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Altseimer et al.

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[54] **APPARATUS AND METHOD FOR LARGE TUNNEL EXCAVATION IN HARD ROCK**

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[52] **U.S. Cl.** **299/14;** 175/11; 299/33

[51] **Int. Cl.** **E21d 9/00**

[58] **Field of Search** .... 299/33, 14; 175/11, 16; 61/45 R

[56] **References Cited**

UNITED STATES PATENTS

3,334,945	8/1967	Bartlett	299/33
3,396,806	8/1968	Benson	175/11
3,693,731	9/1972	Armstrong et al.	175/11

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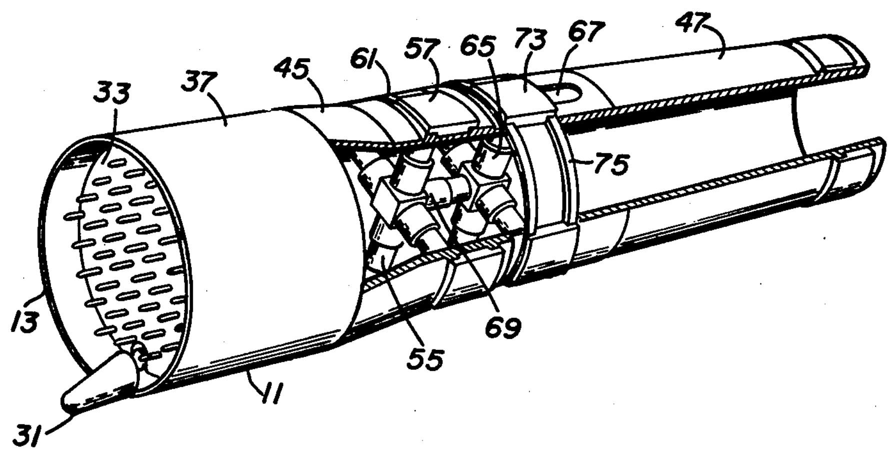
Assistant Examiner—William F. Pate, III
Attorney, Agent, or Firm—Dean E. Carlson; Henry Heyman

[57] **ABSTRACT**

A tunneling machine for producing large tunnels in rock by progressive detachment of the tunnel core by thermal melting a boundary kerf into the tunnel face and simultaneously forming an initial tunnel wall support by deflecting the molten materials against the tunnel walls to provide, when solidified, a continuous liner; and fragmenting the tunnel core circumscribed by the kerf by thermal stress fracturing and in which the heat required for such operations is supplied by a compact nuclear reactor.

