CONF-8304234--1

GEPP-OP-741
3417B-0086A

THE PINELLAS PLANT ION ACCELERATOR FACILITY: AN APPARATUS FOR LOW-ENERGY ION SCATTERING AND NUCLEAR REACTION ANALYSIS

GEPP-OP--741

DE86 001666

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American Vacuum Society
Florida Chapter
Meeting April 19, 1983
St. Petersburg, FL

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Prepared for the
U. S. Department of Energy
Albuquerque Operations Office
Under Contract No. DE-AC04-76DP00656

DISCLAIMER

INTRODUCTION

The General Electric Neutron Devices Department (GEND) Ion Accelerator Facility first came to being in the Chemistry Laboratory of the Department of Energy (DOE) Pinellas Plant in 1975, with the installation of an Accelerator Inc. Model 200 HP Ion Implanter. The machine was originally used for ion implantation work; and since the machine's relocation in 1979 from the main plant building, the facility has been heavily involved in target assessment and material analysis work. An ultrahigh vacuum beam line has recently been added and the present facility represents a unique combination of accelerator and vacuum technology for broad application in low energy nuclear, solid-state and atomic physics, and material science. First, the general design and performance characteristics of the system will be discussed. Some general results of typical applications will be presented followed by some plans for future applications.

ACCELERATOR

Figure 1 shows the overall dimensions of the accelerator system. Figure 2 is an overhead view of the system in its present configuration. The accelerator is a Cockroft-Walton type linear accelerator with terminal voltages continuously variable between 10 and 200 kV through its external direct current (dc) power supply. The power supply also provides auxiliary power through an isolation transformer for operation of equipment in the high voltage terminal. The entire system is housed in a cell with 4-ft. thick concrete walls for radiation protection. All controls are located in a room adjacent to the cell.

The high voltage terminal contains the ion source, handling system for feed gases, and adjustable power supplies for control of the source and accelerator column focusing elements. The valves and power supplies are adjusted by motors mounted on the accelerator column base plate at ground potential, which operate controls in the high voltage terminal through nylon insulating rods. The terminal is enclosed in an aluminum cover that minimizes the risk of sparks from terminal to ground and reduces power losses due to corona. The terminal is attached to the baseplate by four insulating rods.

Figure 3 is a schematic of the accelerator column and beam line optics. The major components consist of the ion source, accelerator column, analyzer/switching magnet, electrostatic quadrupole lenses, analyzing slits, steering plates and 7 degree neutrals trap. All components after the magnet are present in both beam lines.

The ion source presently used is an RF ion source that is particularly efficient for producing ion beams of hydrogen, helium, nitrogen, argon and their isotopes. However, the source is capable of ionizing gasses across the periodic table. Figure 4 is a schematic of the RF ion source which consists of a pyrex cylinder, fitted at each end with a removable metal cap (probe) which serves as an electrode and vacuum seal. Gas is fed into the bottle by a controlled leak and is ionized by an RF electric field created inside the bottle by exciter rings attached to the bottle. The gas handling system consists of a changeable lecture bottle, pressure regulator, roughing valve for purging the gas line, on/off valve, and a remotely operated mechanical leak valve. The efficiency of ion production is increased by an axial magnetic field, created by a solenoid surrounding the bottle. A positive 0 to 10 kV applied to the probe forces positive ions toward the base, where the gap and focus lenses aid in extraction and focusing of the beam. The accelerating potential is measured with a precision voltmeter through a precision high voltage divider network attached to the probe.

The accelerator column is constructed of aluminum electrodes separated by pyrex glass spacers and sealed with Viton O-rings (refer back to Figure 3). The O-rings are compressed by three epoxy-filled glass rods extending the length of the column. The distribution of potential along the column is provided by current from the high voltage end to ground through a string of resistors, each connected to a pair of electrodes on the column. The electrode-resistor string is designed for voltage gradients of less than 20 kV per inch to minimize high voltage arcing. An electrode suppressor ring, biased at about 1 kV below ground and located just beyond the column exit, helps prevents electrons from being accelerated from ground to the high voltage end of the tube. Creation of neutrals at the source is minimized by a small LN_2 trap that condenses excess feed gas molecules that are not ionized by the source.

The analyzing/switching magnet generates a uniform magnetic field in the vertical direction and is used to switch the beam from one beam line to the other and select beam species by virtue of their charge and momentum. The present configuration analyzes the beam through an 18 in. radius of curvature and a 30-degree bending angle with a maximum field of 12.2 kg (M X E = 15). The magnet is water cooled and its power supply is remotely controlled. The magnetic field is monitored with a Hall probe mounted between the pole faces.

Two electrostatic quadrupole lenses help provide final beam focusing on target. These lenses are identical to the elements found in quadrupole mass analyzers except they are operated with dc potentials. When heavy ions are accelerated, the first quadrupole is adjusted for a focus on the analyzing slits. These slits are used for additional species isolation for which the magnet does not have sufficient resolution. The second lens is then adjusted to focus the beam on target. When light ions are accelerated, the slits are used only as a beam diagnostic tool and the lenses are simply adjusted for the best focus on target.

Two sets of parallel plates, one vertical and one horizontal, are used to help steer the beam on target. A pair of curved plates, located in a 7-degree bend, eliminates neutrals in the beam formed by collisions with residual gas molecules along the beam line.

Vacuum at the accelerator end of the system is provided by a 1500 l/s oil diffusion pump, cold trap and an oil sealed, rotary roughing pump. The vacuum at the column is typically 3 to 4 x 10^{-6} torr with the ion source on.

BULK ANALYSIS BEAM LINE

The original accelerator beam line system complements the ultrahigh vacuum system and possesses some very useful characteristics. The system is used for analysis and testing with samples that do not require vacuum quality better than 10^{-6} torr. The bulk analysis scatter chamber is equipped with an O-ring sealed lid that allows quick and easy access. The chamber can be closed and pumped to operating vacuum in less than 30 minutes (refer to Figure 5). The chamber is pumped by a 1500 l/s oil diffusion pump, cold trap and an oil sealed, rotary roughing pump and the system tolerates frequent opening and pump down. Vacuum in the bulk analysis scatter chamber is typically 1×10^{-6} torr.

The chamber is equipped with two goniometers for target positioning and a water cooled target fixture for use with high beam currents. The chamber also accommodates a fixture that is used as a calibrated source for neutron detector calibrations and tests.

ULTRAHIGH VACUUM BEAM LINE

The recently completed ultrahigh vacuum system promises to provide many new capabilities to the accelerator facility (refer to Figure 2). The beam line can be isolated from the accelerator with a valve at the magnet exit when not in use. The system is pumped by a 2000 l/s turbo molecular pump system at the entrance to the beam line and a 600 l/s ion pump at the ultrahigh vacuum scatter chamber.

A unique feature of the ultrahigh vacuum system is that it consists of two LN_2 traps - one between the beam line and accelerator column, and one between the beam line and the scatter chamber. These traps help keep the scatter chamber isolated from the poorer quality vacuum of the accelerator. The ultrahigh vacuum beam line vacuum is typically 2×10^{-8} torr and the scatter chamber vacuum is typically 2×10^{-9} torr with the valves open and the traps filled. Figure 6 shows a typical residual gas analysis (RGA) spectra taken at the ultrahigh vacuum scatter chamber.

The ultrahigh vacuum system will be used for analyses of materials where ultrahigh vacuum is crucial. The chamber is equipped with a multiple sample holder that can be remotely positioned. An RGA mounted on the scatter chamber will be used for beam induced material modification studies.

APPLICATIONS

The accelerator provides a beam of ions of controlled energy and current for target assessment and material analyses. Figure 7 shows a typical setup used in either scatter chamber for nuclear reaction and Rutherford backscattered analysis of materials. The beam is typically collimated to spot sizes $\leq$ 0.1 in. in diameter with beam currents on target $\leq$ 1 μA. Particles scattered from the target are detected by silicon surface barrier detectors. The signals from the detectors are amplified and used to produce particle energy spectra on a multi-channel analyzer (MCA). The spectra can also be transferred and stored on computer files for possible later off-line analysis. The total charge on target is measured by integrating the current induced on the target holder by the stopped, incoming beam. Biasing the target holder and faraday cage eliminate the effects on beam current measurements due to secondary electrons. For nuclear reaction measurements, a 2-μm thick aluminum foil absorption is used to shield the detector from the high flux of backscattered particles. The absorber is removed during backscattering measurements. A precision pulser is used for energy calibration and to monitor the overall gain stability of the system. A calibration ^{241}Am α source is routinely used to make energy calibrations and check detector solid angles.

Table 1 summarizes the types of analyses routinely performed at the facility.

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ION BACKSCATTERING (RBS)

Rutherford backscattering is a broadly applied method for surface analysis and depth profiling of implanted species and, like NRA, is nondestructive. RBS analysis involves obtaining a scattered ion beam energy spectrum and identifying constituent scattering centers from the kinematics of the scattering process. The amount of material present can be determined from the well known Rutherford scattering cross section. In the energy range of the accelerator, protons give the best depth penetration and $^{4}He^{++}$ gives the best mass resolution.

