

[54] CRYOGENIC TOOL

[75] Inventor: **Algerd Basiulis**, Redondo Beach, Calif.

[73] Assignee: **Hughes Aircraft Company**, Culver City, Calif.

[22] Filed: **June 8, 1972**

[21] Appl. No.: **260,873**

[52] U.S. Cl. 128/303.1, 128/400, 119/1, 62/293

[51] Int. Cl. A61b 17/36, F25d 3/00, A01k 11/00

[58] Field of Search.....128/400, 401, 303.1; 119/1; 62/293

[56] References Cited

UNITED STATES PATENTS

3,190,081 6/1965 Pytryga 62/293

3,421,508	1/1969	Nestrock	128/303.1
3,434,477	3/1969	Thomas, Jr.	128/303.1
3,455,304	7/1969	Gans	128/303.1
3,485,060	12/1969	Ziegler	62/293
3,532,094	10/1970	Stahl	128/303.1
3,568,464	3/1971	Drayson	119/1 X
3,618,610	11/1971	Hannant	128/303.1

Primary Examiner—Aldrich F. Medbery

Attorney—W. H. MacAllister, Jr. and Allen A. Dicke, Jr.

[57]

ABSTRACT

The external surface of the working tip of the cryogenic tool is applicable to any point where cooling is desired, for example, affected tissue in cryosurgery. An inner surface of the tip is supplied with a cryogenic liquid thru a capillary active surface from a reservoir. The boiled off cryogen vapor exits from the cryogenic tool to atmosphere.

26 Claims, 13 Drawing Figures

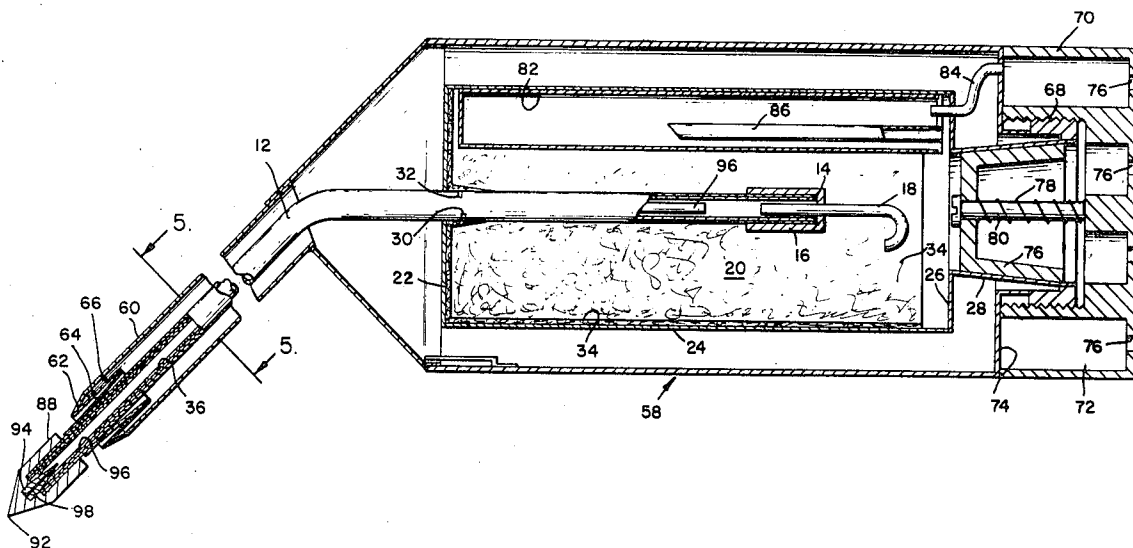


Fig. 1.