3 Claims, 5 Drawing Figures



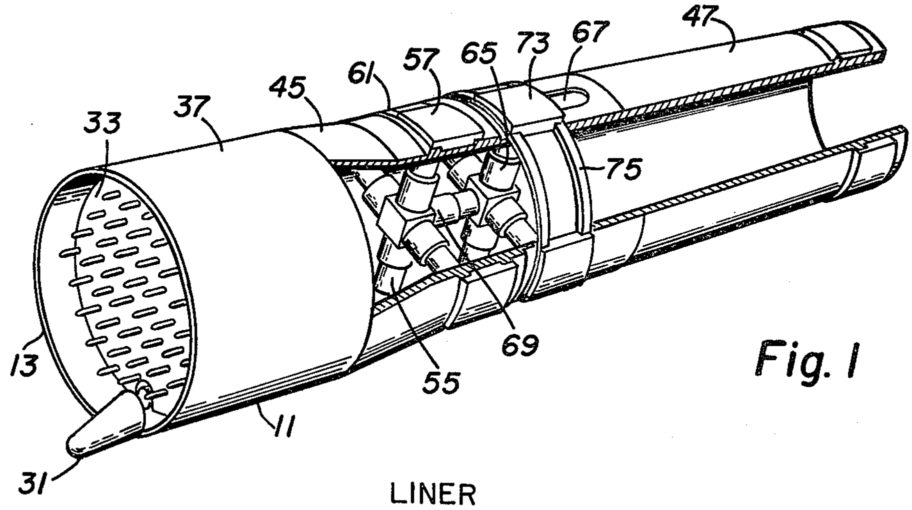


Fig. 1

Fig. 4

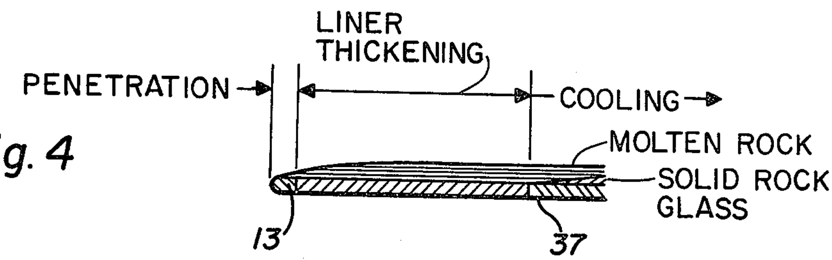
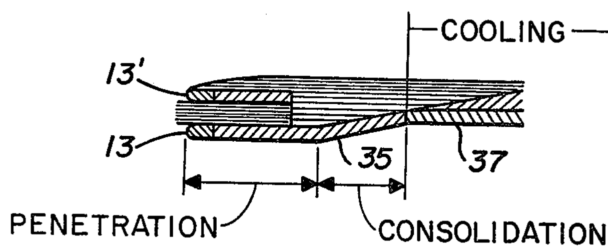


