^8$ neutrons per burst for $8 / \mu sec$ or $50 / \mu sec$ pulse width, respectively.

The value of the ion current calculated from the space charge law is not reached, since not only atomic ions but also a major portion of molecular ions are accelerated and since at high current intensities the beam broadens to such an extent that it hits the extraction electrode. The distance of the target has been chosen so as to make the space charge broadened ion beam cover the whole target of 35 mm diameter in as uniform a way as possible. In this case the target has its maximum lifetime, which was about 15 mAh in our normal applications. In order to keep the accessible solid angle of source neutrons high, the target, kept at high voltage in the high vacuum, is 2.3 cm away from the top lid.

2.4 Electric equipment

The electric equipment consists essentially of a high-voltage device and a pulsing device. The high-voltage device supplies the negative DC accelerating voltage which is variable up to 150 kV. An automatic current control switches the device off as soon as the current exceeds the nominal value of 10 mA. In order to prevent every flashover from switching the high-voltage device off, a delay element has been built in. A protective resistor of 10 kΩ is included in the input line. The high-voltage supply is made with a flexible high-tension lead, the shielding of which is grounded via a protective resistor of 10 kΩ .

The pulsing device supplies pulsing currents up to 50 A and a pulse voltage variable from 90 to 300 V. The pulse duration can be selected by a rotary switch between 8 and $50 / \mu sec$. The maximum repetition frequency is 400 c/s. The limit is set by the thyratrons. The pulsing device contains three thyratrons. These can be triggered one after the other by a control device which is externally triggered. The first thyratron triggered is T_1 thereby connecting C_L through R_3 and R_4 with the cathode of the ion source (see Fig. 3). At the end of the pulse, triggering of thyratron T_2 removes the arc voltage again and discharges C_L through R_4 until both thyratrons are switched off. Then T_3 is triggered and reloads C_L from C_S which is ten times larger and is connected with the power supply. In thyratrons filled with inert gas this cycle is finished after $2 / \mu sec$ and can then be triggered

again. In case of a false triggering sequence of the thyratrons an excess-current switch disconnects the DC supply for a short time.

2.4 Operating experience

Since the completion of the first duoplasmatron accelerator in July 1962 three more neutron generators using this principle have been built. These neutron generators have been used in measurements where a high neutron intensity is important or where the neutron generator had to be small. The following measurements have been carried out with these neutron generators: Measurement of thermalization time in graphite /5/, measurement of the decay constant in extremely small graphite assemblies /6/, measurement of the diffusion length in neutron fields decaying with time /7/, pulsed reactivity measurements on the fast-thermal Argonaut reactor STARK /8/ and an activation analysis. Neutron spectrum measurements using this accelerator are in preparation.

The following experience has been obtained in the course of these measurements: The first cathode we used was a tape of 12 mm width and 100 mm length cut out of a nickel screen (mesh size 0.6 mm thickness of wire 0.15 mm). This tape was coated with a mixture of nickel powder, barium and strontium carbonate dissolved in amyl acetate /2/. The tape supplied a good electron yield, but after a short time it burnt out starting at the edges. In order to eliminate this we then used a tape of molybdenum. It also proved to be unsuitable because the active layer flaked off. Therefore we now make the tape as described in section 2.2. This type of cathode has been in operation in our laboratory for several hundred hours. In order to protect the cathode we originally filled the neutron generator with nitrogen when changing the target. However, this precaution proved to be unnecessary. A target change can be carried out with an experiment interruption of about 2 hours.

The type of diffusion pump oil used strongly influenced the dielectric strength of the accelerator. Use of a high-vacuum carbon oil e.g. Diffilen gave good dielectric strength at the beginning, but after some time an electrode current up to some milliamperes started to flow due to the Malter effect. An inspection of the extraction electrode revealed a brown coating on it around the extraction opening. After removal of this film the old dielectric strength was restored for a short time. Fouling of this type was considerably reduced when using silicone oil DC 705. This oil permits oper-

ation of the accelerator at an extraction voltage of 120 kV for a long time without causing any electron background to arise. Silicone oil DC 705 also allows the neutron generators to be run with diffusion pumps cooled by air instead of water. By using these pumps it is possible to perform experiments in which the use of water would be impossible for safety reasons.

Viton "O"-ring seals, which we used for high vacuum sealing in general, were found to be inappropriate for the ion source because of fluorine gas emission. This emission, which can be detected from the change in the plasma colour, causes a sharp drop in the ion current. Silicone rings do not show this disadvantage.

The cooling oil circuit is hermetically sealed. Care has to be taken to avoid air bubbles from being pumped around in it, because otherwise there may be flashover in the cooling oil channels of the inlet and outlet lines.

The types of cooling oil we tested were transformer oils, Dowtherm A, and very light viscous silicone oil. Out of these, silicone oil proved to be best because at lower pumping power it has a higher circulation rate than the other coolants. Its dielectric strength is as good as that of transformer oil.

The measurements revealed that the neutron source intensity between the bursts was in fact essentially zero.

3. The Neutron Flash Tube (A. Schmidt)

In this accelerator neutron source, the d-t-reaction is used to produce 14 MeV neutrons with a peak instantaneous rate of about $2.5 \cdot 10^{14}$ n/sec. Thus, during each 2 μsec burst about $5 \cdot 10^{8}$ neutrons are generated.

A maximum pulse repetition rate of 250 sec^{-1} can be used, giving an average source strength of more than 10^{11} n/sec. Therefore the device may also serve as a strong source of fast neutrons as required for activation purposes and activation analysis systems.

The accelerator tube is operated as a valved off closed low pressure discharge system whose pressure is uniform and held constant by a special replenisher system. It is filled with a mixture of equal parts of deuterium and tritium gas, deuterium being supplied by means of an electrically heated nickel diffusion leak and absorbed in the replenisher. The tritium is supplied by insertion of a fully saturated tritium-deuterium target. The initial neutron yield is about three times as high as the above figure which refers to the equilibrium conditions reached after approximately two hours of operation, when half of the tritium content of the target has been replaced by deuterons from the beam. The neutron yield then remains constant for at least 25 hours of operation at an average neutron output of 10^{11} n/sec. After longer operating times, the neutron source strength decreases due to target sputtering. The sputtered target can be easily replaced by a fresh one, requiring only half an hour to mount and a subsequent period of four hours to pump the system down again.

