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[54] **INTERSTITIAL X-RAY NEEDLE**

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Related U.S. Patent Documents

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[51] **Int. Cl.**[6] **H01J 35/14**; H01J 35/12

[52] **U.S. Cl.** **378/138**; 378/119; 378/127; 378/130

[58] **Field of Search** 378/119, 121, 378/130, 137, 138, 141, 143, 145, 193, 199, 200, 202, 127

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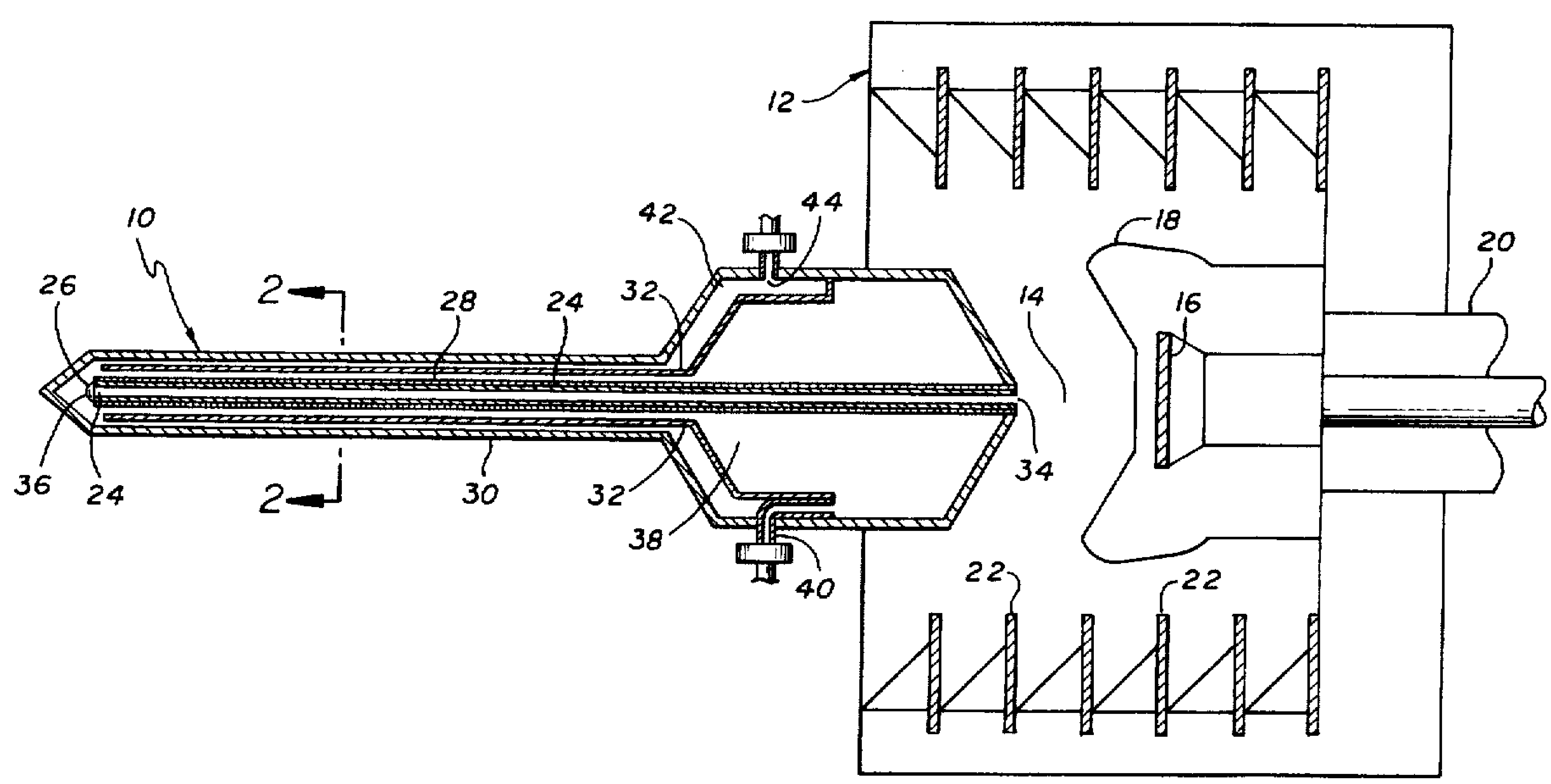
[57] **ABSTRACT**