Figure 11 is a comparison of two targets with different surface oxide thicknesses analyzed with a 150 KeV deuteron beam. The high channel shoulder represents scattering from the metal matrix and the shoulder at about channel 250 is characteristic of scattering from the oxide layer.

FUTURE PLANS

Plans for the very near future include developing procedures for making RBS more quantitative. Also, additional material analysis techniques will be investigated for application at the facility, in particular, ion induced X-ray emission and fast neutron activation analysis.

Table 1. GEND Accelerator Facility Nondestructive Material Analysis Capabilities

METHOD	MEASUREMENT	LIMITATIONS
NUCLEAR REACTION ANALYSIS (NRA)	- NEUTRON YIELDS	- 5% TO 10% UNCERTAINTY
	- HYDROGEN ISOTOPE LOADING UNIFORMITIES	- 5% UNCERTAINTY; ≈/mm RESOLUTION
	- HYDROGEN ISOTOPE DEPTH PROFILES	- 20% UNCERTAINTY; ≈/mm DEPTH, ≈.1 mm RESOLUTION
	- SOURCE ION ENERGY LOSS RATES/STOPPING POWERS	- 20% UNCERTAINTY
	- EFFECTS OF SURFACE & BULK CONTAMINATIONS	- 5% TO 10% UNCERTAINTY
RUTHERFORD BACKSCATTERING (RBS)	- SURFACE CONTAMINATIONS	- MOSTLY QUALITATIVE
	- SOURCE ION ENERGY LOSS RATES/STOPPING POWERS	- 20% UNCERTAINTY
RESIDUAL GAS ANALYSIS (RGA)	- BEAM INDUCED OUTGASSING	- $\approx 10^{-12}$ TORR PARTIAL PRESSURE
	- GAS CONTAMINATION EFFECTS ON MATERIAL PROPERTIES	- 5% TO 10% UNCERTAINTY TO $\approx 10^{-12}$ TORR PARTIAL PRESSURE

ADDITIONAL CAPABILITIES

METHOD	APPLICATION	
CALIBRATED NEUTRON GENERATION	- NEUTRON DETECTOR CALIBRATIONS	- 5% TO 10% UNCERTAINTY
	- NEUTRON DETECTOR DEVELOPMENT STUDIES	
BEAM INDUCED CURRENT MONITORING	- SECONDARY ELECTRON EMISSION	- %5 TO 10% UNCERTAINTY
	- CHARGED ION EMISSION	
	- TERTIARY ELECTRON EMISSION	

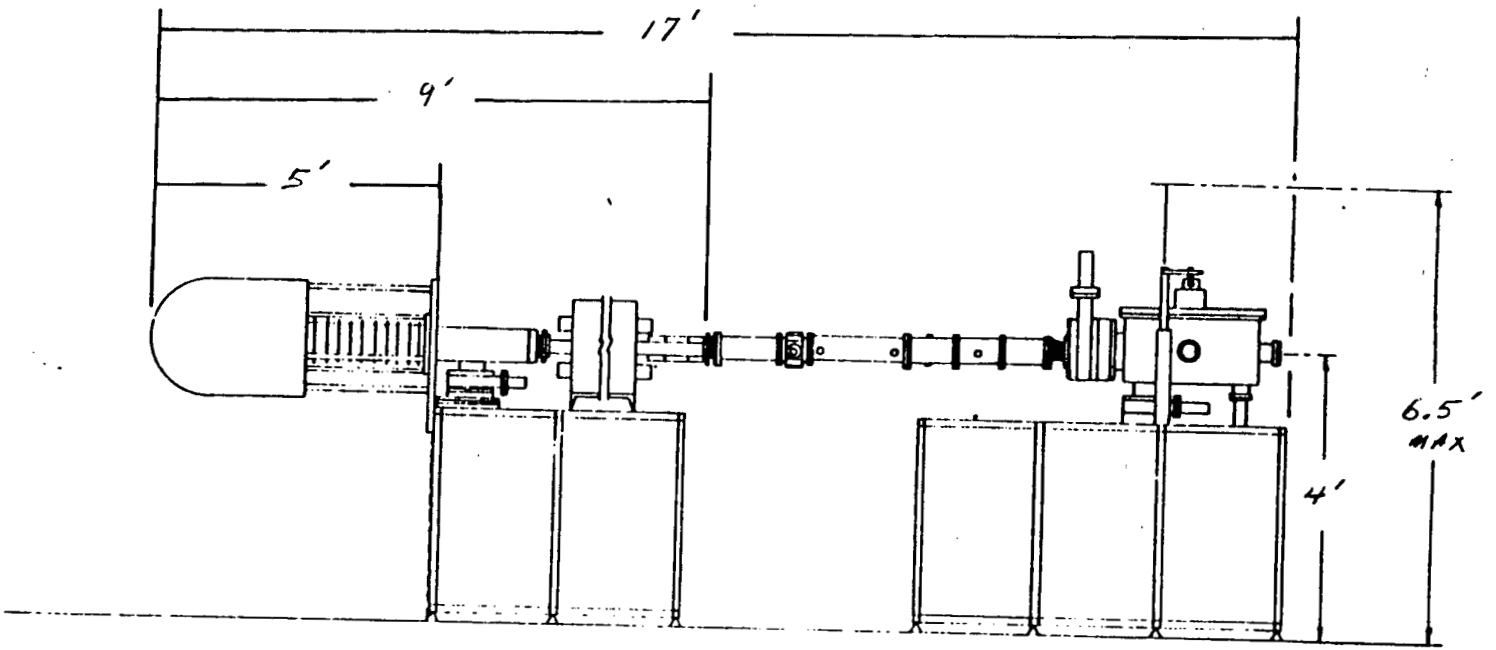


Figure 1. Accelerators, Model 200 HP

1. Pump sta. #1. Diffusion pump system.
2. Electrostatic lenses.
3. Analyzing/switching magnet.
4. UHV beam line isolation valve.
5. Liquid nitrogen traps.
6. Analyzing slits.
7. Pump sta. #3. Turbo molecular pump system.
8. Steering plates.
9. ESA/neutrals deflector plates.
10. Beam shutters.
11. Beam profile monitor.
12. Beam line-scatter chamber isolation valves.
13. Pump sta. #4. Ion pump system.
14. Risidual gas analyzer.
15. Pump sta. #2. Diffusion pump system.
16. Neutron detector development and calibration system.

