United States Patent [19]

Cranberg

[11] **3,860,827**

[45] **Jan. 14, 1975**

[54] **NEUTRON GENERATOR TARGET ASSEMBLY**

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[52] **U.S. Cl.** **250/499,** 250/500, 313/61

[51] **Int. Cl.** **H01j 39/22**

[58] **Field of Search** 250/526, 499, 500, 501; 313/61, 63, 35, 39

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Attorney, Agent, or Firm—Arnold, White & Durkee

[57] **ABSTRACT**

A neutron generator target assembly includes a neutron-emissive target material disposed on a target supporting structure having a conic target supporting surface and a cooling surface in thermal contact with the target supporting surface. Means are provided for flowing a cooling fluid over the cooling surface to dissipate the energy imparted to the target when the target is bombarded by a high intensity ion beam.

6 Claims, 8 Drawing Figures

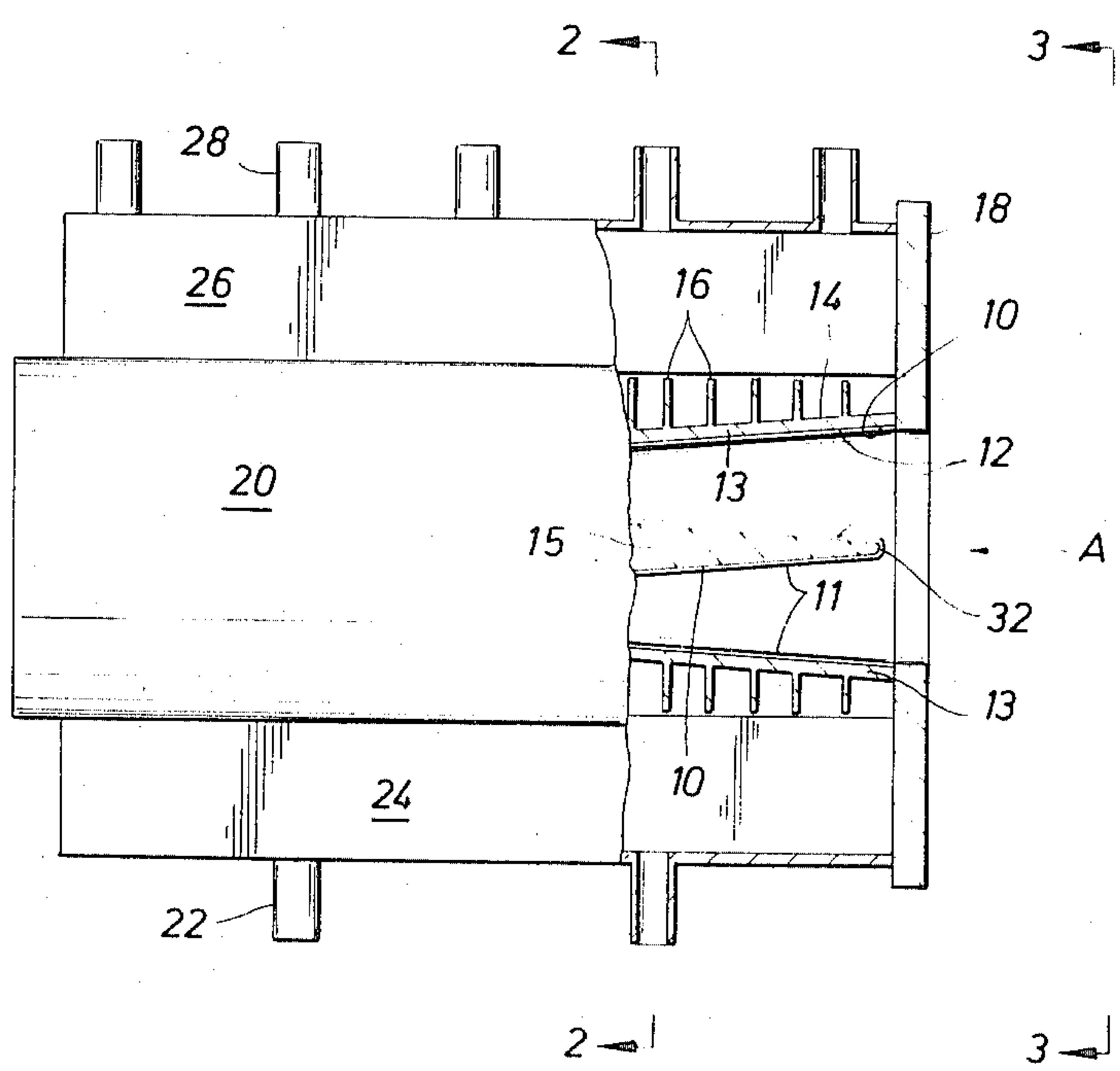


FIG. 1

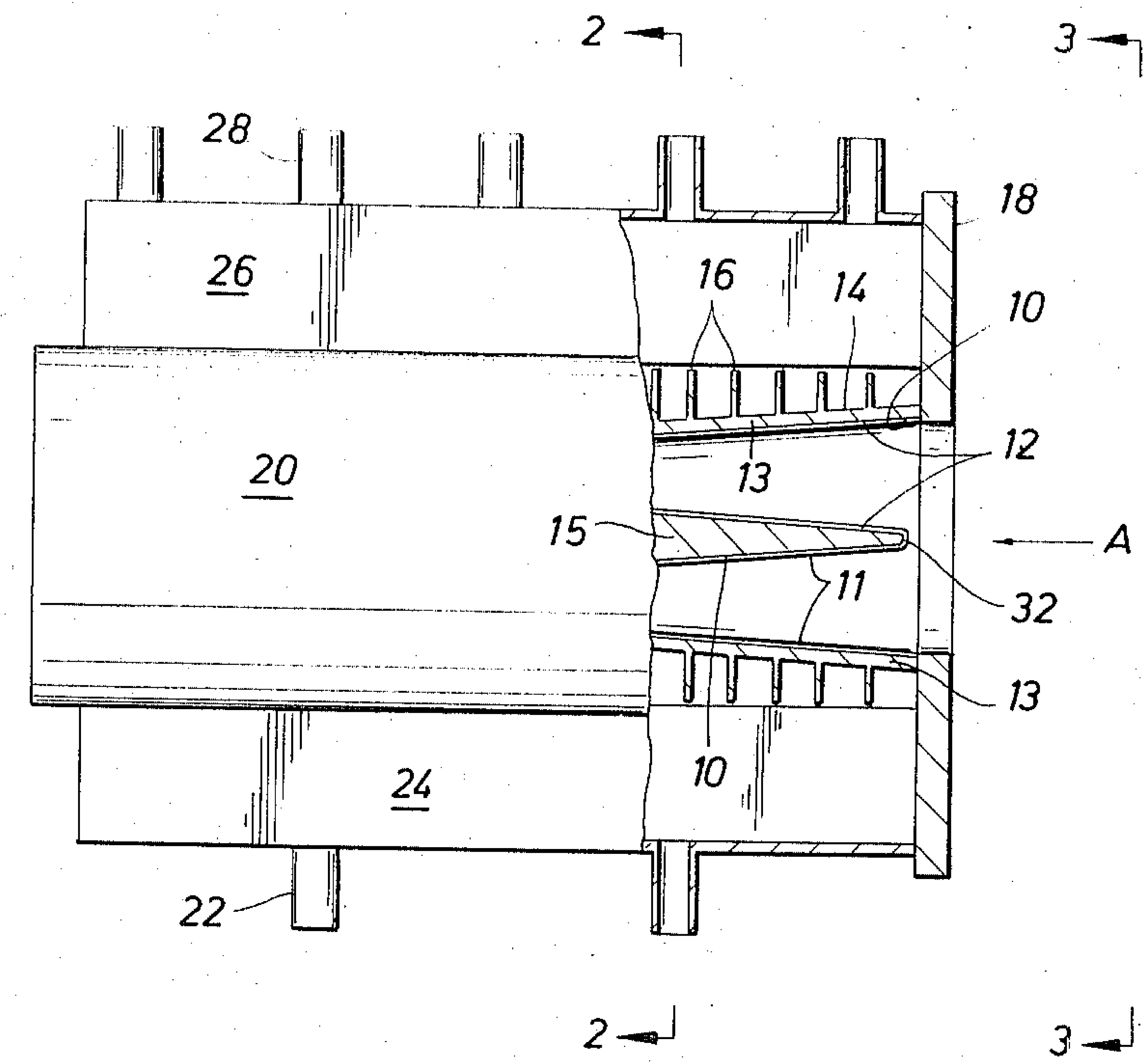
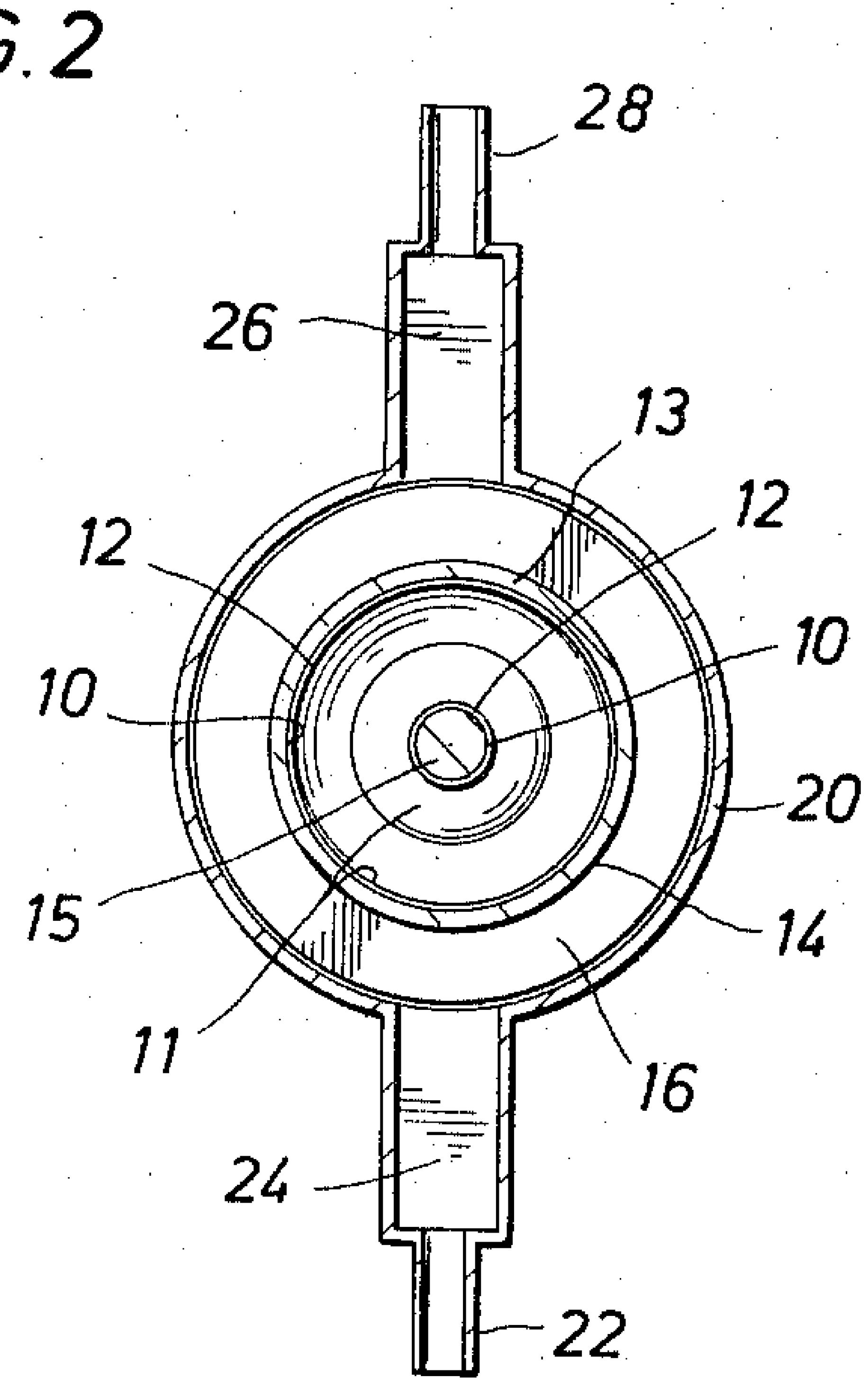