Fig. 3



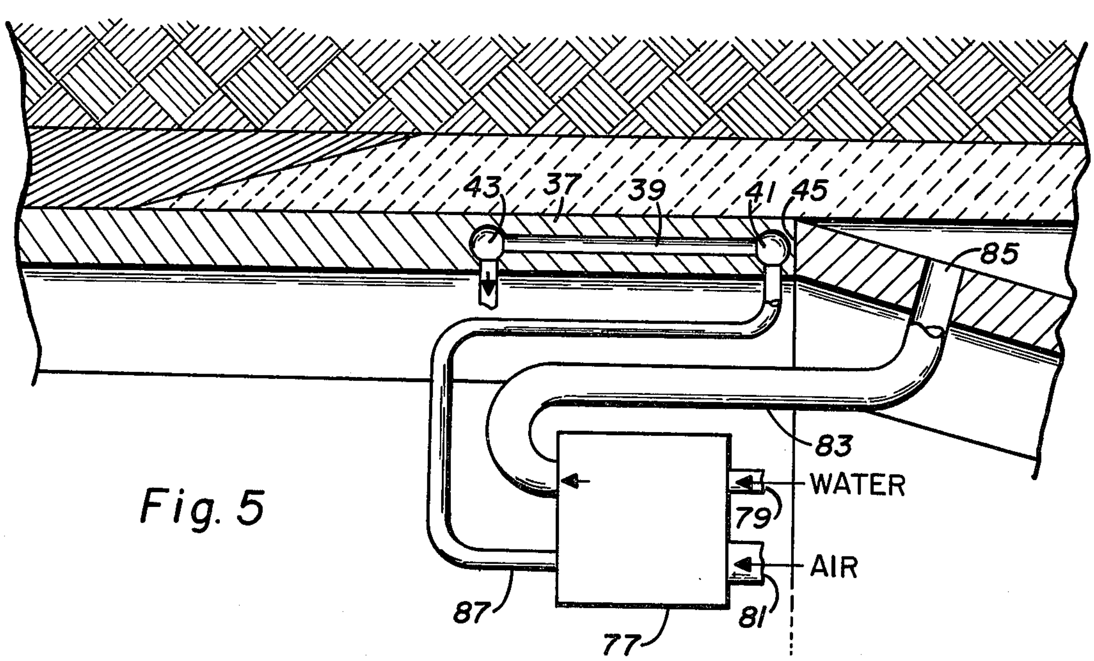


Fig. 5

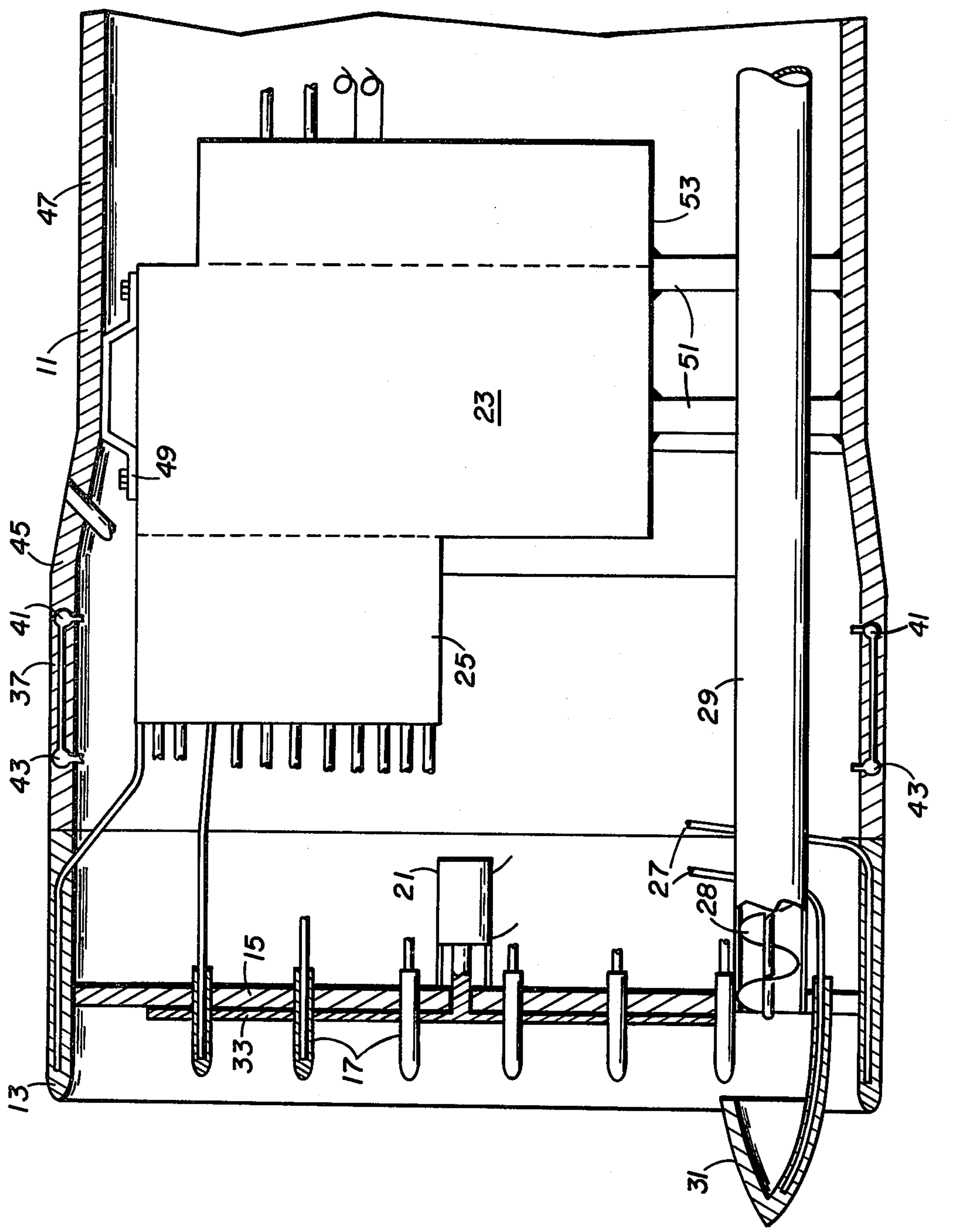


Fig. 2

APPARATUS AND METHOD FOR LARGE TUNNEL EXCAVATION IN HARD ROCK

BACKGROUND OF THE INVENTION

The need for fast economical methods and machines for producing large tunnels and other excavations has considerably increased in importance with the increase in population, industrial congestion and environmental pollution. The production of large tunnels such as are needed, for example, for subway systems in and between cities presents formidable tasks in excavating and removing the tunnel core and supporting the tunnel walls, particularly the roof, against collapse. Although progress has been made in increasing the rate of tunnel excavation by the use of large mechanical tunnel boring machines such as the "MOLE," many problems are encountered in the use of such machines due to the extreme variations in earth through which the tunnel penetrates. For example, in abrasive hard rock the advance rate of the mechanical machine is slow because the cutting rate is low, and progress is impeded by the frequent need to replace the cutters, particularly the gage cutters. The down-time of the machine and the cost of the cutters significantly increases the cost of the project. In addition, the inaccessibility of the tunnel wall immediately adjacent the tunnel face and alongside the tunneling machine prevents the installation of tunnel support where it is indispensable to prevent possible cave-in and possible burial of the machine and crews. When very hard rock is encountered, the MOLEs are discarded in favor of drill and blast techniques. In this case the mechanical forces and vibration transmitted into the surrounding earth by the excavation process results in loosening and breaking loose excess tunnel wall material with attendant increased expense in removal and rehabilitating the tunnel wall as well as the dangerous reduction in the integrity of the tunnel walls, particularly the tunnel roof.

It is a primary objective of the present invention to provide a tunneling machine which is capable of economical excavating in rock and which simultaneously with detachment of the tunnel core at the tunnel face installs an initial supporting liner on the tunnel walls.

Another object is to provide a machine and method capable of an economical excavation rate in hard abrasive rock through the use of a peripheral kerf melter to define the tunnel bore thereby eliminating the short duty cycle and expensive mechanical "gage" cutters.

