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**Singh**

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(54) **SYSTEMS AND METHODS FOR STORING SPENT NUCLEAR FUEL**

3,745,707 A 7/1973 Herr  
3,755,079 A 8/1973 Wesinstein et al.  
3,765,549 A 10/1973 Jones

(Continued)

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FOREIGN PATENT DOCUMENTS

DE 28 21 780 A1 11/1979

(Continued)

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 301 days.

This patent is subject to a terminal disclaimer.

OTHER PUBLICATIONS

Zorpette, Glenn: "Cannet Heat", Nuclear Power, Special Report, in IEEE Spectrum, Nov. 2001, pp. 44-47.\*

(Continued)

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**Related U.S. Application Data**

(63) Continuation-in-part of application No. 10/803,620, filed on Mar. 18, 2004, now Pat. No. 7,068,748.

(51) **Int. Cl.**  
**G21C 19/00** (2006.01)

(52) **U.S. Cl.** ..... 376/272; 376/273; 376/274; 588/16; 250/506.1; 250/507.1

(58) **Field of Classification Search** ..... 376/272, 376/273; 250/507.1, 506.1

See application file for complete search history.

(56) **References Cited**

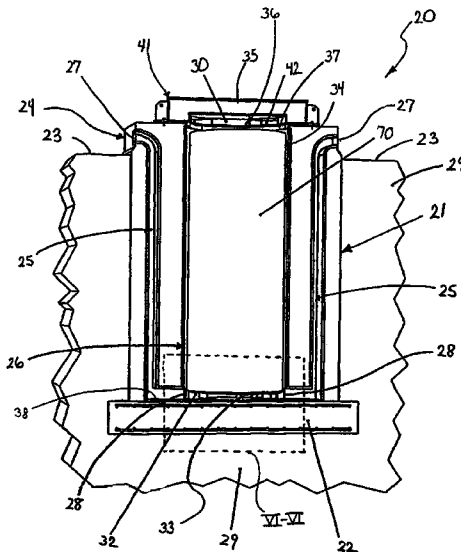
U.S. PATENT DOCUMENTS

3,111,078 A 11/1963 Breckenridge  
3,111,586 A 11/1963 Rogers  
3,629,062 A 12/1971 Muenchow  
3,739,451 A 6/1973 Jacobson

(57) **ABSTRACT**

Systems and methods for storing spent nuclear fuel below grade that afford adequate ventilation of the spent fuel storage cavity. In one aspect, the invention is a system comprising: a shell forming a cavity for receiving a canister of spent nuclear fuel, at least a portion of the shell positioned below grade; and at least one inlet ventilation duct extending from an above grade inlet to a below grade outlet at or near a bottom of the cavity; the inlet ventilation duct connected to the shell so that the cavity is hermetically sealed to ingress of below grade fluids. In another aspect, the invention is a method comprising: providing a below grade hole; providing a system comprising a shell forming a cavity for receiving a canister of spent nuclear fuel, at least a portion of the shell positioned below grade, and at least one inlet ventilation duct extending from an inlet to an outlet at or near a bottom of the cavity, the inlet ventilation duct connected to the shell; positioning the apparatus in the hole so that the inlet of the inlet ventilation duct is above grade and the outlet of the inlet ventilation duct into the cavity is below grade; filling the hole with engineered fill; and lowering a spent fuel canister into the cavity.

**21 Claims, 19 Drawing Sheets**



U.S. PATENT DOCUMENTS

3,800,973 A 4/1974 Weaver  
 3,836,267 A 9/1974 Schatz  
 3,910,006 A 10/1975 James  
 3,917,953 A 11/1975 Wodrich  
 3,935,062 A 1/1976 Keller et al.  
 3,945,509 A 3/1976 Weems  
 3,962,587 A 6/1976 Dufrane et al.  
 3,984,942 A 10/1976 Schroth  
 4,055,508 A 10/1977 Yoli et al.  
 4,078,968 A 3/1978 Golden et al.  
 4,158,599 A 6/1979 Andrews et al.  
 4,278,892 A 7/1981 Baatz et al.  
 4,288,698 A 9/1981 Baatz et al.  
 4,336,460 A 6/1982 Best et al.  
 4,355,000 A 10/1982 Lumelleau  
 4,356,146 A 10/1982 Knappe  
 4,366,095 A 12/1982 Takats et al.  
 4,394,022 A 7/1983 Gilmore  
 4,450,134 A 5/1984 Soot et al.  
 4,498,011 A 2/1985 Dyck et al.  
 4,525,324 A 6/1985 Spilker et al.  
 4,526,344 A 7/1985 Oswald et al.  
 4,527,066 A 7/1985 Dyck et al.  
 4,532,104 A 7/1985 Wearden et al.  
 4,532,428 A 7/1985 Dyck et al.  
 4,585,611 A 4/1986 Perl  
 4,634,875 A 1/1987 Kugeler et al.  
 4,635,477 A 1/1987 Simon  
 4,649,018 A 3/1987 Waltersdorf  
 4,663,533 A 5/1987 Kok et al.  
 4,666,659 A 5/1987 Lusk et al.  
 4,671,326 A 6/1987 Wilhelm  
 4,690,795 A 9/1987 Hardin et al.  
 4,764,333 A 8/1988 Minshall et al.  
 4,780,269 A 10/1988 Fischer et al.  
 4,800,062 A 1/1989 Craig et al.  
 4,834,916 A 5/1989 Chaudon et al.  
 4,847,009 A 7/1989 Madle et al.  
 4,851,183 A 7/1989 Hampel  
 4,971,752 A 11/1990 Parker  
 5,102,615 A 4/1992 Grande et al.  
 5,182,076 A 1/1993 de Seroux et al.  
 5,267,280 A 11/1993 Duquesne  
 5,297,917 A 3/1994 Freneix  
 5,307,388 A 4/1994 Inkester et al.  
 5,319,686 A 6/1994 Pizzano et al.  
 5,387,741 A 2/1995 Shuttle et al.  
 5,469,936 A 11/1995 Lauga et al.  
 5,513,231 A 4/1996 Jones et al.  
 5,513,232 A 4/1996 Jones et al.  
 5,546,436 A 8/1996 Jones et al.  
 5,564,498 A 10/1996 Bochart  
 5,633,904 A 5/1997 Gilligan et al.  
 5,646,971 A 7/1997 Howe  
 5,661,768 A 8/1997 Gilligan et al.  
 5,753,925 A 5/1998 Yamanaka et al.  
 5,771,265 A 6/1998 Montazer  
 5,852,643 A \* 12/1998 Copson ..... 376/287  
 5,862,195 A 1/1999 Peterson  
 5,898,747 A \* 4/1999 Singh ..... 376/272  
 5,926,602 A 7/1999 Okura  
 6,064,710 A 5/2000 Singh

6,064,711 A \* 5/2000 Copson ..... 376/287  
 6,074,771 A \* 6/2000 Cubukcu et al. .... 429/30  
 6,252,923 B1 6/2001 Iacovino et al.  
 6,489,623 B1 12/2002 Peters et al.  
 6,519,307 B1 2/2003 Singh et al.  
 6,519,308 B1 \* 2/2003 Boardman ..... 376/287  
 6,718,000 B2 4/2004 Singh et al.  
 6,793,450 B2 \* 9/2004 Singh et al. .... 414/146  
 7,068,748 B2 \* 6/2006 Singh ..... 376/272  
 2002/0003851 A1 1/2002 Pennington  
 2004/0067328 A1 \* 4/2004 Taniuchi et al. .... 428/34.4  
 2004/0109523 A1 \* 6/2004 Singh et al. .... 376/272

FOREIGN PATENT DOCUMENTS

DE 31 07 158 1/1983  
 DE 31 51 475 5/1983  
 DE 3144113 5/1983  
 DE 3404666 8/1985  
 DE 3515871 11/1986  
 DE 195 29 357 A1 8/1995  
 EP 0253730 1/1988  
 EP 1 061 011 A1 6/2000  
 EP 1312874 A1 \* 5/2003  
 FR 2434463 8/1979  
 GB 2 295 484 A 5/1996  
 GB 2 337 722 1/1999  
 GB 2337722 1/1999  
 JP 62-185199 8/1987  
 JP 2001056392 A \* 2/2001  
 JP 2001-264483 A \* 9/2001  
 RU 2168022 C 6/2000

OTHER PUBLICATIONS

International Atomic Energy Agency, "Multi-purpose container technologies for spent fuel management," Dec. 2000 (IAEA-TECDOC-1192) pp. 1-49.  
 U.S. Department of Energy, "Conceptual Design for a Waste-Management System that Uses Multipurpose Canisters," Jan. 1994 pp. 1-14.  
 Federal Register Environmental Documents, "Implementation Plan for the Environmental Impact Statement for a Multi-Purpose Canister System for Management of Civilian and Naval Spent Nuclear Fuel," Aug. 30, 1995 (vol. 60, No. 168) pp. 1-7.  
 National Conference of State Legislatures, "Developing a Multipurpose Canister System for Spent Nuclear Fuel," State Legislative Report, vol. 19, No. 4 by Sia Davis et al., Mar. 1, 1994, pp. 1-4.  
 Energy Storm Article, "Multi-purpose canister system evaluation: A systems engineering approach," Author unavailable, Sep. 1, 1994 pp. 1-2.  
 Science, Society, and America's Nuclear Waste—Teacher Guide, "The Role of the Multi-Purpose Canister in the Waste Management System," Author—unknown, Date—unknown, 5 pgs.  
 USEC Inc. Article, "NAC International: A Leader in Used Fuel Storage Technologies," copyright 2008, 2 pages.  
 Federal Register Notice, Dept. of Energy, "Record of Decision for a Multi-Purpose Canister or Comparable System," vol. 64, No. 85, May 4, 1999.