An interstitial X-ray needle includes an elongated X-ray tube coupled to an electron emitter at one end of the tube, with a converter element being disposed at a tip of the other end of the tube for converting emitted electrons into X-ray; a solenoid coil wound around the tube for providing a magnetic field that confines the emitted electrons within a narrow beam; an elongated outer casing enclosing the tube and coil; and a pipe coaxially disposed between the casing and the tube for defining an inner annular flow chamber between the tip of the tube and a coolant inlet in the casing and an outer annular flow chamber between the tip of the tube and a coolant outlet in the casing.

21 Claims, 2 Drawing Sheets



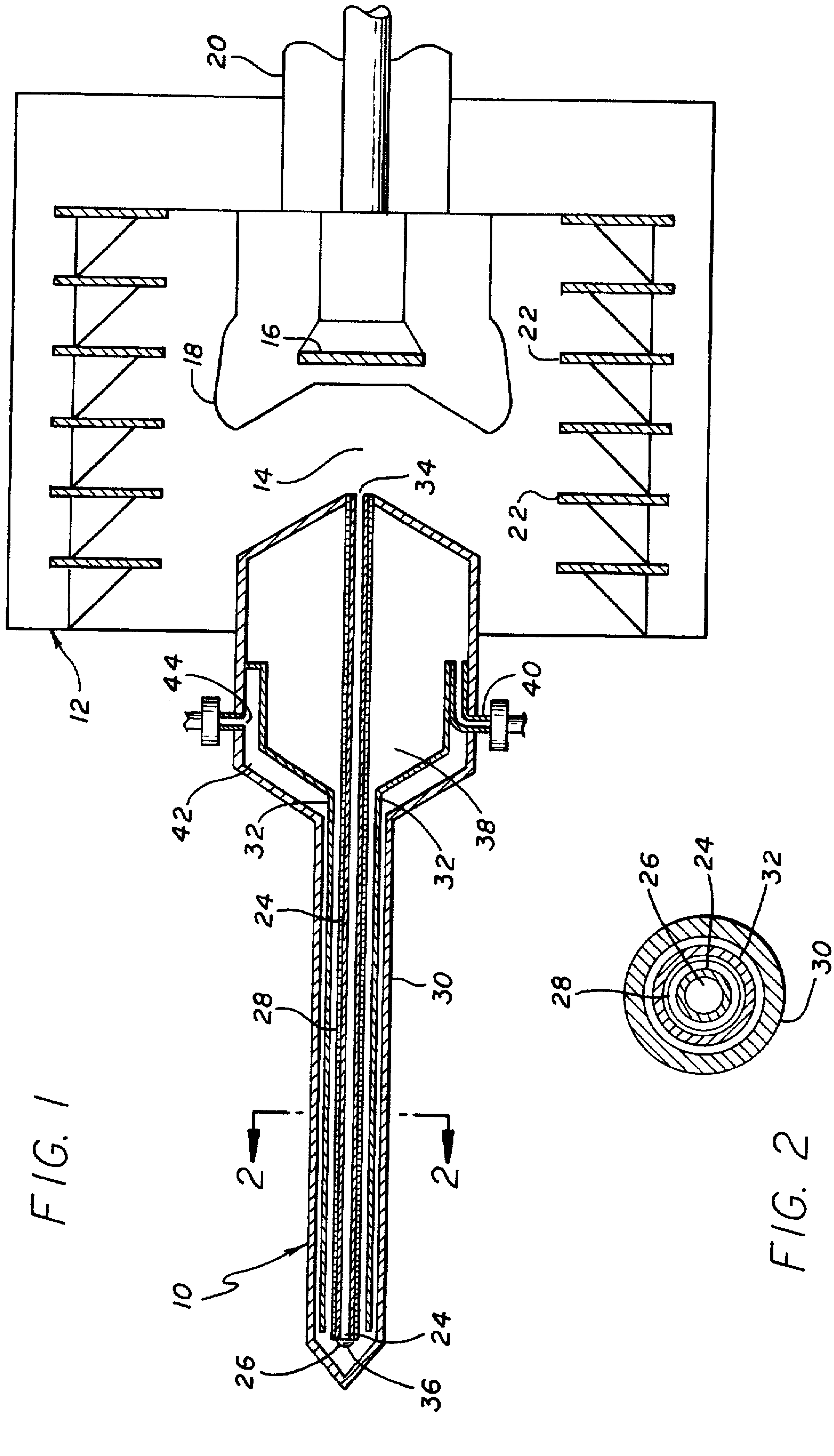

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FIG. 1

FIG. 2

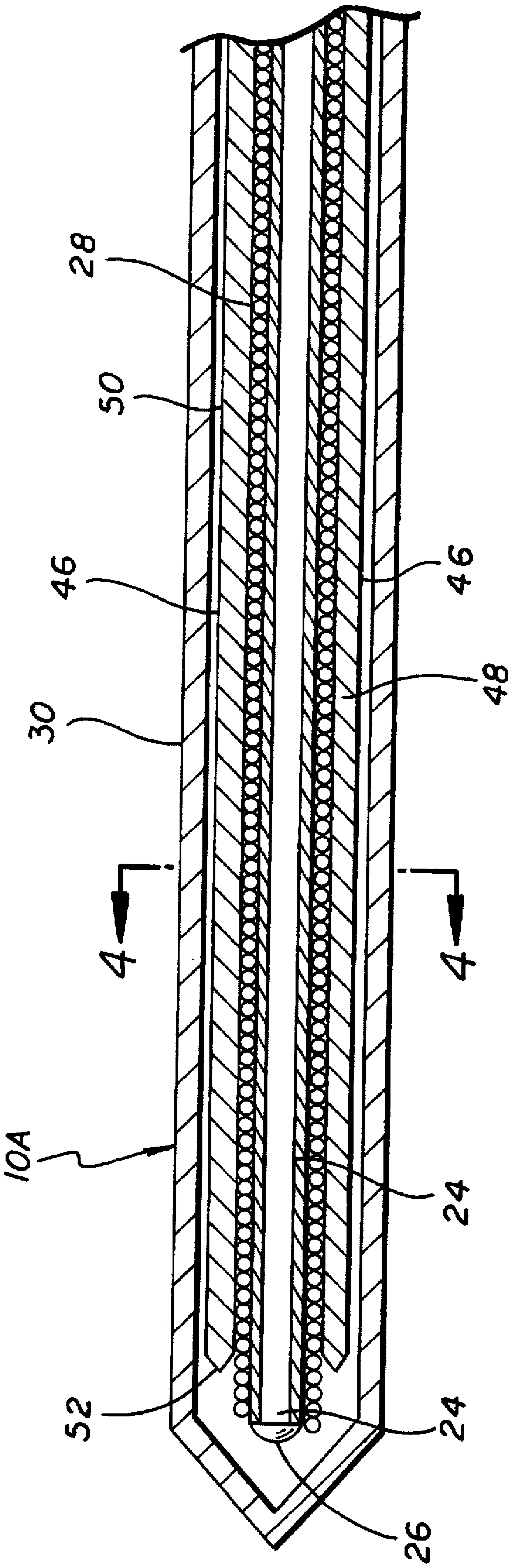

FIG. 3