Still another object is to eliminate the short-life mechanical face cutters by incorporating in the face of the present invention device, arrays of small diameter melting penetrators to detach and fracture the tunnel-face rock by thermal stress fracturing.

Another object of the present invention is to provide a machine and method for tunneling which eliminates the excessive dust, ground shock and fumes incident to the use of the mechanical tunneling machine or drilling and explosive practices by using the melting process.

The above and other objectives and advantages afforded by the present invention will become apparent with reading the following specification taken with the drawings made a part of this specification.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a horizontal isometric view, partly in section, of a preferred embodiment of the invention.

FIG. 2 is a vertical cross-sectional diagrammatical view of the forward part of a tunneling machine in accordance with the present invention.

FIG. 3 is a vertical cross section of one form of kerf melting penetrator and melt deflector.

FIG. 4 is a vertical cross-sectional view of an alternative form of melt penetrator and melt deflector.

FIG. 5 is a diametric cross section of the hull showing cooling details.

DESCRIPTION OF THE PRIOR ART

The utilization of the basic concept of melting earth materials to dig a hole or small tunnel is taught in the prior art. For example, U.S. Pat. No. 3,357,505 issued to Armstrong et al. in 1967, disclosed an electrically heated rock drill. U.S. Pat. No. 3,396,806 issued August 1968 to Benson disclosed a unitized machine for thermal earth drilling utilizing a nuclear reactor for supplying the melting energy requirements. This patent also suggests that the hole could be melted to a larger diameter than required for the finished hole so that melt material would provide the hole casing.

U.S. Pat. No. 3,693,731 issued Sept. 1972 to Armstrong et al. also discloses a nuclear reactor powered earth boring machine and melt material is used as structural hole lining material. However, this patent, like others that disclose machines for drilling tunnels by melting the earth, is a solid front machine which creates an amount of melt equal to the tunnel cross section.