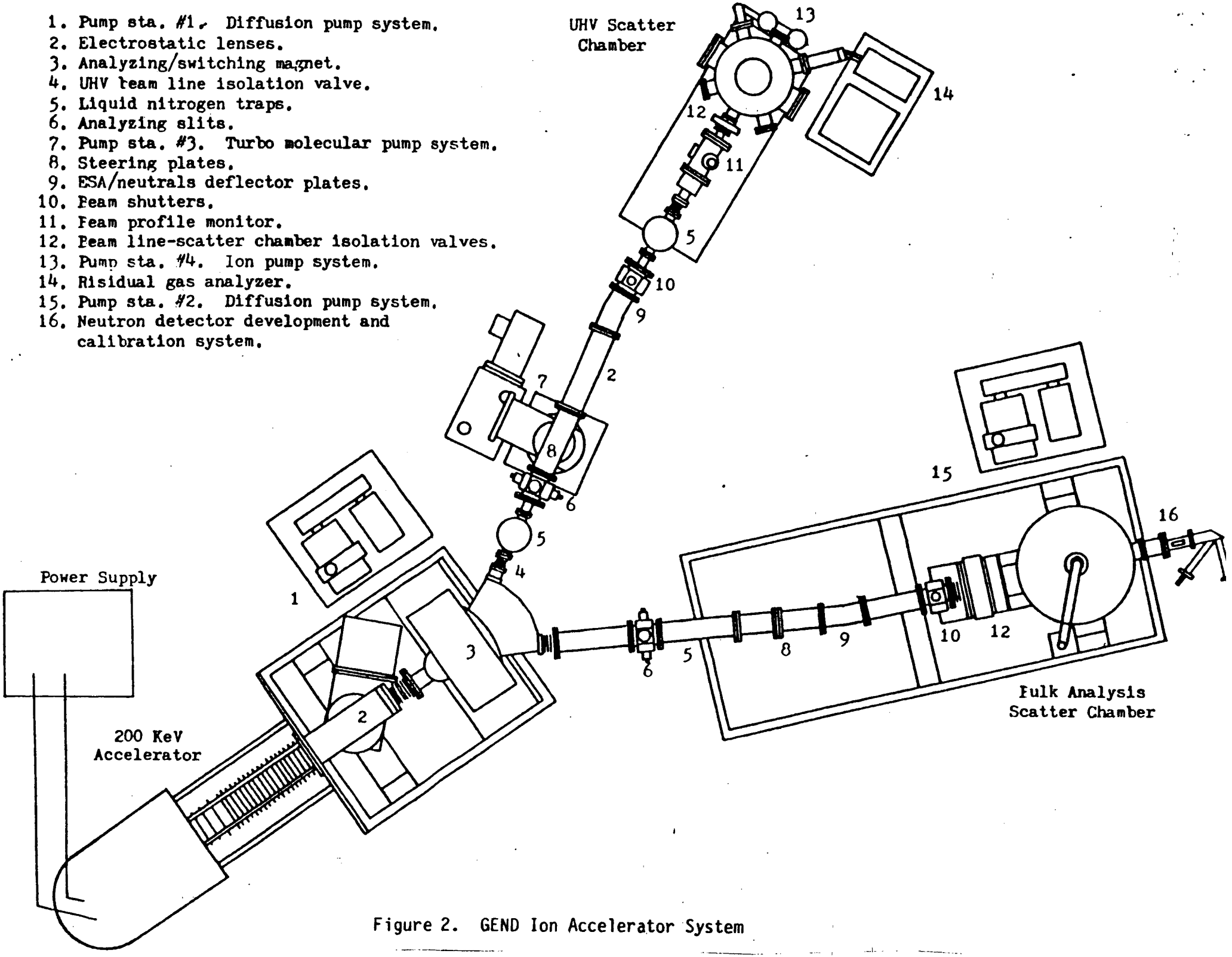


Figure 2. GEND Ion Accelerator System

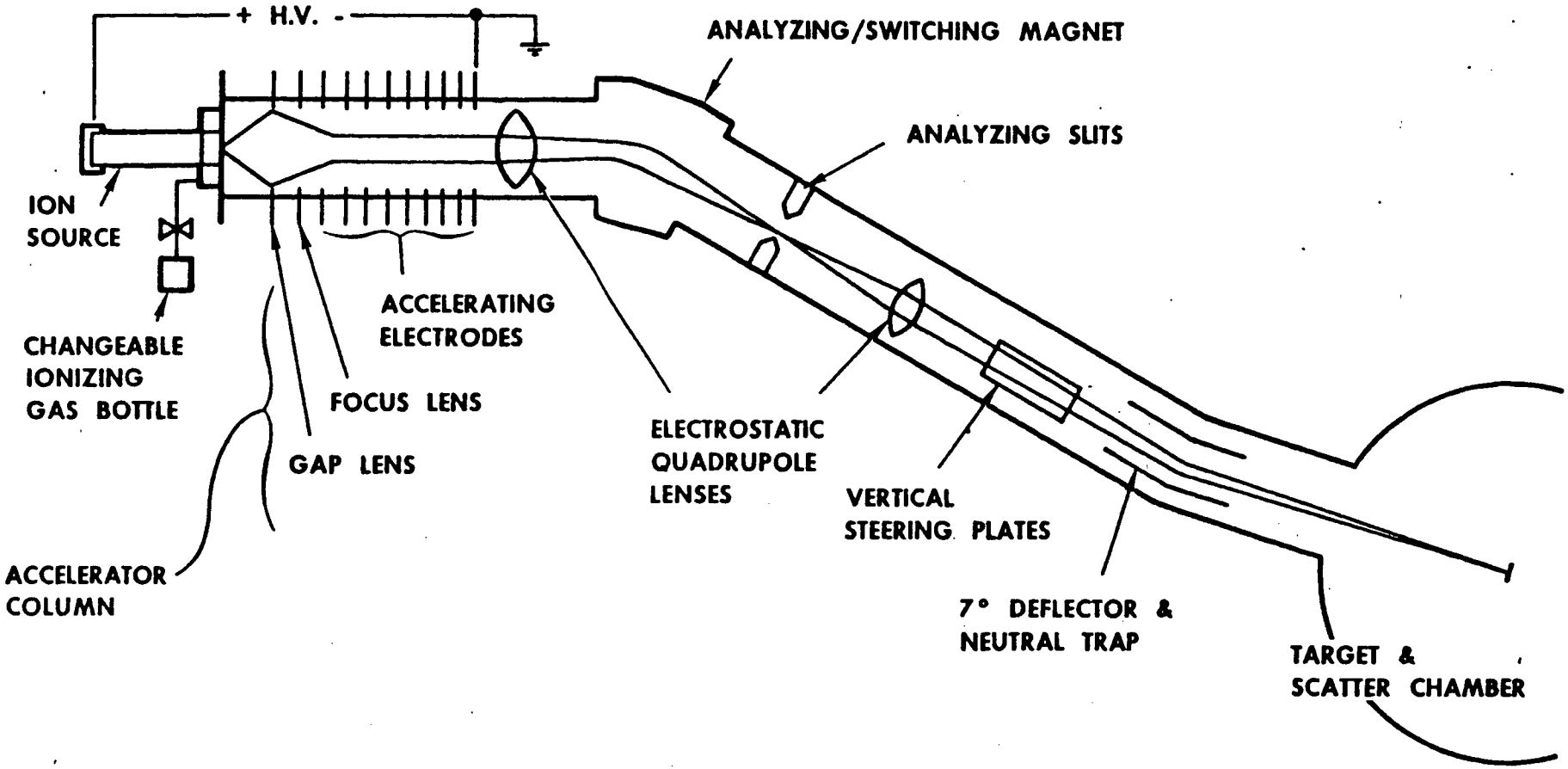


Figure 3. GEND Ion Accelerator Beam Line Optics

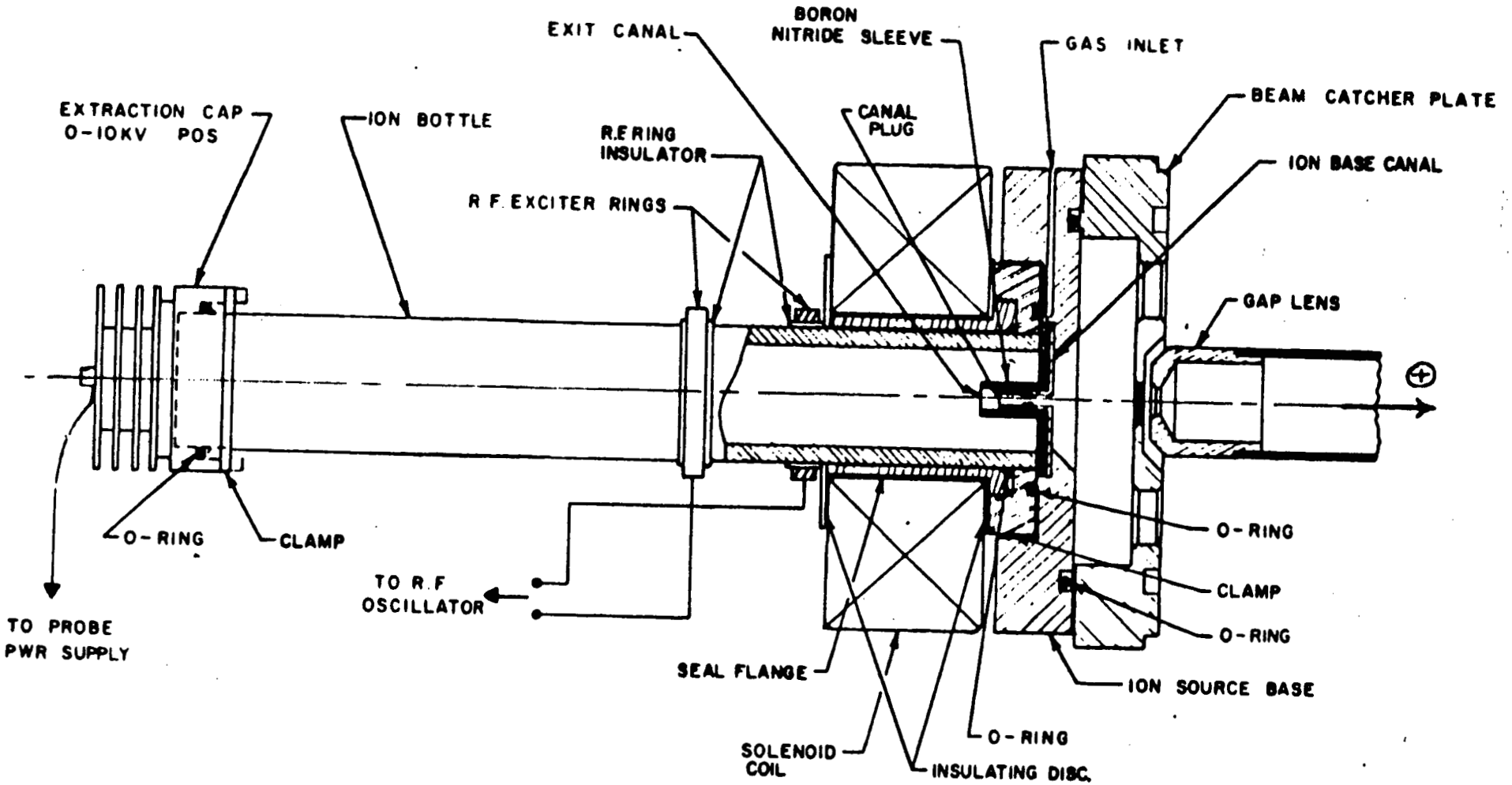


Figure 4. RF Ion Source

