United States Patent

Haas et al.

[15] **3,689,790**

[45] **Sept. 5, 1972**

[54] **MOVING TARGET SEALED X-RAY TUBE**

[72] Inventors: **David J. Haas,** Stamford, Conn.; **Jerome Pichert,** Centerport, N.Y.

[73] Assignee: **Pepi, Inc.,** New York, N.Y.

[22] Filed: **April 29, 1971**

[21] Appl. No.: **138,627**

[52] **U.S. Cl.** **313/60,** 313/30

[51] **Int. Cl.** **H01j 35/04**

[58] **Field of Search** 313/60

[56] **References Cited**

UNITED STATES PATENTS

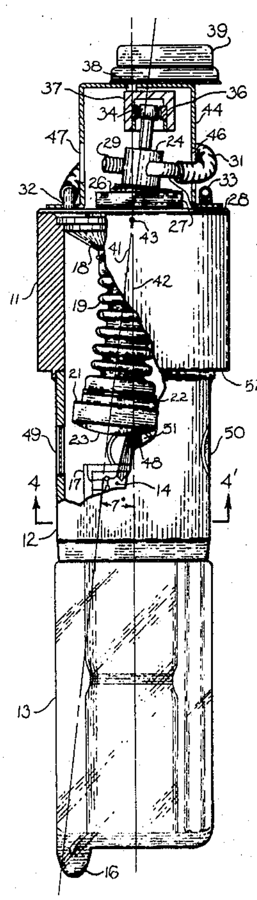
2,058,105	10/1936	Pohl	313/60
2,290,226	7/1942	Du Mond	313/60
2,926,270	2/1960	Zunick	313/60
3,331,978	7/1967	Brown et al.	313/60

Primary Examiner—Roy Lake
Assistant Examiner—Darwin R. Hostetter
Attorney—Donald P. Gillette

[57] **ABSTRACT**

A sealed-off X-ray tube having a convex target surface facing an electron beam source and carried by a rigid support mounted for rotary pivotal motion about a fixed pivot point. A bellows is sealed vacuum tight to the target and to the wall of the tube around the pivot point so that the target, the bellows, and the envelope of the tube form a closed surface. Conduits extend through the pivotal bearing to direct the flow of cooling fluid against the back surface of the target and carry the fluid away. The target surface is spherically convex with a center of curvature at the pivot point. The axis of the target precesses about the axis of the tube but the target does not rotate on its own axis. The target may be moved manually or by motor and with a linear, circular or spiral motion. Because of the curvature of the target, the electron optical forces are substantially unaffected by the precessing motion, and virtually constant X-ray beams radiate through windows of the tube.