FIG. 2



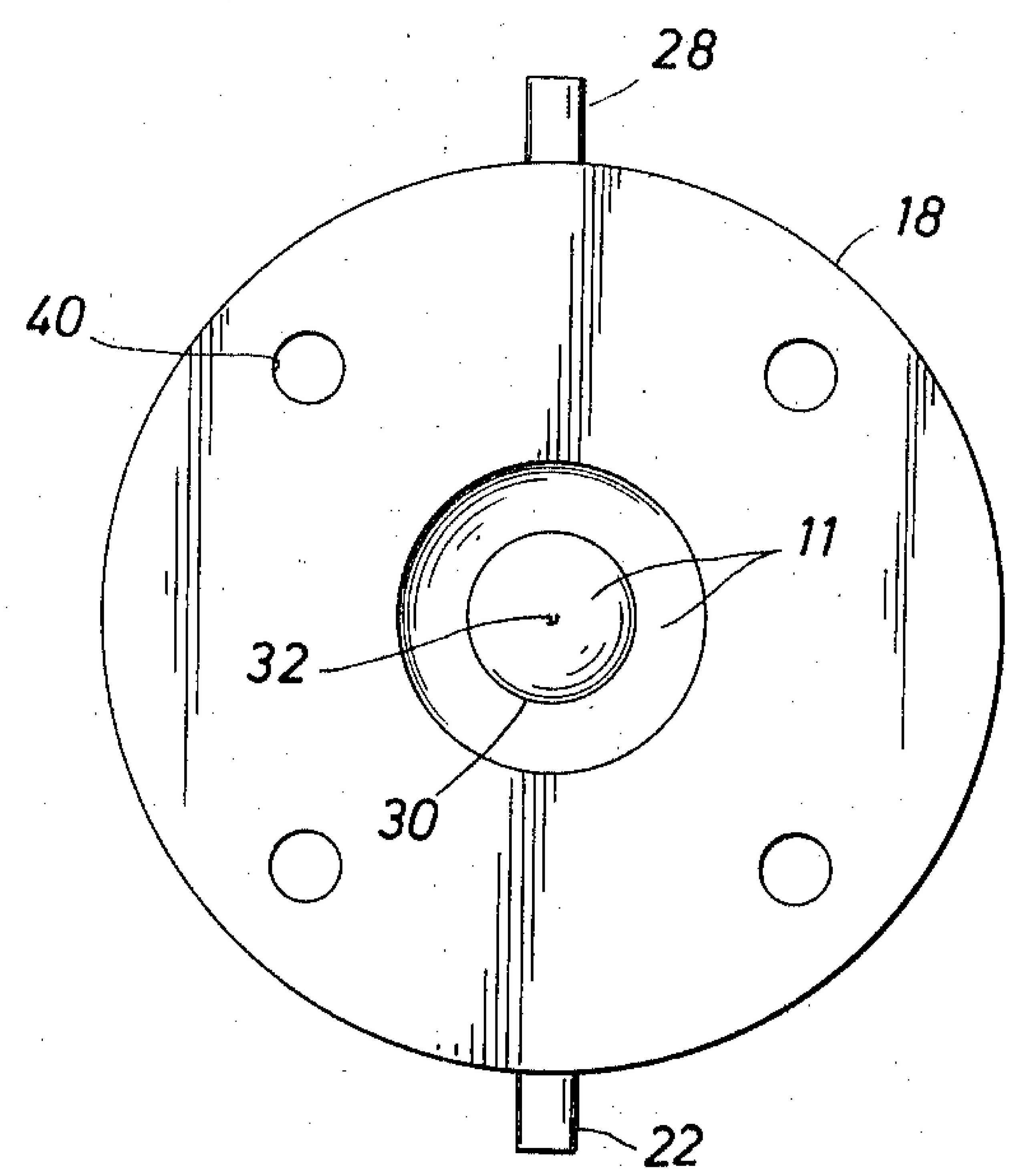


FIG. 3

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FIG. 4

