DESIGN AND TESTING OF A POSITIVE ION

ACCELERATOR AND NECESSARY

VACUUM SYSTEM

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THESIS

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CHAPTER I

INTRODUCTION

The increasing interest in the investigation of the nuclei of atoms has given rise to an increasing need for sources of energetic particles capable of producing nuclear reactions. One of these particles is the neutron. The subsequent activity of elements bombarded with neutrons yields valuable information concerning nuclear properties and nuclear reactions.

Neutrons may be produced in many different nuclear reactions; two reactions in particular have been found very useful. One is the decay of the compound nucleus ${}_6C^{13}$ which is produced by bombarding ${}_4Be^9$ with alpha particles;

$$ {}_4Be^9 + {}_2He^4 \longrightarrow ({}_6C^{13}) \longrightarrow {}_6C^{12} + {}_0N^1 + Q. $$

The excess energy, or Q, of the reaction given above is related to the mass difference of the reactants and the products and the kinetic energy of the incident alpha particle. There are several natural alpha emitters which will produce this reaction with ${}_4Be^9$; two popular sources are radium and polonium. These sources also produce strong gamma radiation, necessitating many safety measures for the

protection of personnel and, sometimes, complicated procedure to eliminate radiations other than the neutron radiation of a desired energy.

A second source of neutrons utilizes nuclear reactions resulting from bombardment with artificially accelerated particles. Of the various atomic particles capable of acceleration, the deuterium ion is a highly useful one because of its low binding energy and the ease with which the molecules of deuterium gas can be dissociated and the subsequent atoms ionized. Copious sources of neutrons can be obtained using accelerated deuterium ions. The reaction

$$_1H^2 + {}_1H^2 \longrightarrow {}_2He^3 + {}_0N^1 + Q$$

(often called a D-D reaction) is exoergic yielding neutrons of approximately 3.25 million electron volts, and because the potential barrier is very low, good neutron yields can be obtained with deuteron energies as low as 100,000 electron volts. For thick targets of solid D_2O (frozen heavy water) the yield is in the vicinity of 0.7 neutrons per 10^7 deuterons.[1]

There are several types of accelerators in present use. These types range from complex synchrocyclotrons and bevatrons to comparatively simple cascade, uniform potential field, type accelerators. Although simple by comparison

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[1] J. G. Beckerley, editor, Neutron Physics, p. 7, quoting Enrico Fermi, lecture series, (1945).

to more complex and expensive accelerators, the cascade accelerator is by no means a simple accelerator. There are many problems associated with the design of the electrodes, electrostatic lenses, potential dropping devices, current leakage facilities, power dissipation, corrosion, seals, connector design, and vacuum technique. Many of these problems have been solved satisfactorily for particular conditions and associated impedimenta, but these problems must be considered when any deviation from some particular assemblage of associated equipment exists.

The many experiments which can be performed, the great amount of original research that can be accomplished with fast neutrons, and the equipment available for use led the author to undertake the construction of an ion accelerator. A 100,000 volt power supply had been constructed previously by P. M. Windham[2] and an ion source had been constructed by K. W. Hannah.[3] Both instruments were constructed under the supervision of C. W. Tittle.

The power supply has since been rearranged and modified by J. C. Mitchell and the ion source has experienced a complete and thorough renovation, examination, and modification

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[2]P. M. Windham, "A Deuterium-Deuterium Type Neutron Source" (unpublished M. S. Thesis, North Texas State College, 1951), p. 25.

[3]K. W. Hannah, "A Positive Ion Source" (unpublished M. S. Thesis, North Texas State College, 1948).

by G. T. Paulissen.[4] Many modifications were necessary, including a completely new ion chamber and associated electrodes. A six-inch oil diffusion pump and a Megavac mechanical forepump were available for the vacuum system. Both of these pumps had accidentally been completely filled with water, necessitating a factory overhaul for the mechanical pump and a thorough cleaning of the oil diffusion pump.