As the target is operated at ground potential and readily accessible, small samples up to 40 mm ∅ can be irradiated at a distance of less than 5 mm from the 50 mm ∅ target surface. Big assemblies can be irradiated at a closest distance to the target of about 25 mm, so that the neutron output into nearly 2π solid angle can be utilized.

There is no spurious neutron production during the pulse intervals, since no acceleration voltage exists then.

3.1 Operating principles of the accelerator (see Fig. 4)

The ions, deuterons and tritons, are generated by means of an intense pulsed high-frequency discharge in the gas mixture at a pressure of about

$2 \cdot 10^{-3}$ torr. The discharge is excited inductively inside a cylindrical pyrex vessel of about 1.3 l volume. The peak power of the rf-pulse is about 200 kW at a frequency of 40 Mc/sec. The pulse lasts for 12.5 μsec which is the time needed to fully dissociate the gas content of the discharge vessel and to achieve enough ionisation to get peak ion current densities of 1 - 2 A/cm^2 at the boundary of the excited plasma. The ions impinging on the target surface cause the release of secondary electrons at a rate of about four electrons per ion. These electrons pass the accelerating gap in the opposite direction, thereby gaining the same amount of energy as the ions. These electrons form a convergent beam which passes the emission orifice and the plasma vessel and strikes a water cooled anode at the other end of the secondary electrons adds up to the ion current, giving a total pulse current in the 50 - 75 A region.

At the time of maximum plasma density and, correspondingly, of the highest emission current (10 - 15 A) through the circular emission orifice, a high-voltage pulse of 2 μsec duration is applied to the high-voltage end flange of the tube, raising the potential of the discharge plasma to +150 kV within about 0.5 μsec. Thus the ions leaving the plasma boundary within the emission orifice are accelerated towards the target electrode which is held at ground potential. This acceleration takes place across a very short gap of only about 2.5 cm extending between the ion emitting plasma boundary and the active target surface. By means of a properly chosen geometry for the electrodes which determine the potential distribution around the beam, and by a properly adjusted curvature of the plasma boundary (for a fixed ac-celeration voltage this is steadily controllable by the applied rf-power), a divergent, nearly rectilinear space charge limited ion flow is obtained. This results in an almost uniform loading of the 50 mm ∅ active target sur-face, whose backing is water-cooled.

3.2   The construction of the accelerator tube (see Fig. 5)

The tube is constructed as a ceramic-metal sealed system. The outer vacuum envelope consists of a hollow cylindrical ceramic tube which has a convoluted outer surface to increase the creep distance with respect to high voltage flashover. The single rf-coil winding is located near the target end of this ceramic body, and its conductor is made by burnt-in silver paint to which silver plated contacts are soldered. The edge of the coil as well as the ends are rounded off by an overlap of the ceramic to

avoid sharp edges and to increase the spark-over voltage at the coil ends. The ends of the ceramic envelope are also silver coated and soft soldered with an indium silver alloy to two annular stainless steel flanges; to these latter are bolted the end flanges with the joints sealed by indium wire. At the center of the target end flange, a thick copper backing tritium-titanium target is inserted and sealed directly by a step-flange seat against the water cooling duct which carries the water at the rear of its backing. The other end flange is the high voltage terminal; it carries the anode support to which the inner discharge chamber is fixed.

This inner discharge chamber consists of a pyrex glass cylinder and two separate annular ceramic end disks of high alumina ceramic. One of these is clamped directly to the water-cooled anode body, which also carries one end of the pyrex glass cylinder. Two small cooling tubes near the inner walls of the discharge cylinder extend from the anode body to the field electrode structure at the other end of this cylinder. There is a metal ring provided with a cooling duct inside which is fed from the two diametrically located cooling tubes. The latter are shielded against the discharge by ceramic beads which are strung on these tubes. The field electrode is screwed onto the cooling metal ring by means of an inside thread on the latter and surrounds the emission orifice in front of the target. The second ceramic end disk is fixed by clamps to the cooling ring, thus shielding the discharge from the field electrode structure. The center hole of the ceramic disk allows the discharge to reach the emission orifice. The whole inner discharge chamber system, as supported by the anode body at one side and clamped to it by means of the field electrode structure at the other side (the clamping stresses are supported by the two cooling ducts) is located in the center of the coil section of the outer ceramics insulator vacuum envelope.

There is a small cylindrical gap between the freely supported pyrex discharge vessel and the inner wall of the outer ceramic envelope which acts as an insulating vacuum space. Since the operating pressure of the system is low, no rf-discharge is excited in this region.

To ensure a low background of x-rays from the impinging fast electrons, the anode is made of an aluminium disc which is soldered to the stainless steel anode structure via a heat-distributing copper body. Inside the anode support but not included inside the vacuum system, the anode cooling ducts

are located. Cooling of the target as well as of the anode is done with
ordinary water in a series flow. There are no insulation difficulties from
the conductivity of the water.

At the maximum pulse repetition rate of 250 c/sec the average power
loading of the target is about 1.2 kW, corresponding to a specific load of
60 W/cm^2. The average ion current is 8 mA ($\hat{=}$ 0.4 mA/cm^2). The anode under
these conditions is loaded by about 4 kW over an area of about 5 cm^2
($\hat{=}$ 800 W/cm^2). This heat flow, by means of the copper insert, is distri-
buted to an area of 25 cm^2 which is cooled away by a fast waterflow at a
rate of 160 W/cm^2. A load of about 800 W is transferred by a part of the
secondary electrons to the edge of the emission-orifice which is cooled by
another waterflow.