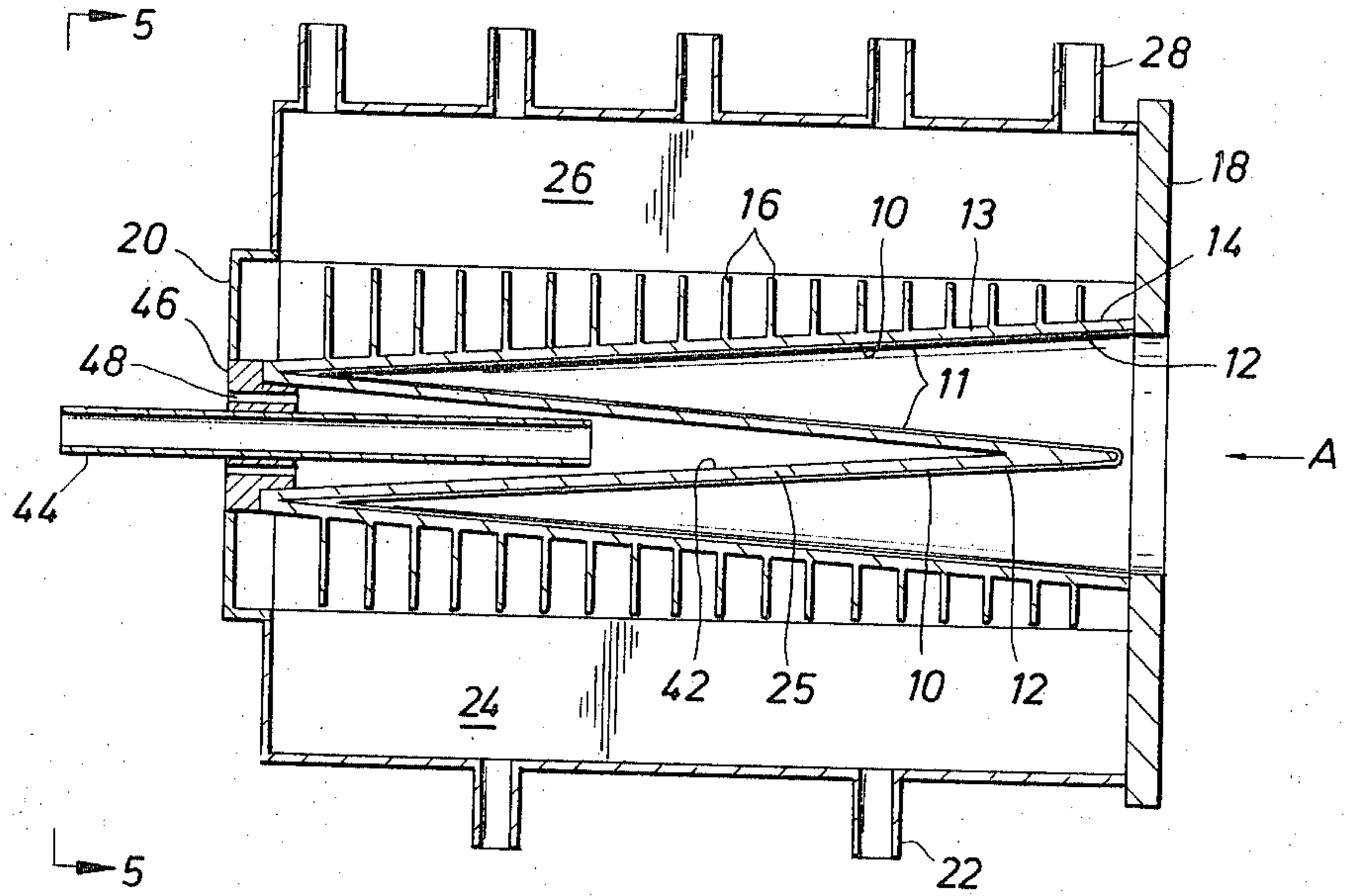


FIG. 5

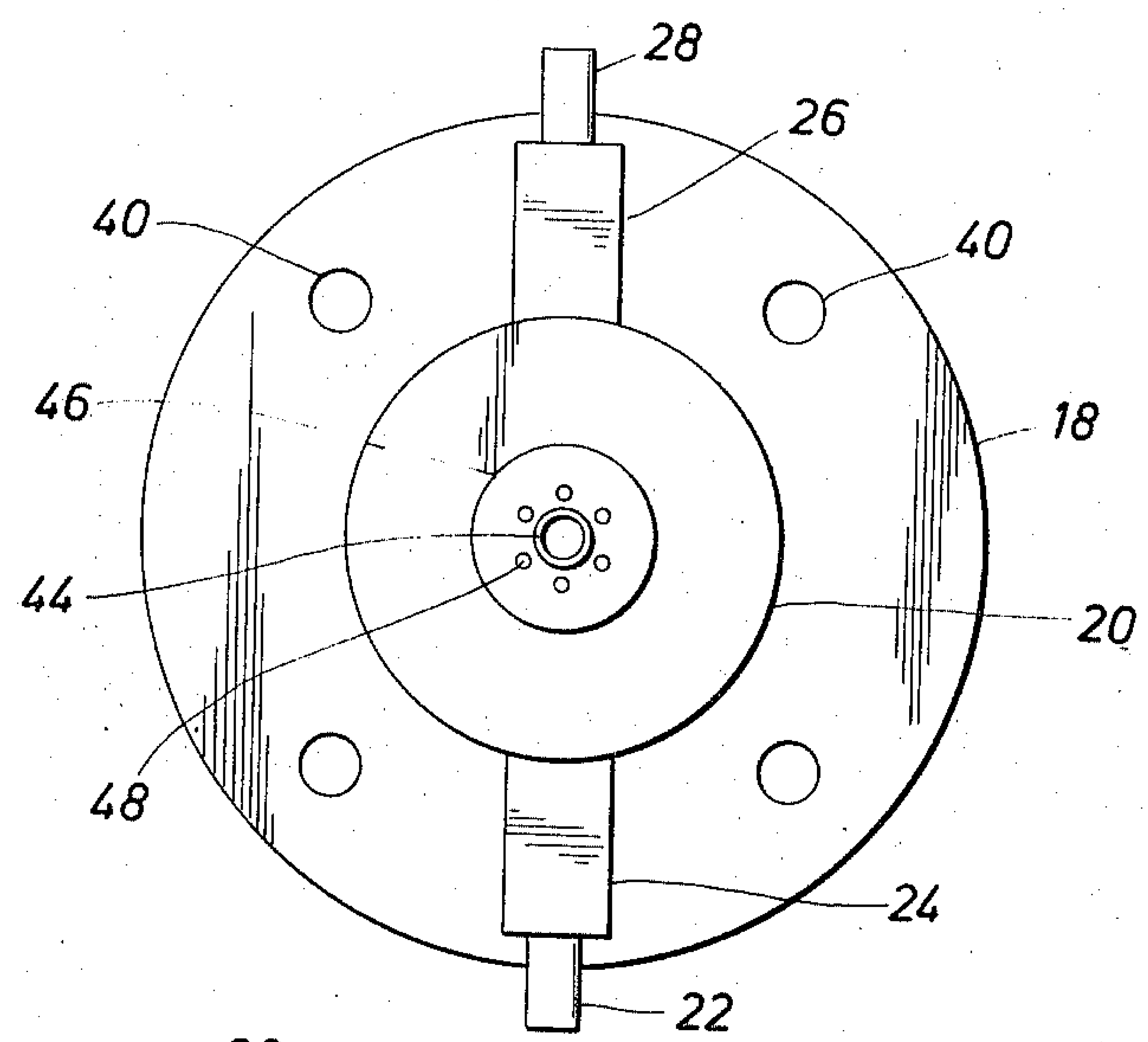
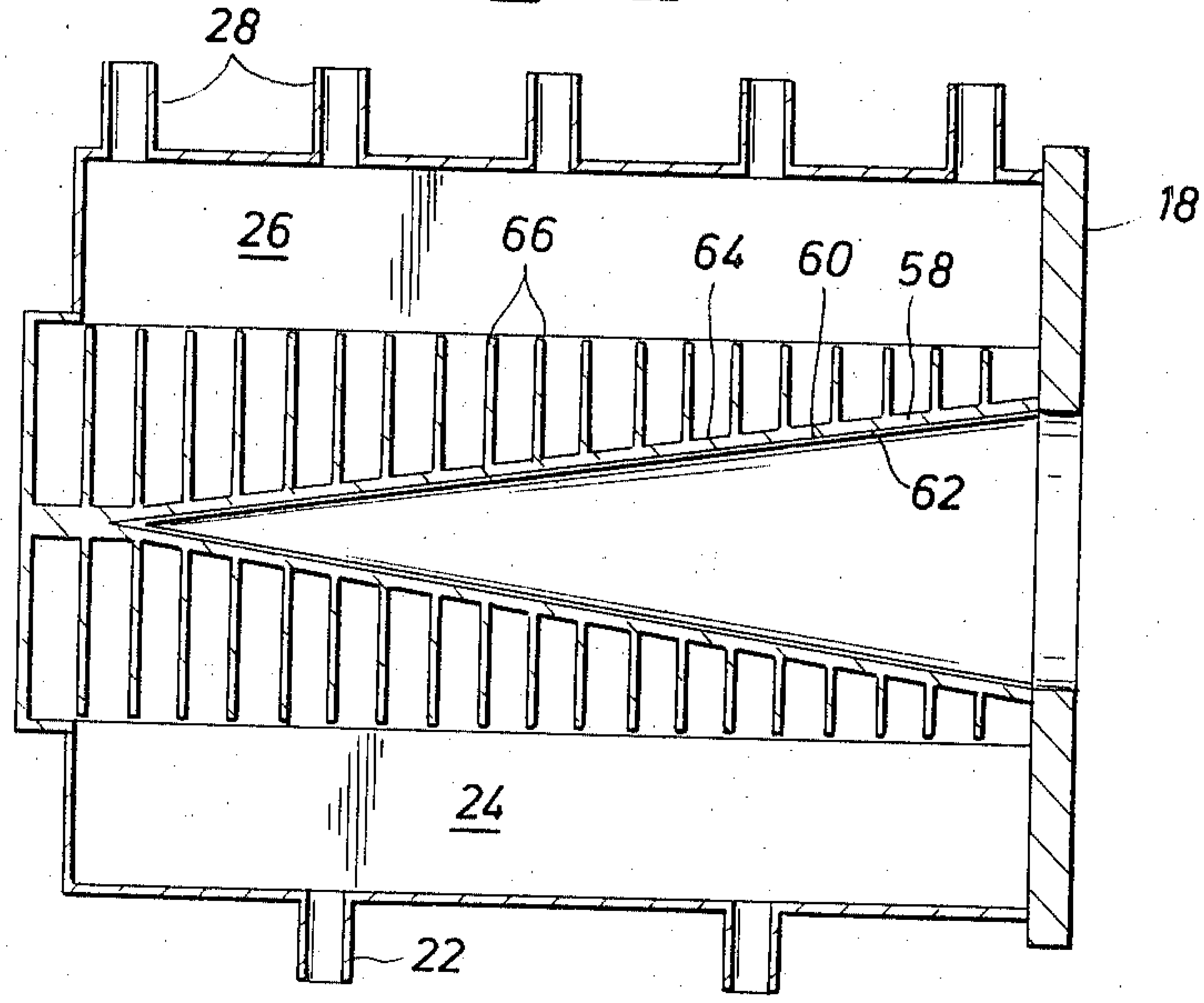