The machine of the present invention is particularly adapted to excavate large tunnels, that is, having a cross-sectional measurement in the range of 2 to 12 metres and larger. The melting of the entire cross section of such large tunnels requires large heat flow rates and creates excessive costs of the heat generating and supply system. The most economical method is for the machine to thermally melt just enough material to detach the core, and to provide adequate tunnel lining material. The core materials can be machanically fractured for disposal. However, in hard rock the disintegration of the core material is best done by heated thermal stress fracturing penetrators.

SUMMARY OF THE INVENTION

Briefly stated, the tunneling machine of the present invention is a self-propelling vehicle carrying on its front face a cylindrical segmented heated ring for melting a kerf in rock. Rearward of the heated ring, hereafter termed "kerf melting penetrator," is a heat dissipating annular cylinder for solidifying the melt into an initial tunnel wall supporting liner. On the front end of the vehicle, set back from the front end of the kerf melting penetrator, is a front end closure plate in which are supported in uniformly spaced arrays forward projecting heated rods for fracturing the core rock by thermal stress. These heated rods, hereinafter termed "thermal stress fracturing penetrators" are heated to a temperature above the melting temperature of the rock in order to provide penetration of the rock. Also, heat is transferred from the penetrators into the solid rock to thermally expand and stress the surface rock which separates or spalls from deeper rock because of shear and tensile stress failures. The heat supply demand for the kerf melting penetrator and the thermal stress fracturing penetrators is in the megawatts range and is supplied by a compact nuclear reactor.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. **1** and **2** of the drawing, the tunneling machine of the present invention includes a structural shell or hull **11** in and on which the machine parts are assembled. Peripheral segmented kerf melting penetrator **13** is mounted on the front end of the machine. The peripheral rock melting penetrator is of a shape to melt a kerf in the rock. The kerf outlines the cross-sectional shape and is either configured as shown in FIG. **4** or is provided with an outwardly flaring skirt shown in FIG. **3** to trowel outwardly the melt to form initial glass liner. The kerf penetrator may be a single annular shaped segmented elongated band such as shown in cross section in FIG. **4** but can also be of the dual type shown in cross section in FIG. **3.** The dual type kerf penetrator comprises a pair of thermal rock melting bands supported in spaced telescoped relationship. The melting function of spacially separated plates is enhanced as a result of the concentrated hot region generated therebetween. For competent rock strata requiring a minimal tunnel support liner the single band type of FIG. **4** is preferable.

A front end closure face plate **15** is attached to the front end of the structural shell within the circumferential boundary of rock penetrator **13** and is set back a fraction of a metre from the leading edge of the kerf melting penetrator.

Rock fracturing penetrators **17** are supported on face plate **15.** Penetrators **17** transmit high temperature to localized areas of the rock face of the tunnel. The coefficient of expansion of rock is such that the localized heated portions spall or break loose from the core by failure in shear and tension.

The thermal stress fracturing penetrators are set back with their penetrating ends in a cross-sectional plane rearward of the plane of the front end of the peripheral penetrators **13.** The spall loosened by the thermal stress fracturing penetrators falls to the lower portion of the machine face and is transported rearwardly of the tunneling machine by any state-of-the-art device such as auger **28** and auger tube **29.** In order to provide adequate clearance for the rock debris to fall to the mouth of the auger, a rock melting nose cone **31** is supported in front of the auger opening. In the event that large fragments of rock become detached from the rock face and become suspended in the arrays of fracturing penetrators, a clearing plate **33** is slidably supported on face plate **15** and is reciprocated as necessary by hydraulic cylinder **21** to clear the fracturing penetrators. This is one way to provide clearance. Another arrangement would provide for retraction of the fracturing penetrators into face **15.** Each penetrator would be made to slide axially to prevent excessive axial loading on any individual penetrator.