7 Claims, 5 Drawing Figures



PATENTED SEP 5 1972 3,689,790

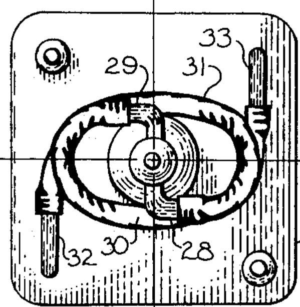


fig. 2

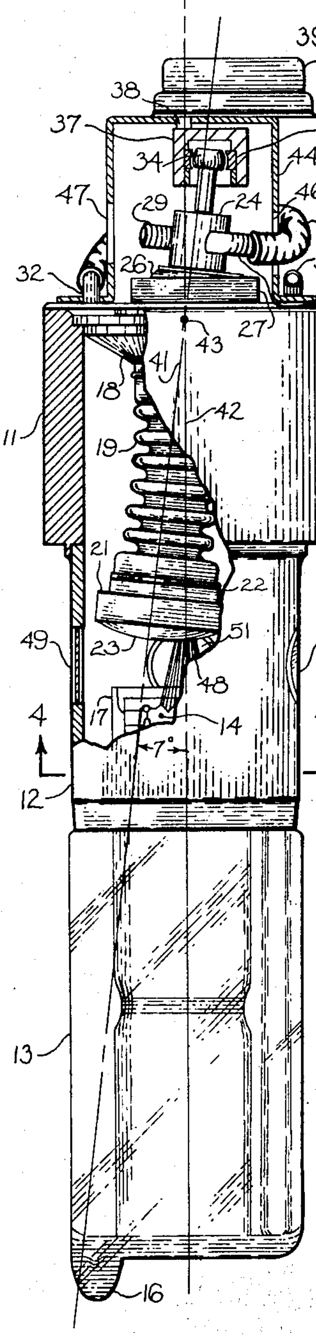


fig. 1

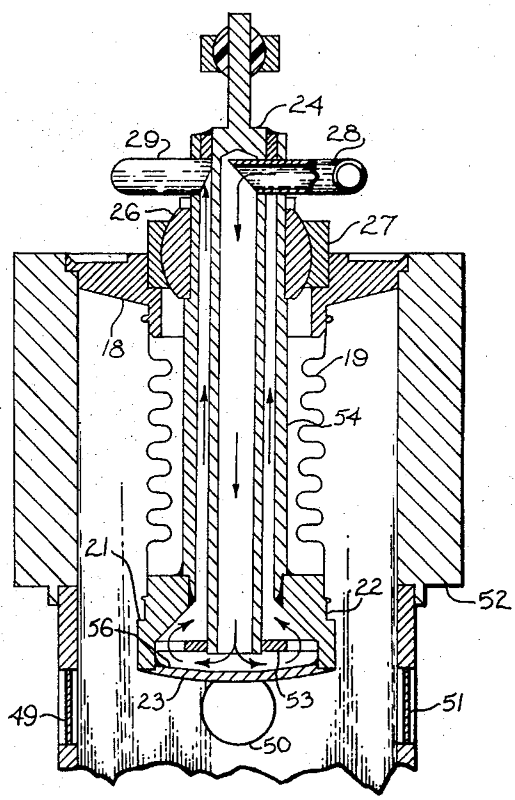


fig. 3

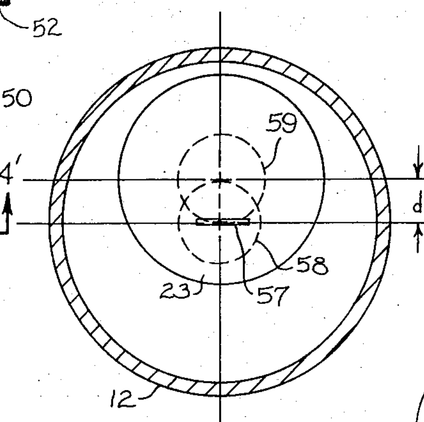


fig. 4

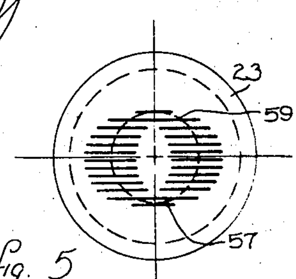


fig. 5

INVENTORS
DAVID J. HAAS
JEROME PICHERT
BY

Donald P. Gillette

ATTORNEY

MOVING TARGET SEALED X-RAY TUBE

FIELD OF THE INVENTION

This invention relates to the field of moving target X-ray tubes and particularly to tubes suitable for continuous operation for X-ray diffraction.

BACKGROUND OF THE INVENTION

Only three types of general commercial X-ray diffraction tubes are manufactured today. These are the sealed-off tube, the rotating anode units, and the microfocus units. Sealed-off tubes, which are by far the most numerous, have fixed electrodes and are noted for their reliability, long life (which averages about **5,000** hours), reproduceable focus spots, and low cost. Typically they have a maximum specific loading of about 400 watts/mm^2 for fine focus tubes and a maximum total loading of about 2,000 watts. Rotating anode tubes are noted for their brightness on fine focus spots. They have a maximum specific loading of about 7 kw/mm^2, which is substantially higher than the maximum specific loading of sealed-off tubes, and their maximum total loading is from 6 to 30 kw for commercial tubes and up to 50 kw for experimental tubes. The typical minimum focus size is 1 mm × 0.1 mm. Microfocus units are noted for their brightness in very small focal spots which are typically less than 0.1 mm in maximum dimension. Their maximum specific loading may be of the order of 30 kw/mm^2, which is four times as high as that of the rotating anode tubes, but their maximum total loading is of the order of only 500 watts. The minimum size of the focal spot is about 0.01 mm.