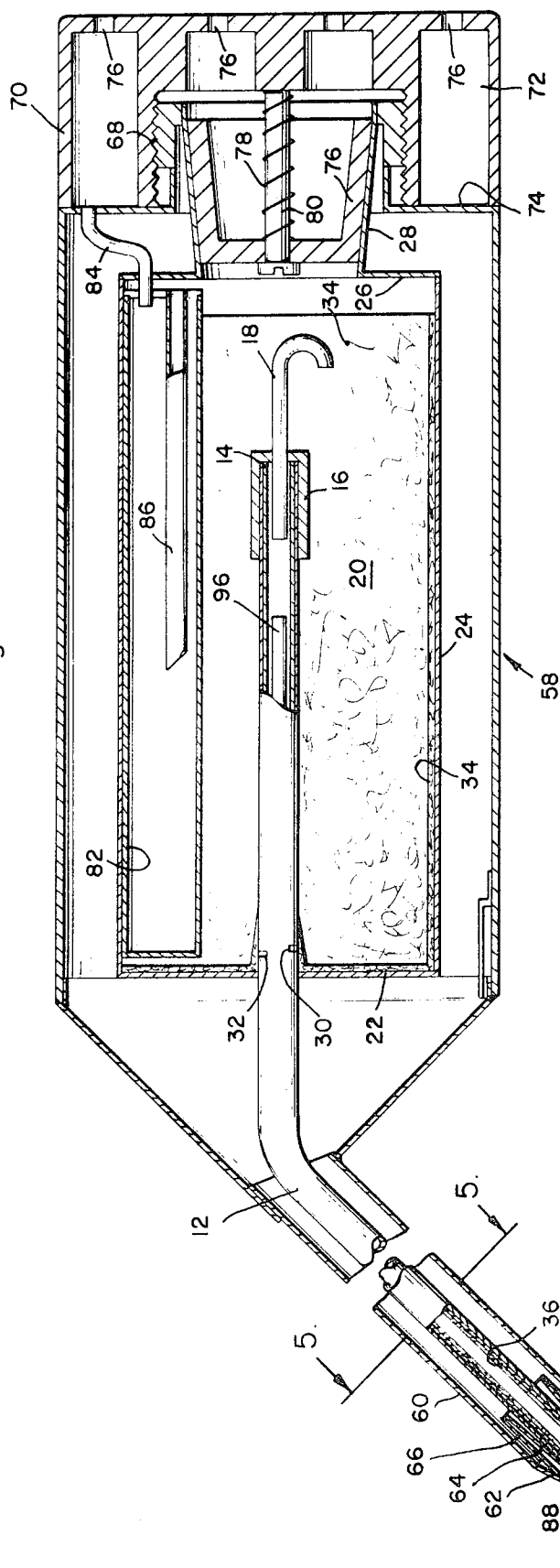


Fig. 2.

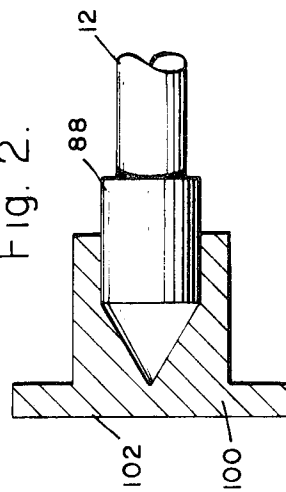


Fig. 3.

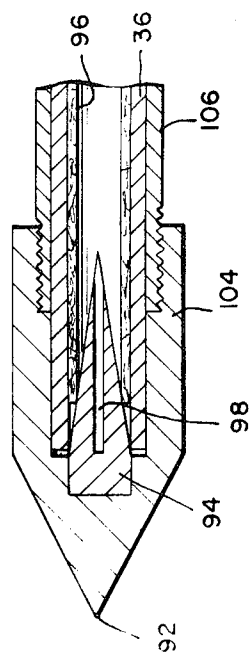


Fig. 11.