The unsatisfactory operation of the original form of the ion accelerator was considered to be due at least in part to the single accelerator gap which utilized a glass tube coated with carbon. A study of successful ion accelerators reported in scientific literature indicated the advisability of constructing a multi-electrode accelerator tube with separately controlled voltage dividers. In order to gain the advantage of first-hand experience and personal observation of the operation of a working system of this type, a visit was made to the Physics Department of the University of Texas, where the accelerator was operated by a group under the supervision of R. N. Little.

The University of Texas cascade accelerator column was chosen as a model; several undesirable features of the accelerator were pointed out by the operators[5] and the elimination

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[4]G. T. Paulissen, "Operation and Control of a Radiofrequency Ion Source" (unpublished M. S. Thesis, North Texas State College, 1953), Chap. III.

[5]Statements by R. N. Little and staff members, personal interview, November, 1952.

of these features presented the primary design problems of this thesis.

The electrode plates of the University of Texas accelerator are thin brass plates ten inches in diameter, separated by porcelain rings having a diameter of five and five-eighths inches. These rings are two and nine-sixteenths inches high, giving the electrode plates a separation of two and nine-sixteenths inches. Soldered onto the outer edges of the electrode plates are corona rings made of copper tubing one inch in diameter. This arrangement reduced the air gap between electrode plates to only one and fifteen-sixteenths inches. This separation allows breakdown across the corona rings at very high potentials. The greater the separation of two conductors in air, the greater is the potential required to cause breakdown between them (approximately 31,000 volts per centimeter of separation for like spheres of one centimeter radius in standard air).[6]

This design deficiency was overcome by planning brass plates one and one-fourth inches thick. This dimension would allow a one-eighth inch shoulder inside the porcelain ring and a plate capable of having a one-half inch radius of curvature on the peripheral edge. When it was learned that brass plates of the desired thickness twelve inches in diameter were quite expensive and not available within

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[6]J. B. Hoag, Electron and Nuclear Physics, p. 461.

seven months, it was decided that the electrodes should be made of steel. Steel is more difficult to machine and is also subject to rust and corrosion, which present additional problems in the production of high vacuum. The vacuum problem was solved by nickel-and-chrome-plating the steel electrode plates after they were machined to shape and size. Four electrode plates and the accelerator support were made of steel. The top plate was constructed of aluminum.

The top plate demanded more intricate machine work performed upon it than did the others, and, as a consequence, it was desirable to obtain a material having good machining properties. Plates of aluminum and of steel of the size required for the electrodes and the accelerator support were not easily obtained, and the tasks of locating and securing suitable material became major ones. The other materials necessary to complete the requirements for the accelerator were either on hand or obtainable locally.

The accelerator column consists of five electrode plates separated by four corrugated porcelain ring insulators. There are four electrode gaps, each located halfway between the electrode plates. A somewhat uniform potential gradient exists along the entire length of the column. This is brought about by the leakage of charge through the surrounding atmosphere from plate to plate, aided by a resistance stack for more nearly uniform potential distribution.

The top plate is to be operated at a positive potential with respect to the bottom plate. The entire accelerator rests on an O-ring seal in conjunction with a vacuum pump manifold. Directly underneath the pump manifold and in line with the accelerator electrode tubes is a coasting tube leading to a target. The target may be any one of many materials; however, copper plate was used to allow the ion beam to deposit a plating of deuterium thereon, thus providing the deuterium target for the D-D reaction.