Rotating anode units and microfocus units require not only the electrical and coolant sources of sealed-off tubes but also complex vacuum pumps. Therefore, these units are either sold or individually made as complete systems, which are far more costly than an X-ray generator using a sealed-off tube. A large number of rotating anode and microfocus X-ray units are discussed or referred to in a special report by DeBarr, A. E. and MacArthur, I. *British Journal of Applied Physics*, 1, p. 305 (1950). One of the references cited therein DuMond, J. W. M. and Youtz, J. P., *Review of Scientific Instruments*, 8, 291 (1937) describes a large, demountable X-ray generator with an anode mounted on gimbals at the end of a long supporting pipe to pivot with a circular motion about the beam axis, but most of the generators with moving anodes have axially flanged disc anodes that rotate on an axis perpendicular to the tube axis.

Most sealed-off tubes have been made for years with four windows through which X-ray beams could radiate from the target area on the internal anode. A tube of this type is shown in U. S. Pat. No. 2,665,391. Usually the cross-section of the electron beam at the area of impact on the target is an elongated rectangle having a length to width ratio in the range from about 4:1 to about 20:1, although in some cases the beam is circular. If the tube has four windows, they are normally placed so that two of them are in line with the long dimension of the impact area and the other two are at 90° to the long dimension.

Sealed-off X-ray tubes have been made according to certain specific sizes and configurations, and there are many X-ray generators built to conform to the tube

sizes and configurations. Such generators are, for example, of the type shown in U. S. Pat. No. 2,453,798. In addition to the generators themselves, there are numerous pieces of auxiliary equipment built specifically to fit onto these generators. Examples of such auxiliary equipment include the diffraction apparatus shown in U. S. Pat. No. 2,549,987, the powder diffraction camera shown in U. S. Pat. No. 2,514,791, and the alignment apparatus shown in U. S. Pat. No. 2,709,752.

Therefore, it is one of the objects of the present invention to provide a sealed-off X-ray tube having a movable target in an envelope that will fit into existing X-ray generators built for fixed-target, sealed-off tubes and can be used with existing auxiliary equipment.

All of the windows of sealed-off tubes are normally placed so that only those X-rays emitted at relatively low take-off angles from the target, i.e., paths that are either parallel or nearly parallel to the surface of the target, pass through the windows. These take-off angles are of the order of 0° to about 15°, and it is important that the target area from which X-rays are emitted at such low angles be as smooth as possible since any roughness would constitute peaks of solid target material extending into the path of the emitted X-rays. As a result, sealed-off X-ray tubes eventually become unusable either because the cathode material is used up or the target becomes eroded. Normally the cathode lasts much longer than the target, and it is erosion of the latter that usually determines the end point of the life of the tube.

It is another important object of the present invention to increase substantially the life of a sealed-off X-ray tube by making the target movable so that different areas can be utilized in succession until each in turn becomes eroded to the point where it can no longer function satisfactorily.

X-ray diffraction apparatus is inherently sensitive to certain variations in the X-ray source. This makes it important that any movable target be so constructed as to present, at all times, virtually a constant electron optical environment to the electron beam so that the resultant impact point will generate, as nearly as possible, a constant amount of radiation both in terms of intensity and of orientation or direction.

It is therefore another object of the present invention to provide an X-ray tube with a target which is a small portion of a spherical surface concentric with the pivot point about which the target moves.

Since the target of the X-ray tube of the present invention can be moved from one location to another, it can be overloaded by being subjected to an electron beam of much higher intensity than would be permissible in the case of a fixed anode. This not only results in the generation of higher intensity X-rays but makes possible, for the first time, long life sealed-off microfocus tubes. For example, a target capable of fitting into the envelope of a standard sealed-off tube but operated with an electron gun capable of forming a microfocus spot will have as many as 100 or more positions that can form impact points for the microfocus beam. These spots can be spaced along a spiral path to cover a large part of the surface of the target. The expected lifetime of each target position before the tiny impact area becomes pitted or eroded is of the order of 100 to 300 hours. Since there may be room for 100 or more such impact areas, the total time before the anode is used up may exceed the life of the cathode so that, contrary to the practice at the present time, the cathode may form the life-limiting factor of the tube. However, it is expected that the filament can easily last more than 1,000 hours. Therefore, a sealed-off tube according to the present invention and built in microfocus form will have such a long life the it is ecomonic to throw it away like an ordinary worn out sealed-off tube and unlike existing microfocus units that must be dismantled and rebuilt.