FIG. 6



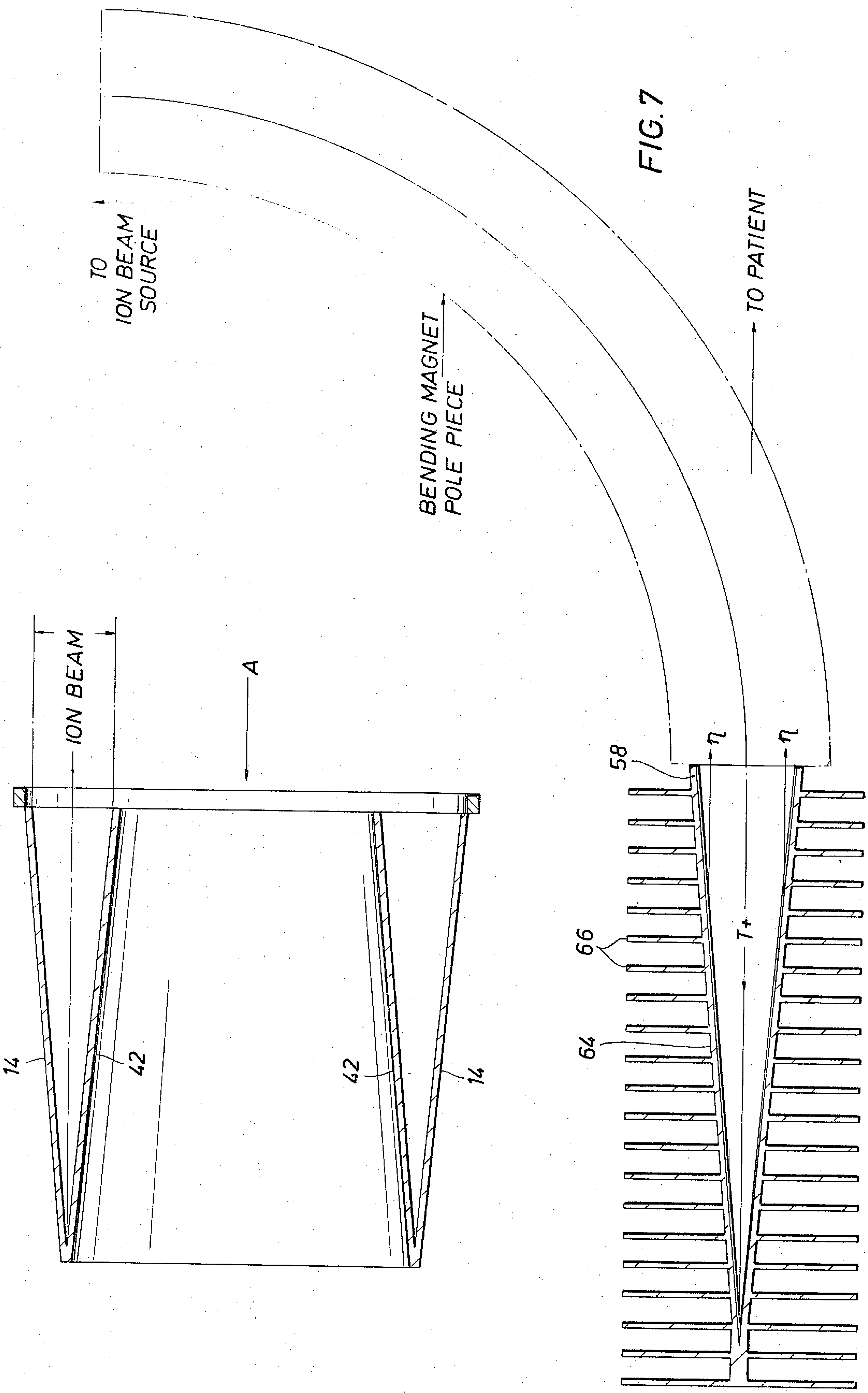

TO
ION BEAM
SOURCE
BENDING MAGNET
POLE PIECE
TO PATIENT
58
66
64
T+
ION BEAM
A
14
42
42
14

FIG. 7

FIG. 8

NEUTRON GENERATOR TARGET ASSEMBLY

BACKGROUND OF THE INVENTION

The present invention relates to apparatus for generating high energy neutrons and, more particularly, to a neutron generator target assembly adapted for use with particle accelerators producing high intensity ion beams.

The generation of high energy neutrons by the $T(d,n)He^4$, or D-T, reaction is generally well known in the art. This reaction may be carried out at low energy by impinging deuterium ions on a tritiated target or by impinging tritium ions on a deuterated target. Each deuterium-tritium reaction produces a 14 MeV neutron. About 10^5 ions impinge on the target for each neutron produced, and the energy of the impinging ions is deposited in the target. the reaction $^7Li(d,n)$ is another prolific source of energetic neutrons at low bombarding energy.

The use of high energy neutrons in the irradiation of cancers is finding increasing acceptance as an effective therapeutic technique. The theoretical and clinical work performed to date strongly indicate the need for neutrons of about 14 MeV at an intensity level at the source, assuming isotropic emission, of at least four times 10^{12} per second, in order to provide effective therapeutic irradiation in practically short treatment times of a patient situated about 125 cm from the neutron source. However, 14 MeV neutron fluxes of this intensity have not heretofore been obtainable from the D-T reaction in particle accelerator neutron generators, and the target lifetimes of the existing high intensity neutron sources have been undesirably short.

It is generally recognized in the art that increased neutron fluxes may be obtained by increasing the current of the bombarding ion beam and by using target materials having a greater specific yield of neutrons (specific yield is defined as neutron yield per unit energy deposited in the target).

The target materials having the greatest specific yield are pure deuterium and tritium gas. In gas targets, however, the gas must be maintained under sufficient pressure to assure an adequate concentration of target ions for reaction with the accelerated particles, and the containment requirement presents engineering problems which are particularly difficult at the beam currents required to produce the neutron fluxes necessary for cancer therapy.

Heavy (deuterated) or tritiated water or ice, while requiring approximately two and one-half times as much ion beam current for a given neutron yield as the pure deuterium or tritium gas target, are still useful target materials. Loss of ice by sputtering or evaporation can be compensated by replenishment in situ, and a solid ice target may be exposed to an accelerator vacuum system if the temperature of the target is maintained at less than about −100° C. Ice maintained at this temperature has a vapor pressure less than 10^{-5} torr, which is compatible with the requirements of accelerators. It will be appreciated, however, that the production of a high intensity neutron beam involves imparting considerable energy to the target, and this energy is preferably removed while maintaining the target temperature at about −100° C or below. Operation at temperatures in excess of −100° C would require differential pumping between target and accelerator.

Several means for cooling neutron generator targets are disclosed by J. Spaa in an article, "A Beam-Scanned Rotating Heavy-Ice Target for High Loads," Journal of Scientific Instruments, v. 35, pp. 175–178, May 1958. Spaa used liquid air to cool a heavy ice target carried on a flat, annular surface of a hollow rotating disk. However, the cooling involved only about 500 watts from a 0.6 mA beam at about 1,000 keV. The neutron flux obtainable from the reaction $D(d,n)He^3$ was about two times 10^{10} per second, and the target lifetime was about 5 hours without replenishment.

Dissipation of beam energy from deuterated or tritiated metal targets is also a serious problem when high ion beam currents are involved. This is because target heating causes the deuterium or tritium gas to escape from the target, shortening its useful life.