The heat source for the penetrators is nuclear reactor **23** as shown in FIG. **2.** The nuclear reactor is of the compact type such as developed for space propulsion. One form of suitable reactor is shown in U.S. Pat. No. 3,693,731. As shown in the referenced patent, the heat energy generated in the reactor is transferred to the rock melting and fracturing penetrators by a liquid metal heat exchanger **25** and heat pipes **27.**

The thermal power requirements for any desired size nuclear system tunneling machine are determined in accordance with well known heat transfer and nuclear

reactor design data. The melting temperature of basalt is about 1420°K and of tuff, it is about 1470°K. The ambient temperature of the rock is assumed to be about 290°K. To assure fluidity of the melt necessary to form the tunnel liner, the rock is heated to an average melt temperature of 1570°K. The glass liner thickness needed to provide safe interim support depends on the integrity of the earth in which the tunnel is being constructed. Considerations of liner thickness may include such variables as overburden pressure, type of ground, water flow, geologic consistency and tendency to swell. Due to these imponderables, tunnel designers have used empirical rules which have proved to be safe and practical. According to one such rule, the permanent concrete lining should have a thickness equal to approximately 8 percent of tunnel diameter. From a comparison of glass or solid rock lava strength in compression to that of concrete, it is deduced that interim adequate tunnel support is afforded by a glass liner thickness equal to 4 percent of tunnel diameter in unfavorable ground and 2 percent of tunnel diameter in rock of favorable quality. Typical values of the heat of fusion in joules per kilogram of rock is 418×10^3 and the specific heat is 1000 joules per kilogram-kelvin. From this data and allowing about 40 percent loss of heat, not available for rock melting, and selecting an advance boring rate of about 1.5 metre per hour, calculations show that a nuclear reactor power output capability of 25 MW is more than adequate for any earth material to be encountered for a tunnel of 7.3 metre diameter. The energy requirement for other size tunnels can be readily extrapolated.

FIG. **5** shows a fragmentary cross section of liner forming band **37.** Band **37** is provided with water conducting bores **39** which in turn are connected to water inlet manifold **41** and water outlet port **43.** In order to reduce thermal shock to the solidifying glass and make use of well known counterflow heat exchanger principles, the water circulation system is provided in the rearward portion of the liner forming band **37.** The molten rock is actually cooled to solidification in two ways. The heat is dissipated radially outward into the surrounding rock and by inward flow into the water cooling system in the liner forming band **37.** The structural characteristics of the liner are determined by the rate of solidification cooling from about 1570° to about 900°K. The solid glass is further cooled by forced air passing between the hull of the machine and the glass liner. In order to minimize low density utility air flow to the machine from the tunnel portal, water is used in heat exchanger **77** to cool both the tunnel air and the liner to acceptable life support level. Heat exchanger **77** is provided with cold water entering duct **79** to cool hot air which has circulated in contact with the solidified tunnel liner. The cooled air is pressure forced through duct **83** to port **85** through the hull wall. Exit water from the heat exchanger has been warmed somewhat by the tunnel air and is conducted by duct **87** to duct **39** in glass liner forming band **37.** The hot water circulated out of manifold **43** is transferred to appropriate heat extraction equipment for heat conservation purposes, e.g., the generation of auxiliary electric power. The hull is reduced in cross-sectional diameter rearwardly of the liner forming band **37** by means of relatively short rearwardly converging hull portion **45.** An elongated reduced cross-section hull portion **47** extends from the converging hull portion **45** to the rear end of the machine. The reduced cross section of the rearward portion of the hull admits of the external coolant air passage and steerability of the machine.