Under full load conditions, about 600 watts of rf-power are transferred
to the discharge plasma. By means of wall losses, this power is transferred
to the pyrex discharge vessel at a maximum rate of 1 W/cm^2, heating the pyrex
to about 400°C. This heat is radiated to the wall of the ceramic vacuum
envelope where it is conducted away to the outside which is air-cooled. The
temperature of the ceramic envelope rises to about 80°C.

3.3   The vacuum system (see Fig. 6)

The appendage system for pumping and pressure regulation is attached
to the target flange of the accelerator tube by means of a copper gasket.
It consits of a 1 l/sec Vacion ion-sputtering pump which is used for the
final pumpdown of the system after having inserted a fresh target and can
be valved off during the operation of the tube with a Granville-Philips
valve. A small electrically heated nickel diffusion leak serves for letting
in small amounts of deuterium gas. A second Granville-Philips valve serves
to close the system from the mechanical forepump which acts as a roughing
pump for the initial pumpdown of the system after target exchange. This
small two stage mechanical pump has an end vacuum of 10^{-5} torr if the liq-
uid nitrogen cold trap is used. Also attached to the vacuum appendage sys-
tem is the pressure-regulator.

The pressure regulator (Fig. 7) is a special small ion sputtering
pump which simultaneously acts as a hydrogen replenisher, as its titanium
cathodes can be heated to release their stored hydrogen content. By means

of the pump current the pressure can be measured and controlled automatically to a preset value with the aid of an amplifier acting on the heater. At the same time the system acts as a selective pump, removing all other gases from the system except the hydrogen isotopes, thus keeping the tube clean during operation /9/.

By careful construction of this system it is possible to hold all the built-in titanium at the same temperature. Also, it is designed so that no sputtered material can get outside to colder surfaces where it would pump off hydrogen in an uncontrolled manner. A nearly fully closed cylindrical titanium cathode box surrounds a tungsten wire anode ring, which is held by two feed-through insulators and can be heated from a small insulation transformer. The system which is thermally well insulated is mounted in a stainless steel envelope which fits into a small 1 kGs permanent magnet. It works like a small ion sputtering pump at a speed of about 0.1 l/sec using a voltage of 3 kV. The cathode box can be fairly uniformly heated by irradiation of the inside tungsten anode to temperatures up to $700^{\circ}C$ and stores easily 10 - 20 cm^3 of NTP hydrogen. When the accelerator is not used, this pump is cooled down and removes all the discharge gas down to atleast 10^{-6} torr before the discharge extinguishes.

3.4 The lay-out of the equipment (Fig. 6)

The whole device consists of two parts: the accelerator tube carriage (Fig. 8) and the control unit (Fig. 9). The latter contains the main supplies and the timing and control equipment to drive the two high power line-type pulsers. The power pulses are fed through cables to the accelerator carriage.

The accelerator tube carriage contains the accelerator tube, the arrangement for evacuation, gas filling and pressure regulation, the cathode pulsed rf-generator with its pulse transformer and the high voltage 150 kV accelerator pulse transformer. The accelerator tube is mounted horizontally on the carriage with the target side of the tube resting at the front part of the carriage frame. Above the target end flange is mounted the appendage vacuum system. The target is easily accessible from the front. The anode terminal of the tube is directly supported by the high voltage output terminal of the acceleration voltage pulse transformer.

Near the target end of the tube, below the single rf-coil winding, the pulsed rf-oscillator power generator is assembled. It consists of four ra-

diation cooled transmitting tubes (Telefunken RS 639) in push-pull operation. Two tubes are operated in parallel on each side of the tank circuit which consists of the coupling coil around the flash tube and a single 50 pF vacuum capacitor.

The output amplitude of the pulse moderator which drives the rf pulse-generator is steadily variable by means of a manually controlled variac. This modulator delivers at maximum -8 kV peak voltage pulses with a duration of 12.5 μsec into a load of 125 Ohms. At the maximum pulse repetition rate 1.6 kW are delivered to the load. These pulses are transformed by the rf-generator pulse-transformer at a ratio of 1 : 4 to -32 kV peak voltage pulses which are fed to the cathodes of the rf-generator. At peak pulse voltage the rf-voltage at the terminals of the coupling coil is about 50 kV peak rf. The center tap of the coupling coil is connected to a small 100 W power supply. This excites the rf-generator during the intervals between pulses in order to get a small constant preionisation inside the discharge vessel. In this way, statistical starting effects are avoided.

The accelerator pulser output amplitude is steadily variable by a motor driven variac; it is capable of delivering pulses with -25 kV peak voltage and 2 μsec duration into a 50 Ohm load at a pulse repetition rate of 250 The peak power is 12.5 MW. These pulses are fed to the tube carriage by a matched cable and are transformed in the accelerator pulse transformer at a ratio of -1 : 6 to +150 kV at an impedance level of 1800 Ohm which matches the resistance of the accelerator tube. The maximum average power of the pulser is 6 kW.

The device can be triggered externally as required by the experiments. The minimum interval between pulses has to be 4 msec. The input signal fires a blocking oscillator which delivers a trigger pulse to a waveform monitoring oscilloscope. With the aid of a lumped parameter delay-line switch, two pulses can be selected which drive the power switching hydrogen thyratrons. The first one fires the rf-generator pulser, the second one, after a time delay of 12 μsec, drives the accelerator pulser. The time delay between these pulses corresponds to the build-up time of the discharge plasma in the flash tube.

3.5 Operating experience

The neutron flash tube system in its present form as displayed in Fig. 8 and 9 was completed in September, 1964. Prior to this, experiments

had been performed with preliminary glass accelerator tubes. In order to
avoid contamination problems in these early investigations, the tube was
mostly operated with light hydrogen fillings. Due to the use of an uncon-
voluted tube and to improper rf-coil construction, this system was not
stable against outside flashover at voltages above 100 kV. The present
assembly does not show this effect; it has operated at voltages up to
160 kV without outside flashover. Operation at higher voltages was not
possible so far due to limitations in the pulse transformer. A disappoint-
ing feature of the new system was the breakdown of the inner discharge vessel
which was originally made from a high-alumina ceramic. These were therefore
replaced by pyrex vessels which gave successful operation.