BRIEF DESCRIPTION OF THE INVENTION

The tube of the present invention comprises an evacuated envelope, part of which is normally made of rigid metal with four X-ray permeable windows in it. The body of this metal portion is a hollow cylinder closed at one end by a rigid metal wall and sealed at the other end to a glass insulating cylinder that supports the filament, or cathode, and provides a long enough leakage path to permit a high voltage to be applied between the cathode and the anode.

The anode assembly is suspended within the tube from the rigid wall opposite the cathode. At the end of the anode facing the cathode is a spherical target surface, the perimeter of which is sealed to one end of a bellows. The other end of the bellows is sealed to the rigid end wall of the tube to form part of the vacuum-tight structure. Within the bellows is a rigid member that supports the target and simultaneously serves as a conduit for cooling fluid. The complete cooling conduit consists of a concentric set of hollow pipes, the inner one of which extends near the back surface of the target to direct cooling fluid against the target. Surrounding the inner pipe is an outer pipe which serves as the exit conduit for fluid that has absorbed heat from the target. The entire cooling conduit system rigidly supports the target and is sealed water-tight so that none of the cooling fluid reaches the inner surface of the surrounding bellows.

The concentric cooling and support conduit structure extends through a spherical bearing, the outer race of which is rigidly held in the end wall of the tube. The spherical bearing permits the anode assembly, which includes the target, its associated rigid conduit and support structure, and the bellows, to pivot in any direction around a complete circle. The maximum angle of deflection is determined by the geometry of the tube but is normally of the order of about 7°. In addition to its primary purpose of serving as part of the vacuum-tight tube enclosure, the bellows also prevents the target from rotating about its own axis. For this reason the motion of the target may be described as a precessing motion.

The stem of the central support structure extends beyond the intake and outlet coolant connections and may be attached to a rotary driving device comprising a motor and an eccentric support for a second spherical bearing. The precessional motion of the entire anode, or, more specifically, the deflection angle of the anode assembly, is determined by the relative geometry of the two spherical bearings. Instead of using a motor to cause the stem of the support structure to precess, the same motion may be produced by manually moving the stem to certain prescribed locations. These locations may be determined by a detent structure. As a further alternative, the extent of offset of the second spherical bearing may be varied continuously as the anode assembly precesses, thereby causing the center of the target to follow a spiral path.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in connection with the drawings in which:

FIG. 1 is a side view of a sealed-off tube constructed according to the invention with part of the side wall broken away to show the interior construction;

FIG. 2 is an end view of the tube in FIG. 1;

FIG. 3 is a cross-sectional view of the anode of the tube in FIG. 1;

FIG. 4 is a cross-sectional view of the tube in FIG. 1 along the line 4—4 and showing one position of the target within the tube; and

FIG. 5 illustrates a series of target areas on the target in FIG. 4.

DETAILED DESCRIPTION OF THE INVENTION

The X-ray tube in FIG. 1 is in the form of an elongated cylinder with a metal body 11 at one end. The body is a rigid structure with a circularly cylindrical channel extending through it. Extending from one end of this hollow metal body and sealed to it is a hollow cylindrical tube 12, the other end of which is sealed to a re-entrant glass cylinder 13 that forms a support for a filamentary cathode 14 within the cylindrical portion 12. At the bottom end of the glass member is a seal-off nipple 16 which is the remnant of an exhaust tubulation through which air is removed from the body of the X-ray tube during the final stage of manufacture. The cathode is surrounded by a beam-forming electrode structure 17 which helps to define the focus of electrons emitted by the cathode. Various known embodiments of beam-forming structures may be used to produce electron beams of any desired focal qualities from regular focus to microfocus.

At the top of the body 11 is a rigid disc 18 on which the anode structure is supported. The rim of the disc 18 is sealed to the body 11. The anode structure comprises a bellows 19, one end of which is sealed to the disc 18, a target 21, and various support and coolant conduit members. The periphery of the target is sealed to a connecting ring 22 to which the bellows 19 is also sealed, and these components, together with the body 11, the tube 12, the re-entrant glass cylinder 13, and the disc 18 form the complete vacuum-tight enclosure.

The target 21 has a spherical, convex front surface 23 and a back surface that is almost concentric with the front surface.

