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Author

Gough, R.A.

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A FAST-CLOSING VACUUM VALVE FOR THE BERKELEY 88-INCH CYCLOTRON*

R. A. Gough, R. Lam, C. Martinez and D. Morris

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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Abstract

A fast-closing vacuum valve has been built to protect the Berkeley 88-Inch Cyclotron against radioactive contamination during bombardments of highly radioactive targets. A 2.5 cm diameter through-hole can be vacuum sealed in ∿3 ms by means of a wedge-shaped teflon gate which is moved into the closed position by the pressure created from an explosive charge. This charge can be triggered by a fast electronic signal from an ion gauge, a helium leak detector or other suitable gas analyzer. Response times of an ion gauge at 10^{-5} - 10^{-4} Torr to a sudden pressure increase have been measured to be ∿1 ms.

*Work performed under the auspices of the U. S. Energy Research and Development Administration.

1. Introduction

Fast-closing vacuum valves have been needed for some time in nuclear research[1,2]. Such a valve[1] was developed in 1969 for use at the Berkeley 88-Inch Cyclotron to protect the accelerator from radioactive contamination during bombardments of a tritium gas target. Further development of this project was made necessary by the recent initiation of a heavy element research program[3] which requires heavy ion bombardment of highly radioactive transuranic targets mounted on thin foils. These experiments frequently employ a gas jet technique in which a pressure of ∿750 Torr of He (or other gas) places the target foil under considerable mechanical stress[4]. Should the foil rupture due to thermal and/or mechanical stresses, radioactivity could be transported into the cyclotron dee tank by a sonic expansion of carrier gas into the cyclotron vacuum. If a radioactive excursion of this nature contaminated the cyclotron accelerating chamber, routine maintenance would be very difficult and decontamination procedures could be very costly in terms of both money and down-time.

In order to prevent cyclotron contamination, a fast-closing "slammer" valve has been made operational. Since some transport medium, such as a carrier gas or water from a faulty cooling line, is necessary to transport the radio-activity toward the cyclotron, an ion gauge or vacuum analyzer is an appropriate sensor for triggering this value. A fast triggering circuit has been developed which responds to the signal from such a device. Commercial explosives, in the form of squibs[5], were chosen as a power source for the valve because of their very high degree of reliability (>99.9%), the reproducibility, uniformity and magnitude of the force they create and their compatibility with fast electronic firing mechanisms. The valve has a very light, replaceable teflon gate and a hardened steel body which, unlike spring-loaded mechanical prototypes tested, has shown no signs of distortion even after many firings. The time required to re-arm the unit after firing is approximately 15 min. including pump-down time.

2. Mechanical Features

An artists rendering of the valve is shown in fig. 1. A proper choice of materials is thought to be an important aspect of its design. For example, the use of teflon for the valve gate has several advantages. Its low inertial mass and low coefficient of friction permit the gate to be accelerated and decelerated very quickly. Its light weight and malleability tend to prevent distortion of the valve body, which is made of hardened steel. Furthermore, the teflon/steel surfaces make an excellent vacuum seal. Locating pins are used for proper alignment of the end caps. However, the very high energy supplied by the squibs ensures proper closing of the valve despite any slight misfits or misalignments. Not shown on fig. 1 are 8 tapped holes for mounting the unit in the beam transport line.

Some experimentation was necessary to determine the proper sizing of the teflon gate with respect to the groove in which it travels. A standard 3° Morse taper was cut on both the groove, using electron discharge techniques, and the teflon gate. When the valve is fired and the gate is approaching the valve seat, the leading edge of the gate makes a vacuum seal $\sim$5 mm before reaching the end of its travel. During this last 5 mm the gate is decelerated by the wedging action of the taper. We have found that about 5% compression on the teflon gate makes a good vacuum seal and permits the valve to close satisfactorily when fired with a 550 mg charge of Bullseye pistol powder, chosen for its fast-burning characteristics. One gate, designed for 10% compression, failed to close fully when the valve was fired with a similar 550 mg charge. Too little compression could result in a poor vacuum seal, or cause the gate to bounce from the valve seat and settle in a partially open position. A thin metal contact strip is screwed to the bottom surface of the gate so that when the valve gate is fully closed, it electrically grounds the contact wires (see fig. 1) to the valve body.