During the last two months, test runs with tritium-titanium targets
and a tritium-deuterium gas mixture were made. A very satisfactory per-
formance of the device over extended periods of time was observed at the
following accelerator parameters:

Accelerator voltage:	140 keV
Target ion current:	15 A (this measurement goes back to a calori-metric calibration)
Repetition rate:	150 - 200 per second
Pulse length:	2 /usec.

The neutron yield showed a strong decrease initially but then remained
constant for more than 20 hours. It was possible to operate the device com-
pletely unattended for periods of several hours. This is facilitated by an
automatic overload and mismatch protection system incorporated in the pulsers'
control circuits.

An absolute source strength measurement was made, using the $Al^{27}(n,\alpha)$
N^{24} and the $F^{19}(n,2n)F^{18}$ reactions. The induced activities were absolutely
determined by the 4π-β-γ coincidence method. These determinations were per-
formed at an accelerator voltage of 105 kV with the pulse parameters as above.
Both measurements were in good agreement and a source strength of $(2 \pm 0,2) \cdot$
$\cdot 10^8$ neutrons per pulse was found. Extrapolating this value to 140 kV, the
source strength of the flash tube is $5 \cdot 10^8$ neutron per pulse.

3.6   Acknowledgements

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Figure Captures

Fig. 1   Sectional view of the neutron generator with duoplasmatron source.

Fig. 2   Neutron generator with duoplasmatron source.

Fig. 3   Principle diagram of the pulsing device of the duoplasmatron ion
         source.

Fig. 4   Principle of the neutron flash tube accelerator.

Fig. 5   The accelerator tube.

Fig. 6   Layout block diagram.

Fig. 7   Pressure control system.

Fig. 8   Accelerator tube carriage.

Fig. 9   Control unit.

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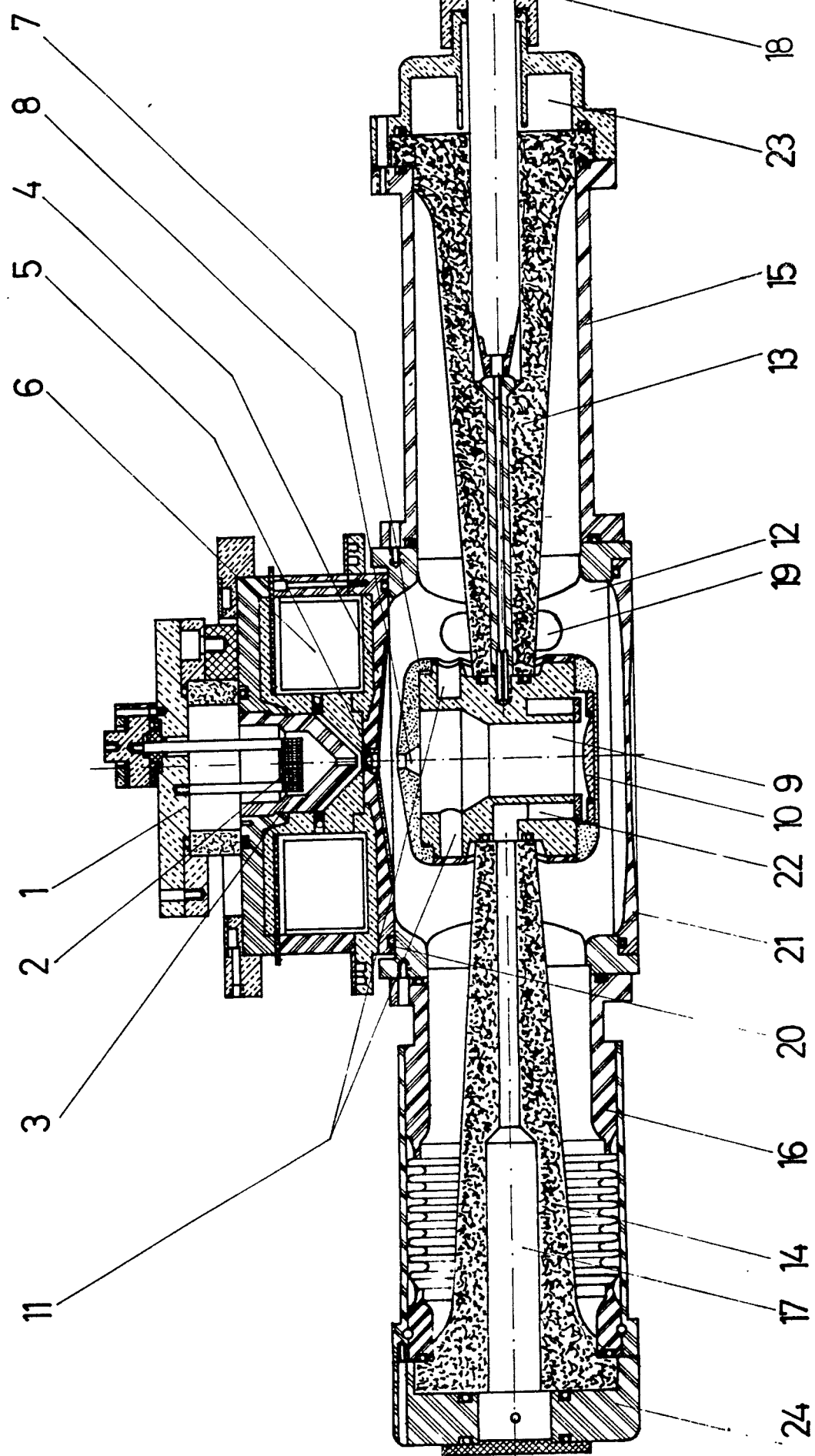
100mm

Brass
Copper.
Alumina
Steel
Ceramics
Plexiglas

Fig. 1: Sectional View of the Neutron Generator with Duoplasmatron Source.