CHAPTER II

DESIGN AND CONSTRUCTION OF THE ACCELERATOR

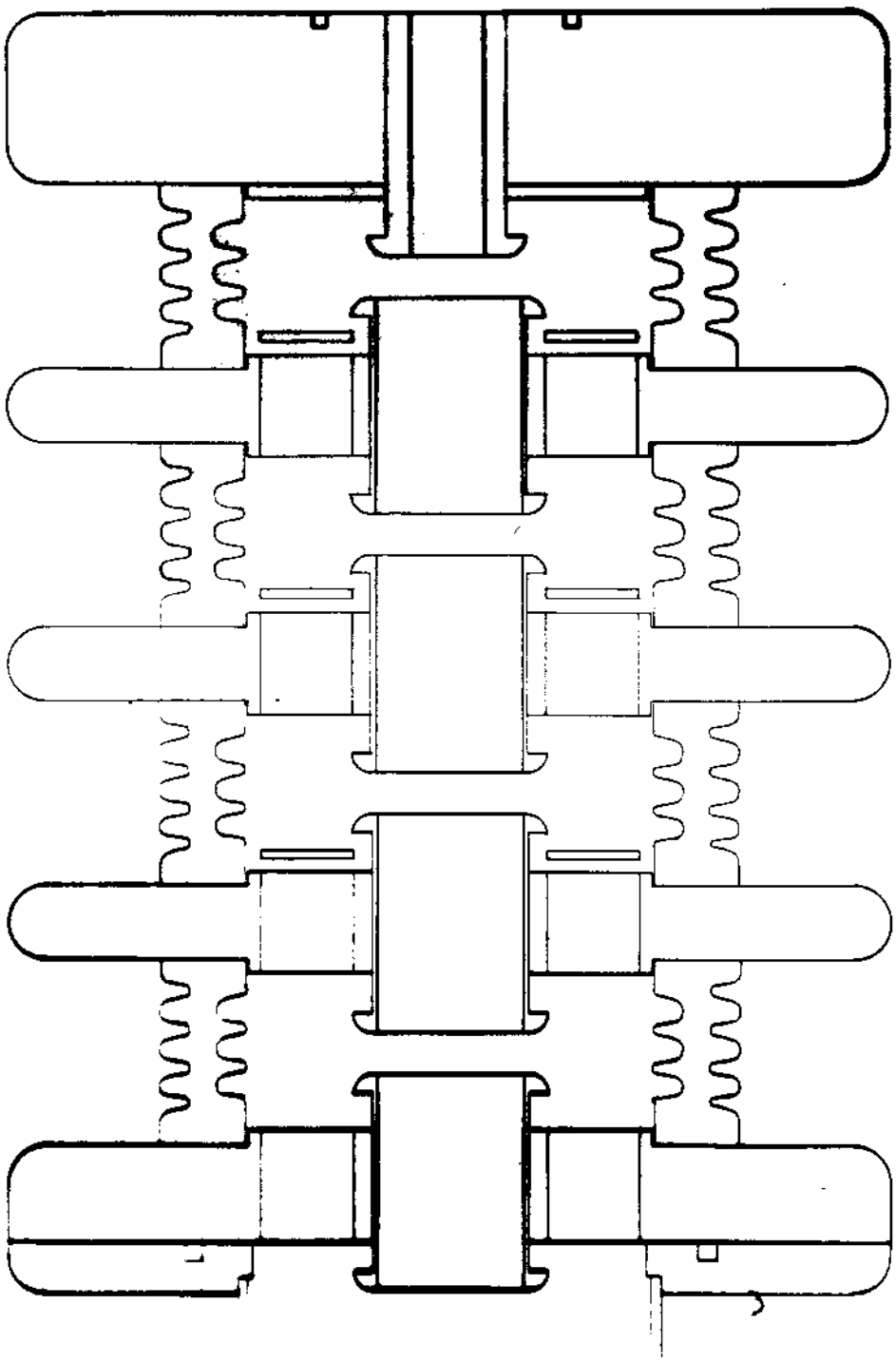
The design of the University of Texas accelerator limited its operation to accelerating potentials of approximately 100,000 volts, due to breakdown through air with average humidity at potentials of this amount. A greater separation between electrode plates should decrease the tendency for breakdown by decreasing the electric field intensity between these plates. The porcelain rings that were used to separate the electrode plates were obtained from the University of Texas and are identical to the rings used in the accelerator there. The use of these rings required that the electrode plates themselves must have exactly the same separation as the plates of the University accelerator.