The squib is not designed to provide a vacuum seal; the explosion chamber is normally at atmospheric pressure. In the valve open position the teflon gate fits tightly into the groove and generally will seal the vacuum. However, gunpowder residue sometimes spoils the surface quality of the groove walls nearest the explosion chamber. In order to avoid cleaning this residue after each firing, a metal foil (with O-rings on either side) is used as a secondary seal. Thus the procedure for re-arming the valve after each firing is simplified; it is necessary to remove and replace the squib, the gate and the vacuum foil. This is done with the valve still in the beam line by removing the four draw bolts to disassemble the unit.

3. Electrical Design

A block diagram of the electronics and a simplified squib firing circuit are shown in fig. 2. There are two independent channels from which the trigger signal can be derived. Each channel can accommodate up to 8 inputs from some appropriate sensor such as an ion gauge or vacuum analyzer. At present two ion gauges (one for each channel) are used to monitor the beam line pressure near the entrance to the target chamber. A Granville-Phillips (G.P.) power supply (series 260) is used because its output is compatible with the TTL (transistor transistor logic) input requirements. However, a voltage follower has been added to the output of the electrometer amplifier for better isolation and impedance matching. The output of the voltage follower, which has the same voltage level as the meter reading on the G.P. unit, is compared with an adjustable voltage derived from a 10-turn helipot such that the dial reading of the helipot is the same as the meter reading of the G.P. power supply. This correspondence simplifies the setting of the trip-point of each channel. The comparator output is fed into a Schmitt trigger and a one shot multivibrator to produce a fast rising trigger pulse with a minimum width of 5 msec. The trigger pulse is then fed into a NAND gate, used for arming or disarming each channel, followed by an OR circuit which permits either channel to independently trigger the gate of the SCR used to switch on the firing circuit. The response time of the trigger circuit to a sudden pressure rise is $\sim$1 ms and is completely dominated by the response time of the ion gauge.

The squib is fired by a simple capacitive discharge from a 2000 μF/450 V capacitor bank in series with an SCR which acts as an electronic switch. The capacitor bank is charged to (and maintained at) 350 V by a high voltage dc power supply while the SCR is biased off. When the trigger pulse turns on the SCR as described above, the energy stored by the capacitor ($\sim$100 joules) is discharged through the fuses of the squib, and the heat thus generated ignites the gunpowder. A current pulse of 140 A peak (exponentially decaying to 50 A in 4 msec) causes the gunpowder to be completely burned in less than 0.1 msec.

The electrical continuity of the firing circuit and of the squib can be readily verified by lowering the capacitor voltage to 3.5 V and discharging the capacitor into the squib. The current pulse through the squib is then sufficiently reduced that it will not cause the squib to fire. A return signal from the current sampling resistor (see fig. 2) serves to confirm the circuit continuity. If the trigger signal is initiated from an ion gauge, the entire trigger and firing chain can be simultaneously tested. This can be done by turning on the "de-gas" switch on the G.P. power supplies thereby completely checking each channel independently.

4. Tests

In order to test the performance of the slammer valve, a 10 m straight section of 10-cm-diameter, unbaffled beam tube was set up with a 2.9-cm-diameter Ni vacuum foil on one end and a He mass analyzer on the other. Surrounding the external side of the Ni foil was He gas at 1 atm. pressure. The slammer valve was placed in the line $\sim$9 m from the foil. Two ion gauges (type RG 75) were installed between the vacuum foil and the slammer valve: one was located ∿25 cm from the valve, and the other, used to trigger the valve, was located ∿25 cm from the foil. The anodes of the ion gauges were connected to a dual trace storage oscilloscope. The beam tube was maintained at a pressure of $\sim 3\times 10^{-5}$ Torr by a diffusion pump system. The tests were initiated by puncturing the foil with a sharp pointer and the responses of the ion gauges and mass analyzer were observed. The pointer provided a time zero signal at the moment of electrical contact with the foil. By releasing the pointer from a spring-loaded fixture, the time zero signal was very reliable, and the test results were very reproducible. This signal started both the oscilloscope trace and a precision digital timer. The timer was stopped by the valve closed signal generated by the valve gate (see section 2).