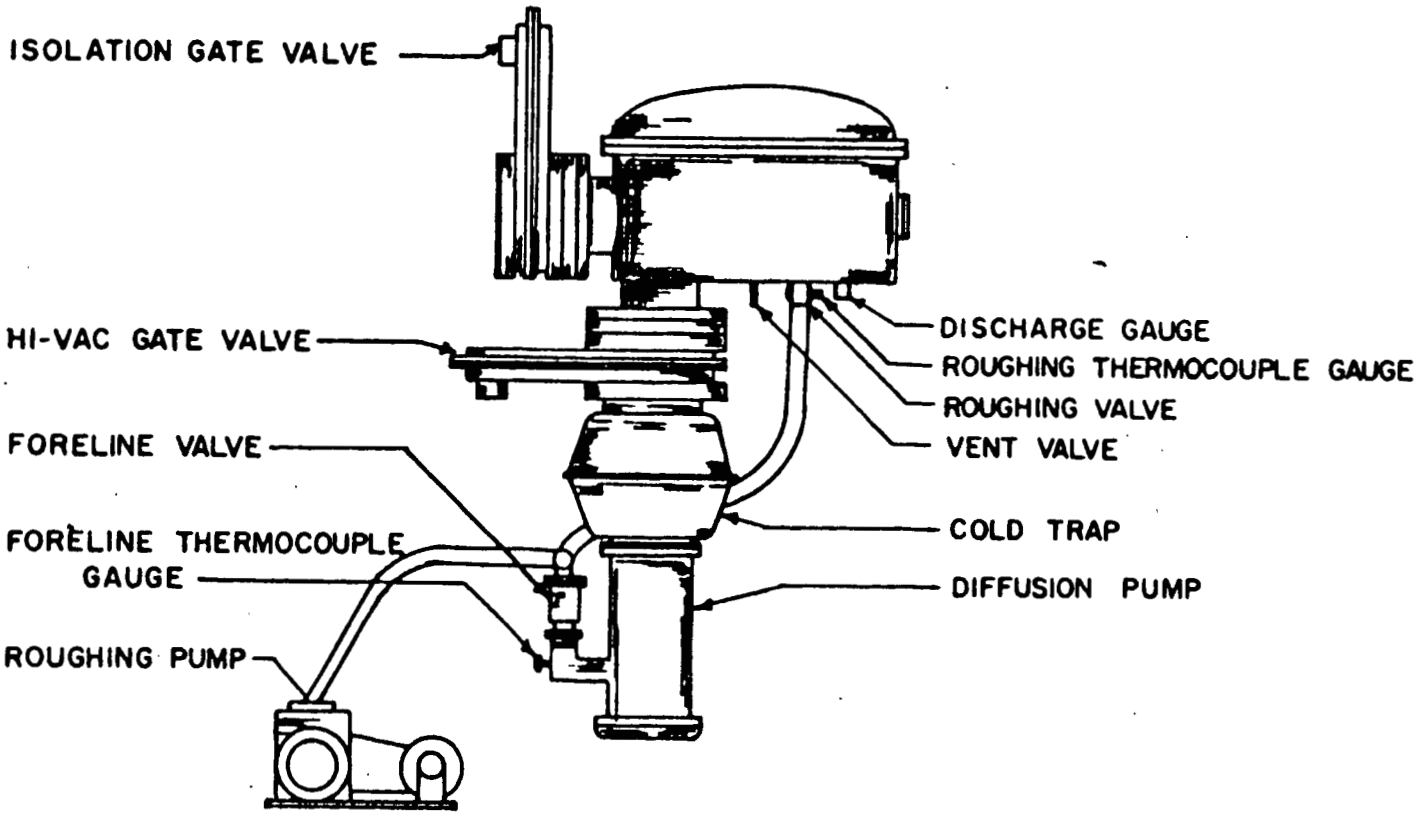


Figure 5. Target Chamber Pump Station

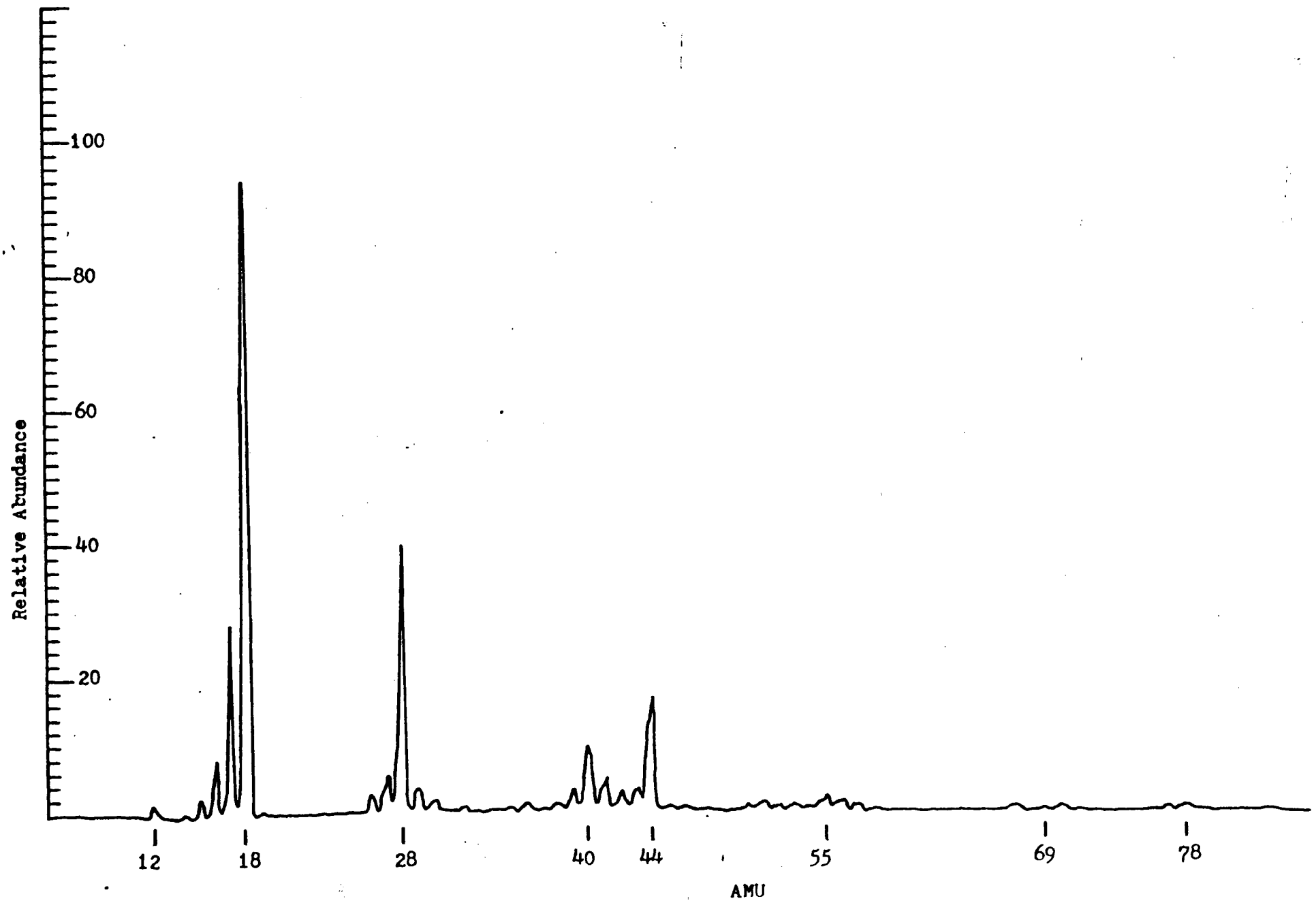


Figure 6. Residual Gas Analysis Spectrum at Ultrahigh Vacuum Scatter Chamber With Pressure at 2.15 x 10^{-9} Torr