\* cited by examiner

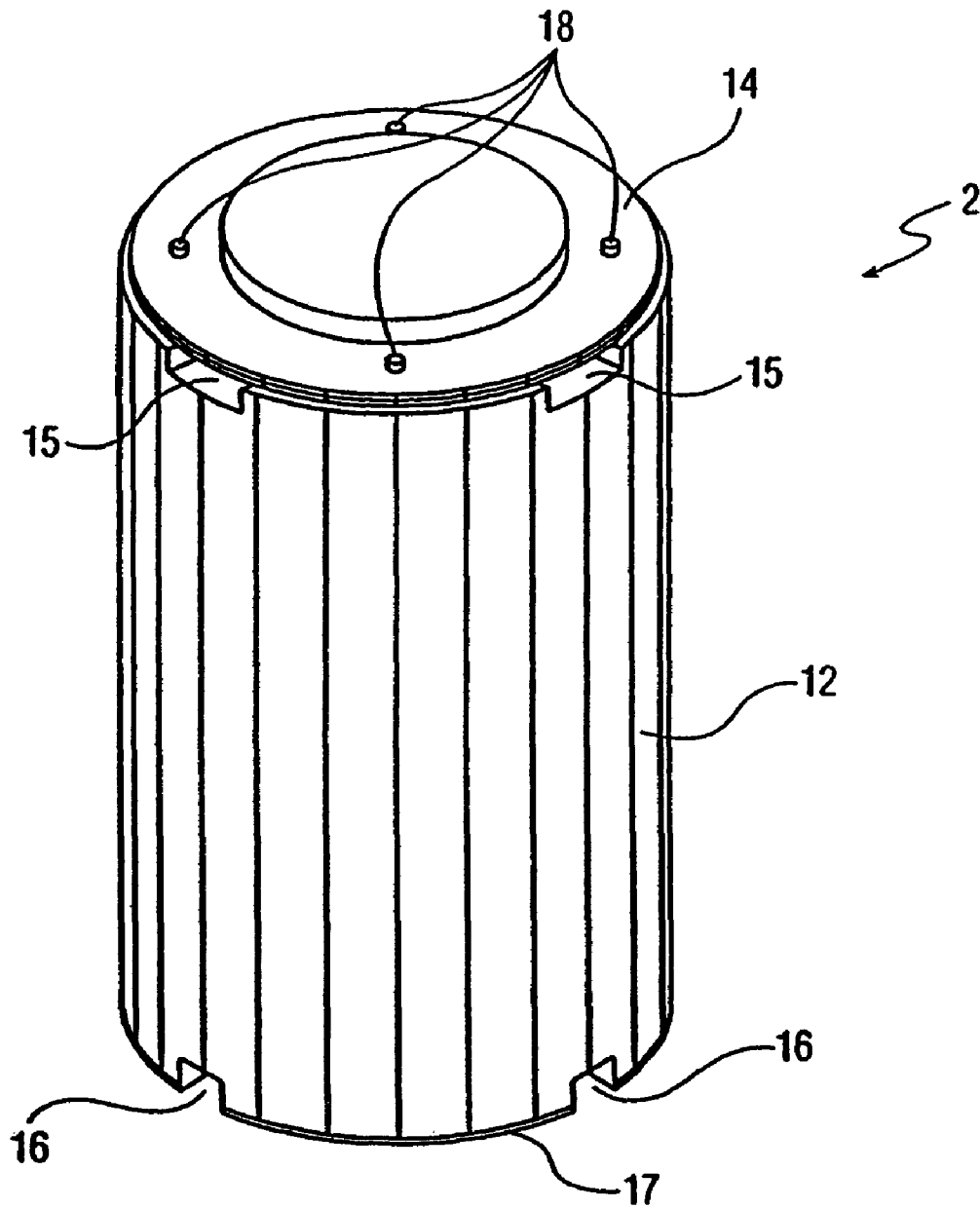


FIG. 1  
PRIOR ART

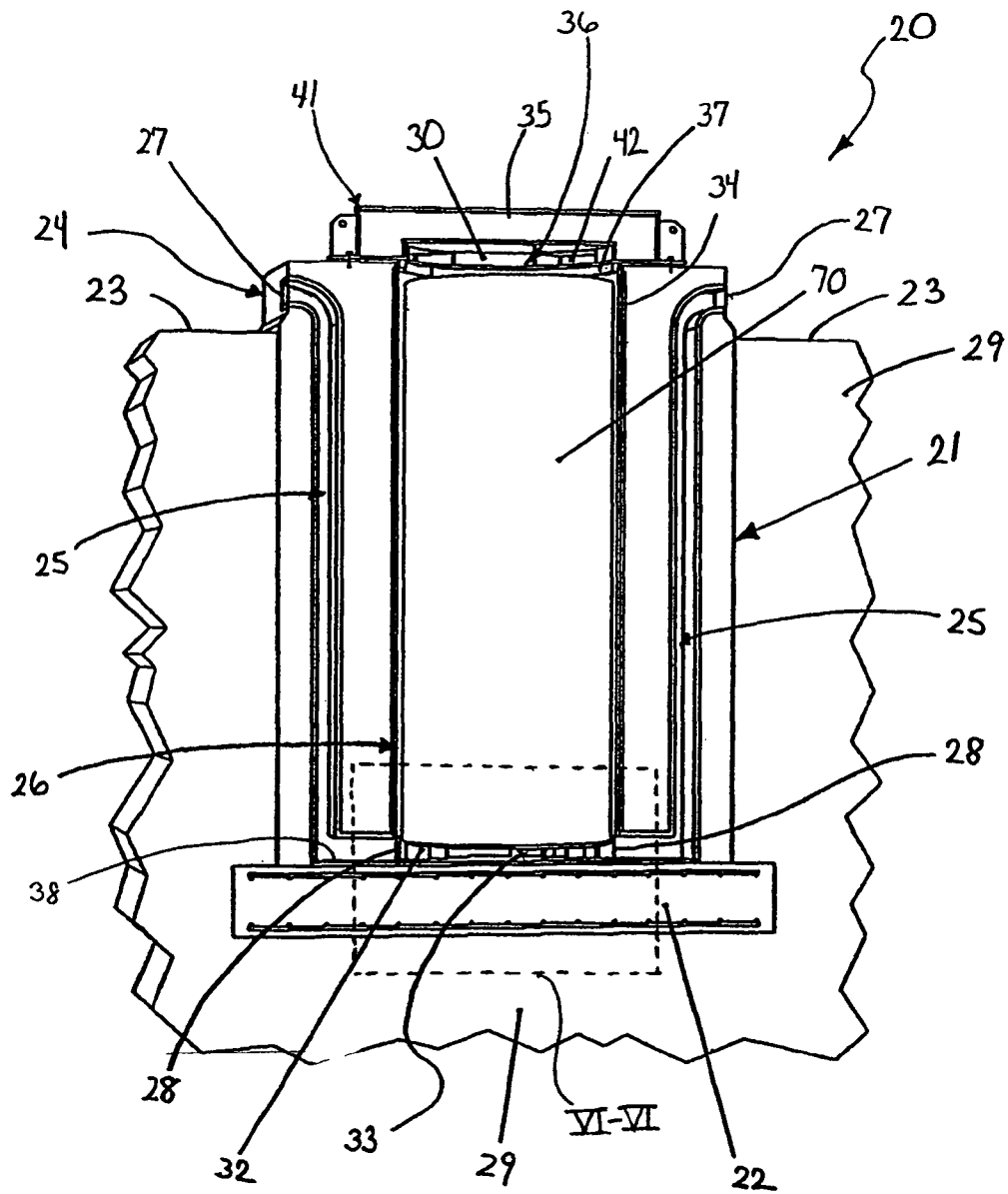


FIG. 2