The ion gauge response times were found to depend on the rate at which the He could be supplied through the puncture hole in the foil. In cases where this hole was small, or partially blocked by the pointer, the response times would be slow. If a large hole were made suddenly in the foil a faster response time was seen. In all of the tests, the response times of the two gauges were in proportion to their distance from the foil. The fastest response times corresponded to a Mach 1 expansion of the He into the tube. Since the radioactive material could not be transported from the foil to the valve faster than by the leading edge of the shock wave, which arrived at the valve ∿10 ms after the foil was punctured, this time represented an upper limit to the acceptable valve closing time. In fact, it took ∿1 ms before the signal from the triggering ion gauge was large enough to reliably trigger the slammer valve which closed ∿3 ms after the foil was punctured. Many test firings were performed and these reaction times never varied by more than a few hundred microseconds. In none of the tests was He detected behind the slammer valve.

5. Operational System

To establish the slammer valve as an operating system, the electronic control circuitry has been installed in a separate chassis located in the cyclotron control room. In order to minimize attenuation of the squib ignition pulse, the capacitor bank and associated firing circuitry are located near the squib in the cyclotron vault. The valve itself is located in a beam transport line leading to the specially equipped high level cave area, as shown in fig. 3, approximately 9.5 m upstream from the target chamber. The beam is brought to a 1.0 cm diameter focus through the valve using a magnetic quadrupole doublet with the aid of a retractable quartz/TV monitoring system. A circular collimator prevents beam from directly striking the valve. Also shown in fig. 3 are two air-driven commercial vacuum valves designated VAO and V_{Exit}. These valves were originally designed to close automatically should the beam line pressure exceed 0.05 Torr, but they have a relatively slow closing time $\sim$1 sec. When the slammer system is operational, firing the slammer valve will also cause valves VAO and V_{Exit} to close as added protection in case the slammer fails to completely seal. Two ion gauges (operating redundantly) are located near the target chamber and are presently connected to the first input of each triggering channel.

A sophisticated interlock system has been devised to virtually eliminate the chance of human error. Once this sytem is activated, valve VAO cannot be opened until the slammer valve is armed and similarly the slammer valve cannot be disarmed until valve VAO is closed. The system cannot be in an armed condition if the firing capacitors lose voltage or if either ion gauge filament is not drawing current. In the event of such a system failure during operation, the valve VAO would automatically close and the slammer valve would be automatically disarmed. Between firings it is also necessary to verify squib circuit continuity (as described in section 3) before the system can be re-armed.

In order to avoid accidental firings, another interlock feature prevents arming the system if either trip-point is set below the actual pressure. Despite the apparent complexity of the interlock circuits, only one button must be actuated to disarm the system, for example to permit access to the target area, and only one button must be actuated to re-arm the system.

Also located on the control chassis is a sequence of diagnostic lights to indicate if the SCR gate (see fig. 2) has opened, if the squib has fired and if the valve gate is fully closed. They also indicate which channel(s) caused the valve to be fired.

A simple simulator has been built to substitute for the circuits relevant to valves VAO and V_{Exit}. It is also possible to substitute an ordinary fuse for the squib. This simulation has proven very useful for debugging and for operator training. In this way, for example, the trigger circuit was desensitized to random electrical noise - a problem which caused several misfirings in the early stages of development. The slammer system has now been successfully operated for $\sim$2 months on the simulator and for over 100 hours of real time operation without incident.

6. Summary

The use of an electro-explosive device is probably the most reliable and certainly the fastest method of closing a vacuum valve. While the valve herein described has only a 2.5 cm-diameter through-hole, the principles of its operation are applicable to larger valves. Some experimentation would be necessary to match the mechanical tolerances and the required explosive force for a larger valve, as discussed in section 2. The electronic trigger circuitry is generally applicable to any fast-acting valve. Further details of the valve and the electronic circuits are available on request from the authors.

Acknowledgements

It is a pleasure to thank A. Hartwig for his early contributions to this project and J. Bowen and D. Hendrie for their continuing interest and helpful discussions.

Footnotes and References

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2) R. L. Hahn, R. L. Stone, J. R. Tarrant and L. D. Hunt, Nucl. Instr. and Meth. 86 (1970) 331; R. L. Hahn, R. L. Stone, J. R. Tarrant, L. D. Hunt and M. L. Mallory, Nucl. Instr. and Meth. 96 (1971) 481.

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5) Available from Holex Incorporated, Hollister, California 95023.