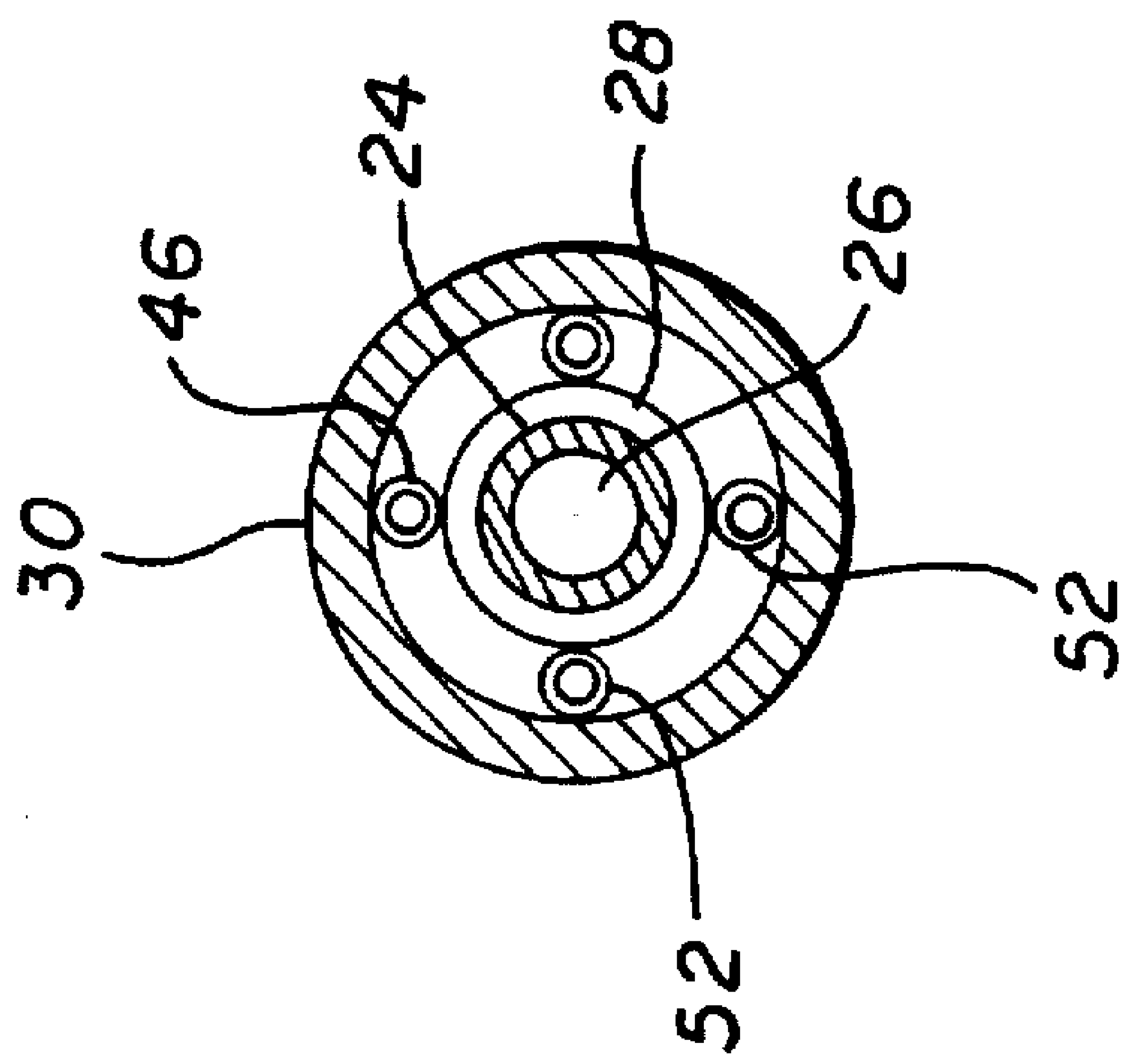

FIG. 4

INTERSTITIAL X-RAY NEEDLE

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND OF THE INVENTION

The present invention generally pertains to X-ray apparatus and is particularly directed to an interstitial X-ray needle.

An X-ray apparatus is used for radiation therapy of cancer patients. One such apparatus, as described in U.S. Pat. No. 2,748,293 to Reiniger, includes an elongated X-ray tube with a converter element being disposed at a tip of the tube for converting emitted electrons into X-rays; and an elongated outer casing enclosing the tube and defining a coolant flow chamber through which coolant may flow to transfer heat from the tip of the tube. The tube is inserted into a cancer patient's body through a body cavity to position the converter element so that the X-rays can be concentrated at the tumor and thereby minimize radiation damage to adjacent undiseased tissue. However, the size of such an X-ray apparatus is too large for insertion of the tube through the skin, whereby the applicability of X-ray therapy for treatment of cancerous internal body parts has been limited to only those body parts that can be accessed through body cavities.

SUMMARY OF THE INVENTION

The present invention provides an interstitial X-ray needle, comprising an elongated X-ray tube coupled to an electron emitter at one end of the tube, with a converter element being disposed at a tip of the other end of the tube for converting emitted electrons into X-rays; a solenoid coil wound the tube for providing a magnetic field that confines the emitted electrons within a narrow beam; an elongated outer casing enclosing the tube and coil; and means within the casing defining coolant flow chambers for directing coolant to and from the tip of the tube.