The electrode plates of the University accelerator, as indicated in Chapter I, were made of three-eighths inch brass plate with a copper corona ring of one inch diameter soldered to it. This arrangement gave an effective inter-electrode spacing of only one and fifteen-sixteenths inches. In addition to this reduced spacing, a region of very high electric field intensity between the corona rings was created because of the one-half inch radius of curvature of the

corona rings. This situation was apparently undesirable and needed modification.

The primary design of the electrode plates was therefore centered around the need for eliminating the region of high electric field intensity and increasing the effective interelectrode spacing. In the applications of very high potentials it is necessary to maintain large radii of curvature on all conducting surfaces subjected to high potentials in order to reduce current losses from leakage into the atmosphere. Small radii of curvature give rise to regions of great electric field intensity, which in turn give rise to high current losses. These facts preclude the possibility of using thin plates without corona rings.

The use of thick plates seemed to be the solution. With thick plates an effective corona ring could be incorporated along the periphery without extrusion above the electrode plate surface. Figure 1 shows a cross-sectional view of the accelerator column and it may be seen therefrom that the electrode plates contain a corona ring of one-half inch radius of curvature without a subsequent diminishing of the interelectrode spacing. This interelectrode spacing is effectively five-eighths inch greater than the spacing of the University of Texas accelerator. It is believed that, because of the increased spacing, not only will more stable operation be achieved at 100,000 volts accelerating potential but also that the column will be capable of operating at potentials up to, and perhaps in excess of, 200,000 volts.



Scale: 13/32 inch = 1 inch

Fig. 1.--A cross-sectional diagram of the accelerator components.

The accelerator column consists of five electrode plates separated by corrugated porcelain rings. The porcelain rings are corrugated in order to increase the surface path length between the electrodes, thus decreasing the probability of current leakage over the surface of the porcelain insulator. A 2.129 inch hole was bored through the center of each of the lower four electrode plates to receive a tubular copper electrode. Each copper electrode (as shown in Figures 1 and 2) is made in two parts. Each part has one end flared and curved back with a radius of curvature of one-fourth inch. The two sections were pressed into place in the electrode plate and soldered for security. Small channels were previously cut in the receiving hole to facilitate out-gassing.

Each of the four lower plates has eight one and one-fourth inch holes bored around the center hole in order to facilitate more rapid evacuation of the entire column. These holes present the disadvantage of providing a large path outside of the electrode path from the bottom to the top of the column. The high potentials placed across the column will give rise to field emission electrons, which will, in turn, be accelerated up the column. The electrons may acquire sufficient energy to reappear in the form of X-radiation when the electron strikes the metals of the column. Small baffle plates one-eighth inch thick and five inches in diameter were placed one-fourth inch above each

set of pumping holes of each of the three center electrode plates. Each small plate serves as an electron baffle, yet allows rapid gas passage through the electrode plates. The electrons will strike these plates with an energy no greater than 25 per cent of the total potential across the accelerator, thereby minimizing the hazard of X-radiation.

The top electrode plate is made of aluminum. It has an aluminum electrode directed toward the electrode in the second plate. The electrode in the aluminum plate is smaller than the other electrodes, with a bore of only one inch. The top plate is two and three-eighths inches thick; the plate was made of this thickness because it was planned to put a variable electrode in this plate. This plan was temporarily abandoned because of the intricate nature of the machine work necessary to insert a control rod in the electrode. The top plate will receive the ion source and in order to facilitate this reception, a three and one-fourth by three-sixteenths inch neoprene O-ring (Parker Number 27-42) was used. The ion source is bolted to the top plate with three seven-sixteenths inch machine bolts.