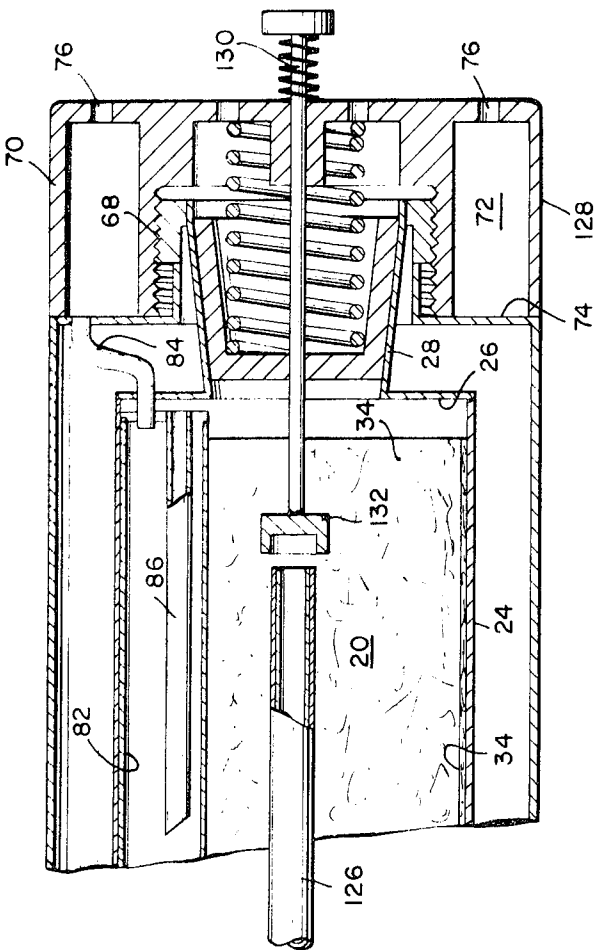


Fig. 2A.

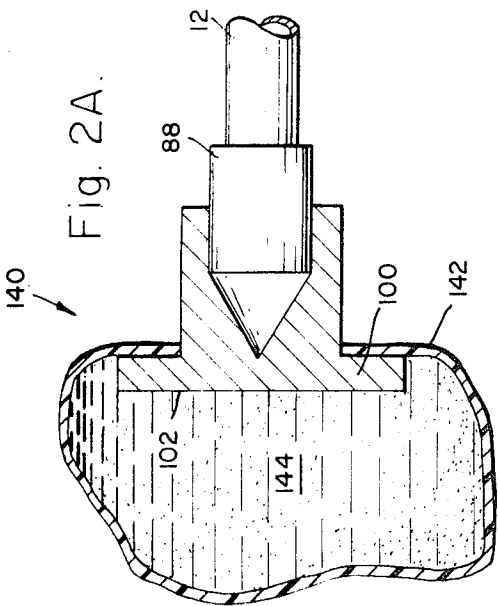
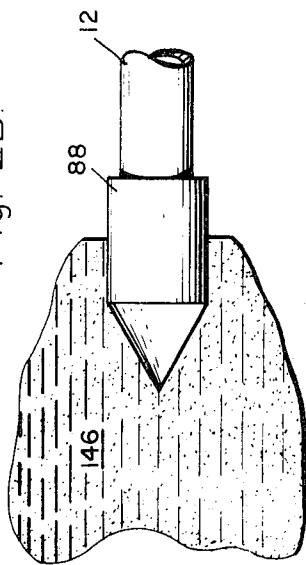
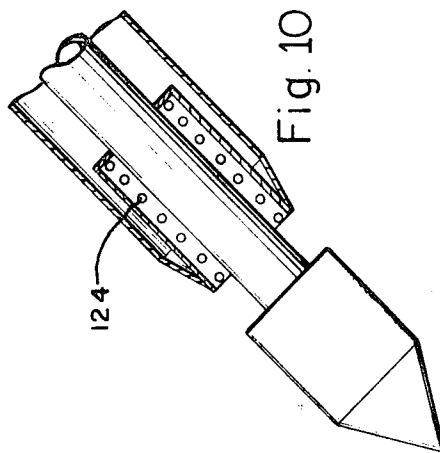
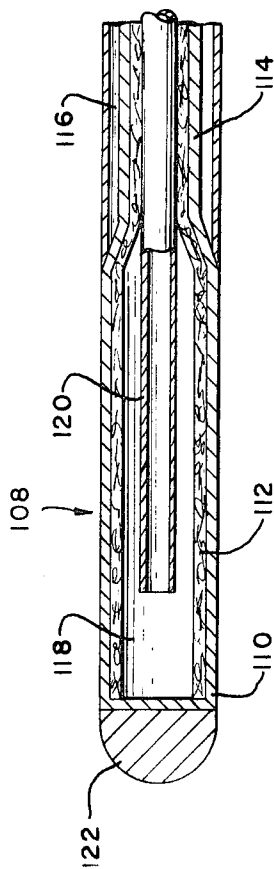
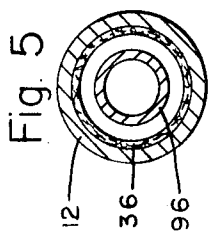
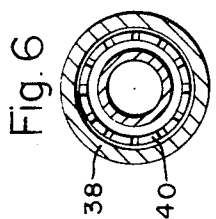
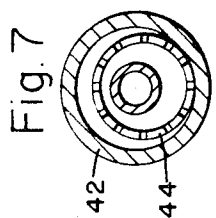
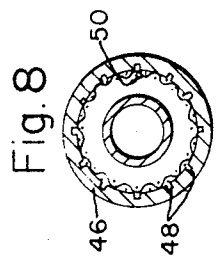
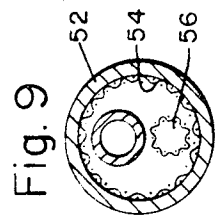


Fig. 2B.