The interstitial X-ray needle of the present invention may be of such small diameter that a portion of the casing extending at least approximately five centimeters from the tip of the tube has a maximum outside diameter of approximately two millimeters. An X-ray needle of such diameter may be inserted in a patient's body without significant damage to tissue between the skin and the tumor site, thereby significantly increasing the applicability of X-ray therapy for treatment of cancerous internal body parts.

To prevent electron loss and stray X-radiation, the solenoid coil is wound around the beam-transport tube in order to provide a magnetic field that tightly confines the emitted electrons.

In one aspect of the present invention, the coolant-flow-chamber-defining means comprises a pipe coaxially disposed between the casing and the tube for defining an inner annular flow chamber between the tip of the tube and a first opening in the casing and an outer annular flow chamber between the tip of the tube and a second opening in the casing.

In another aspect of the present invention, the coolant-flow-chamber-defining means comprises a plurality of pipes disposed between the casing and the tube wherein each pipe defines an input flow chamber between the tip of the tube and at least one inlet opening in the casing and wherein the space between the tube and the casing not occupied by the pipes defines an output flow chamber between the tip of the tube and an outlet opening in the casing.

Additional features of the present invention are described in relation to the description of the preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a diagram of an X-ray apparatus including a preferred embodiment of the interstitial X-ray needle of the present invention.

FIG. **2** is a sectional view of the needle of FIG. **1** taken along lines **2**—**2**.

FIG. **3** is a diagram of a portion of the needle illustrating an alternative preferred embodiment of the flow-chamber defining means.

FIG. **4** is a sectional view of the needle of FIG. **3** taken along lines **4**—**4**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. **1** and **2**, an X-ray apparatus containing a preferred embodiment of the interstitial X-ray needle of the present invention includes the needle **10** and a diode housing **12** for receiving the needle. The diode housing **12** includes a vacuum chamber **14** containing an electron emitter **16** and a control grid **18**. The electron emitter **16** is connected to a high voltage cable **20**, which is connected to a high voltage source (not shown). Insulators **22** are stacked between the electron emitter **16** and the diode housing **12**.

The needle **10** includes an elongated X-ray tube **24**, a converter element **26**, a solenoid coil **28**, and elongated outer casing **30** and a pipe **32**.

The X-ray tube **24** has an open end **34** which opens into the vacuum chamber **14** to couple the X-ray tube **24** to the electron emitter **16**.

The converter element **26** is disposed at a tip **36** of the other end of the tube **24** for converting electrons emitted from the electron emitter **16** into X-rays.

The solenoid coil **28** is wound around the tube **24** for providing a magnetic field that confines the emitted electrons within a narrow beam. The electron beam can be confined to a diameter of approximately 0.4 millimeter when the solenoid coil **28** provides a magnetic field of approximately 20 gauss. For a coil **28** having 13 ohms resistance and wound at 20 turns-per-centimeter, the required current in the winding is only 0.8 amperes and the required voltage across the coil is only 0.1 volts, whereby the power expended in the winding is only 0.08 watts.

The outer casing **30** encloses the tube **24** and coil **28**.

The pipe **32** is coaxially disposed between the outer casing **30** and the tube **24** for defining an inner annular flow channel **38** between the tip **36** of the tube **24** and a coolant inlet **40** in the casing **30**, and an outer annular flow chamber **42** between the tip **36** of the tube **24** and a coolant outlet **44** in the casing **30**.

For a needle **10** of the embodiment of FIGS. **1** and **2**, including a ten-centimeter long tube **24** having an inside diameter of 0.64 millimeter and an outside diameter of 0.81 millimeter wound with a single layer of #33 magnetic wire of 0.22 millimeter diameter at approximately 40 turns-per-centimeter, an outer casing **30** having an outside diameter of 2.8 millimeters and an inside diameter of 2.16 millimeters, and a pipe of 1.52 millimeters inside diameter and 1.83 millimeters outside diameter, a water flow rate of 87 milliliters-per-minute is obtained at an inlet pressure of 20 pounds-per-square-inch, whereby for a 20 watt heat rate at the tip **36** of the needle **10**, the water temperature rise over ten minutes is less than 5 degrees Celsius.