The support and coolant conduit members in the complete anode structure include a support post 24 that extends through the inner part 26 of a spherical bearing. The outer part of the bearing is a race 27 which is press-fitted into a recess in the disc 18. The post 24 is hollow and has conduits in it, one of which is connected to an inlet pipe 28 and the other to an outlet pipe 29. The inlet pipe 28 is shown connected by a flexible hose 31 to another pipe 32 that extends into the member 11. A similar hose, which is not shown, would also connect the pipe 29 to another pipe 33 which is supported in the opposite side of the member 11.

The central portion of the post 24 extends into a second spherical bearing comprising a spherical segment 34 held in a race 36 in an eccentric connector 37. The latter is attached to the output shaft 38 of a motor 39.

The post 24 is shown tilted slightly to one side so that its axis 41 is at an angle of about 7° with respect to the axis 42 that extends throught the center of the spherical race 27. The axes 41 and 42 cross each other at the pivot point 43 which is also the center of the spherical segment 26, and the axis 42 continues through the center of the output shaft 38 of the motor. A sheet metal cap 44 is attached to the upper surface of the disc 18 and the member 11 and supports the motor 39. This shell 44 has two slots 46 and 47 to permit the inlet hose 31 and the outlet hose 30 to pass through in order to make connection with the pipes 28 and 29.

Electrons from the cathode 14 are formed into a beam 48 on the axis 42. This beam strikes whichever part of the spherical surface 23 happens to be on the axis 42. The electrons striking this impact area cause the emission of X-rays in all directions, but only certain X-rays are able to escape from the cylindrical member 12. These are the X-rays that can pass through any one of four windows, of which only three windows 49–51 are shown in the drawing. X-rays can actually be emitted at a grazing angle and still pass through the windows 49–51. The grazing angle is parallel to the surface 23 within the area struck by the beam 48. However, the centers of the windows 49–51 lie on a plane slightly below this level so that a line through the centers of these windows and intersecting the axis 42 at the surface 23 would make an angle of about 6° with respect to that part of the surface 23 of the target. This is the same angular relationship that is present in existing fixed anode tubes of the same external configuration. Specifically, the windows 49–51 are so located that the plane passing through their centers is at a predetermined distance from the bottom surface 52 of the member 11. Apparatus in which tubes of this type may be used are provided with receptacles that have matching surfaces and ports spaced according to this dimension.

FIG. 2 shows an end view of the tube in FIG. 1 and illustrates one way in which coolant connections are made. The sides of the body 11 are flat and form a square. The pipes 32 and 33 are at diametrically opposite corners of the square and connect with fluid passages (not shown) that emerge from the body 11 in the same locations as the fluid passages in present-day sealed-off X-ray tubes having fixed anodes. The flexible hose 31 that connects the pipe 32 to the inlet pipe 28 is shown, as is a similar hose 30 that connects the outlet pipe 29 to the pipe 33. These flexible hoses are made relatively long so that they will be flexible enough to accommodate movement of the anode structure.

FIG. 3 is a cross-sectional view of the anode portion alone. In this enlarged view the target 23 is shown centered in the hollow metal body 11 rather than being at an angle thereto.

The surface 23 of the target is rigidly attached to the end cap 22 which in turn is positioned by an internal spider 53 which in this case has three points to position the end cap with respect to the hollow center support post 24. The axis 41 of the support post passes directly through the center of the spherical surface 23 and these components are rigidly joined together with each other and with the outer race 27 of the main spherical bearing before the final finishing of the spherical surface 23. In this way the spherical surface may be made precisely concentric with the pivot point 43 at the center of the spherical segment 26 of the main spherical bearing.

Surrounding the support post 24 is a hollow tubular member 54 which is also sealed vacuum tight to the cylindrical part 22 of the target. At the upper end of the support post 24 above the spherical segment 26 is an entrance port for the coolant inlet pipe 28. The end of the inlet pipe is slightly bevelled to direct coolant, usually water, down through the center of the support post 24 in the direction indicated by the arrows. At the bottom, the coolant flows radially outwardly and against the concave inner surface 56 of the target to cool the target by direct flow of the coolant. Thereafter, the coolant flows up between the post 24 and the surrounding tube 54 to the outlet pipe 29 which is sealed at the upper end of the outer pipe and is also slightly bevelled to facilitate entry of the coolant.

The bellows 19 is directly sealed to the disc 18 and to the cylindrical part 22 of the target but is not subjected to any coolant pressure since the support post 24, the surrounding hollow pipe 54, the inlet and outlet pipes 28 and 29, and the target components 21–23 form a sealed conduit system. As a result, the bellows is only subjected to atmospheric pressure which is the difference in pressure between the inside of the bellows and the evacuated part of the tube which is outside of the bellows.