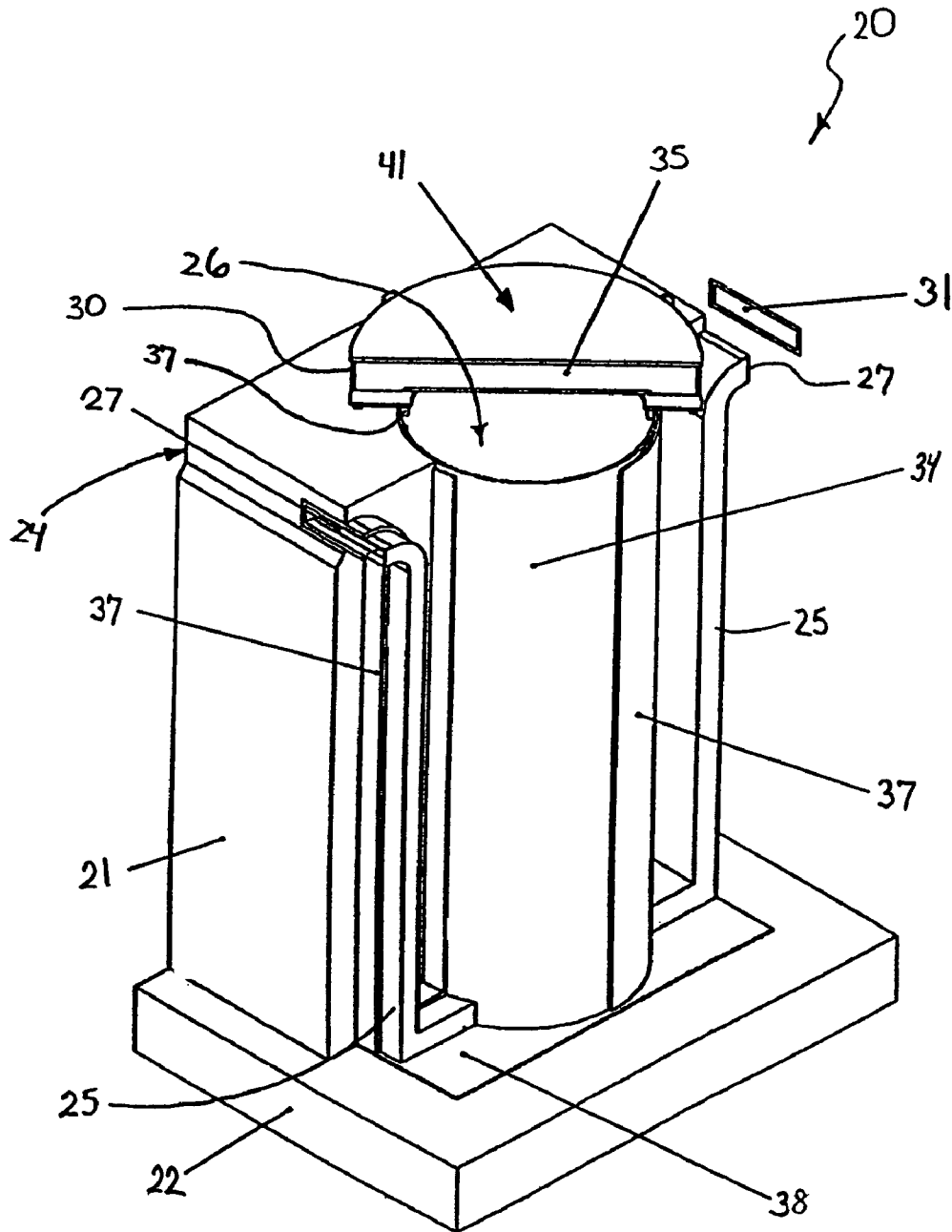


FIG. 3

FIG. 4

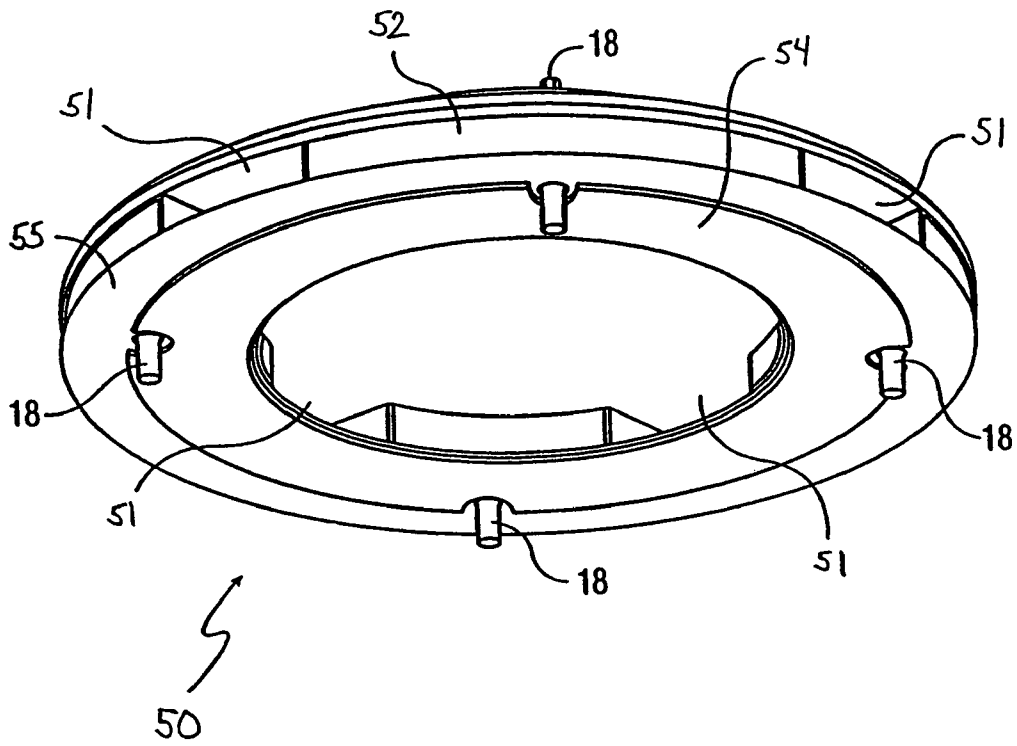
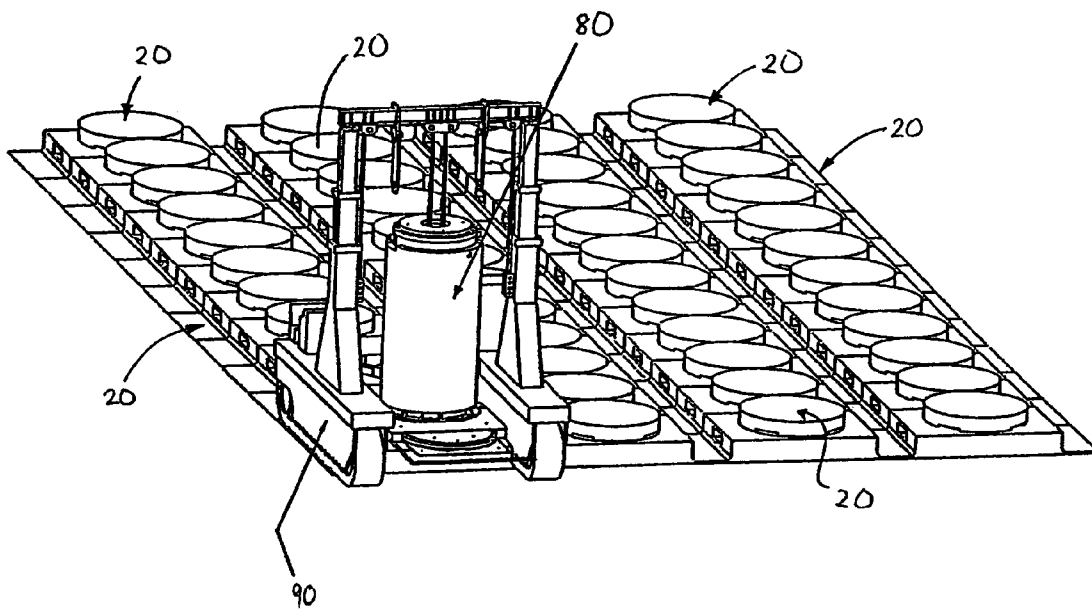