Efforts to produce high neutron fluxes with such targets are exemplified by Booth, R. and Barschall, H. H., "Tritium Target for Intense Neutron Source," UCRL—73525, University of California Lawrence Radiation Laboratory, 1971, which discloses use of a rotating, water-cooled, tritiated titanium target on a disk of copper alloy maintained at about 100° C. When bombarded with about 8 mA of 400 keV deuterons, the target produced a maximum of about two times 10^{12} neutrons per second. This, however, is still a factor of two to five below the desired flux level.

SUMMARY OF THE INVENTION

The present invention comprises a neutron generator target assembly adapted for use with a high intensity ion beam to produce a flux of fast neutrons. A neutron-emissive target material is disposed on a cone-shaped or conic target supporting structure having an axis parallel or anti-parallel to that of the impinging beam of accelerated ions. The target supporting structure includes a thermally conductive path between the target material and a cooling fluid by which the heat input to the target by the impinging ion beam may readily be removed. The target surface is tilted or inclined with respect to the axis of the ion beam so that the energy imparted to the target by the beam is distributed over a greater area than would be the case for a target surface normal to the same beam. This arrangement facilitates dissipation of beam energy, thereby stabilizing the target by allowing it to operate at appropriate temperatures, and provides a neutron source which is compact as seen from either direction along the cone axis.

In one aspect of the present invention, a neutron generator target assembly includes a target-supporting structure defining the surface of a hollow cone. Target material is disposed on this interior or concave surface, which in operation faces the ion beam source. The target-supporting structure also defines a heat transfer cooling surface in thermal contact with the target material, so that the ion beam energy may be transferred through this structure from the target to a cooling fluid.

In another aspect of the present invention, a neutron generator target assembly includes a conic target-supporting structure defining a first hollow frustoconical surface surrounding and coaxial with a second simple conical or frustoconical surface to form a folded cone. In operation, both the apex and base of the folded cone face the ion beam. In this embodiment of the present invention, the target material is disposed on and defines a surface having a generally V-shaped cross section. This target-supporting structure also defines at least one cooling surface in thermal contact with the target material, and means for flowing a cooling fluid, such as, for example, liquid nitrogen, over the cooling surface to dissipate the energy imparted to the target by the ion beam.

It is one object of the present invention to provide an improved neutron generator target assembly for use with a high intensity ion beam to produce a flux of fast neutrons.

It is another object of the present invention to provide a neutron generator target assembly having an improved useful life under bombardment by a high intensity ion beam to produce a flux of fast neutrons.

It is a further object of the present invention to provide a neutron generator target assembly suitable for use with a high intensity ion beam to produce a flux of at least four times 10^{12} per second of 14 MeV neutrons.

Still another object of the present invention is to provide an improved neutron generator target assembly adapted to be fluid cooled.

A still further object of the present invention is to provide a neutron generator target assembly wherein the energy input to the target by an impinging ion beam may be dissipated by the vaporization of a cryogenic liquid.

Another object of the present invention is to provide an improved neutron generator target assembly particularly adapted for use with a high intensity ion beam to produce a flux of high energy neutrons for applications in which small target size is not a requirement.

Among the other and further objects of the present invention is to provide an improved neutron generator target assembly adapted to maintain a heavy ice target at a temperature no greater than −100° C under bombardment by a triton beam of sufficient intensity to produce a flux of at least four times 10^{12} of 14 MeV (D-T) neutrons per second.

Another object of the present invention is to provide an improved neutron generator target assembly to obtain high fluxes of neutrons at 180° to the direction of the ion beam which is incident on the axis of the target, with a minimum of attenuation of the neutron intensity by target coolant and structural materials over fields of view of ±5 degrees from the axis of the ion beam.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an elevation view in partial section of one embodiment of a neutron generator target assembly in accordance with the present invention.

FIG. **2** is a cross-sectional end view taken along line 2—2 of the neutron generator target assembly of FIG. **1**.

FIG. **3** is an end view of the neutron generator target assembly of FIG. **1**.

FIG. **4** is a cross-sectional elevation view of another embodiment of a neutron generator target assembly in accordance with the present invention.

FIG. **5** is an elevation view of the left end of the neutron generator target assembly of FIG. **4**.

FIG. **6** is an elevation view in cross-section of still another embodiment of a neutron generator target assembly in accordance with the present invention.

FIG. **7** is a schematic elevation view of a target in accordance with the present invention together with a 90 degree bending magnet in an arrangement which enables neutrons to be obtained from the target with minimum loss due to scattering or absorption by materials of the target support and by the coolant.

FIG. **8** is a cross-sectional elevation view of still another embodiment of the present invention in an arrangement which further facilitates target cooling.

DESCRIPTION OF PREFERRED EMBODIMENTS

Neutron generator target assemblies in accordance with the present invention include a target-supporting structure adapted to carry a neutron emissive target material disposed on a first target supporting surface to define a target surface, and having a second heat-transfer or cooling surface which is in thermal contact with the target supporting surface and which is adapted to dissipate the heat built up in the target under bombardment by a high energy ion beam.

In describing the geometric character of the target or target-supporting surfaces, the terms "conic" and "folded cone" are used. The term "conic" will be used herein to refer to surfaces which may be defined by all or a portion of a moving line passing through a fixed vertex and intersecting a closed curve. Such a line may be straight or may comprise one or more curves, but the surface traced will be generally that of the surface of a cone. The term "folded cone" will be used herein in reference to a conic surface formed by folding the upper half of a cone inside out to a position within and coaxial with the lower half of the cone to produce an annular surface having a generally V-shaped cross section. References to conic surfaces include both simple and folded cones.

Use of like reference numerals in the various views of the drawings indicates reference to the same object.

Referring now to FIG. **1**, one embodiment of a neutron generator target assembly in accordance with the present invention is illustrated in partial sectional elevation. This target assembly includes a target-supporting structure **13** defining a folded cone target supporting surface **10** having an axis of symmetry as indicated by arrow A and upon which is disposed a layer **12** of a neutron emissive target material to define a target surface **11**. The structure **13** also defines a heat transfer or cooling surface **14**, including a plurality of annular fins **16**. The target-supporting structure is preferably formed of a material having a high heat conductivity, such as, for example, copper.

The target-supporting structure **13** is enclosed within a generally cylindrical housing **20** having a plurality of inlets **22** and outlets **28** to distribution **24** and collection **26** plenums, respectively. The target material is cooled by flowing a cooling fluid over the cooling surface **14**. The cooling fluid is introduced into the housing through the inlets **22**. The distribution plenum **24** aids in maintaining an even flow of fluid over the cooling surface **14**, including the fins **16**. The cooling fluid is collected in the other plenum **26** and exits through the outlets **28** as shown.

Both the housing **20** and the target-supporting structure **13** are attached, as by brazing, to a head plate **18**. The head plate **18** serves as means for connecting the target assembly to a particle accelerator vacuum system, and includes a central aperture through which the target material may be exposed to an ion beam.

FIG. **2** is a cross-sectional end view of the embodiment of the present invention illustrated in FIG. **1**, and shows more clearly the relationship between the distribution **24** and collection **26** plenums of the housing and the target-supporting structure itself. Reference numeral **32** refers to the apex of the folded cone, and reference numeral **30** refers to the intersection of the inner and outer concentric conic surfaces comprises the folded cone.