FIG. 4 shows a view of the target surface 23 looking directly upwardly along the axis of the hollow cylindrical tube 12 when the target is displaced a maximum amount in one direction. In this drawing the target is displaced upwardly. The impact area of the electron beam is indicated by a small rectangle 57 which, as may be seen, is located on the axis of the cylindrical tube 12. However, this impact point does not strike the center of the target 23 because the latter is displaced upwardly a distance *d*. As the target 23 precesses along a circular path, its center follows the circle 58 indicated in dotted lines but the center of impact area 57 follows a different circle 59 also indicated in dotted lines.

FIG. 5 shows the locus traced out by the impact point 57 as the target 23 precesses. The impact point 57 is indicated in the same position as shown in FIG. 4. Other impact areas are indicated by horizontal lines spaced around the circle 59 drawn through the centers of all of these lines. It is clear that there can easily be 20 or more entirely separate impact areas each of which can be used until it becomes eroded. Thus, the tube has a life that may, at least theoretically, be 20 times as great as the life of an ordinary sealed-off X-ray tube with a fixed target.

The angular position of the target as it moves around a circle may be determined by stepping the shaft 38 of the motor 39 in FIG. 1 to certain specific locations or it may be done by moving the upper end of the support post 24 by hand. In the latter case it may be desirable to provide a detent ring adjacent the upper end of the support post to fix the locations to which the post can move.

As the post is moving by the motor **39**, it is also possible to allow the motor to rotate continuously at a speed of approximately 1 revolution per second to perhaps 6 revolutions per second. The higher the speed of rotation the greater the chance of encountering resonant vibrations, but the cooling effect on the target **23** is better when the electron beam does not strike one spot for a very long time.

It is also possible to adjust the eccentricity of the eccentric connector **37** to change continuously so that the center of the target **23** will follow a spiral path instead of a circular or linear one. In this way, and by means of a slight and well-known change in the electron optical structure around the filament **14**, a sharply focused beam, which is also referred to as a microfocus beam may be directed to as many as 100 different locations over the surface of the target. Each of these locations could accept normal beam intensity for as much as 100 hours or more and the tube life would be many times as great as the life of a normal tube with a fixed anode or a tube that was made in a demountable form, as micro-focus tubes normally are.

What is claimed is:

1. A sealed-off X-ray tube comprising:
   A. An evacuated envelope comprising:
      1. a rigid wall, and
      2. an X-ray permeable window;
   B. An electron beam source directing a beam along a first axis; and
   C. An anode comprising:
      1. a target comprising a convex surface facing said electron beam and having a second axis,
      2. rigid means supporting said target,
      3. bearing means defining a common pivot point on both said axes supported by said rigid wall and supporting said rigid means to permit circular pivotal motion thereof about said pivot point, and
      4. a bellows sealed vacuum-tight to said wall surrounding said bearing means and vacuum-tight to said target.

2. The sealed-off X-ray tube of claim 1 in which said bearing means comprises a spherical bearing having an outer race supported by said rigid wall and an inner race in the form of a spherical segment, said rigid means extending through said spherical segment and being firmly secured therein.

3. The sealed-off X-ray tube of claim 1 in which said surface of said target facing said beam is spherically convex and concentric with said pivot point.

4. The sealed-off X-ray tube of claim 3 comprising, in addition, a hollow tubular member attached to said target on the perimeter thereof and extending away from said electron beam, and said bellows is sealed directly to said hollow tubular member.

5. The sealed-off X-ray tube of claim 3 in which the surface of said target opposite said spherically convex surface is concave.

6. The sealed-off X-ray tube of claim 5 in which said bellows is sealed vacuum-tight to said target.

7. The sealed-off X-ray tube of claim 5 in which said rigid member comprises:
   A. A hollow post mechanically connected near one end to said target to support said target and mechanically connected to said bearing means;
   B. A hollow tube surrounding said post and sealed vacuum-tight at one end to said target and sealed vacuum-tight at the other end to said support post;
   C. An inlet pipe connected directly into said support posts outside of said evacuated envelope and sealed water-tight to said support post; and
   D. An outlet pipe extending into the space between said support posts and said outer tubular member and sealed water-tight to the latter.

* * * * *