FIG. 5



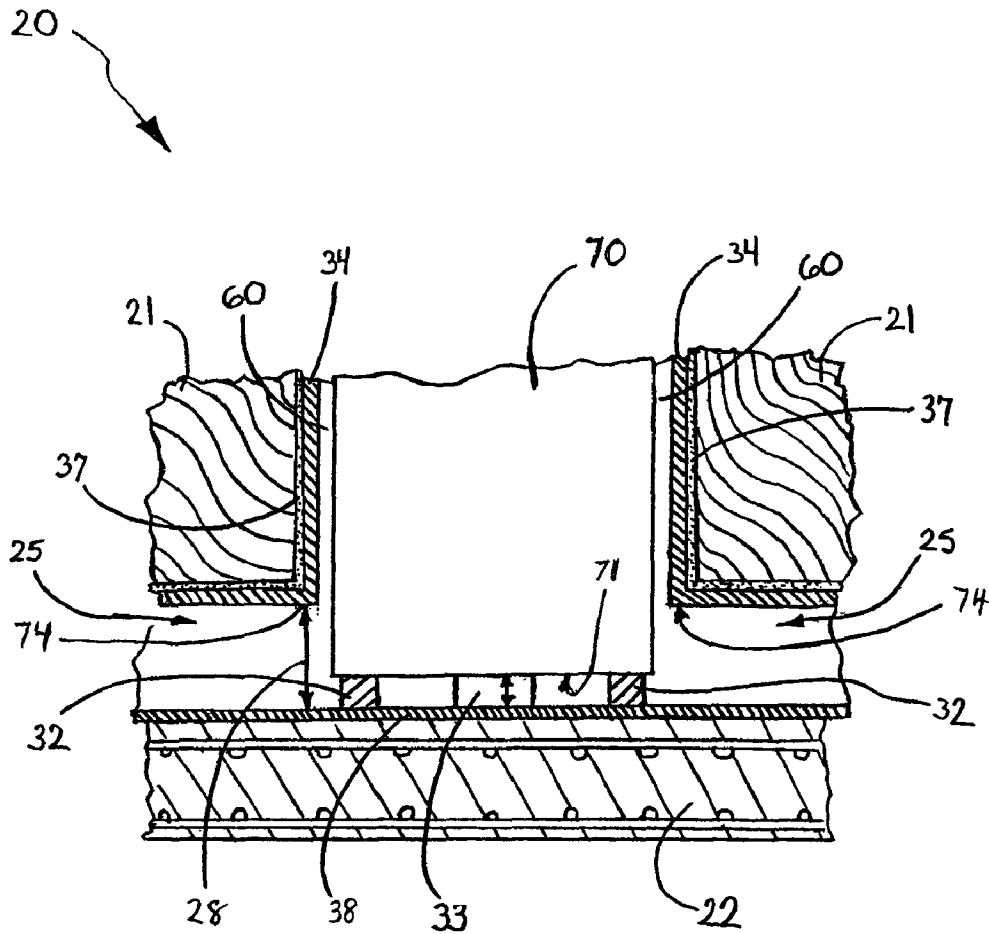


FIG. 6



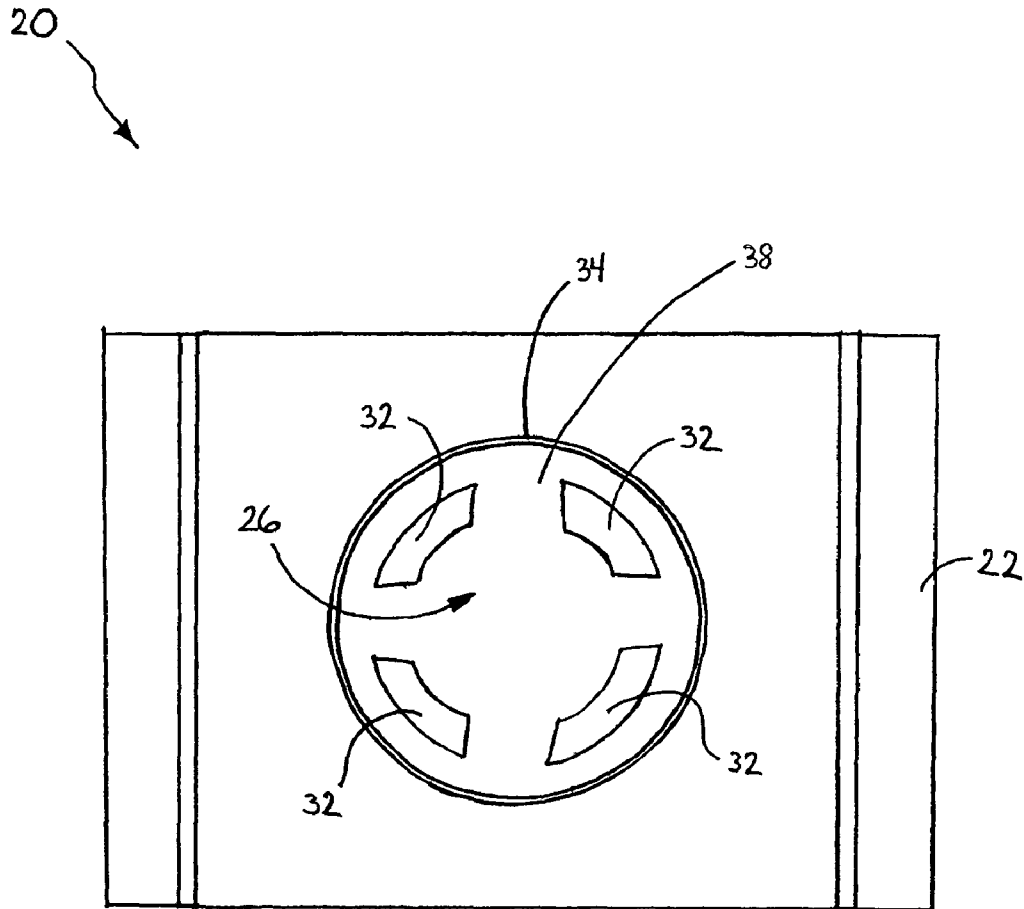


FIG. 7

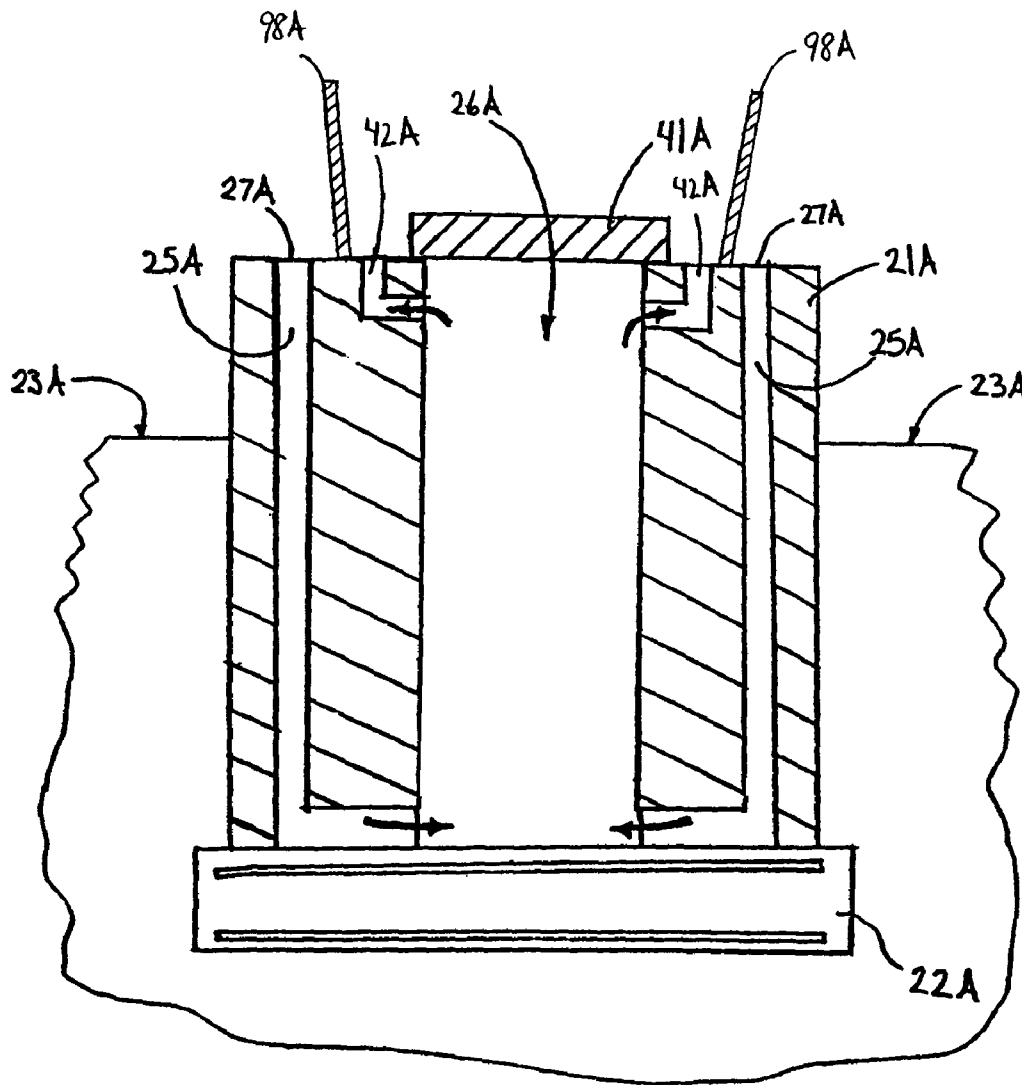


FIG. 8A

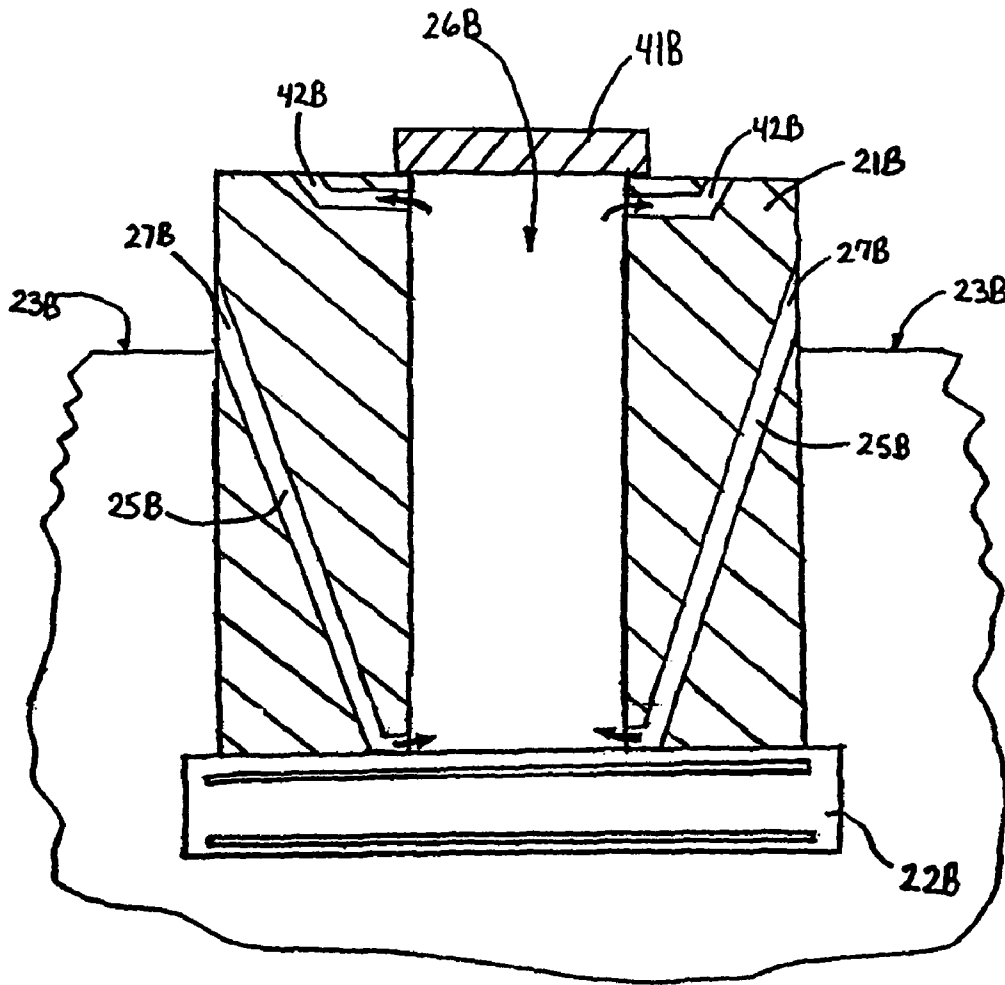


FIG. 8B

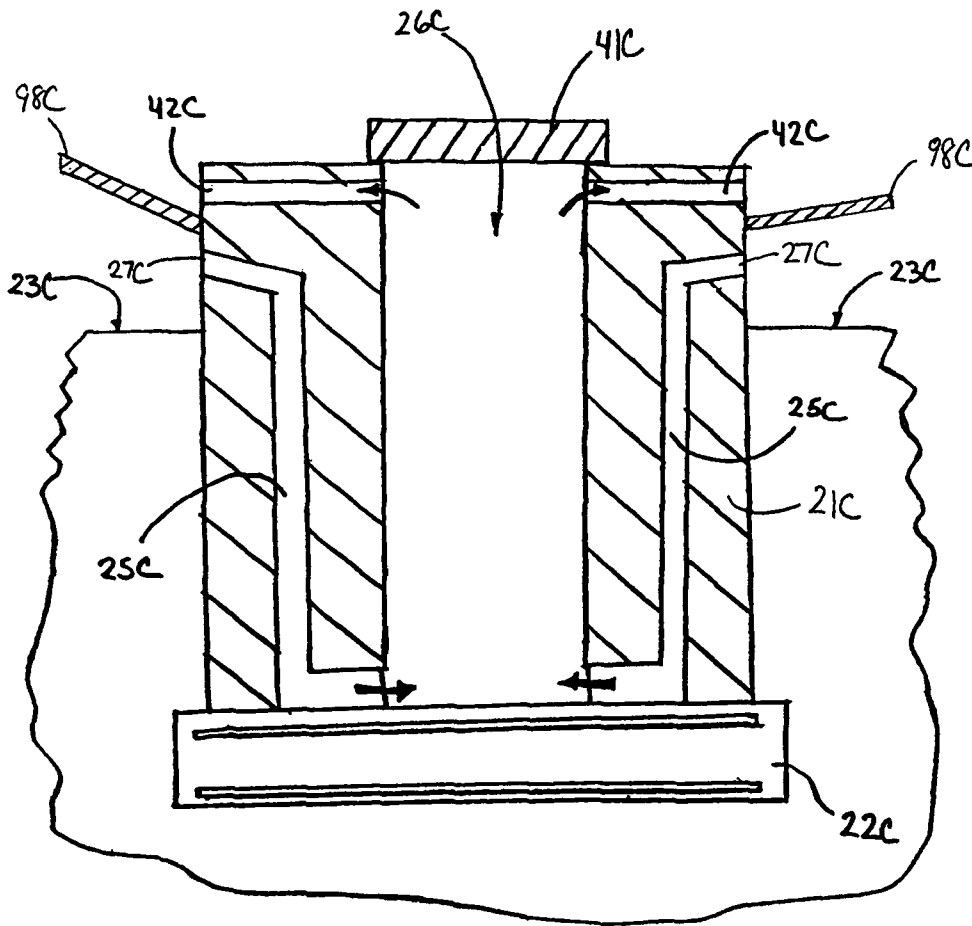


FIG. 8C

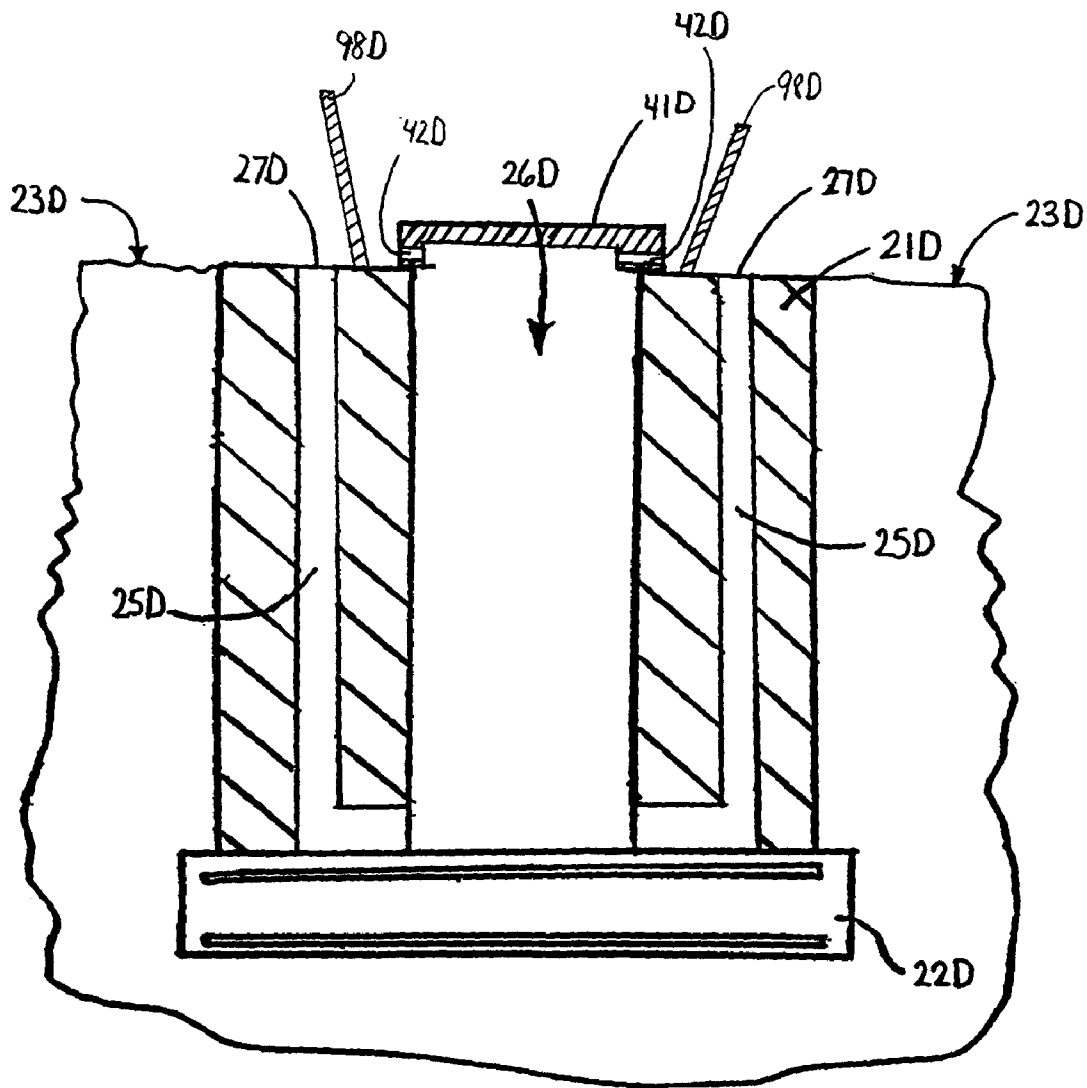


FIG. 8D

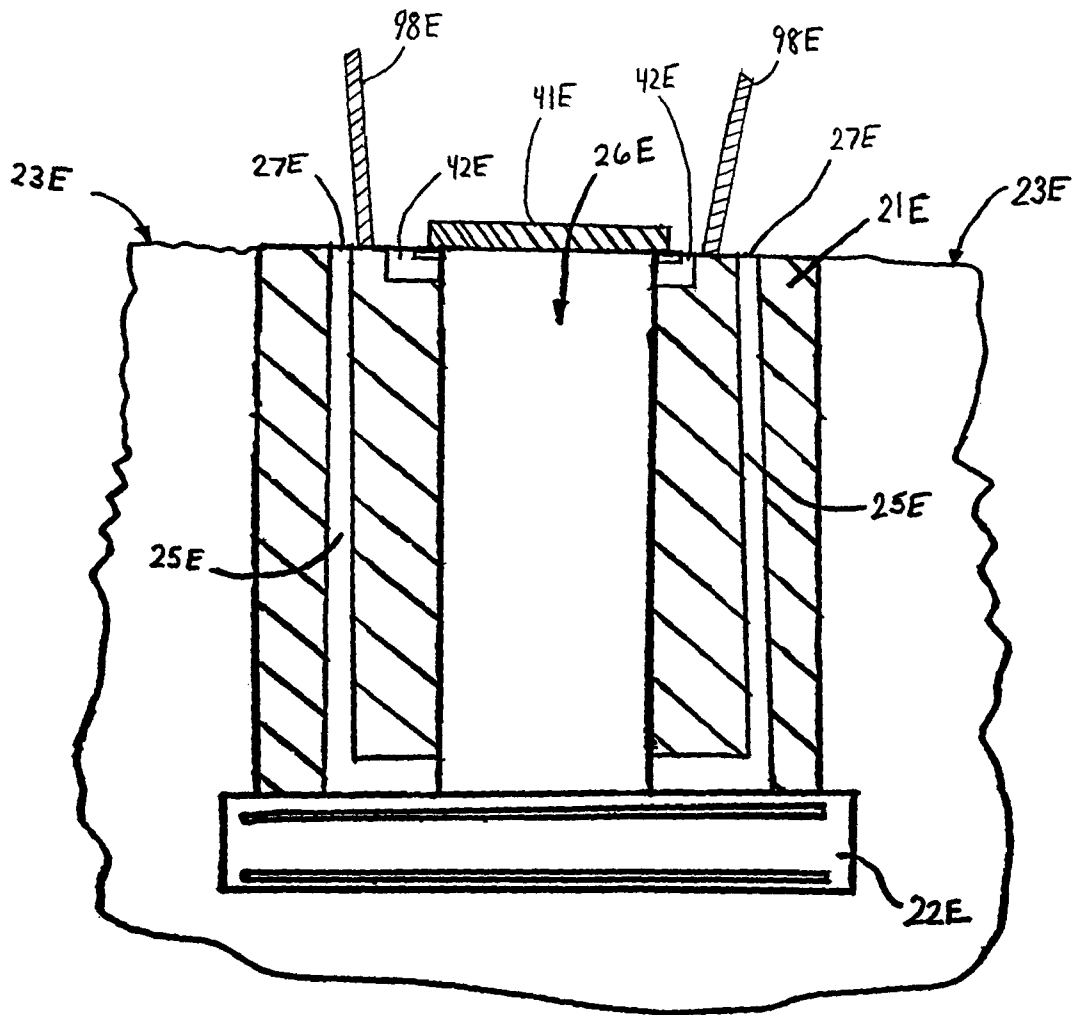


FIG. 8E

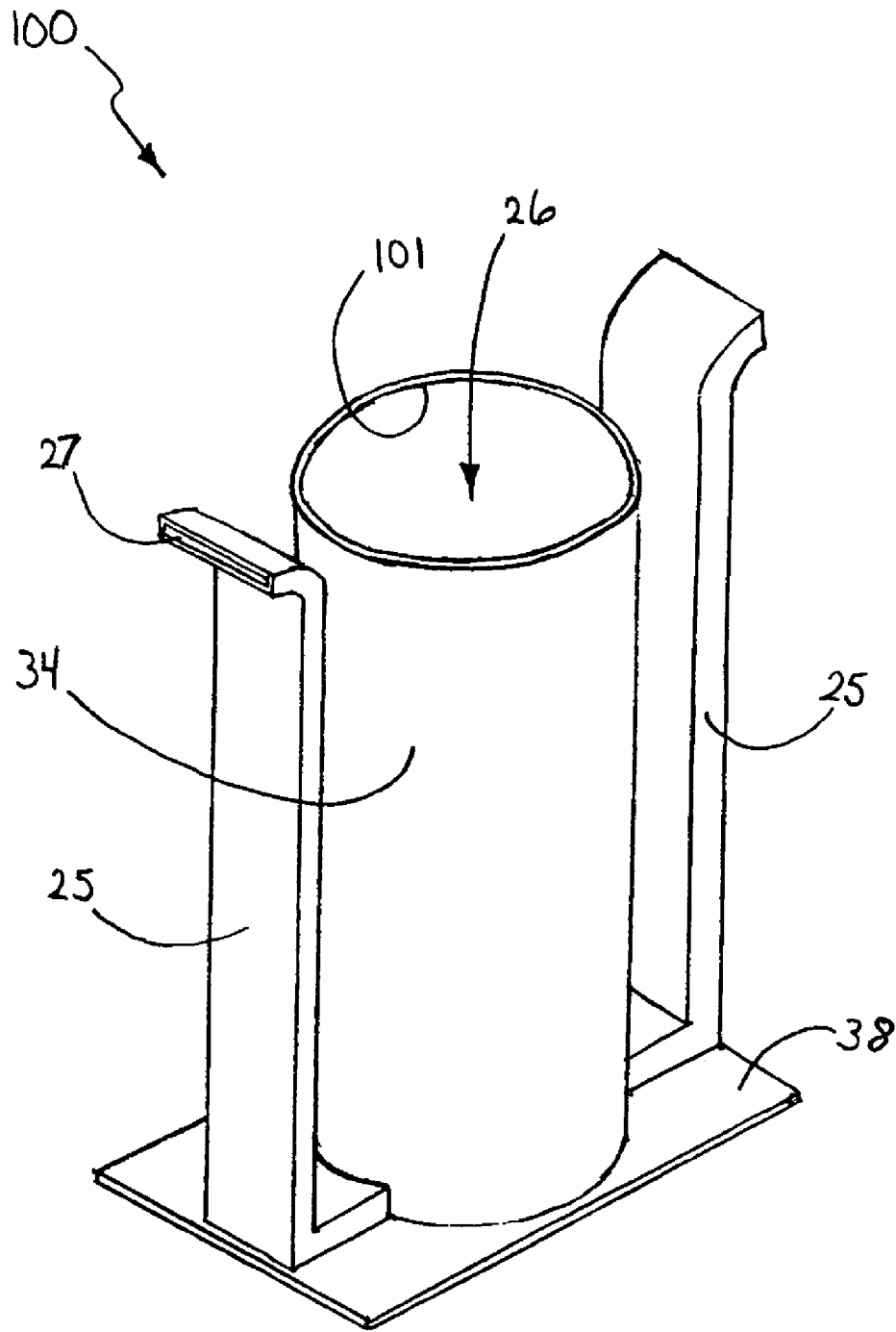


Figure 9

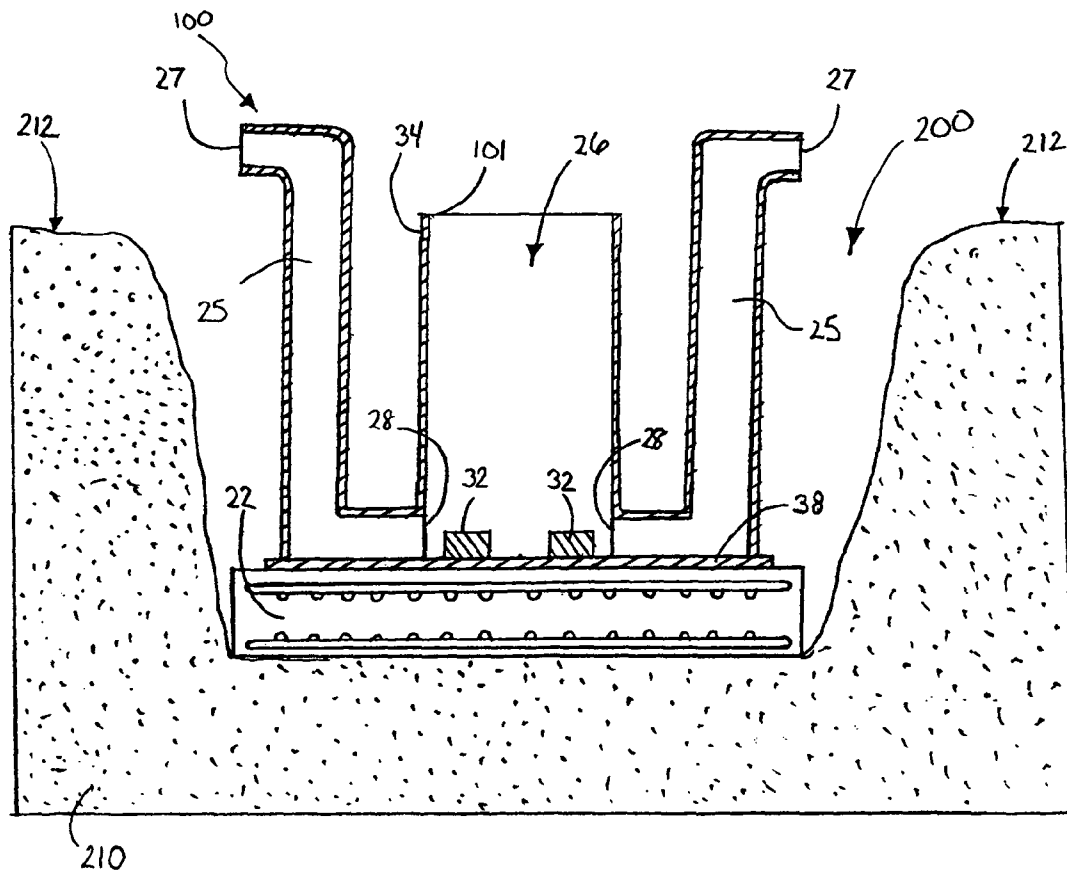


Figure 10



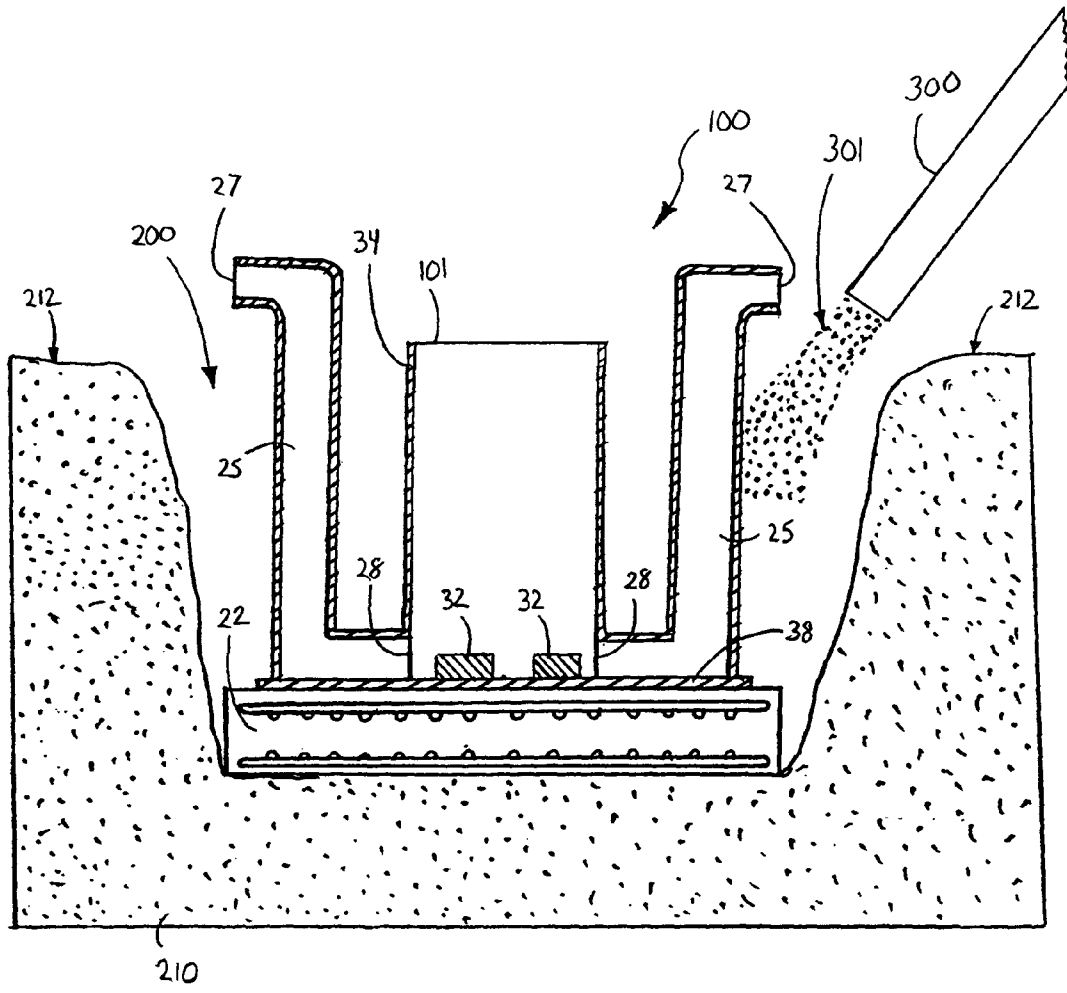


Figure 11

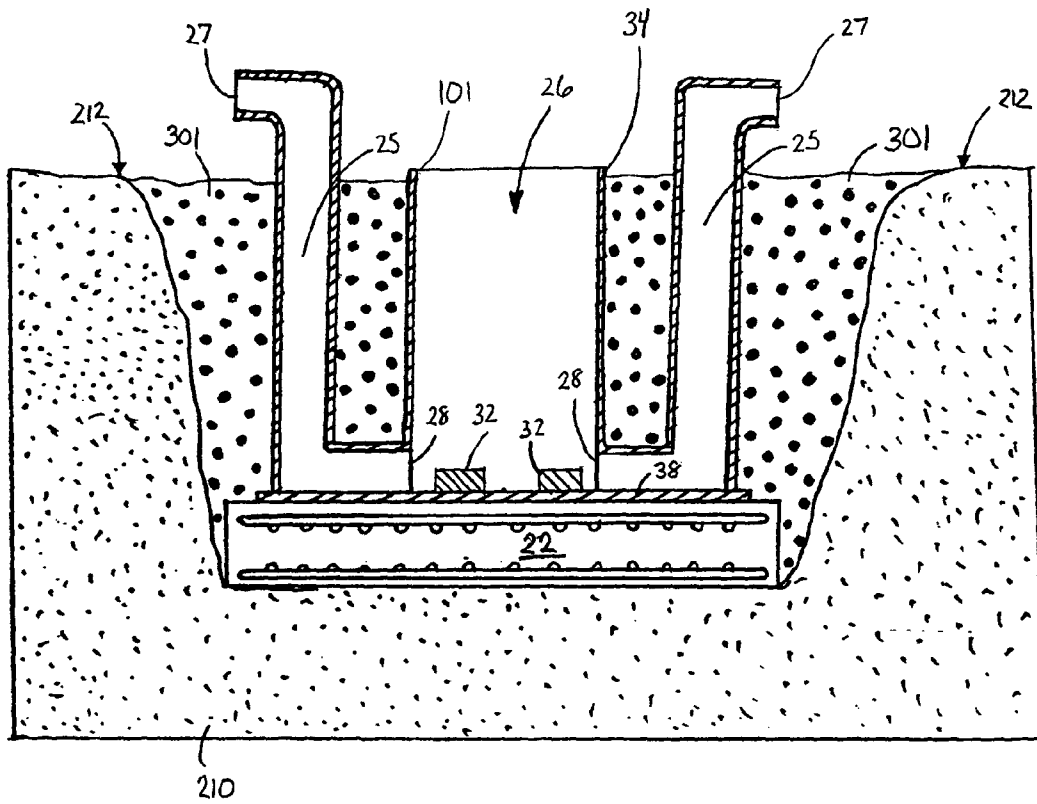


Figure 12

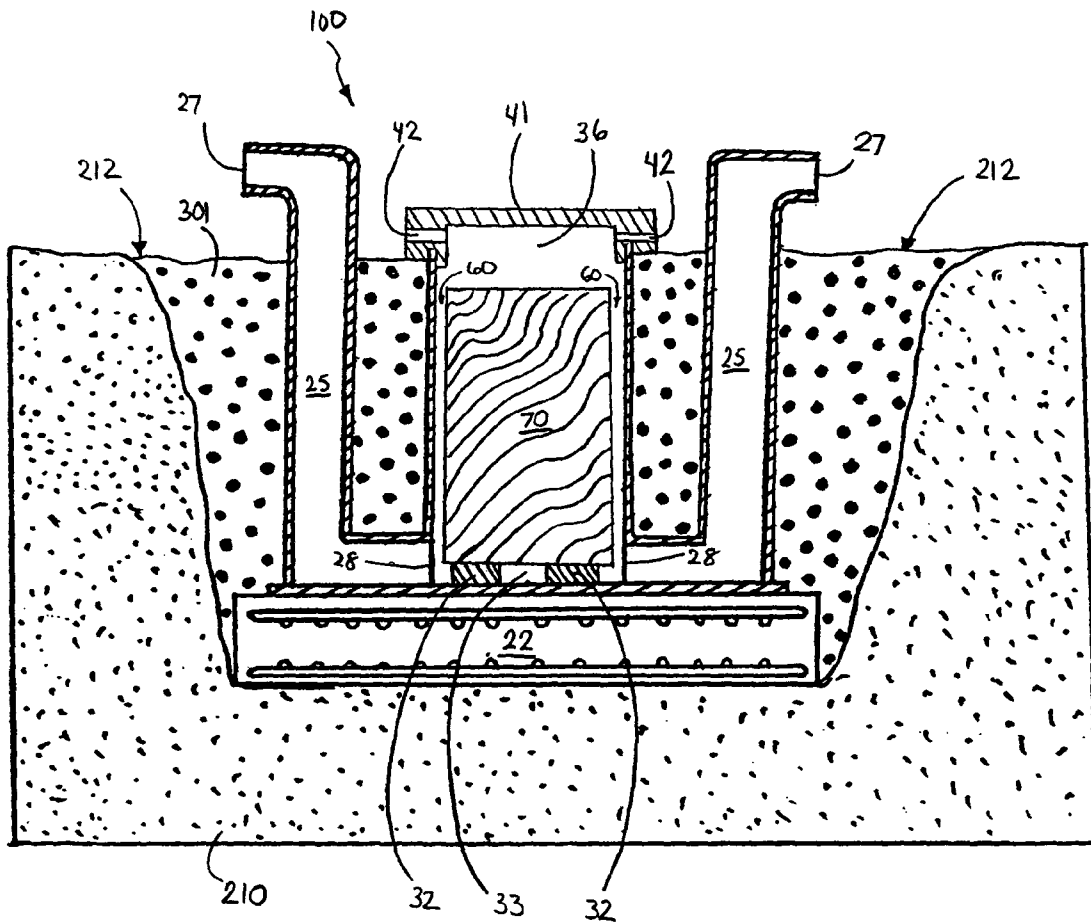


Figure 13

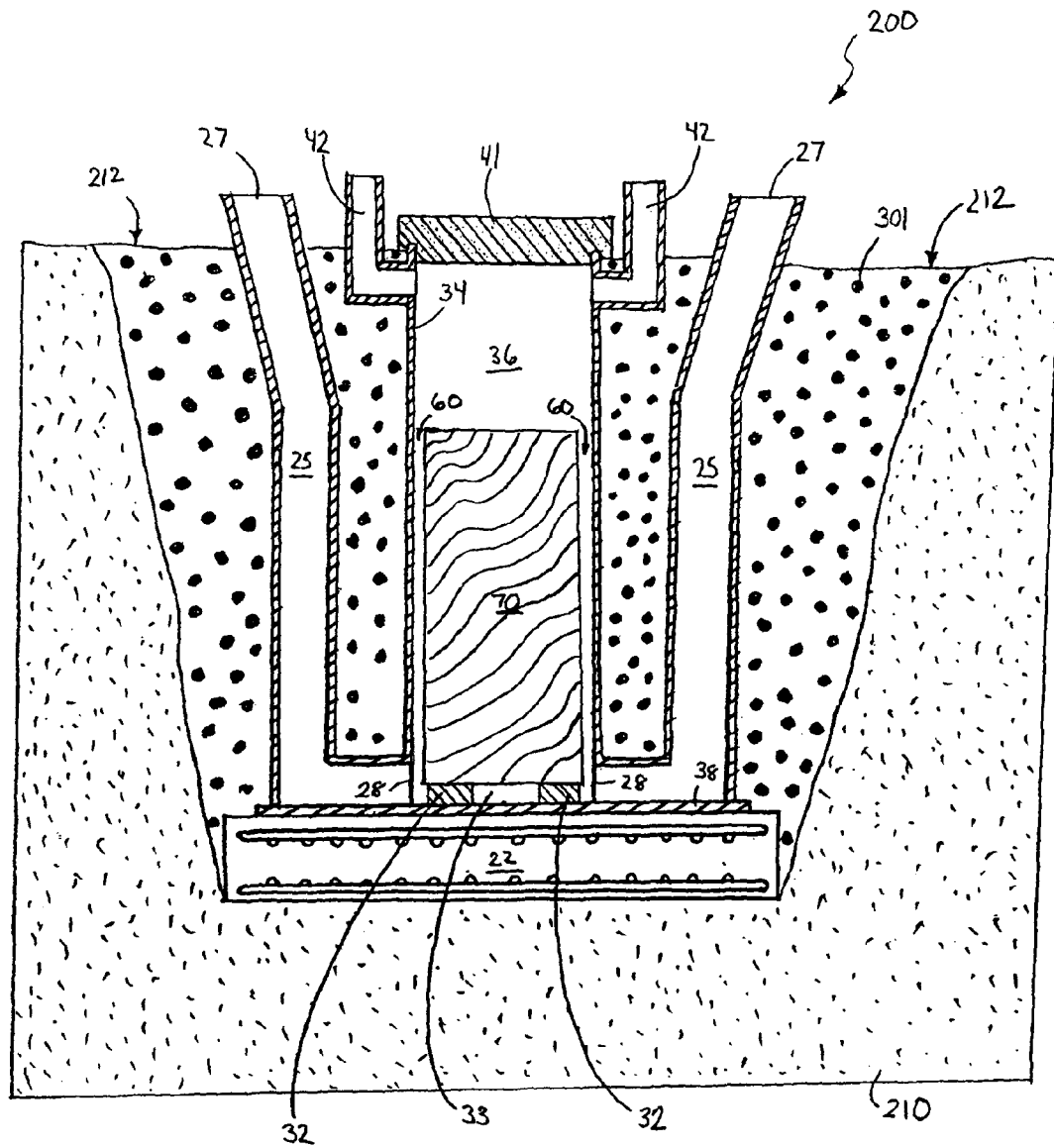


Figure 14

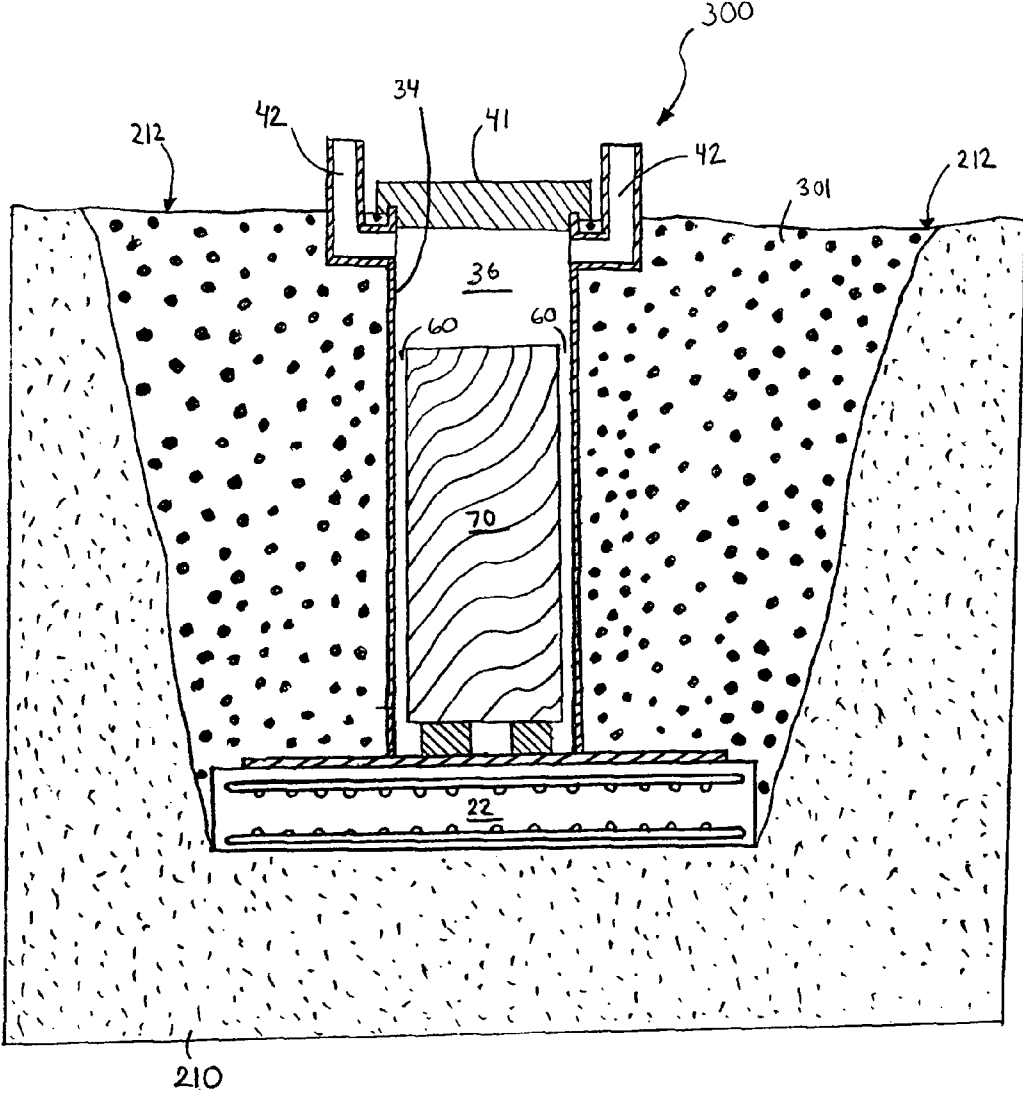


Figure 15

## SYSTEMS AND METHODS FOR STORING SPENT NUCLEAR FUEL

### CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of co-pending U.S. patent application Ser. No. 10/803,620, filed Mar. 18, 2004 now U.S. Pat No. 7,068,748.

### FIELD OF THE INVENTION

The present invention related generally to the field of storing spent nuclear fuel, and specifically to systems and methods for storing spent nuclear fuel in ventilated vertical modules.

### BACKGROUND OF THE INVENTION

In the operation of nuclear reactors, it is customary to remove fuel assemblies after their energy has been depleted down to a predetermined level. Upon removal, this spent nuclear fuel is still highly radioactive and produces considerable heat, requiring that great care be taken in its packaging, transporting, and storing. In order to protect the environment from