CRYOGENIC TOOL

BACKGROUND OF THE INVENTION

This invention is directed to a cryogenic tool particularly useful for cryosurgical techniques.

The structure presently commercially available for employment in cryosurgical techniques comprises a large liquid cryogen reservoir, in which liquid nitrogen is the preferred material. The liquid cryogen is delivered under pressure thru a flexible hose to a hand piece which has a cooled surface thereon at which film boiling takes place. Flow is controlled by a valve at the reservoir, so that liquid cryogen delivery for cooling the cooled surface has a built-in delay, corresponding to the length of the structure between the valve and the cooled surface. Thus, the prior art structures are slow in cooling. Furthermore, liquid cryogen is delivered for heat exchange, so that boiling from a pool of liquid cryogen causes the cooling of the "surface". The bulk quantities of the cryogen inhibit heat transfer because of the built up insulative layer of vapor on the heat transfer surface. The hose interconnecting the reservoir with the hand piece is necessarily cumbersome, because of the needed insulation to prevent excess cryogenic liquid boil-off.

Accordingly, the commercially available structures are slow in response from the time the liquid cryogen valve is opened to the time the cooled surface is at operating temperature. Furthermore, it is difficult to maneuver the end piece with its cooled surface because of the needed complexity of the cryogen liquid delivery hose. The hose is limited in length and therefore the radius of operation from the liquid cryogen reservoir is restricted. In view of the heat transfer condition at the cooled tip, film boiling, the cooled tip does not substantially reach the liquid cryogen boiling temperature. The disadvantages can be overcome by providing cryogenic tool which is sufficiently light and small to be hand-held and employs liquid cryogen delivery and heat transfer characteristics which permit the working tip to quickly reach a temperature approaching that of the evaporating liquid cryogen.

SUMMARY OF THE INVENTION

To aid in the understanding of this invention, it can be stated in an essentially summary form that it is directed to a cryogenic tool which employs capillary delivery of liquid cryogen from the interior of a reservoir to a surface in such quantities as to permit film boiling on the surface.

Accordingly, it is an object of this invention to provide a cryogenic tool which has a working tip which is supplied with cryogenic liquid from a reservoir thru a capillary delivery means so that the supply is controlled to prevent flooding so that evaporative cooling occurs for cooling the working tip. It is another object to provide a cryogenic tool which is hand-held, with a probe carrying a working tip on the outer end thereof, and a reservoir on the upper end. It is a further object to provide a reservoir containing a capillary active surface which feeds liquid cryogen to the probe in various reservoir positions. It is another object to provide a reservoir for liquid which has capillary means on the interior surface thereof so that the capillary means can feed liquid cryogen thru the probe into the heat exchange relationship with the working tip.

Other objects and advantages of this invention will become apparent from the study of the following portions of this specification, the claims, and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal section thru the cryogenic tool of this invention.

FIG. 2 shows an alternative replaceable tip positioned on the permanent tip of the cryogenic tool of FIG. 1.

FIG. 2A shows another type of thermal applicator tip.

FIG. 2B shows a further type of thermal applicator tip.

FIG. 3 is a longitudinal section of the probe portion of another species of the cryogenic tool showing a different tip attachment means.

FIG. 4 is a longitudinal section thru the end of the probe of another species of the cryogenic tool, showing a prostatic probe termination.

FIG. 5 is a transverse section thru a species of the probe wherein a fibrous mat is used for capillary flow.

FIG. 6 is a section through another species of the probe, wherein concentric tubes are used for capillary flow.

FIG. 7 is a section through a further species of the probe wherein a crescent annulus is used for capillary flow.

FIG. 8 is a section through another species of the probe wherein longitudinal channel corrugations covered with screen are used for capillary flow.

FIG. 9 is a section through a further species of the probe wherein a stainless steel fibrous wicking with an artery is used for capillary flow.

FIG. 10 is a longitudinal section through another species tip wherein an electrical heater is used to stop cryogen liquid flow to the working tip.