FIG. **3** is an end view of the neutron generator target assembly of FIG. **1.** As shown, head plate **18** includes in this embodiment a plurality of bolt holes **40** by which the target assembly may be attached to a particle accelerator vacuum system for operation.

The cooling fluid distribution plenum **24** constitutes a fluid distributing means to assure an appropriate distribution of the cooling fluid over the heat transfer surface **14.** It will be appreciated that the plenum **24** may contain one or more baffles or other devices known in the art for accomplishing good fluid distribution.

The number of spacing of the fins **16** defined by the heat transfer surface **14** may be selected as desired to achieve suitable overall heat transfer characteristics, depending on the energy input to the target material and the cooling fluid used. It will be appreciated that under certain conditions of modest heat load, no fins at all will be required and the heat transfer surface **14** may be a simple frustoconical surface. In the illustrated embodiment of the present invention, the central conical element **15** of the target-supporting structure is solid. This solid element is preferably of a material having a high head conductivity so that the heat flow from the target material to the cooling fluid is generally axially along this element and then outwardly to the cooling fluid at the base of the element.

FIG. **4** illustrates an alternative embodiment of a neutron generator target assembly in accordance with the present invention. This embodiment is similar to that illustrated by FIG. **1,** except that the inner conical target supporting element **25** is hollow and defines an inner heat transfer surface **42.** A cooling fluid inlet duct **44** extends within the target supporting element **25** to assure distribution of cooling fluid over the heat transfer surface **42.** The inlet duct **44** is held in place by an end member **46.** The end member **46** also includes a plurality of cooling fluid exit ducts **48** as shown.

FIG. **5** is an end view of the neutron generator target assembly illustrated in FIG. **4,** indicating the relative positions of the cooling fluid inlet **44** and outlet **48** ducts.

FIG. **6** illustrates yet another embodiment of a neutron generator target assembly in accordance with the present invention. In this embodiment, target-supporting structure **58** defines a generally conic target-supporting surface **60** over which is disposed a layer of a neutron emissive target material **62** to produce a corresponding conic target surface. The target-supporting structure **58** also defines a heat transfer or cooling surface **64,** including a plurality of spaced apart annular fins **66** to enhance the heat transfer characteristics of the surface **64.**

The angle at which an ion beam parallel to the target assembly axis will impinge the target surface is one-half the apex angle of the conic or folded cone target support. As this angle of intersection decreases, a given ion beam will illuminate a greater target surface, and the thickness of target material necessary to present an infinitely thick target to the impinging ions decreases. Decreasing target thickness, of course, correspondingly decreases resistance to heat flow from the ion beam to the target support structure. Increasing the area of illumination permits the ion beam energy to be dissipated over a greater target surface area, so that specific heat loading is reduced.

An ion- or electron-beam target which is normal to the beam or inclined at an angle to it will usually have a central hot spot, which will be the focus of deterioration of the target. This hot spot is due to two facts: ion and electron beams from conventional accelerators have an intensity profile with a maximum at the beam center; and the center of the target spot is not cooled as efficiently as the edges of the spot by radial heat transfer by the material of the target and target support when the latter is planar or near-planar.

A properly designed cone-shaped target, whose axis coincides with the axis of the ion beam, can eliminate both effects. Cooling fins at the apex of the cone assure efficient cooling of that point, and tailoring of the shape of the cone to the intensity profile of the ion beam will assure uniform heating of the face of the cone by the beam.

For a beam with a rectangular intensity profile, the straight-sided cone shown in FIG. **6** will assure uniform heating of the target surface. For the more common gaussian beam profile, the taper of the cone will be nonuniform, and will be such as to present a convex surface to the beam.

If a neutron generator target cone having a base diameter of two centimeters and a length of 12.5 centimeters is illuminated by an ion beam having a diameter of two centimeters, about six times as much surface will be illuminated as for a flat target normal to the beam. For a folded cone, about 12 times the area of a flat surface will be illuminated. The thickness of target required to stop the beam will also be reduced by a factor of 6 for the cone and by a factor of 12 for the folded cone.

Neutron generator target assemblies in accordance with the present invention and having the above-described configuration are particularly suited to cancer therapy, wherein the neutron source must deliver a uniform intensity to areas of a patient which are sharply defined by appropriately designed neutron collimators, with the patient at about 125 centimeters from the source. Areas to be exposed range up to squares 20 cm on edge. Thus the maximum angle subtended by the patient area at the target is just the angle of the target cone, described above, so that neutrons emerging from the target at 180° to the ion beam, as shown in FIG. **7,** reach the patient unattenuated by the target support, cooling fins, or cooling fluid.

FIG. **8** suggests still another embodiment of the present invention. In this embodiment, the folded cone target assembly resembles a truncated version of the embodiment of FIG. **4** in which the inner conic surfaces do not meet at an apex, but are separated. The embodiment of FIG. **8,** when sized to have the same instantaneous intersecting target surface area with a 2 cm diameter ion beam as the embodiment of FIG. **4,** results in a target assembly with a much larger total target surface area. This larger total area enables the ion beam energy to be dissipated over a greater area when the target and ion beam are moved relative one another, as for example by rotating the target surface about its axis of symmetry as indicated by arrow A.

It will be appreciated that neutron-emissive target material to be used in any specific application may be selected from among those materials known to those in the art to be suitable under the conditions to be encountered. For example, deuterated or tritiated titanium, zirconium, or other metal may be used. Deuterated or tritiated ice also may be used. Lithium **7** may be used. The target may even be of pure copper, with which a mixed deuterium-tritium ion beam is used to build up target ions in the metal base. Or the structure described here may be placed at the end of a gas target to dissipate the residual energy of the beam. Choice of target materials will be based on a number of factors, including neutron flux desired, target stability, ion beam intensity required, and others as known in the art.

When deuterated or tritiated ice is selected as the target material, several advantages accrue. One advantage is relatively high specific yield. Another is ease of target replenishment. The selection of ice as the target material conditions selection of a cooling fluid, because the ice must be maintained below about −100° C for compatibility with the particle accelerator vacuum system to which it is exposed in operation. Liquid nitrogen, which boils at a temperature of about −195° C, is particularly suited to such applications because of its ready availability and low cost, although other cryogenic liquids may satisfactorily be used for this purpose.

When the target service temperature and heat load permits, fluids other than cryogenic liquids may of course be used for target cooling. Water is quite satisfactory in a number of cooling applications, and air or other gases may also be used.

In applications wherein the heat of vaporization of the cooling fluid is used in achieving the necessary heat dissipation, provisions must be made to accommodate the resulting pressure and flow conditions. For example, heavy-duty construction and unobstructed flow paths are preferred.

In Operation

In operation a neutron generator target assembly in accordance with the present invention is coupled to a suitable particle accelerator, as, for example, by bolting the face plate or flange **18** of one of the illustrated embodiments to a corresponding flange on the accelerator. The accelerator vacuum system is then evacuated. Preferably, means are provided by the accelerator for relative movement of the target assembly with respect to the accelerated ion beam, such as, for example, a flexible bellows or beam scanning devices, so that the beam may successively illuminate various areas of the target to distribute the energy input over the target surface. Relative movement may be achieved by moving the target with respect to the beam, by moving the beam with respect to the target, or by a combination of both. The target assemblies of the present invention are particularly adapted to be rotated about their symmetric axes to dispose the ion beam heat load over as large an area as possible.