radiation exposure, spent nuclear fuel is first placed in a canister. The loaded canister is then transported and stored in large cylindrical containers called casks. A transfer cask is used to transport spent nuclear fuel from location to location while a storage cask is used to store spent nuclear fuel for a determined period of time.

In a typical nuclear power plant, an open empty canister is first placed in an open transfer cask. The transfer cask and empty canister are then submerged in a pool of water. Spent nuclear fuel is loaded into the canister while the canister and transfer cask remain submerged in the pool of water. Once fully loaded with spent nuclear fuel, a lid is typically placed atop the canister while in the pool. The transfer cask and canister are then removed from the pool of water, the lid of the canister is welded thereon and a lid is installed on the transfer cask. The canister is then properly dewatered and filled with inert gas. The transfer cask (which is holding the loaded canister) is then transported to a location where a storage cask is located. The loaded canister is then transferred from the transfer cask to the storage cask for long term storage. During transfer from the transfer cask to the storage cask, it is imperative that the loaded canister is not exposed to the environment.

One type of storage cask is a ventilated vertical overpack "VVO"). A VVO is a massive structure made principally from steel and concrete and is used to store a canister loaded with spent nuclear fuel. VVOs stand above ground and are typically cylindrical in shape and extremely heavy, weighing over 150 tons and often having a height greater than 16 feet. VVOs typically have a flat bottom, a cylindrical body having a cavity to receive a canister of spent nuclear fuel, and a removable top lid.

In using a VVO to store spent nuclear fuel, a canister loaded with spent nuclear fuel is placed in the cavity of the cylindrical body of the VVO. Because the spent nuclear fuel is still producing a considerable amount of heat when it is placed in the VVO for storage, it is necessary that this heat energy have a means to escape from the VVO cavity. This heat energy is removed from the outside surface of the canister by ventilating the VVO cavity. In ventilating the VVO cavity, cool air enters the VVO chamber through bottom ventilation ducts, flows upward past the loaded canister, and exits the VVO at an elevated temperature through top ventilation ducts. The bot-

tom and top ventilation ducts of existing VVOs are located circumferentially near the bottom and top of the VVO's cylindrical body respectively, as illustrated in FIG. 1.

While it is necessary that the VVO cavity be vented so that heat can escape from the canister, it is also imperative that the VVO provide adequate radiation shielding and that the spent nuclear fuel not be directly exposed to the external environment. The inlet duct located near the bottom of the overpack is a particularly vulnerable source of radiation exposure to security and surveillance personnel who, in order to monitor the loaded overpacks, must place themselves in close vicinity of the ducts for short durations.