Figure Captions

Fig. 1. An isometric view of the slammer valve.

Fig. 2. An electrical schematic of the triggering and firing circuitry.

Fig. 3. A schematic layout of the slammer valve beam line.

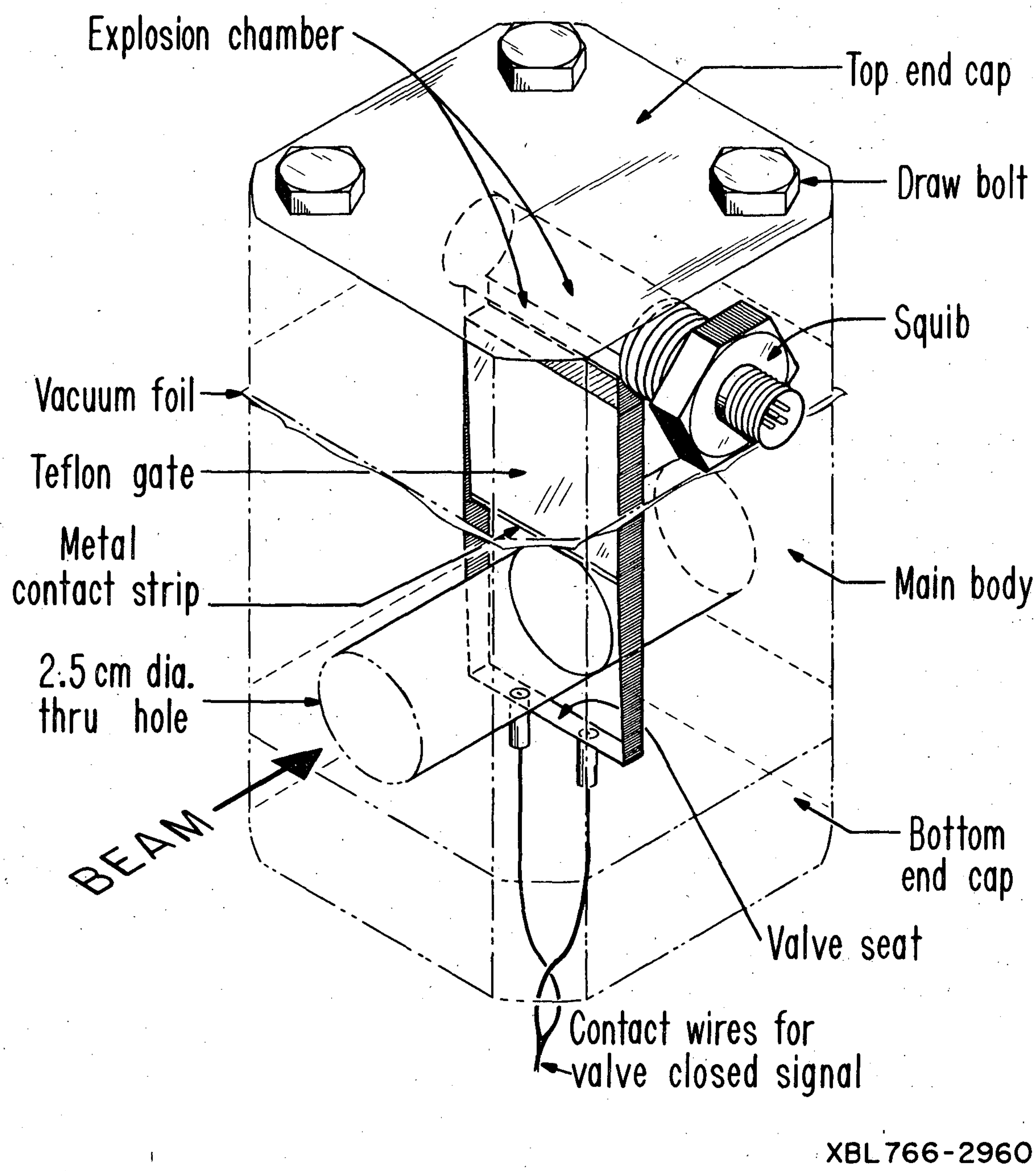
Explosion chamber
Top end cap
Draw bolt
Squib
Vacuum foil
Teflon gate
Metal contact strip
Main body
2.5 cm dia. thru hole
BEAM
Bottom end cap
Valve seat
Contact wires for valve closed signal
XBL 766-2960