Refering again to the embodiment illustrated in FIG. 4 as exemplary of the present invention, the target material **10,** for example deuterated ice, may be deposited on the target supporting surface **12** by conventional means. Flow of a suitable cooling fluid, liquid nitrogen, for example, in the case of an ice target, removes sufficient heat energy from the assembly at the cooling surfaces **14** and **42** to maintain the ice at a temperature compatible with the accelerator vacuum system.

An intense beam of accelerated tritons is directed along an axis parallel to the axis of the target structure to impinge a portion of the deuterated target. Each reaction between a triton and deuteron produces a 14 MeV neutron. The energy of the impinging ion beam is transferred first to the target ice, tending to raise its temperature and cause vaporization in the vacuum environment of the system. This energy is transferred through the target supporting structure **13** and **25,** across the heat transfer surfaces **14** and **42,** and to the liquid nitrogen coolant. This coolant absorbs great amounts of heat on vaporization, dissipating the same.

The neutron flux generated in this manner is generally isotropic, but the elongated nature of the target favors collimation of the beam in both directions along the target axis. The neutrons are made available from the target through suitable ports for their desired uses. Neutrons which emerge at 180° to the direction of the incident ion beam will not suffer the attenuation experienced by those which emerge in the zero-degree direction and traverse the target support, cooling fins, and cooling fluid.

It will be appreciated that the efficiency or specific yield of the target may be improved by impacting the target with only those ions whose energy is most suitable for producing the desired reaction. In this way the ions having other energies do not add to the heat input to the target. This ion screening may be accomplished by use of an ordinary bending magnet in the accelerated ion stream to deflect the undesirable, heat producing ions. This magnet also facilitates extraction of a neutron beam at **180**° to the direction at which ions impinge on the target, as shown in FIG. **7.**

The production of a flux of at least four times 10^{12} per second of 14 MeV neutrons from the D-T reaction may be achieved by accelerating a 2 centimeter diameter, 19 mA beam of 250 keV tritons onto a deuterated ice target such as that shown in FIG. **4,** when the target has a base diameter of 2 cm and a length of 12.5 cm. The heat input to the target under such conditions is about 4,800 watts, which may be dissipated by the vaporization of about 81 liters per hour of liquid nitrogen.

As is well known to those familiar with intense neutron sources, a major target problem is the phenomenon known as sputtering. Sputtering is the removal of target material due to impact of energetic impinging ions. Another is the problem of evaporation due to elevated temperature resulting from dissipation of ion beam energy in the target material.

The target assemblies of the present invention overcome the sputtering and evaporation problems in several respects. The inclined target surfaces enable the use of much thinner layers of target material, for example, ninety percent thinner than possible with targets normal to the impinging ion beam, so that the heat input to the target material by the ion beam may be dissipated quickly.

In addition, the conic geometry of targets in accordance with the present invention places target surfaces in close opposition to one another, so that there is a much greater likelihood that target material lost by sputtering from one location on the target will be redeposited at another location on the target than would be the case for a flat target.

Neutron generator target assemblies in accordance with the invention provide improved useful lifetimes under intense ion beam bombardment due to their conic geometry as discussed above. Also, by permitting the use of ice as a target material in intense ion beam environments not heretofore practicable, target assemblies in accordance with the present invention make possible greatly extended target lifetimes by regeneration of the target surface. Ice target regeneration may be continuously or intermittently accomplished by spraying a fine mist of deuterated or tritiated water, as appropriate, onto a portion of the target surface. This generation or replenishment may be carried out during ion bombardment. The effective cooling provided by the cryogenic cooling fluids enables the almost instantaneous freezing in place of the target spray, ready for exposure to the ion beam for neutron generation. By this process, high intensity neutron generator targets may be used for continuous periods many times longer than heretofore possible.

In FIG. 8 a further variation of the basic invention is disclosed whereby the conical target support structure is part of a disk whose axis is an axis of rotation. By imparting a rotational motion to the disk, the energy of the ion beam is spread over a target area even more extended than in the embodiments illustrated in the prior figures, without increasing the ion beam-target intersecting area, thereby making possible the use of more intense ion beams for a given increase in temperature of the material of the target. It will be understood that the target support structure of FIG. 8 may include cooling fins and means for cooling as described above. It will also be understood that the embodiment illustrated in FIG. 8 can be combined with an ion beam bending magnet as illustrated in FIG. 7, so that the neutrons delivered to a cancer therapy or other patient need not traverse the materials of the target support and coolant.

It will be understood by those skilled in the art that numerous modifications may be made to the specific embodiments hereinabove discussed without departing from the spirit or scope of the present invention. For example, the target geometry may be modified by using slightly curved lines, and the relative beam and target sizes and coolant flows may likewise be varied. Similarly, the number and size of the cooling fins may be modified as necesssary to assure that the transfer of heat energy from the target structure to the cooling fluid takes place at a suitable rate.

What is claimed is:

1. A fluid-cooled neutron generator target assembly for supporting neutron emissive target in an ion beam to produce a flux of neutrons, comprising:

a target support member having:

a first target-supporting surface defining the exterior surface of a conic section;

a second target-supporting surface defining the interior surface of a frustoconical section coaxial with, surrounding, and intersecting said first target-supporting surface to define a conic target-supporting surface having a generally V-shaped cross section for supporting a layer of neutron emissive target material to produce a neutron flux generally collimated parallel to said conic axis when the target is bombarded by an ion beam parallel to said axis;

a first cooling surface in thermal contact with said first target-supporting surface; and

a second cooling surface in thermal contact with said second target-supporting surface; and

means for flowing a cooling fluid over said cooling surfaces to remove energy imparted to the target material by the ion beam and to maintain the target material at a desired temperature.

2. A fluid-cooled neutron generator target assembly as recited in claim 1, wherein one of said cooling surfaces includes a plurality of spaced apart annular fins to enhance heat transfer between said target support member and the cooling fluid.

3. A fluid-cooled neutron generator target assembly as recited in claim 1, wherein said first target-supporting surface defines the exterior of a simple cone having an apex in the plane defined by the base of said second, frustoconical section.

4. A fluid-cooled neutron generator target assembly as recited in claim 1, wherein said first target-supporting surface defines the exterior of a frustoconical section.

5. A fluid-cooled neutron generator target assembly as recited in claim 1, including a neutron-emissive target material selected from the group consisting of deuterated titanium, tritiated titanium, deutered zirconium, and tritiated zirconium to produce a flux of D-T neutrons responsive to bombardment by the ion beam.

6. A fluid-cooled neutron generator target assembly as recited in claim 1, including a neutron-emissive target material selected from the group consisting of deuterated ice and tritiated ice to produce a flux of D-T neutrons responsive to bombardment by the ion beam and wherein said cooling means comprises means for flowing a cryogenic liquid over the cooling surfaces to maintain the target material at a temperature below about −100° C.

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