Nuclear reactor **23** is rigidly supported in the hull by affixing means such as brackets **49** and stanchions **51.** Liquid metal heat exchanger **25** thermally couples the nuclear reactor core to heat pipes **27.** The working ends of the heat pipes are closely coupled thermally to kerf penetrators **13** and fracturing penetrators **17.** The output control mechanism and fail-safe scram control for the reactor are housed in reactor control housing **53** and are similar to the mechanism shown in FIG. **4** of U.S. Pat. No. 3,693,731.

Crawler mechanism for propelling the tunneling machine is shown in FIG. **1** and is similar to the art MOLE-TYPE machines. Two sets of radially arranged hydraulic wall gripping ram arrays are used. The most forward set consists of **55** and **65.** The aft set is identical and not illustrated. Array **65** is slidably supported in hull **11** for axial reciprocation. Ram array **55** is provided with radially extensible liner gripping pads **57** and is supported in the hull with restraint against movement in the direction of elongation of the hull. Ram array **65** is provided with tunnel wall gripping pads **73.** Propulsion ram **69** is supported in an axial position in associated relation with ram arrays **55** and **65** to controllably reciprocate ram array **65** or, when **65** is stationary due to the gripping pad actions, the remaining machine is reciprocated. Operation of the propulsion and gripping mechanism either for forward or backward motion and for machine axial orientation is self obvious. Selective extension of the ram array pistons permits controllable guidance of the machine.

Utility services such as electricity, cooling water, and debris removal are connected to the tunneling machine from the earth's surface by conduits, cables, etc. through the rearward open hull of the machine.

Although the illustrative embodiment of the kerf melting and tunnel face removal machine has been described as cylindrical, there is an advantage inherent in this type of tunneling which is that it need not be cylindrical, but can be any shape most economical with respect to the desired cross section of the tunnel being bored.

From the foregoing it is seen that the present invention provides a tunneling or excavation machine that is capable of rapid penetration and disintegration of rock in the way of construction of any desired size. The combination of a nuclear reactor heat source, rock melting kerf penetrator, tunnel wall glass liner and thermal stress tunnel face rock fracturing penetrators provides an economically advantageous mechanism which is capable of achievement with various modifications of the component parts. Therefore, although an exemplary embodiment of the invention has been shown and described, it will be obvious that modifications and adaptations can be made without departing from the spirit of the invention.

What we claim is:

1. An earth drilling machine for excavating tunnels comprising an elongated hollow hull having a frontal portion with cross section equal to the cross section of the final tunnel prior to installation of final tunnel wall lining and a rearward portion reduced in cross-section relative to the frontal portion, a rock melting kerf penetrator affixed to and projecting longitudinally forward of the front end of the hull and having a peripheral shape similar in configuration with the front portion of the hull, a hull closure face plate affixed to the interior of the hull at the front end thereof, a plurality of rod-shaped thermal stress fracturing penetrators supported in said hull closure face plate with their direction of elongation parallel to the direction of elongation of the hull, and projecting forward of the front surface of the hull closure plate, rock debris removal means supported in a peripheral portion of the hull closure plate, a nuclear reactor supported within the hull of the machine, heat pipe heat conduction means coupled to the reactor core at one end and to the kerf melter and thermal stress fracturing penetrators at the other end; the rear end of the kerf melting penetrator skirt and the front end of the hull being smoothly joined together, thermal cooling means coupled to the front end of the hull whereby said front end of the hull supports the molten rock against the excavation walls and simultaneously solidifies said molten rock into a tunnel wall initial supporting liner.

2. The earth tunneling machine of claim **1** in which the cross-sectional shape of the hull is cylindrical, and said rock kerf melting penetrator segments form a cylindrical projection on said hull.

3. The earth tunneling machine of claim **2** in which the rock kerf melting penetrator is a single segmental cylindrical array heated to a temperature above about 1470°K whereby a narrow kerf is melted in the tunnel rock face and the thickness of the molten zone in the excavation wall increases, as the rock kerf melting penetrator is propelled forwardly, due to heating by the body of the penetrator.

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