FIG. 11 is a longitudinal section through another species of reservoir, wherein liquid cryogen flow is controlled by a valve cap on the vent tube.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a generally central longitudinal section through preferred embodiment of the cryogenic tool 10 of this invention. The cryogenic tool 10 has a tubular duct 12 which serves as the main cryogen conduit in the cryogenic tool. The upper open end 14 of the duct 12 may carry a cap 16 from which a vapor vent tube 18 extends. The upper open end 14 is positioned within a reservoir 20. The reservoir has a lower wall 22 which is secured to tube 12. It has an outer wall 24, which is conveniently cylindrical. Furthermore, reservoir 20 has an upper wall 26 to which is secured filler funnel 28.

Liquid feed openings 30 and 32 are orifices or perforations in tubular duct 12 within reservoir 20, at the lower end adjacent lower wall 22. The inside of outer wall 24, and the interior of lower wall 22 are lined with capillary active material 34. This material extends up over the exterior of tubular duct 12 to cover feed openings 30 and 32 and extend through them to touch the lining 36 in duct 38. The capillary active lining 34 can be of suitable nature for the liquid that it is intended to feed. In the specific example, liquid nitrogen or other liquid cryogen is the liquid which is to be fed, and therefore a lining of stainless steel fibers deposited to

form random mat and sintered together is a suitable working material. As referred to in this specification, stainless steel means those grades of stainless steel which are not subject to embrittlement at cryogenic temperature. Rather than a sintered mat of fibers, the capillary material 34 can be in the form of one or more layers of woven metal screen, with the screen preferably being of stainless steel material.

The interior of tubular duct 12 is also provided with a lining 36 of capillary active material. FIG. 5 is a section through preferred embodiment of the capillary active material, and again, it is a random deposited mass or mat of stainless steel fibers which are sintered together to form a felt-like mass. It lines the entire interior tubular duct 12.

FIG. 6 illustrates a tubular duct 38, which corresponds to tubular duct 12, which contains a perforated inner tube 40 which is concentrically arranged within duct 38, with a spacing of such size as to produce the capillary liquid feed force for feeding the liquid cryogen through tubular duct 38. Perforations are required to permit the vapor of boiled-off liquid cryogen to pass into the central space. The liquid cryogen passes through concentric capillary space while the vapor passes through tube 40 and out vapor vent tube 18.

FIG. 7 is a tubular duct 42, which corresponds to tubular duct 12, and which has perforated inner tube 44 therein. Inner tube 44 is positioned against one wall of the duct to define a crescent space therebetween. The crescent space provides the capillary spacing which provides capillary feed force for the liquid cryogen. Tube 40 is perforated to permit the return of cryogen vapor.

FIG. 8 is another embodiment of a suitable tubular duct for the feeding of liquid cryogen, and the return of boiled-off cryogen vapor. Tubular duct 46, which corresponds to duct 12, has longitudinal grooved channels or interior corrugations 48 therein. These channels extend from one end to the other of the duct, and are of such size as to provide capillary force. While open channels are considered to be satisfactory, a screen or mask of sintered metallic fibers 50 is preferably to enhance liquid feed by capillarity. Another configuration of a suitable tubular duct is illustrated in FIG. 9, with tubular duct 52, which is equivalent to duct 12. Duct 52 contains capillary feed means 54, which may be a felt-like sintered mass of metallic fibers, or may be a woven screen of one or several layers. In this case, the capillary feed means 54 is provided with an artery 56, which reduces the pressure drop in the capillary feed. Any one of these tubular ducts can be employed to supply liquid cryogen from the reservoir 20 to the closed lower end thereof. The capillary lining 34 is in communication through liquid feed openings 30 and 32 with the capillary lining 36 interiorly of the tubular duct. Therefore, liquid from anywhere in reservoir 20 is fed to the interior of the duct. The upper end of the duct is closed by cap 16 to prevent liquid escape from the upper end thereof back to the reservoir. However, vapor vent tube 18 permits the escape of vapor from the interior channel of the tubular duct back into the reservoir.

The exterior of reservoir 20 and exterior of most of the length of tubular duct 12 are prevented from substantial heat leak by dewar envelope 58. The envelope extends around and is spaced from the reservoir, and extends around and is spaced from tube 12. As seen in

FIG. 1, the lower end of tube 12 is enclosed by the tube 60, which forms the portion of dewar envelope 58 extending down around tube 12. The lower end of tubes 12 and 60 are joined by conical transition pieces 62 and 64 and tube 66, which prevent the coolest part of the transition between duct 12 and tube 60 from being engageable with hand, so that the entire tube 60 can be comfortably and manually engaged.