The bottom electrode plate is attached to a twelve by three-fourths inch steel flange. The flange has accommodations for a six and three-fourths by one-fourth inch neoprene O-ring (Parker Number 27-67). Six seven-sixteenths inch machine bolts connect the flange to the bottom electrode plate. The two fit together in such a

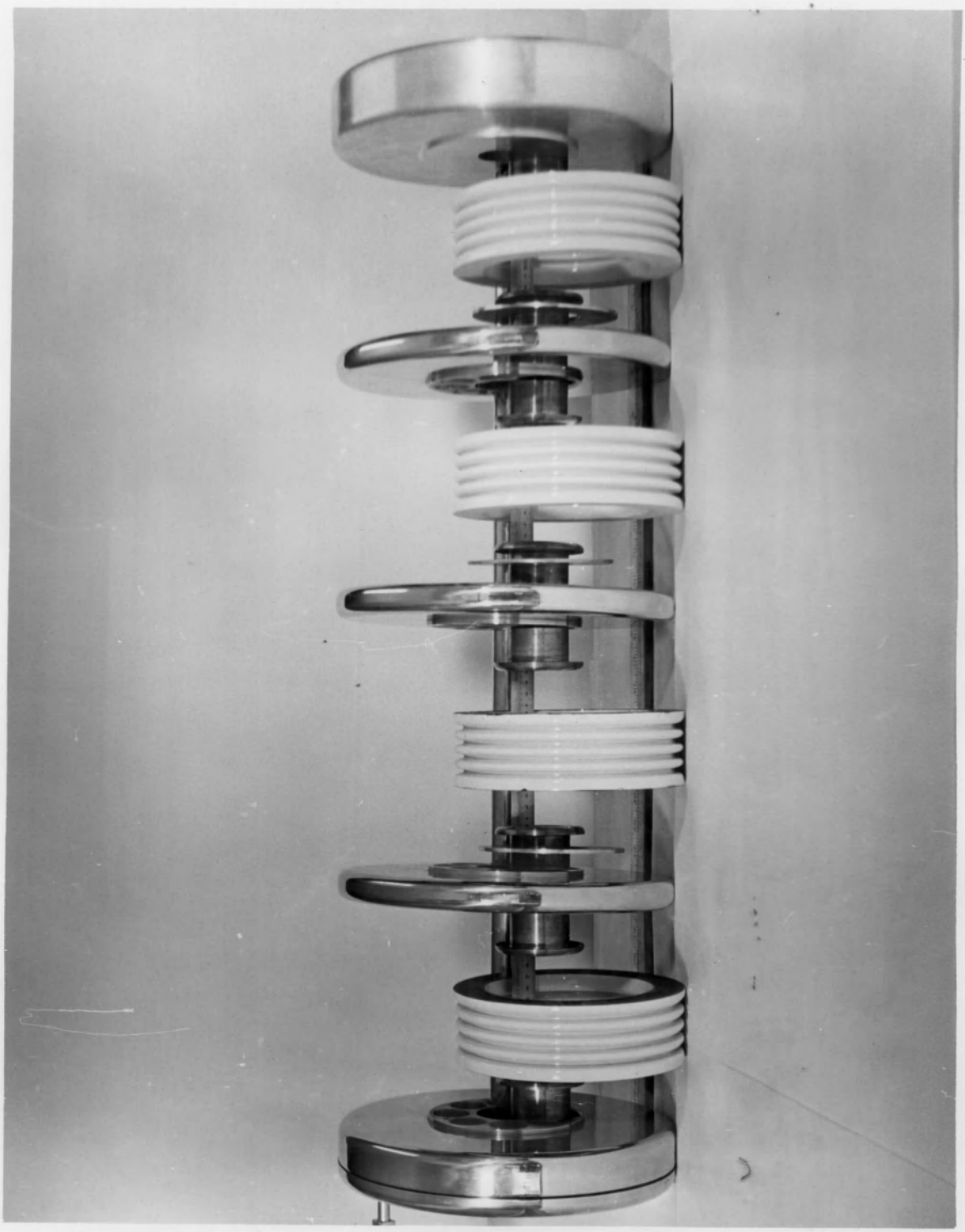


Fig. 2.--An expanded view of the accelerator components

manner that they appear to be one piece. This was done to eliminate extra curvature at their junction. A five and three-fourths inch brass tube extends from this flange to the vacuum system and thence to the target.