1 – 6   Duoplasmatron Ion Source

1   Cathode
2   Hot Cathode (emission up to 40 A)
3   Intermediate Electrode
4   Anode
5   Ion Emitter
6   Magnet Coil

7 – 11 and 22 Collector Electrode with Target

7   Collector Electrode
8 and 9 Ion Flight Channel
10   Target
22   Cooling Oil Channels
12   Steel Housing
11   Gas Extraction Channels

13   Supporting Insulators with Current Input
14   Supporting Insulators with Cooling Oil Pipe 17
15   Steel Tube Adapter with Flange for Connect-
          ing Supporting Insulator
16   Adapter with Metal Bellows
17   Cooling Oil Pipe
18   150 kV High-Voltage Cable
19   Connection Bore to Vacuum Pump
20   High-Vacuum Seal
21   Top Lid
23   Collar Flange with Current Transformer for
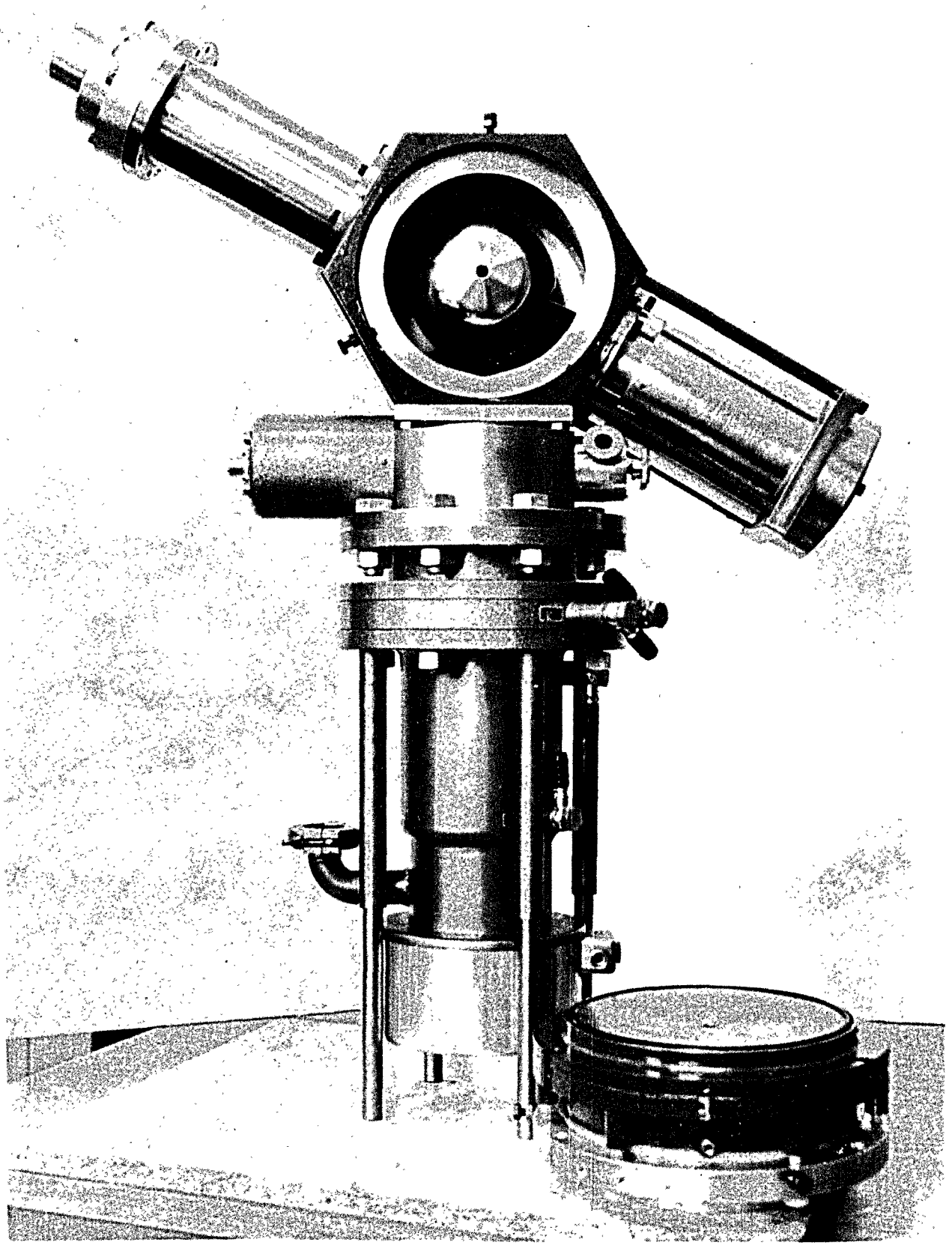   Measuring Ion Pulses
24   Collar Flange
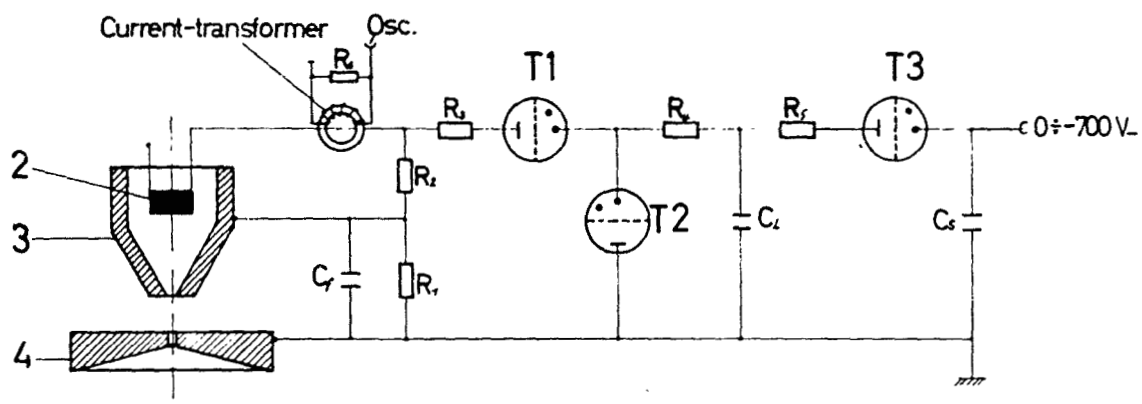
Fig. 2: Neutron Generator with Duoplasmatron Source