The upper end of dewar envelope 58 joins with filler funnel 28 and has threads 68 on the exterior thereof for the removable attachment of cap 70. Cap 70 engages upon threads 68 and has an annular recess 72 which is open facing the upper shoulder 74 of dewar envelope 58. Annular recess 72 is vented through vent holes 76.

Cap 70 carries truncated closure plug 76. Spring 78 urges plug 76 to the left, while cap screw 80 prevents plug 76 from moving totally free of the cap. Thus, plug 76 can rotate with respect to the cap, and is spring thrust into filler funnel 28 to close the filler funnel. The main body of cap 70, plug 76 and cap screw 80 are preferably made of low thermal conductive material which is capable of withstanding cryogenic temperature. Polymer composition materials which fall into this category include nylon and teflon.

Liquid cryogen trap 82 is in the form of a closed end tube secured on the inside of reservoir 20, preferably against the outer wall thereof. It is connected by means of vapor outlet tube 84 through upper shoulder 74 into annular recess 72 in the cap. Inlet from reservoir 20 to trap 82 is by means of vapor inlet tube 86 which is open from the upper end of trap 82 to approximately the center of the trap. Thus, cryogen vapor coming from the upper end of tubular duct 12 passes out through vapor vent tube 18, through trap 82 and is vented to atmosphere vent through cap 70. Trap 82 is configured so that if the cryogenic tool 10 is turned with cap 70 down, liquid cryogen will not be immediately expelled.

Liquid cryogen in reservoir 20 is fed from the reservoir into tubular duct 12 through the continuous active capillary lining material to the tip end of the duct. This feed is gravity independent. At the tip end, tip 88 is secured to the duct 12, and the lining 36 extends into recess 90 in the tip so that it is in direct engagement with the material of the tip. The material of tip 88 is preferably of high thermal conductivity, and it is not embrittled at cryogenic temperatures. Copper is suitable material. Liquid cryogen is thus delivered by capillary action to the base of recess 90 directly beneath the working end 92 of the tip. The working end 92 is illustrated in FIGS. 1 and 2 as a pointed end. With a flat bottom in the recess 90, evaporative cooling will occur without flooding, which would cause film boiling, because of the controlled flow of liquid cryogen through capillary lining. However, in order to enhance heat transfer, the area over which evaporative cooling is accomplished is enlarged by providing inwardly directed point 94, of high thermal conductivity material which is in thermally conductive relationship with the main body 88 of the tip. Thus, liquid cryogen is delivered to the surface of the inwardly directed point and evaporates therefrom. The resulting cryogen vapor is delivered up the hollow interior of tubular duct 12.

It is convenient to confine returning cryogen by installing a vapor duct 96 interiorly of capillary lining, with a space between the capillary lining and vapor duct, as illustrated in FIGS. 1 and 5. The vapor duct 96 terminates adjacent vapor vent tube 18 so that the

cryogenic vapor both within and without vapor duct 96 can exit from vapor vent tube 18. In order to prevent vapor duct 19 from sealing on the inwardly directed point 94, the point 94 carries vapor channels 98 cut into the sides thereof.

FIG. 2 illustrates the installation of an interchangeable and replaceable tip 100 directly over the exterior of the permanently installed tip 88. Replaceable tip 100 is of high thermal conductivity, preferably of a sterilizable material and has a suitable working face 102. As an example, FIG. 2 shows a large area face such as is suitable for dermatological techniques.

FIG. 2A shows a tip 140 which is formed as a flexible plastic bag 142 containing a freezable solution 144. The solution can be water or jelly, containing metal particles to enhance thermal conductivity. The bag is shaped to the proper surface contour, then frozen and used as a cryogenic applicator tip.

FIG. 2B is similar and shows a tip 146 which is a similar solution molded to shape, then frozen and used for cryogenic surface application. Both of these tips can be used with tip 88, as shown.

FIG. 3 illustrates a tip 104 replaceably screw threaded onto the lower end of tubular duct 106. The tip and duct are respectively the same as tip 88 and duct 12, except for the screw thread interengagement therebetween which permits the removal and replacement of tip 104. The interengaging structure between the tip and duct are such that the tip is guided onto the lining of active capillary material so that the material is in direct contact with the interior of replaceable tip 104.