All of the steel parts of the accelerator column were nickel-plated by a rather new process. This process is one in which a more dense, less porous, thicker plating can be achieved. The plating has the further advantage of being so tightly bound that welding may be done on the steel without causing the plating to peel. To reduce the probability of the adsorption of gases to this surface, a 0.001 inch plate of hard chrome was plated over the nickel. The copper, brass, and aluminum parts were thoroughly cleaned with carbon tetrachloride before assembly. The parts were heated in an oven to 110 degrees centigrade and then were assembled over an aligning mandrel. The joints were made using Apiezon W black wax, whose vapor pressure at room temperature is below 10^{-6} millimeters of mercury.[1]

Figure 3 is a view of the assembled column without the ion source, power supply, vacuum system, and safety features necessary to protect personnel from the high potentials used with the accelerator.

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[1] Bulletin 1565-D, J. G. Biddle & Co., July, 1947.

Fig. 3.--The assembled accelerator column

CHAPTER III

VACUUM SYSTEM

The gas pressure in the accelerator must be very low in order to prevent collisions between the accelerating ions and the molecules of gas in the column. This pressure must also be in the vicinity of 10^{-5} millimeters of mercury to prevent arc discharge across the electrode tubes. Ordinary mechanical pumps are incapable of producing a kinetic vacuum of such low pressure. In order to achieve this low pressure, an MC 700 oil diffusion pump manufactured by Distillation Products, Inc., Rochester, New York, was used. This diffusion pump has a Megavac pump for its forepump.

The MC 700 oil diffusion pump has a six-inch bore, and in the original form had no baffle system. Although the pumping rate of these pumps was quite high, some means of preventing the oil vapors from working up into the accelerator should previously have been employed. The author, therefore, constructed the baffle system shown in Figure 4. A piece of six inch steel pipe was machined on the inside. A nine inch flange was brazed to either end and a piece of three-eighths inch copper tubing was wrapped around the outside of the pump. All of this was painted with two coats of black glyptol varnish. Water was circulated through the tubing in order to carry away heat, thus aiding in the

condensation of oil vapors in that area. Inside the housing formed by the steel pipe was placed a group of brass plate rings having diminishing diameters in such manner that each successive plate was smaller than the one above it, yet large enough to hide the center opening in the plate. There were five plates in all, and these were spaced approximately one and three-fourths inches apart. The junction between the pump and the baffle system was sealed with a six and one-half by one-eighth inch neoprene O-ring (Parker Number 30-38).

The baffle system was connected to a five and three-fourths inch brass manifold to which were connected the accelerator support flange and the target assembly. A six and one-half by one-eighth inch neoprene O-ring (Parker Number 30-38) sealed the junction between the baffle system and the manifold. The accelerator support and the target assembly were soldered to the manifold.[1]

Testing of the vacuum obtained in the assembled equipment is limited by the lack of adequate vacuum gauges. At this time the only pressure-measuring devices on hand are a Pirani gauge and a McLeod gauge. A Pirani gauge is not effective for measuring pressures below 10^{-4} millimeters of mercury, and the McLeod gauge employs mercury that must be cold-trapped if used; otherwise the mercury vapor will contaminate the system by adhering to the system's walls. A