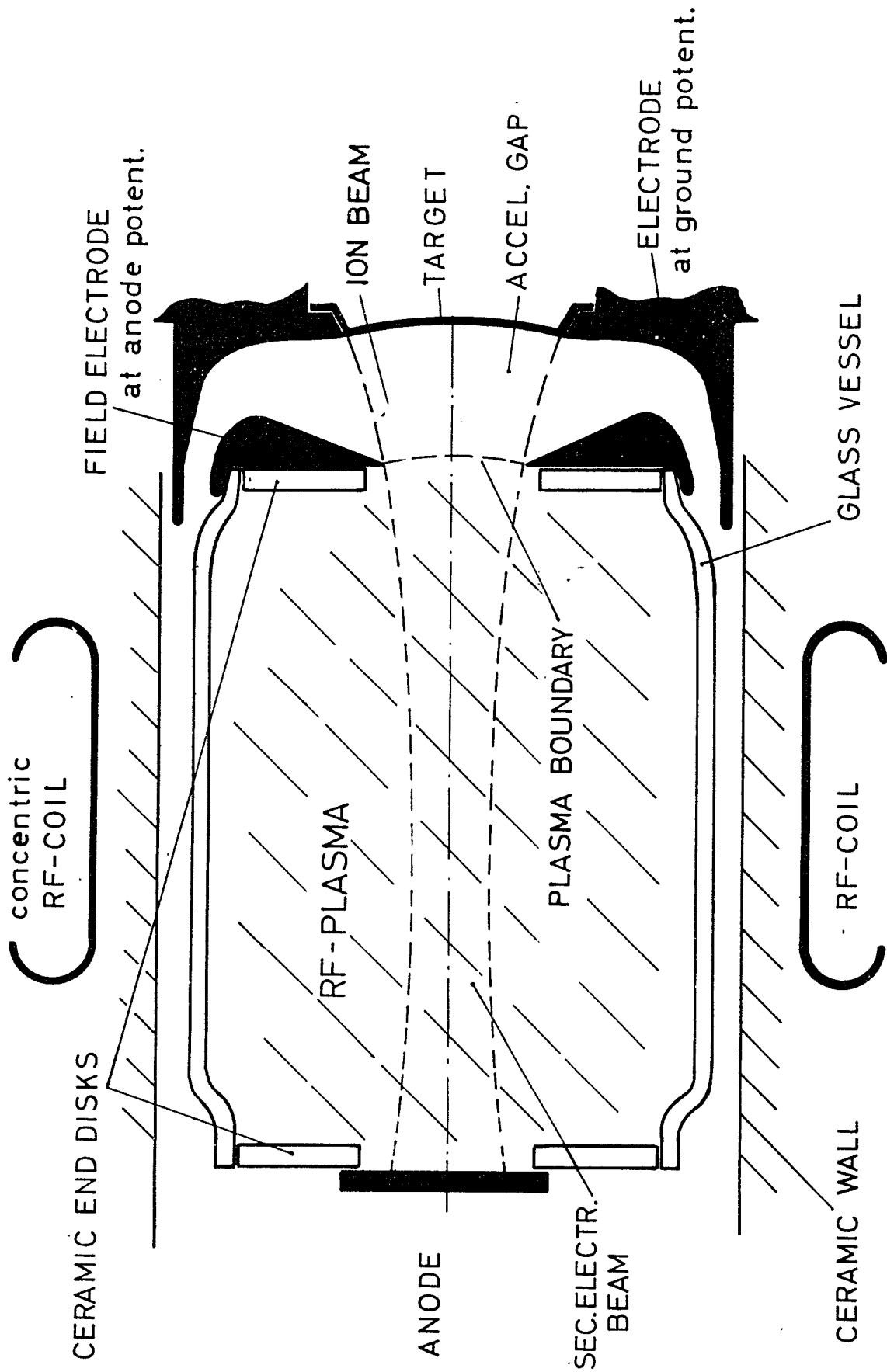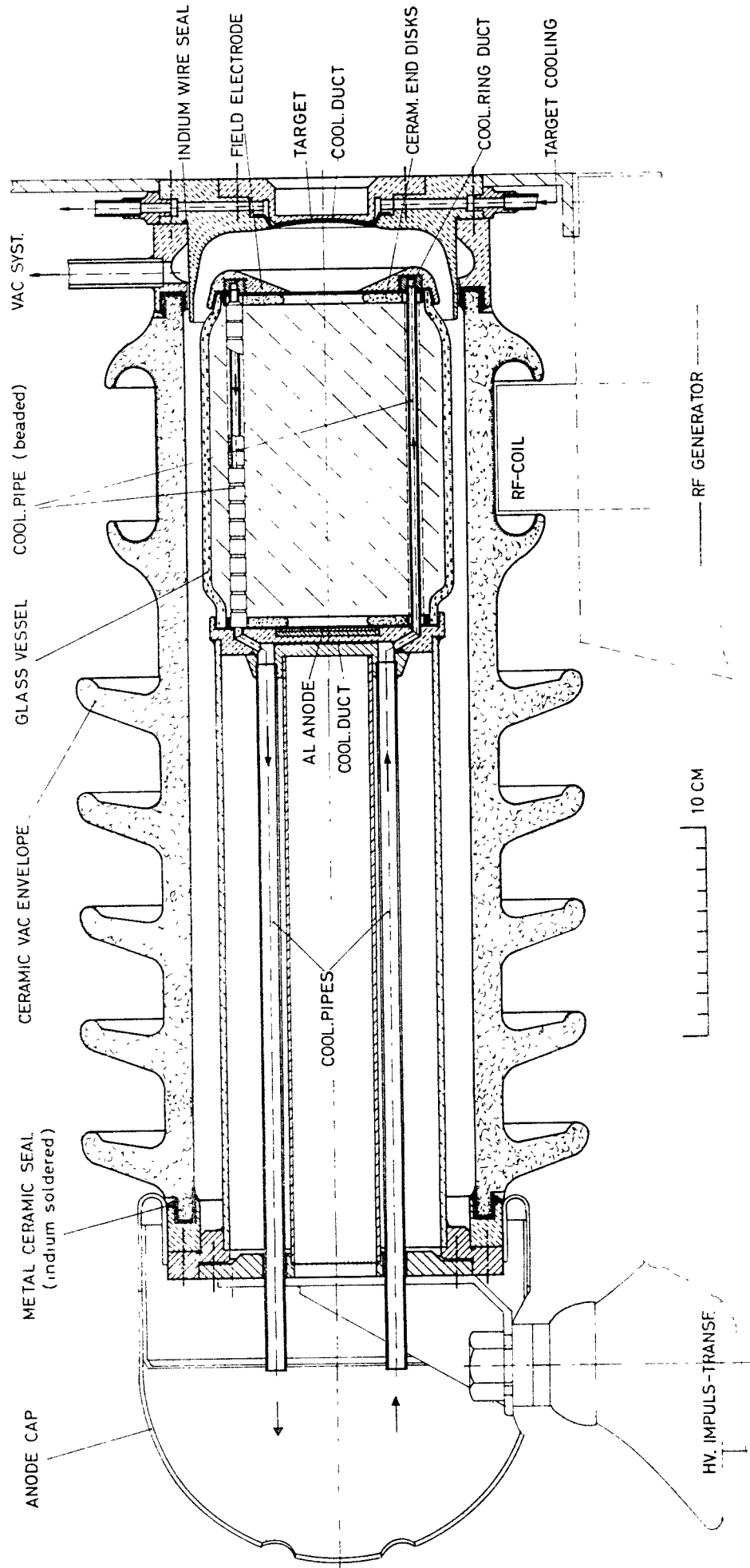Fig. 3:   Principle Diagram of the Pulsing Device of the Duoplasmatron
           Ion Source