Referring to FIGS. **3** and **4**, in an alternative preferred embodiment, the needle **10**A includes an elongated X-ray tube **24**, a converter element **26**, a solenoid coil **28**, an elongated outer casing **30** and a plurality of pipes **46**. The pipes **46** are disposed between the casing **30** and the tube **24**. Each pipe defines an input flow chamber **48** between the tip **36** of the tube **24** and at least one inlet opening (not shown) in the casing **30**; and the space **50** between the tube **24** and the casing **30** not occupied by the pipes **46** defines an output flow chamber between the tip **36** of the tube **24** and an outlet opening (not shown) in the casing **30**.

For a needle **10**A of the embodiment of FIGS. **3** and **4**, including a ten-centimeter long tube **24** having an inside diameter of 0.64 millimeter and an outside diameter of 0.81 millimeter wound with a single layer of #33 magnetic wire of 0.22 millimeter diameter at approximately 40 turns-per-centimeter, an outer casing **30** having an outside-diameter of 2.8 millimeters and an inside diameter of 2.16 millimeters, and four pipes each having outlet orifice jets **52** of 0.15 millimeter directed at the tip **36** of the needle **10**A, a water flow rate of 10 milliliters-per-minute is obtained at an inlet pressure of 50 pounds-per-square-inch, whereby for a 20 watt heat rate at the tip **36** of the needle **10**A, the water temperature rise over ten minutes is approximately 28 degrees Celsius.

The tube **24**, casing **30** and pipe **32** or pipes **46** typically are rigid and straight, but also may be made of flexibe materials or may be curved rather than straight so as to enable insertion of the tip of the needle to portions of the body that are not directly accessible through soft tissue.

The X-ray apparatus described herein may be operated at a relatively low power level of 14 watts when delivering a radiation dose of approximately 100 Gray over ten minutes duration to tissue located one centimeter from the converter element **26** by operating with an electron emitter voltage of 200 kilovolts and a beam current of 0.07 milliamperes.

In addition to providing benefits incident to its size, the miniature interstitial X-ray needle of the present invention also may generate controlled hyperthermic temperatures for application to the treated tumor, which combined with the radiation treatment may provide a synergistic healing effect.

What is claimed is:

1. An interstitial X-ray needle, comprising

an elongated X-ray tube coupled to an electron emitter at one end of the tube, with a converter element being disposed at a tip of the other end of the tube for converting emitted electrons into X-rays:

a solenoid coil wound around the tube for providing a magnetic field that confines the emitted electrons within a narrow beam;

an elongated outer casing enclosing the tube and coil; and

means within the casing defining coolant flow chambers for directing coolant to and from the tip of the tube.

2. A needle according to claim **1**, wherein the flow-chamber-defining means comprises a pipe coaxially disposed between the casing and the tube for defining an inner annular flow chamber between the tip of the tube and a first opening in the casing and an outer annular flow chamber between the tip of the tube and a second opening in the casing.

3. A needle according to claim **1**, wherein the flow-chamber-defining means comprises a plurality of pipes disposed between the casing and the tube wherein each pipe defines an input flow chamber between the tip of the tube and at least one inlet opening in the casing and wherein the space between the tube and the casing not occupied by the pipes defines an output flow chamber between the tip of the tube and an outlet opening in the casing.

4. An interstitial X-ray needle, comprising

an elongated X-ray tube coupled to an electron emitter at one end of the tube, with a converter element being disposed at a tip of the other end of the tube for converting emitted electrons into X-rays;

a solenoid coil wound around the tube for providing a magnetic field that confines the emitted electronss within a narrow beam;

an elongated outer casing enclosing the tube and coil; wherein a portion of the casing extending at least approximately five centimeters from the tip of the tube has a maximum outside diameter of approximately two millimeters; and

means within the casing defining coolant flow chambers for directing coolant to an from the tip of the tube.

5. A needle according to claim **4**, wherein the flow-chamber-defining means comprises a pipe coaxially disposed between the casing and the tube for defining an inner flow chamber between the tip of the tube and a first opening in the casing and an outer annular flow chamber between the tip of the tube and a second opening in the casing.