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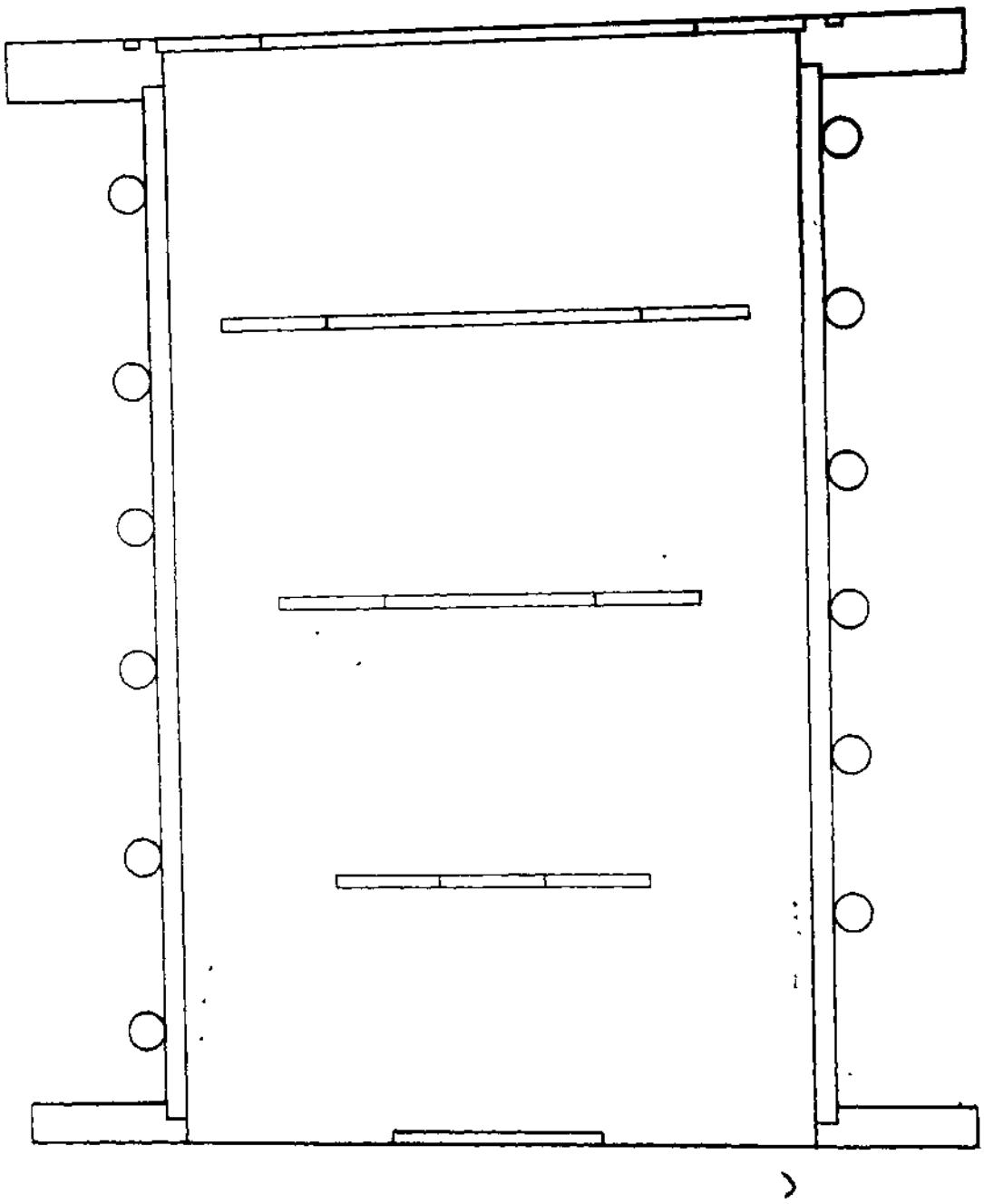
[1]P. M. Windham, op. cit., p. 21.



Scale: 19/32 inch = 1 inch

Fig. 4.--Oil diffusion pump baffle system

self-calibrating ionization gauge is needed. This gauge is capable of measuring pressures down to 10^{-7} millimeters of mercury.