FIG. 4 illustrates a prostatic tip 108 which is formed as a tube 110 having a lining of capillary active material 112. Tubular duct 114 is the same as duct 12, and is supplied with a liquid cryogen from a reservoir. Duct 114 is surrounded by insulation layer, such as an evacuated dewar, or a vacuum space filled with multiple foil super insulation, or the like. Tube 110 is formed as an expanded part of the duct 114, and there is continuity between the capillary lining material of the duct and the capillary lining 112. Thus, liquid cryogen is supplied to the inside wall of tube 110, and evaporates therefrom to fill the interior space 118 of tip 108 with boiled-off cryogen vapor. Vapor tube 120, preferably perforated in the interior space 118, extends up the tubular duct to discharge the vapor to the reservoir as previously described. The lower end of prostatic tip 108 has an insulated tip 122 which can be supplied with heat from any convenient source, such as from the outer tube forming the exterior of insulation 116. By this means, there is evaporative cooling of the interior surface of tube 110 to permit it to be used in prostatic cryosurgery.

In cryosurgery it is desirable to effectively cease refrigeration when desired to stop the cryogenic cooling action at the point of application. This can be accomplished either by stopping the inflow of liquid cryogen or by boiling off liquid cryogen before it reaches the tip. FIG. 10 illustrates an electric heater coil 124 on a tubular duct similar to duct 12, between the insulator housing on the duct and the tip secured on the end thereof. Upon the application of electric current to the heater, electrically derived heat is directly applied to the duct, so that the liquid cryogen is evaporated in that portion of capillary active material directly therein. None of it reaches the tip. By this means, refrigeration

ceases at the tip. The electric heater coil 124 can be controlled at any convenient point.

FIG. 11 illustrates a duct 126, the same as duct 12, at its upper end within reservoir 20. Cap 128 is similar to cap 70 as to its structure and positioning. It carries a slide rod 130 therethrough which carries a cap 132 on its inner end. By manually depressing the slide rod through cap 128, cap 132 engages over the outer end of duct 126, thereby closing off the vapor exit therefrom. Vapor pressure builds up to block inflow of liquid cryogen into the duct 126, through its liquid feed openings corresponding to feed openings 30 and 32. With no more liquid feed, evaporation at the tip ceases, to stop refrigeration.

The particular cryogen used is dependent upon several factors. Liquid nitrogen is inert and is conveniently and inexpensively available. It evaporates at a sufficiently low temperature to provide for proper cryosurgery. The evaporative cooling technique achieved by feeding the liquid cryogen by capillary action to the evaporative surface permits the inner surface of the tip upon which the evaporation is taking place to reach temperatures within about 1° C of the evaporating cryogen temperature. Thus, low temperatures are achieved. Liquid argon is also a suitable liquid cryogen, but is expensive. Liquid oxygen is less expensive than liquid argon, but has the disadvantage of combustion danger. Freon type compounds are relatively expensive, and if economic loss was not objectable, and the temperature provided by one of the freons was required, it could be employed.

This invention having been described in its preferred embodiment, and several additional embodiments also described, it is clear that this invention is susceptible to numerous modifications and embodiments within the ability of those skilled in the art. Thus, the scope of the invention is defined by the scope of the following claims.

What is claimed is:

1. A cryogenic tool comprising:

a reservoir for the storage of cryogenic liquid which boils at sub-atmospheric temperatures, a lining of capillary active material within said reservoir so that when some of said reservoir lining is in contact with cryogenic liquid, the entire lining is wet with cryogenic liquid;

a tubular duct extending from said reservoir, said duct having a capillary active surface therein, and having a reservoir end and a working end, said reservoir end of said tubular duct being open to the atmosphere for discharge of cryogen vapor therefrom to the atmosphere, a liquid cryogen opening between said reservoir and the interior of said duct intermediate its end so that said lining of capillary active material in said reservoir is in contact with the active capillary surface in said duct and can feed liquid cryogen through said opening into the interior of said duct to feed liquid cryogen to the active capillary surface in said duct so that the active capillary surface within said duct can feed liquid cryogen toward the working end of said duct;

a working tip on the end of said duct and an evaporative surface within said duct in thermal communication with said working tip, said evaporative surface being fed with liquid cryogen from the capillary active surface in said duct so that liquid cryogen is fed to the evaporative surface whereby evap-

orative cooling takes place and the cryogen vapor returns through said duct to the atmosphere.