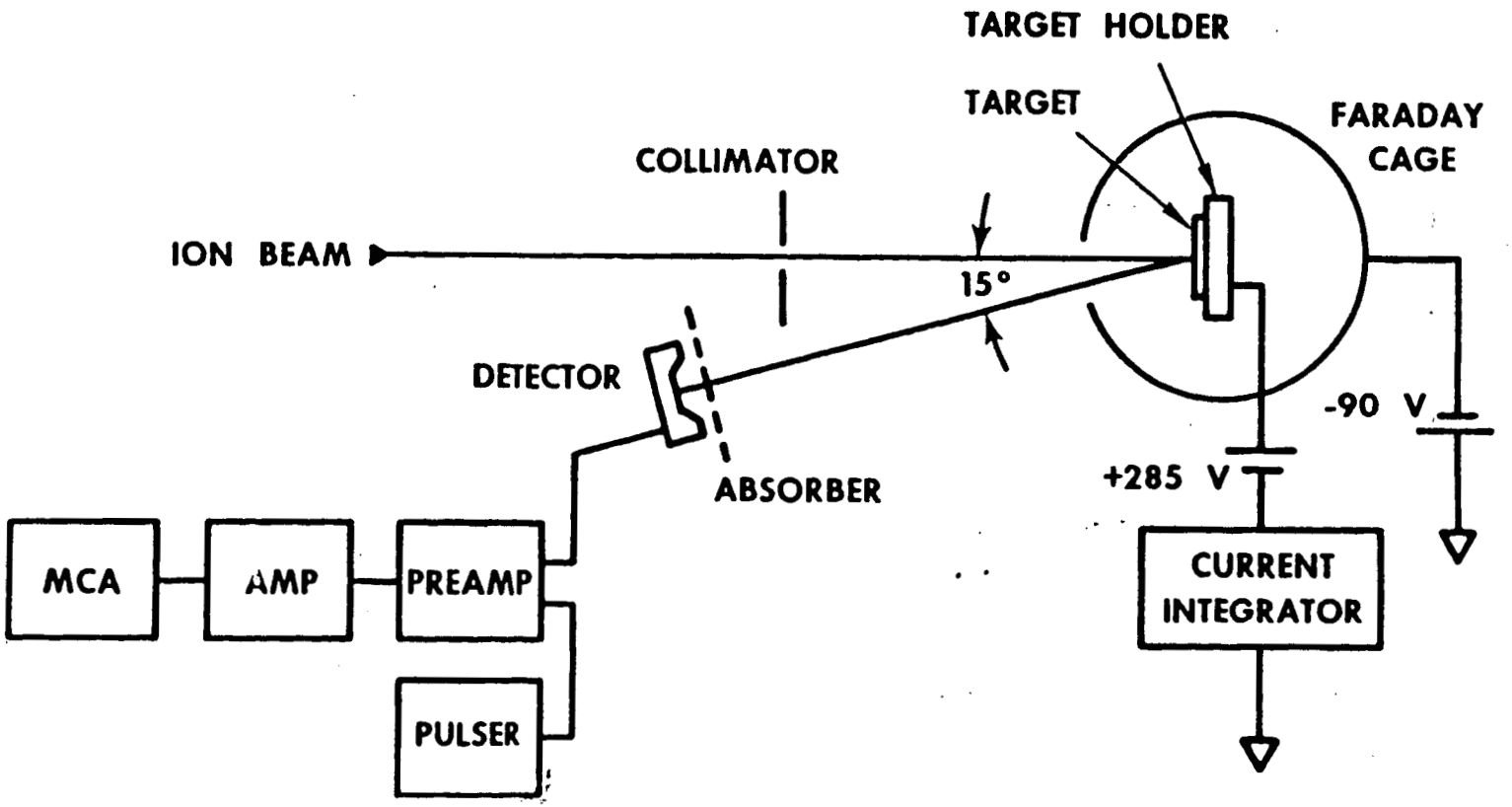


Figure 7. Typical Experimental Setup Used For Rutherford Backscattering and Nuclear Reaction Measurements

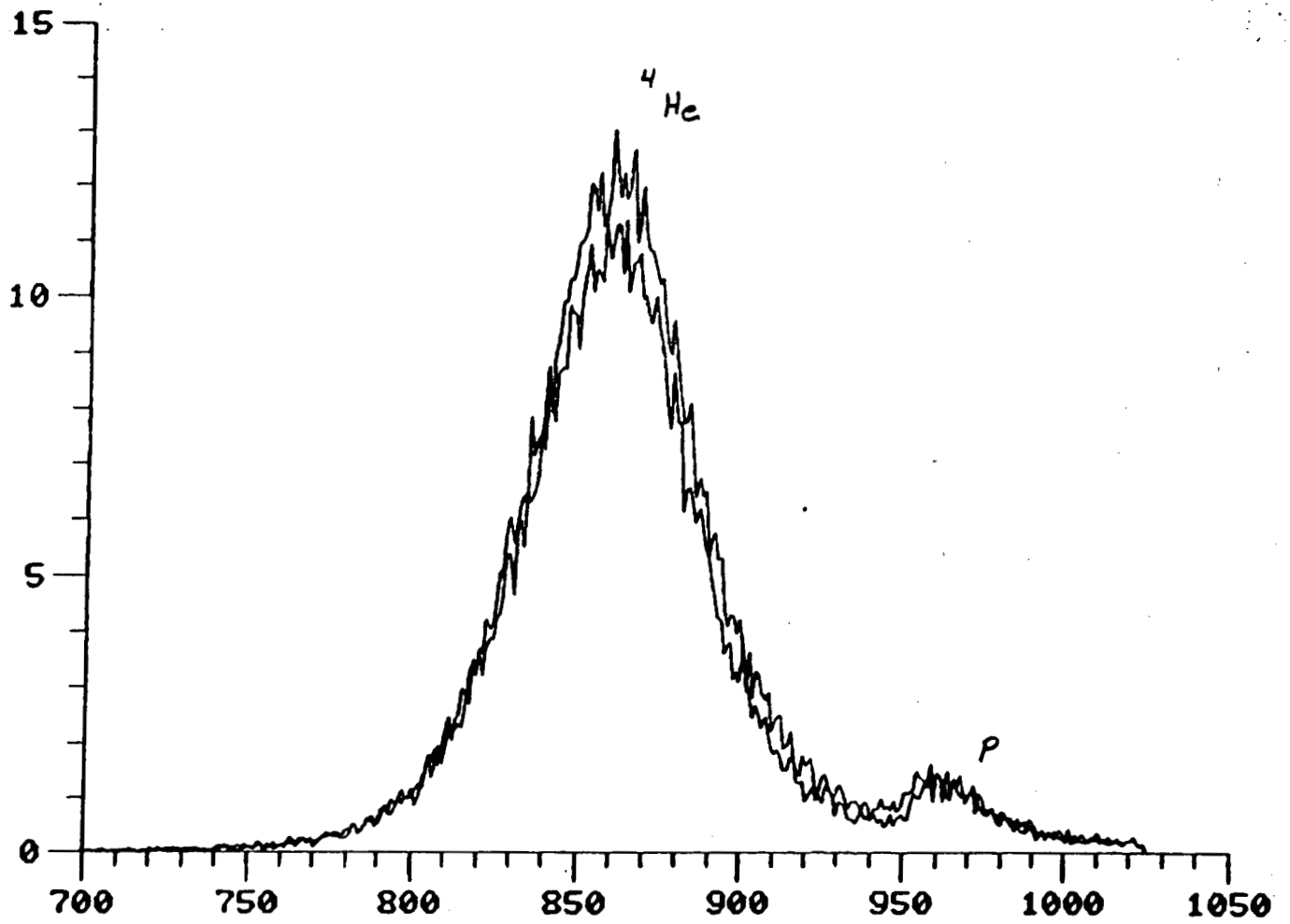


Figure 10.

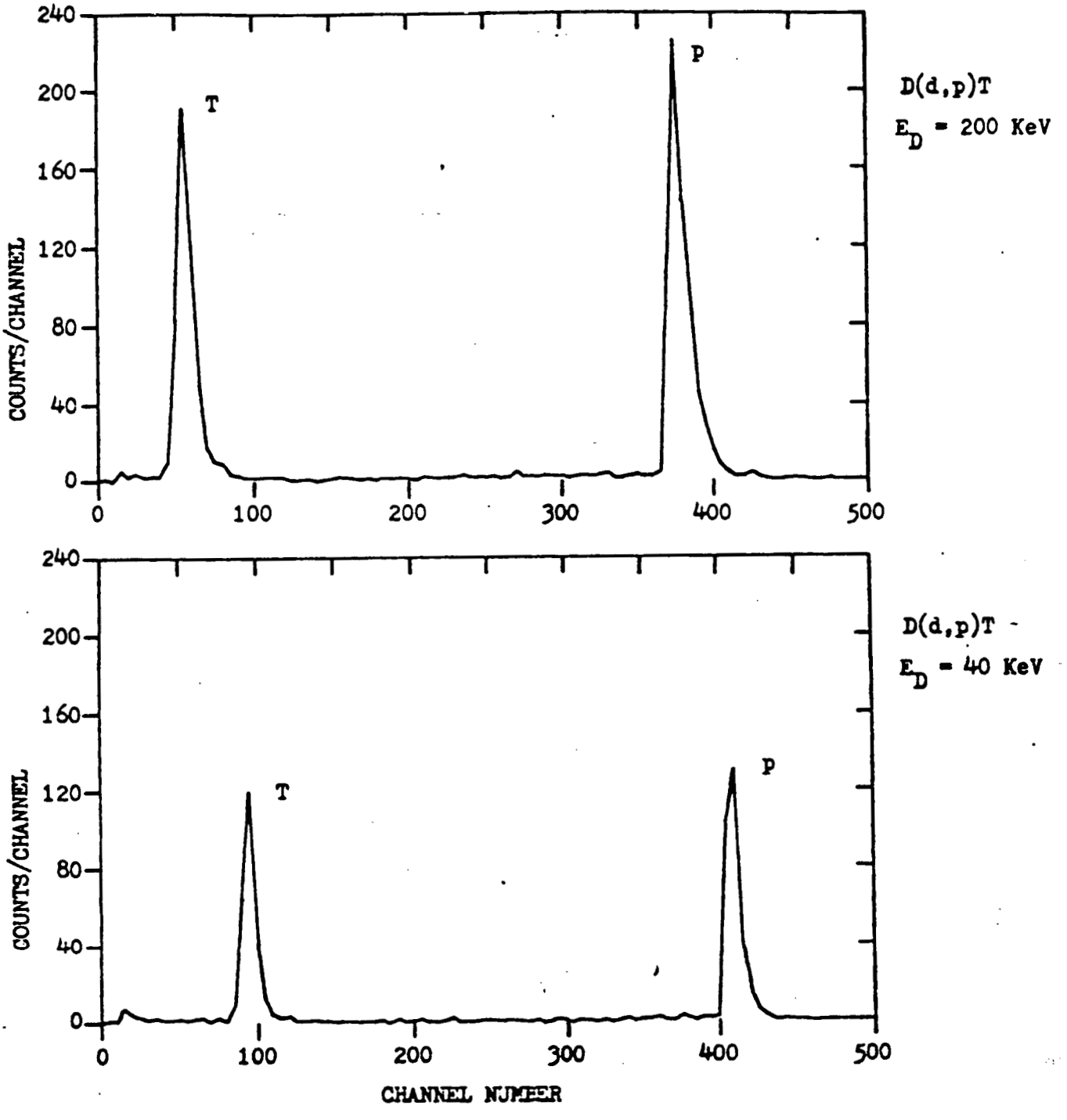


Figure 8. Particle Energy Spectra For the D(d,p) T Reaction on ErD_2 at 40 and 200 KeV