6. A needle according to claim **4**, wherein the flow-chamber-defining means comprises a plurality of pipes disposed between the casing and the tube wherein each pipe defines an input flow chamber between the tip of the tube and at least one inlet opening in the casing and wherein the space between the tube and the casing not occupied by the pipes defines an output flow chamber between the tip of the tube and an outlet opening in the casing.

7. An interstitial X-ray needle, including,

first means for producing a plurality of electrons,

second means for including a tube for directing the electrons from the first means in a particular path,

third means disposed at the end of the particular path for converting the electrons to X-rays,

fourth means including a casing disposed in enveloping relationship to the tube for cooling the third means, and

fifth means disposed on the tube for confining the electrons to a beam during the direction of the electrons in the particular path to the third means.

8. An interstitial X-ray needle as set forth in claim 7 wherein

the third means receives the electrons after the passage of the electrons in the particular path through the tube and converts the electrons to X-rays.

9. An interstitial X-ray needle as set forth in claim 8 wherein

the tube has a tip and the third means includes a converter element disposed at the tip of the tube to receive the electrons after the passage of the electrons through the first tube and to convert the received electrons to X-rays.

10. An interstitial X-ray needle as set forth in claim 9 wherein

the tube and the casing are disposed in a coaxial relationship.

11. An interstitial X-ray needle as set forth in claim 7 wherein *the casing envelopes the second means, the third means and the fifth means and provides for a flow of a cooling fluid past the third means to cool the third means.*

12. An interstitial X-ray needle as set forth in claim 7, including,

there being a space between the tube and the casing,

there being at least one hollow pipe in the space between the tube and the casing, the hollow pipe being included in the fourth means for introducing fluid to the third means to cool the third means,

the hollow pipe only partially occupying the space between the tube and the casing, and

the remaining space between the tube and the casing providing for the flow of the cooling fluid from the third means.

13. An interstitial X-ray tube as set forth in claim 7 wherein

the fifth means is operative to confine the electron beam to a diameter no greater than approximately four tenths of a millimeter (0.4 mm).

14. An interstitial X-ray tube as set forth in claim 7 wherein

the casing has a width no greater than approximately 2.8 millimeters.

15. An interstitial X-ray needle, including:

first means for producing a plurality of electrons,

a tube disposed to receive the electrons from the first means and to pass the electrons through the tube,

second means disposed at the end of the tube for receiving the electrons after the passage of the electrons through the tube and for converting the received electrons to X-rays,

a casing disposed in enveloping relationship to the tube, there being a space between the tube and that casing,

third means for passing a cooling fluid through the space between the tube and the casing and past the second means to cool the second means, and

fourth means disposed in the space between the tube and the casing for confining the electrons to a beam during the passage of the electrons through the first tube to the second means.

16. An interstitial X-ray needle as set forth in claim 15, including,

a housing enveloping the tube and the casing and the first means.

17. An interstitial X-ray tube as set forth in claim 16 wherein the casing has a diameter no greater than approximately 2.8 millimeters.

18. An interstitial X-ray tube as set forth in claim 15 wherein

the tube has a tip and the second means includes a converter element disposed at the tip of the tube to receive the electrons after the passage of the electrons through the tube and to convert the received electrons to X-rays.

19. An interstitial X-ray tube as set forth in claim 15, including,

at least one hollow pipe partially occupying the space between the tube and the casing to provide for the passage of the cooling fluid through the hollow pipe to the second means and to provide for the passage of the cooling fluid from the second means through the remaining space between the tube and the casing,

the hollow pipe being included in the third means.

20. An interstitial X-ray tube as set forth in claim 15 wherein

the fourth means is operative to confine the electron beam to a diameter no greater than approximately four tenths of a millimeter (0.4 mm).

21. An interstitial X-ray needle, including:

first means for producing a plurality of electrons,

a tube disposed to receive the electrons from the first means and to pass the electrons through the tube,

second means for receiving the electrons after the passage of the electrons through the tube and for converting the electrons to X-rays,

a casing disposed in spaced relationship to the tube,

third means for passing a cooling fluid through the space between the tube and the casing and past the second means to cool the second means, and

magnetic means disposed on the tube in the space between the tube and the casing for confining the electrons to a beam during the flow of the electrons through the tube.

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