CHAPTER IV

TESTING ASSEMBLY AND RECOMMENDATIONS

A suitable permanent location for installation of the accelerator has not as yet been readied. In lieu of this location, a small portable steel pipe derrick has been constructed which will serve both as a test stand and a storage medium. The derrick consists of four legs topped by a "u"-shaped piece of angle iron upon which may be bolted the accelerator support flange. The test stand has provisions to receive the pump manifold, baffle system, and the diffusion pump in their proper operational positions. All of these components are rigidly mounted and may be moved as a unit. The forepump will rest on the floor, but this is of no consequence in moving, as it is connected to the diffusion pump only by a rubber hose.

The test stand is approximately three and one-half feet high. The accelerator and ion source will add an additional two and one-half feet to the structure, making a total height of approximately six feet.

In the assembly as described there is sufficient space below the pump manifold for a target assembly. When the radiofrequency exciter supply and focussing voltage supply have been isolated for 100,000 volts and sufficient corona

protection completed for the ion source, the unit may be placed in operation as a neutron source on the test stand.

The target for test assembly consists of a three inch brass tube soldered to the pump manifold, a short length of glass tubing sealed to the three inch brass tube with hard wax, and a copper disc attached by use of hard wax to the lower end of the glass tube. The deuterium ion beam will plate a layer of deuterium on the copper and subsequently the D-D reaction will occur.[1]

The resistance bank now in use as a potential distributor on the power supply is also used to aid in distributing the potential down the accelerator column. This bank is used at present because the power output of the power supply is not well enough known to ascertain whether or not the supply will provide enough current for an additional resistance stack. If it will produce enough current and another leak for current is necessary, a water resistance stack is recommended.[2]

There are many ways in which this instrument as a whole may be improved upon and its effectiveness extended. One such improvement would be an ion beam analyzer. The ions that will be obtained from the accelerator will have mass

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[1]Statement by R. N. Little, personal interview, November, 1952.

[2]Statement by R. N. Little, personal interview, November, 1952.

numbers ranging from one perhaps through eight. Only the ions of mass two will be effective in producing neutrons, and the rest will serve only to heat the target. To cite an example of the use of an analyzer, The University of Texas recently added a beam analyzer to its neutron source. The ion current before this addition was approximately 400 microamperes and the neutron yield was in the vicinity of 10^6 neutrons per second. After being analyzed, the ion current was only 198 microamperes, yet the neutron yield was still of the same order of magnitude.[3] This indicates that only 50 per cent of the ions were producing neutrons and that the other 50 per cent were heating the target.

Another recommendation concerns the physical layout of the neutron source components. At present there are three rooms which could house the components in a very efficient arrangement. Room 113 now houses the entire source and, needless to say, this is a dangerously crowded situation. The room is filled and there are many plumbing pipes that are dangerously close to the high voltage equipment. Room 113 is in the basement and directly over it is a large storage room that could very comfortably and efficiently house the power supply, ion source controls, and the main portion of the ion accelerator and source. There is also the added advantage of having all of the high voltage equipment removed from all personnel.

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[3]Statement by R. N. Little, personal interview, August, 1953.

It is further recommended that a large hole be opened from the center of the floor of the storage room into Room 113. The accelerator could then extend through this hole, to such an extent that the pump manifold could be attached to the ceiling of Room 113. This would allow the target to be placed in the center of Room 113; thereby reducing the back-scattering that might occur if much material were near the target area. The proposed arrangement would also provide sufficient space for the addition of a beam analyzer without interfering with the target area.

There is a room adjacent to and west of Room 113 that would profitably be used as a control room. A door could be opened into this room directly from Room 113 and a ladder provided for access to the storage room from Room 113; thereby making all parts of the neutron source available to the operator without necessitating shutdown or extra monitors.

Many more devices, such as vacuum valves between the pump manifold and the target and between the accelerator and the ion source, are needed. There are unlimited possibilities in the construction of targets, for there are many reactions that an accelerated deuterium ion can cause. Much can be done in the development of remote control devices.

These are only a few of the many opportunities for study and improvement which the accelerator offers. There is a wide variety of experiments yet to be performed on the

frontiers of nuclear research, and with an instrument of this nature a great range of possibilities is open to the student of nuclear physics.

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