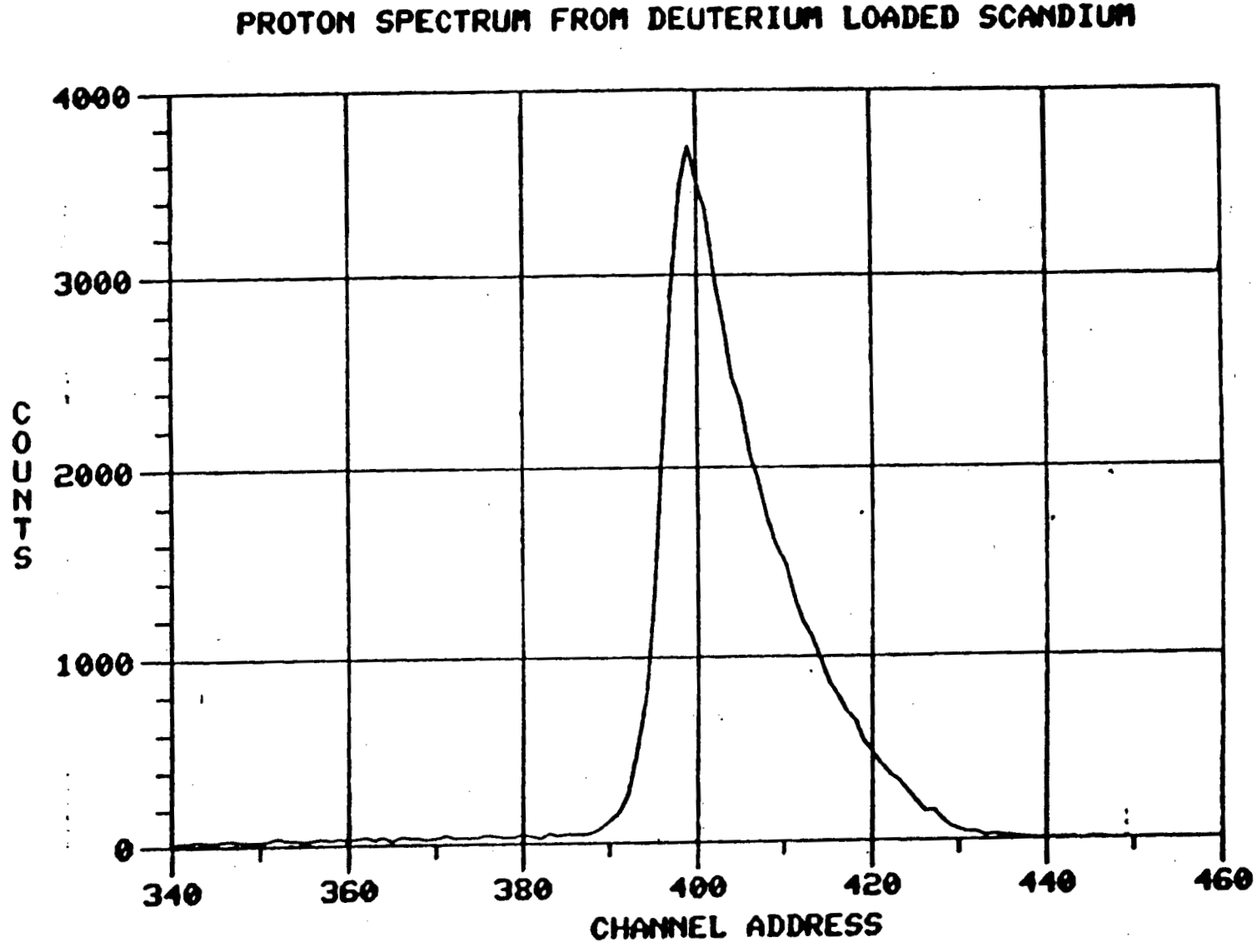


Figure 9. Proton Spectrum From Deuterium Loaded Scandium

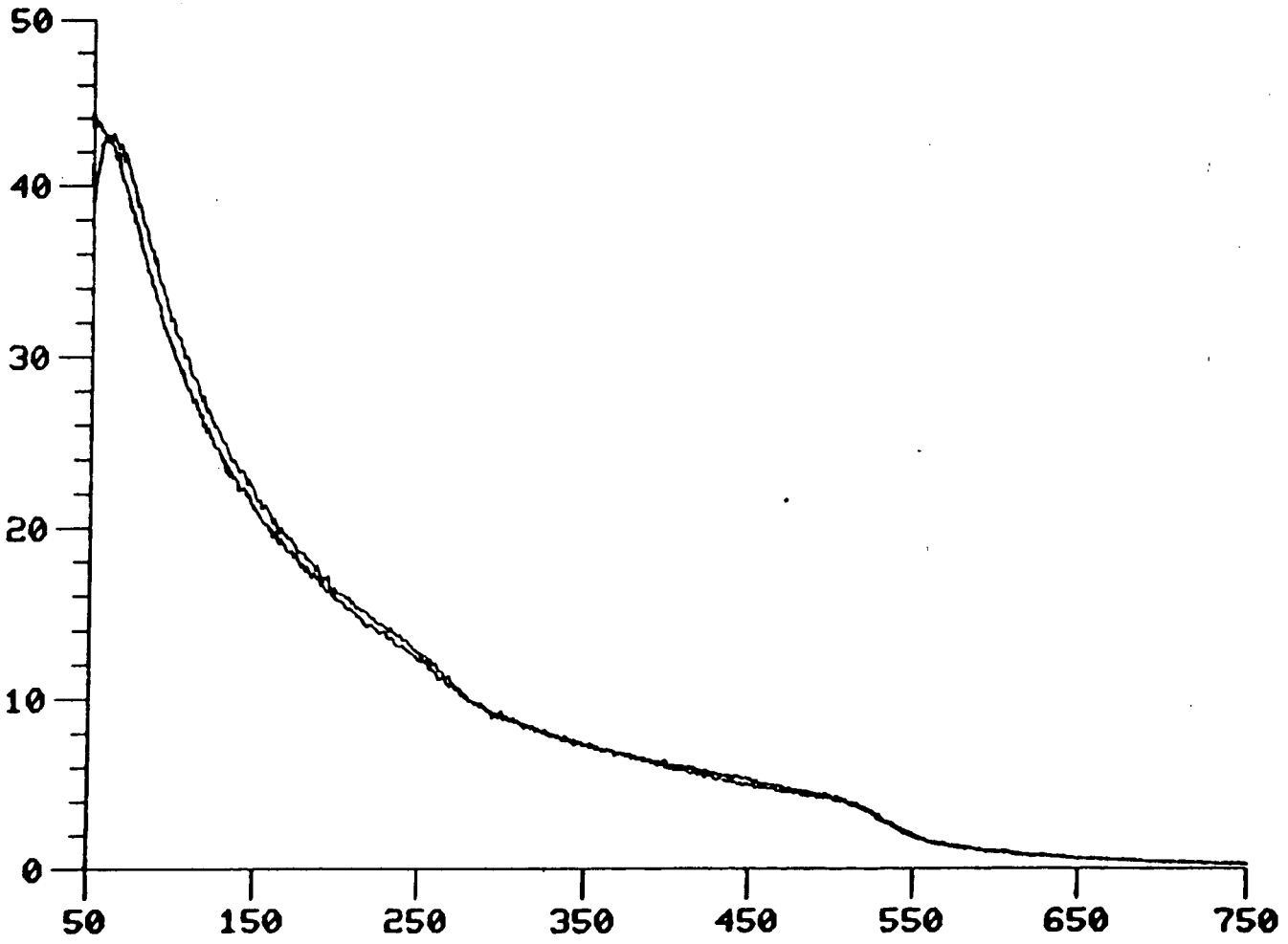