Fig. 1

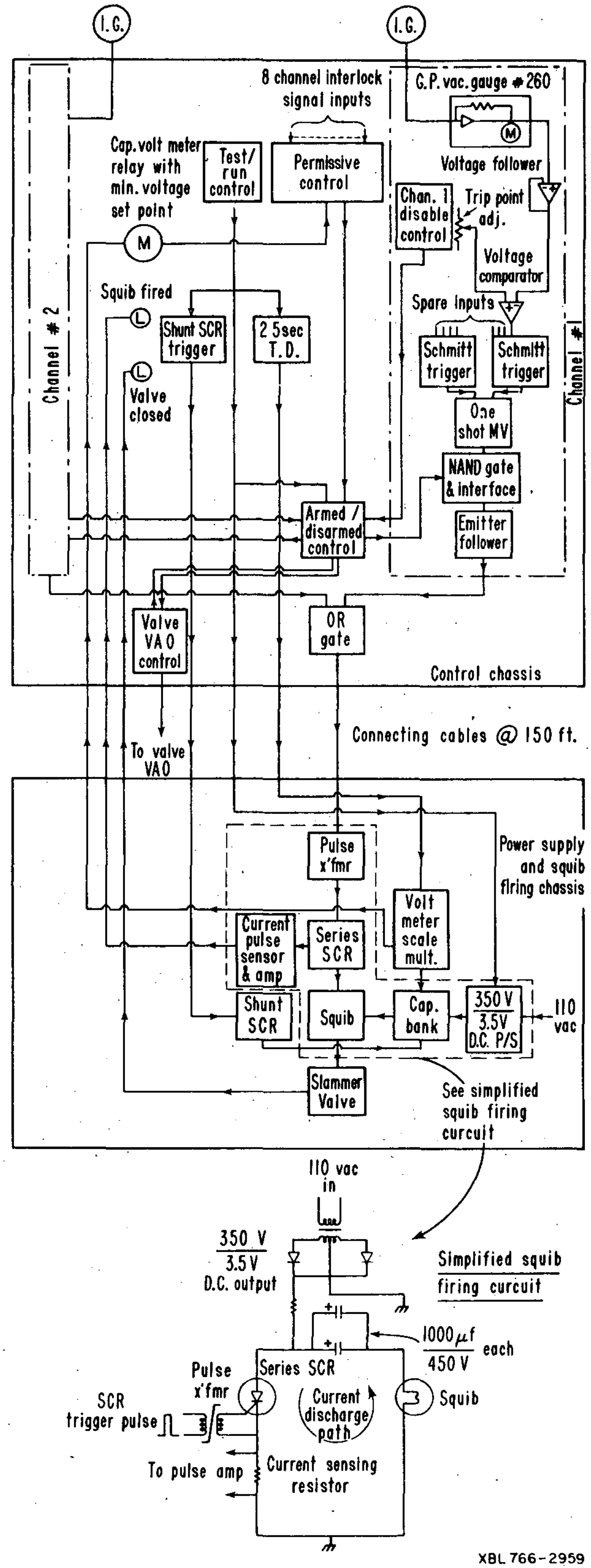
I.G.
I.G.
8 channel interlock signal inputs
G.P. vac. gauge #260
Voltage follower
Cap. volt meter relay with min. voltage set point
Test/run control
Permissive control
Chan. 1 disable control
Trip point adj.
Voltage comparator
Squib fired
Shunt SCR trigger
2.5sec T.D.
Spare inputs
Schmitt trigger
Schmitt trigger
Channel #2
Channel #1
Valve closed
One shot MV
NAND gate & interface
Armed / disarmed control
Emitter follower
Valve VAO control
OR gate
Control chassis
To valve VAO
Connecting cables @ 150 ft.
Pulse x'fmr
Power supply and squib firing chassis
Current pulse sensor & amp
Series SCR
Volt meter scale mult.
Shunt SCR
Squib
Cap. bank
350 V 3.5 V D.C. P/S
110 vac
Slammer Valve
See simplified squib firing curcuit
110 vac in
350 V 3.5 V D.C. output
Simplified squib firing curcuit
1000 μf 450 V each
Pulse x'fmr
Series SCR
SCR trigger pulse
Current discharge path
Squib
To pulse amp
Current sensing resistor
XBL 766-2959