FIELD ELECTRODE at anode potent.

ION BEAM

TARGET

ACCEL. GAP

ELECTRODE at ground potent.

concentric RF-COIL

RF-PLASMA

PLASMA BOUNDARY

RF-COIL

CERAMIC END DISKS

GLASS VESSEL

ANODE

SEC.ELECTR. BEAM

CERAMIC WALL

Fig. 4: Principle of the Neutron Flash Tube Accelerator

INDIUM WIRE SEAL
FIELD ELECTRODE
TARGET
COOL. DUCT
CERAM. END DISKS
COOL. RING DUCT
TARGET COOLING

VAC. SYST.

RF-COIL

RF GENERATOR

COOL. PIPE (beaded)

GLASS VESSEL

CERAMIC VAC ENVELOPE

10 CM

AL ANODE
COOL. DUCT

COOL. PIPES

METAL CERAMIC SEAL
(indium soldered)

ANODE CAP

HV. IMPULS-TRANSF.

Fig. 5: The Accelerator Tube

Fig. 6: Layout Block Diagram

LEAD THROUGH

MAGNET

TUNGSTEN WIRE
ANODE

TITAN.CATHODE BOX

TO ANODE

TO CATHODE

HV-SUPPLY
3.5 KV/2 MA

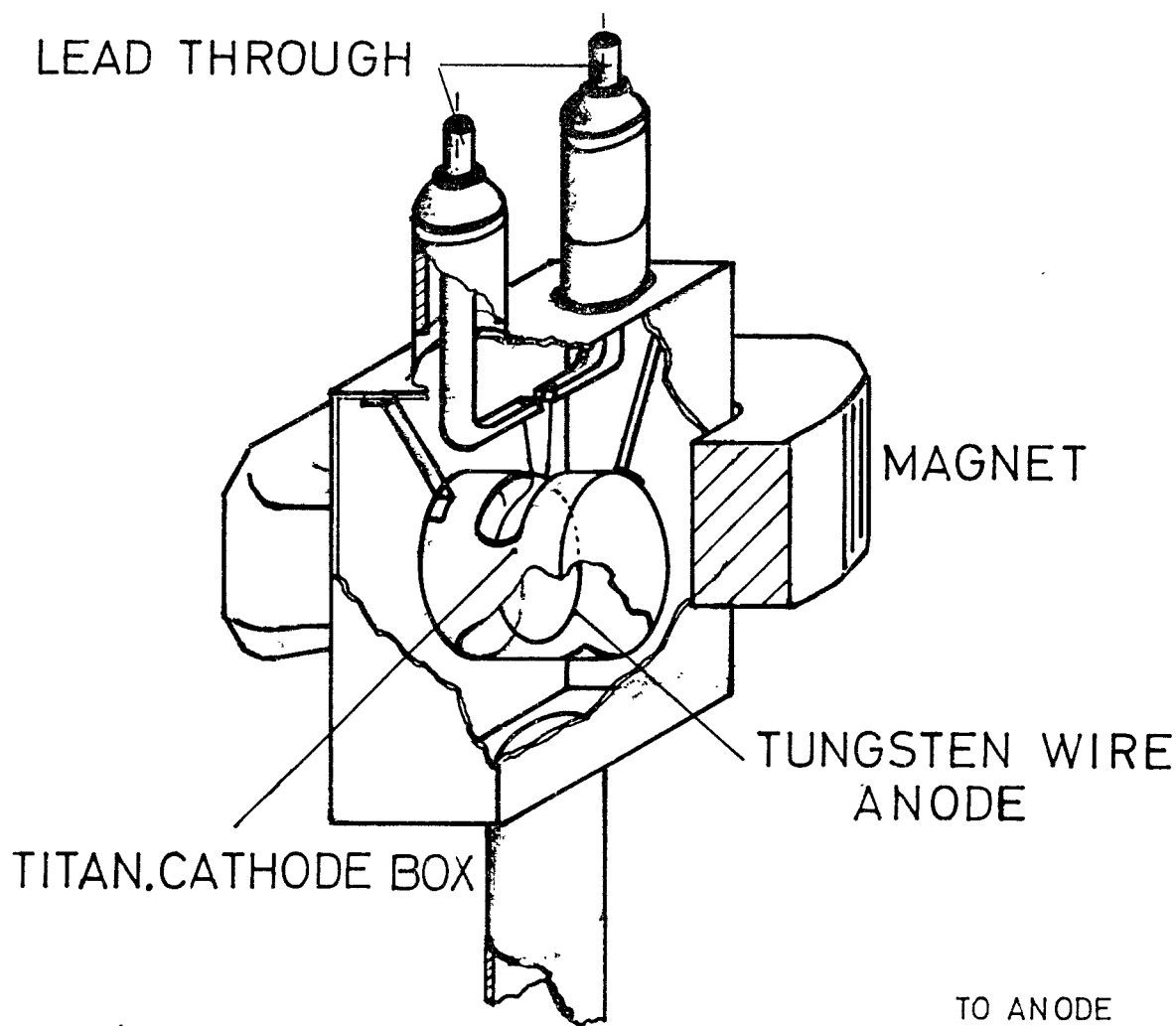PRESSURE
PRES. CURR.
0...2 MA
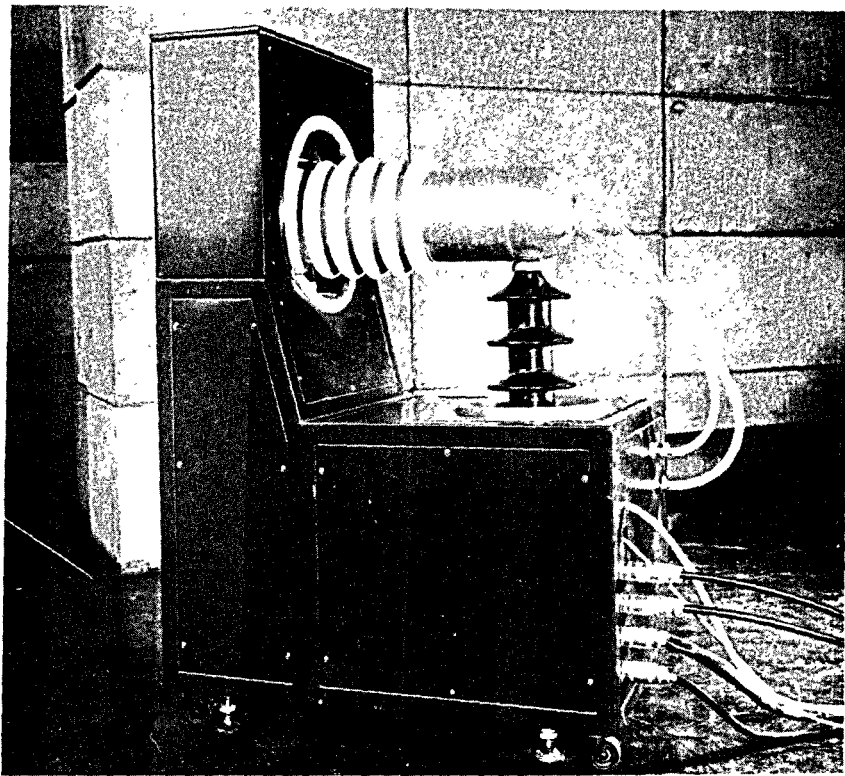
SERVO
AMPLIFIER

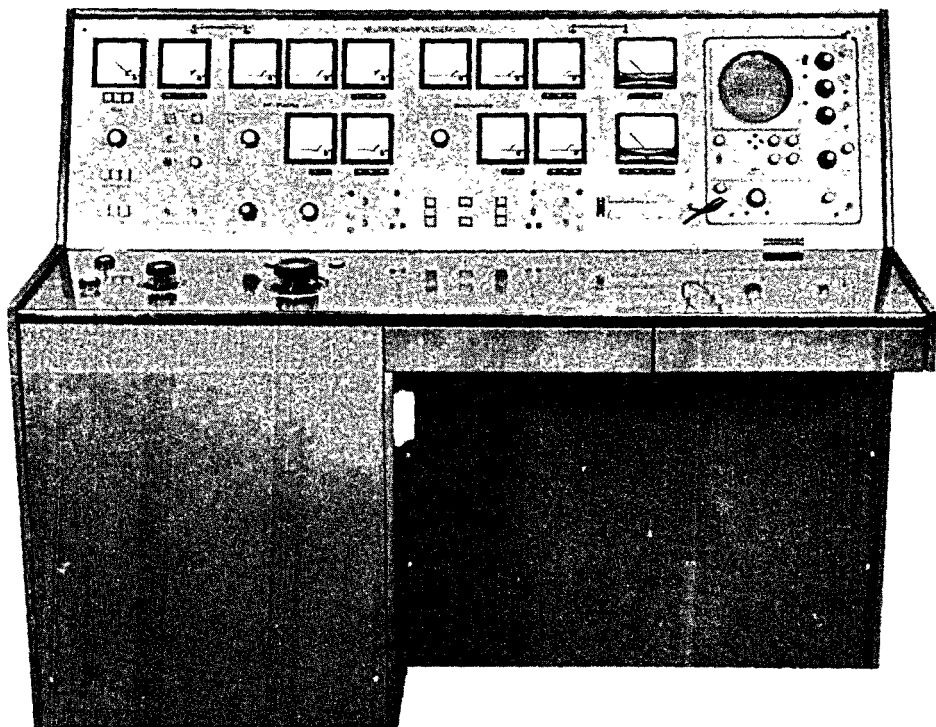Fig. 7: The Pressure Control System

Fig. 8: Accelerator Tube Carriage

Fig. 9: Control Unit