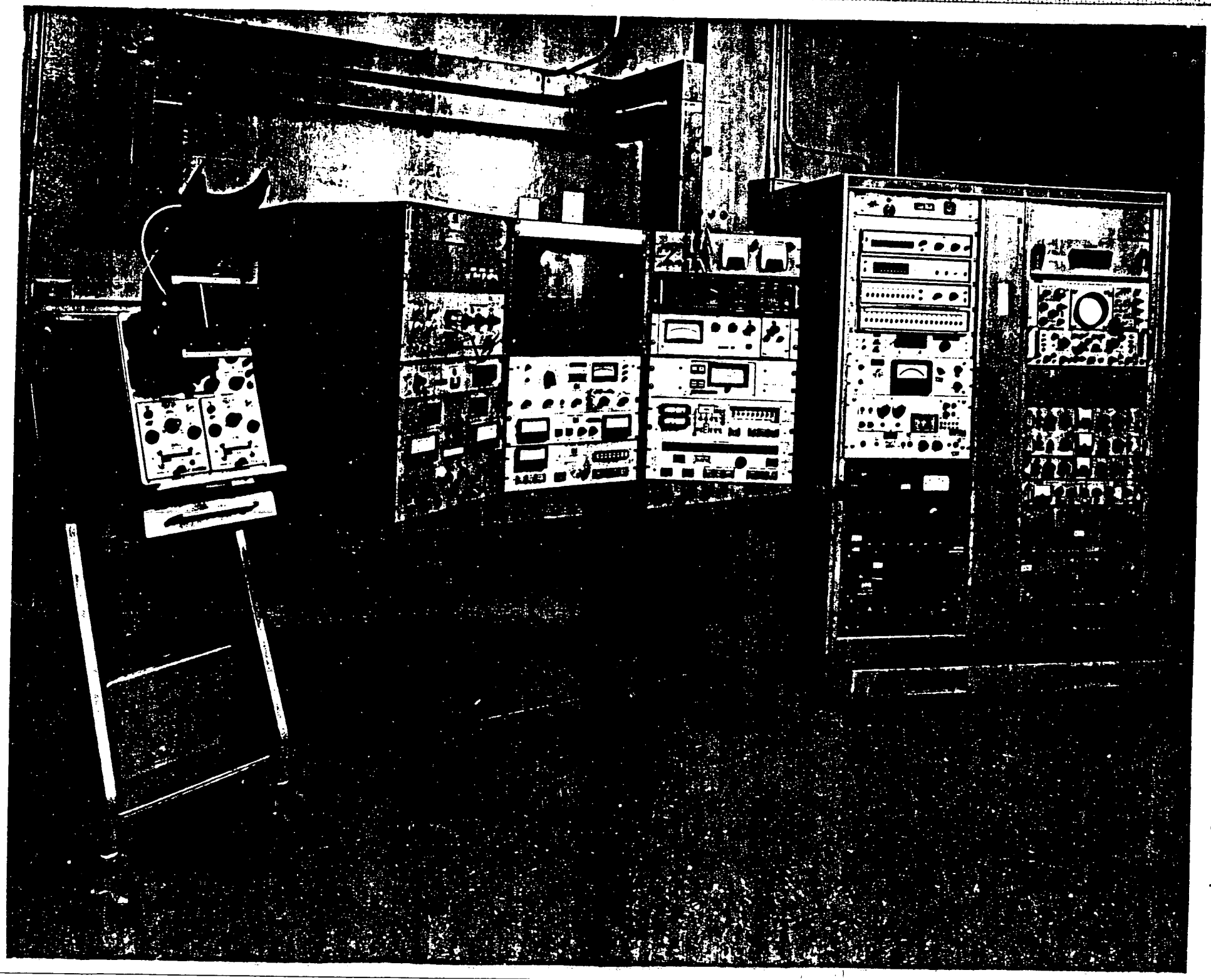
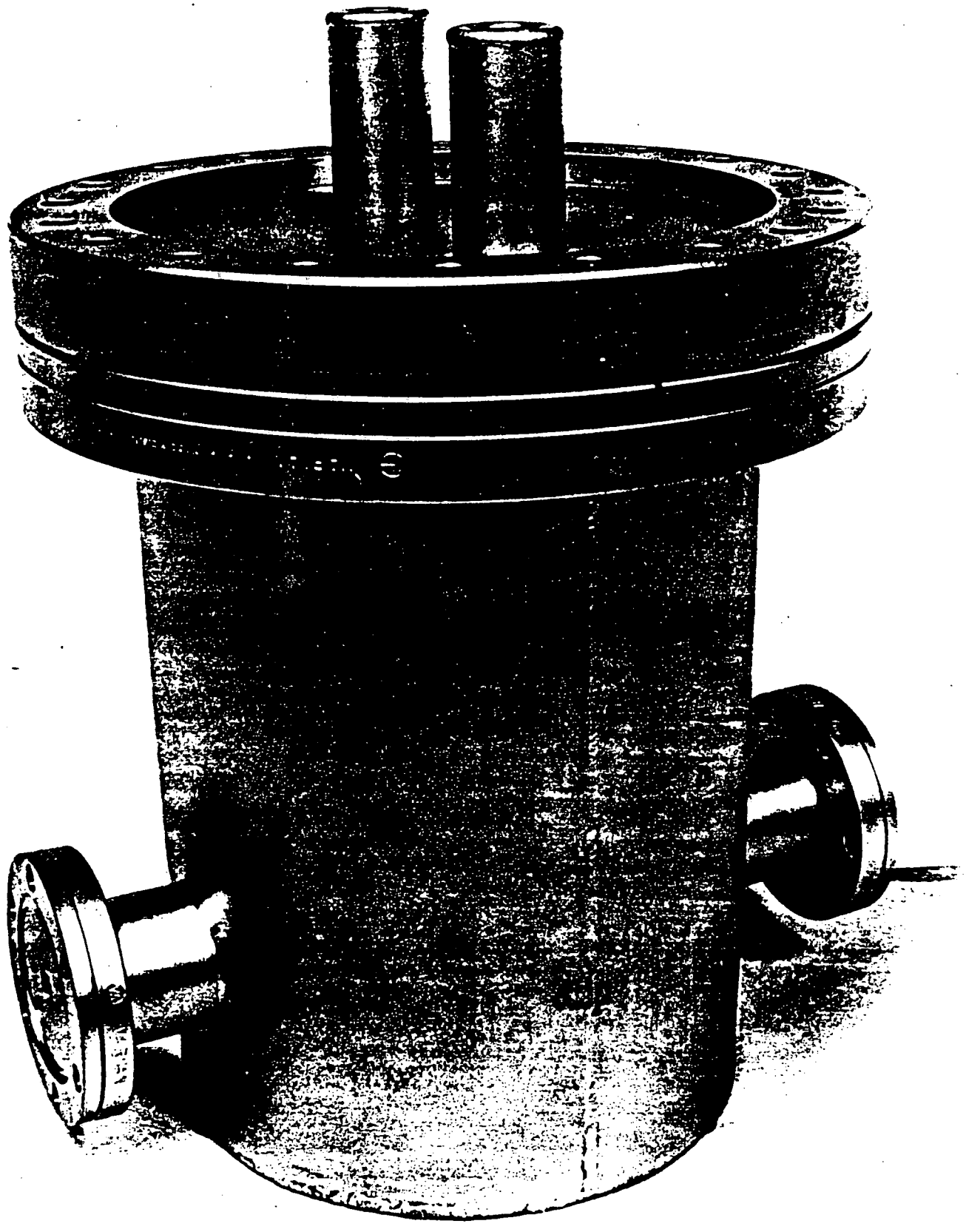
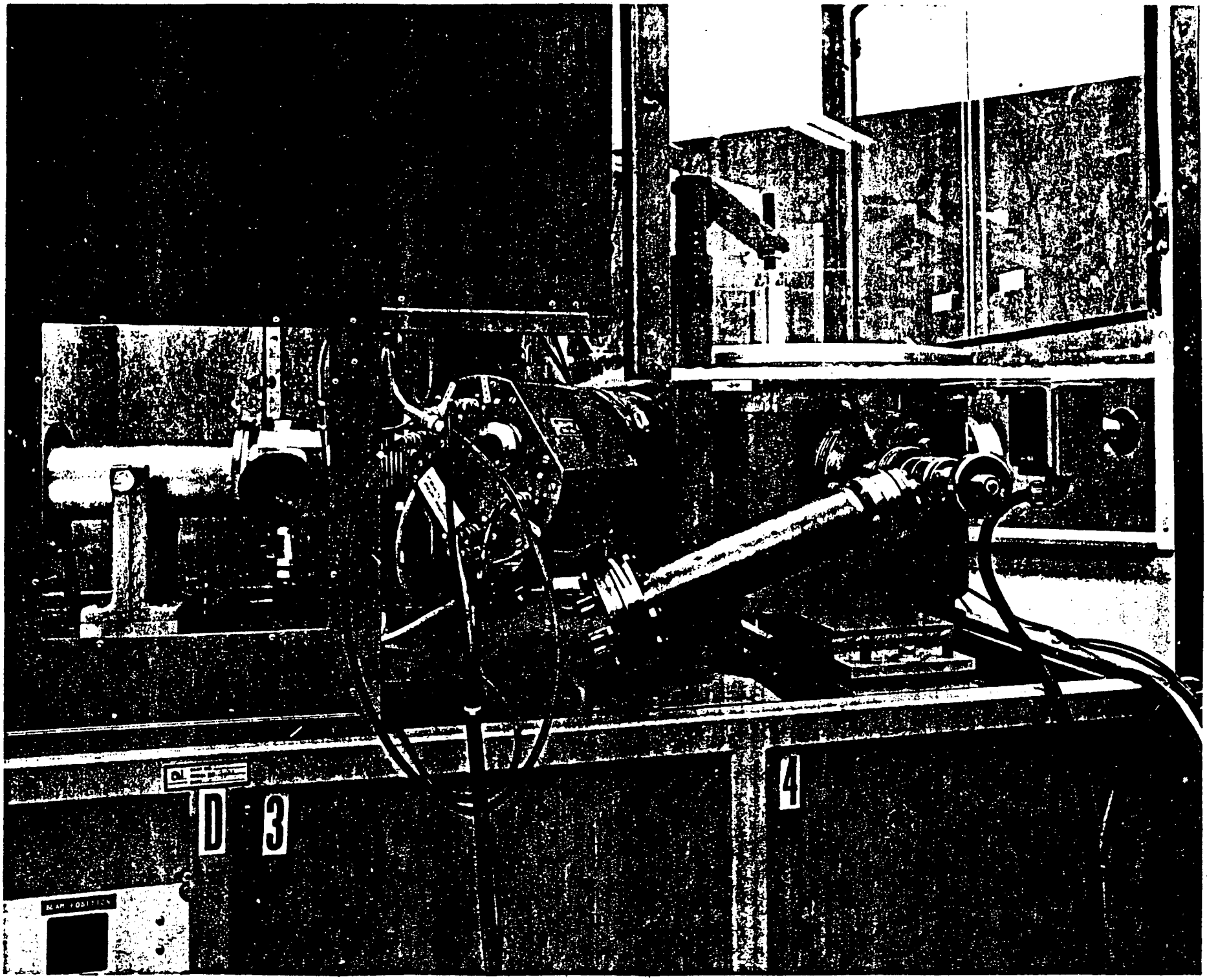