Fig. 2

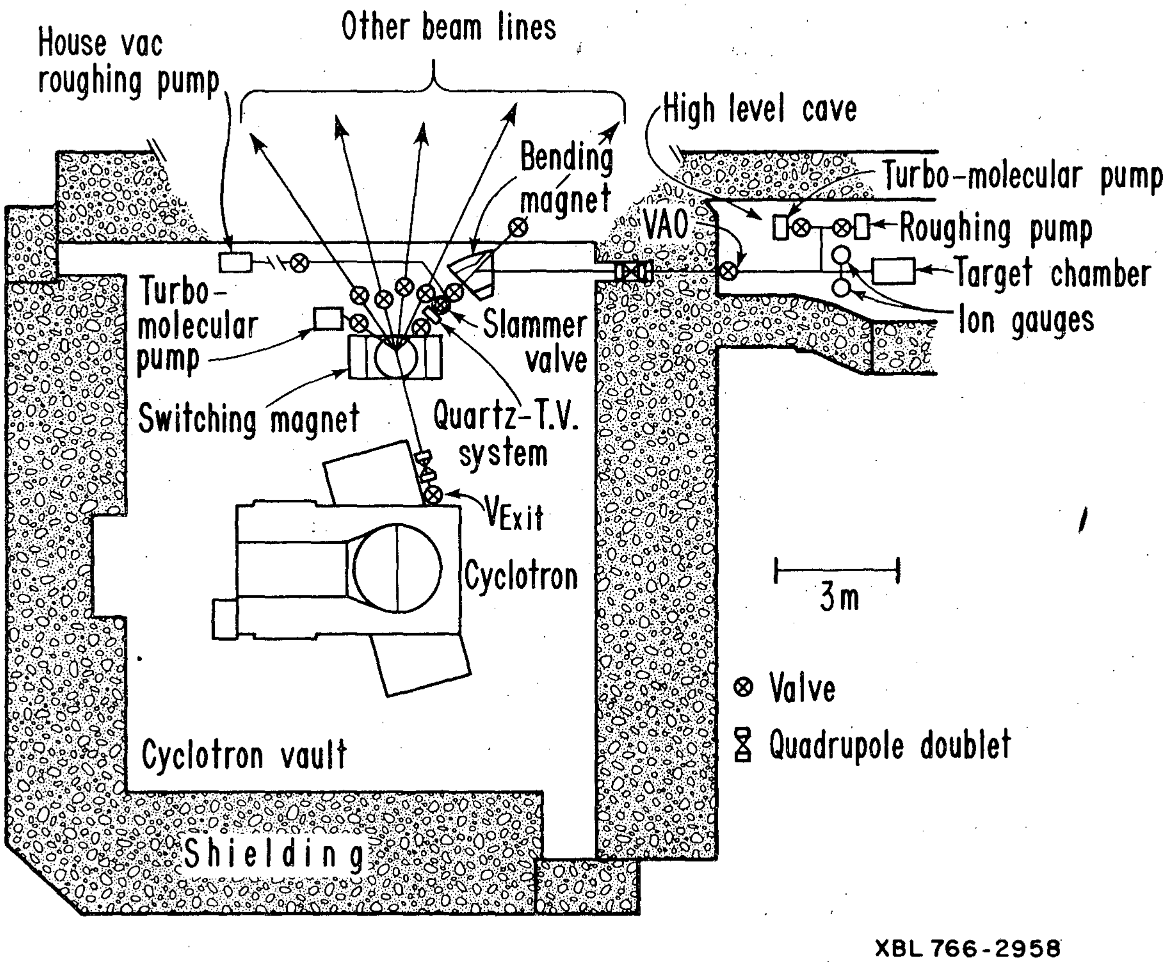
House vac
roughing pump
Other beam lines
High level cave
Bending
magnet
Turbo-molecular pump
VAO
Roughing pump
Target chamber
Ion gauges
Turbo-
molecular
pump
Slammer
valve
Switching magnet
Quartz-T.V.
system
VExit
Cyclotron
3m
Valve
Quadrupole doublet
Cyclotron vault
Shielding
XBL 766-2958

Fig. 3