2. The cryogenic tool of claim 1 wherein a supplementary working tip is positioned over said working tip, in thermal communication therewith, so that the supplementary working tip can be removed and interchanged.

3. The cryogenic tool of claim 1 wherein said working tip is removable from the working end of said duct so that said working tip can be removed and replaced.

4. The cryogenic tool of claim 3 wherein said working tip is engaged upon said duct by screw thread engagement therebetween.

5. The cryogenic tool of claim 1 wherein said evaporative surface in thermal communication with said working tip is substantially conical surface with its point directed away from said working tip, toward said duct.

6. The cryogenic tool of claim 5 wherein said capillary active interior surface of said duct is in physical contact with said evaporative surface.

7. The cryogenic tool of claim 6 wherein a vapor tube extends from adjacent said working tip through said duct into said reservoir, for the return of cryogen vapor to said reservoir.

8. The cryogenic tool of claim 7 wherein said evaporative cone has a longitudinal groove in the surface thereof, and said vapor tube is engaged over said evaporative cone, said groove preventing sealing of said tube on said cone.

9. The cryogenic tool of claim 1 wherein said tip is an elongated tube of larger diameter than said duct, said tube tip having a substantial portion of its surface cooled by evaporation of cryogen therein.

10. The cryogenic tool of claim 9 wherein the capillary active material in said duct is in contact with capillary active material lining said tube tip to deliver liquid cryogen for evaporation within said tube tip.

11. The cryogenic tool of claim 10 wherein said tube tip has an insulated nose thereon.

12. The cryogenic tool of claim 1 wherein said capillary active material within said duct is a mass of stainless steel fibers sintered together to form a felt-like mass.

13. The cryogenic tool of claim 1 wherein said capillary active lining comprises a concentric annulus formed by a perforated tube substantially concentrically positioned within said duct so that there is a capillary space therebetween.

14. The cryogenic tool of claim 1 wherein said capillary active surface within said duct comprises a crescent annulus formed between a perforated tube non-concentrically positioned within said duct and the interior of said duct.

15. The cryogenic tool of claim 1 wherein said capillary active surface comprises a plurality of channels longitudinally directed on the interior of said duct.

16. The cryogenic tool of claim 15 wherein a capillary active layer is positioned within said duct interiorly of said channels.

17. The cryogenic tool of claim 1 wherein said capillary active lining of said duct includes an artery in contact with the capillary active surface.

18. The cryogenic tool of claim 1 wherein a heater is positioned around said duct between said reservoir and said working tip so that when heat is applied to said duct by said heater, liquid cryogen flowing from said reservoir toward the working end of said duct is evaporated before it reaches the working end of said duct to stop cooling at the working end of said duct.

19. The cryogenic tool of claim 1 wherein a removable cap is positionable over the end of said duct within said reservoir, so that when said removable cap is away from said end of said duct, vapor can escape from said duct into said reservoir and liquid cryogen can flow through said feed opening toward said working end of said duct, and when said cap is positioned over the end of said duct within said reservoir, vapor pressure within said duct prevents liquid cryogen from passing from said reservoir through said feed opening to said duct, so that refrigeration at the working end of said duct ceases.

20. The cryogenic tool of claim 1 wherein a trap vessel is positioned to receive vapor from said reservoir and discharge it toward the atmosphere, said trap vessel inhibiting the flow of liquid cryogen to the atmosphere.

21. The cryogenic tool of claim 20 wherein said trap vessel comprises a tube positioned within said reservoir, a vapor inlet to said trap extending substantially half way into said trap tube, an outlet tube from said trap reservoir extending from said trap tube out of said reservoir.

22. The cryogenic tool of claim 1 wherein said reservoir has a substantially truncated conical fill opening therein, a cap detachably secured to said reservoir, a plug movably mounted with respect to said cap engaging in said fill opening, removably close said fill opening.

23. The cryogenic tool of claim 22 wherein said plug is resiliently urged with respect to said cap into closure engagement within said fill opening.

24. The cryogenic tool of claim 1 wherein a mass which is fluid at room temperature and is solid at cryogenic temperature is positioned on said working tip.

25. The cryogenic tool of claim 24 wherein said mass is enclosed in a polymer composition material bag.

26. The cryogenic tool of claim 25 wherein a metallic boss engages on said working tip and said bag engages around a portion of said bag so that said boss is in thermal communication with said mass and with said working tip.

* * * * *