Figure 11.



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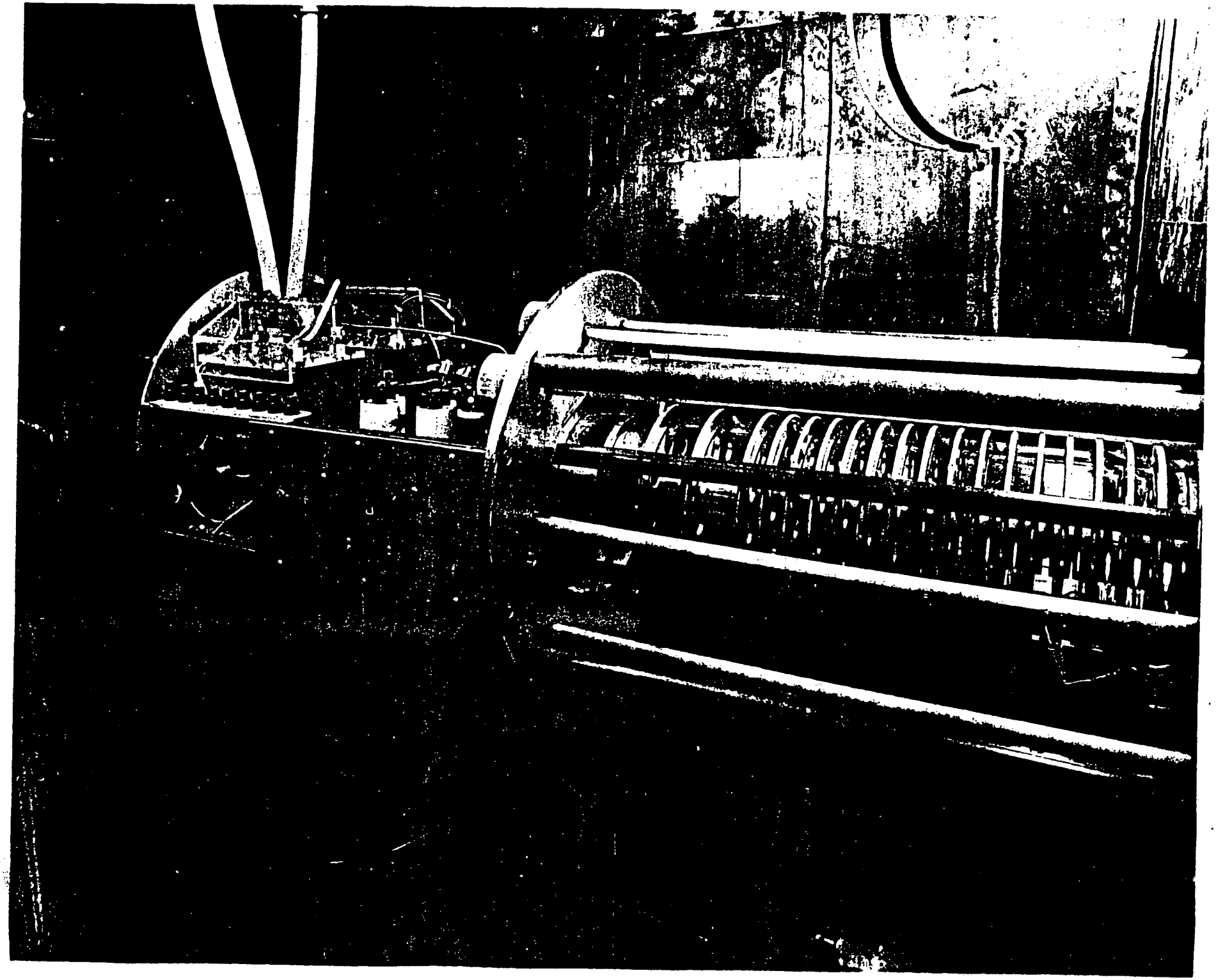

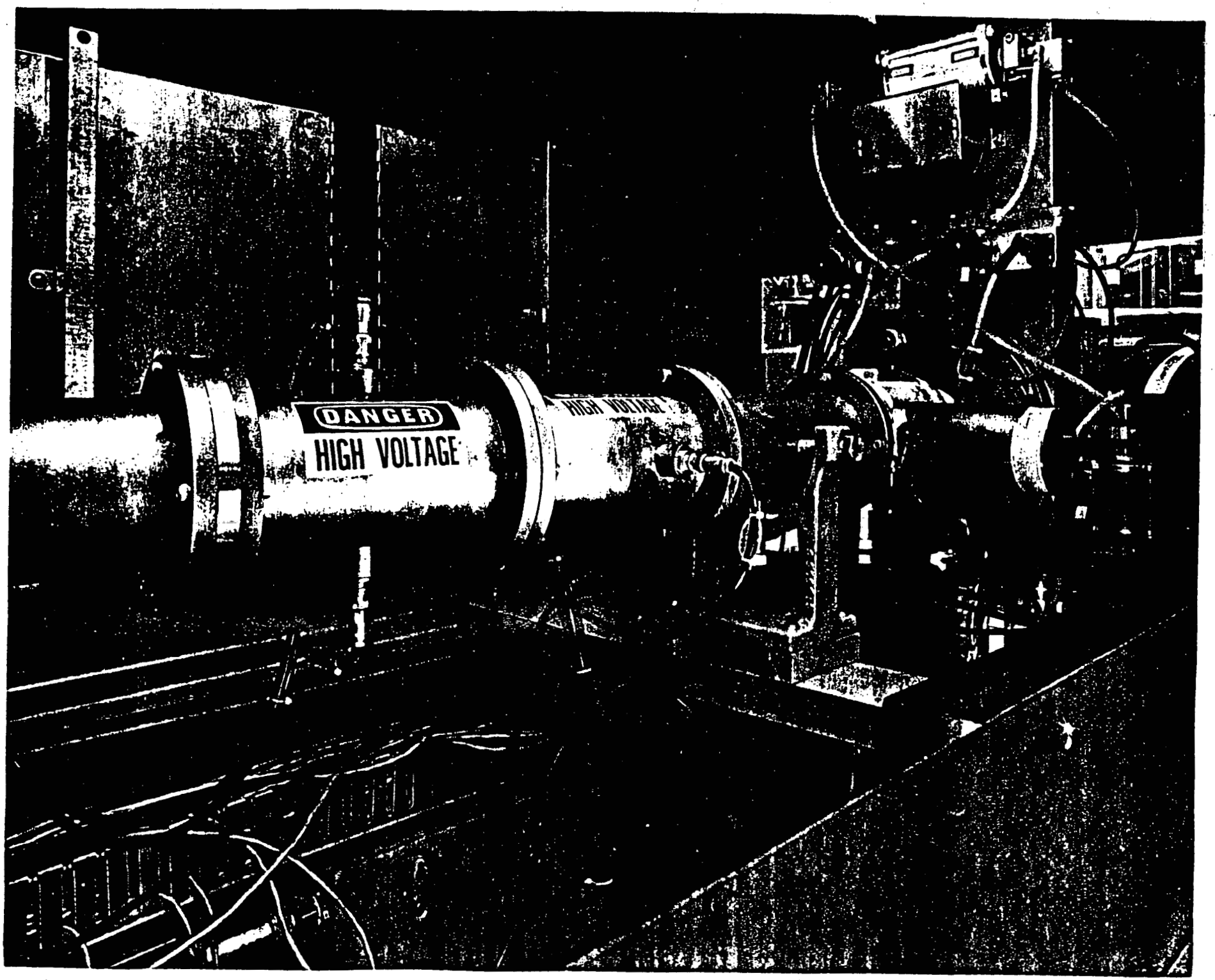
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