Additionally, when a canister loaded with spent nuclear fuel is transferred from a transfer cask to a storage VVO, the transfer cask is stacked atop the storage VVO so that the canister can be lowered into the storage VVO's cavity. Most casks are very large structures and can weigh up to 250,000 lbs. and have a height of 16 ft. or more. Stacking a transfer cask atop a storage VVO/cask requires a lot of space, a large overhead crane, and possibly a restraint system for stabilization. Often, such space is not available inside a nuclear power plant. Finally, above ground storage VVOs stand at least 16 feet above ground, thus, presenting a sizable target of attack to a terrorist.

FIG. 1 illustrates a traditional prior art VVO 2. Prior art VVO 2 comprises flat bottom 17, cylindrical body 12, and lid 14. Lid 14 is secured to cylindrical body 12 by bolts 18. Bolts 18 serve to restrain separation of lid 14 from body 12 if prior art VVO 2 were to tip over. Cylindrical body 12 has top ventilation ducts 15 and bottom ventilation ducts 16. Top ventilation ducts 15 are located at or near the top of cylindrical body 12 while bottom ventilation ducts 16 are located at or near the bottom of cylindrical body 12. Both bottom ventilation ducts 16 and top ventilation ducts 15 are located around the circumference of the cylindrical body 12. The entirety of prior art VVO 2 is positioned above grade.

### DISCLOSURE OF THE PRESENT INVENTION

It is an object of the present invention to provide a system and method for storing spent nuclear fuel that reduces the height of the stack assembly when a transfer cask is stacked atop a storage VVO.

It is another object of the present invention to provide a system and method for storing spent nuclear fuel that requires less vertical space.

Yet another object of the present invention is to provide a system and method for storing spent nuclear fuel that utilizes the radiation shielding properties of the subgrade during storage while providing adequate ventilation of the spent nuclear fuel.

A further object of the present invention is to provide a system and method for storing spent nuclear fuel that provides the same or greater level of operational safeguards that are available inside a fully certified nuclear power plant structure.

A still further object of the present invention is to provide a system and method for storing spent nuclear fuel that decreases the dangers presented by earthquakes and other catastrophic events and virtually eliminates the potential damage from a World Trade Center or Pentagon type of attack on the stored canister.

It is also an object of the present invention to provide a system and method for storing spent nuclear fuel that allows an ergonomic transfer of the spent nuclear fuel from a transfer cask to a storage VVO.

Another object of the present invention is to provide a system and method for storing spent nuclear fuel below grade.

Yet another object of the present invention is to provide a system and method of storing spent nuclear fuel that reduces the amount of radiation emitted to the environment.

Still another object of the present invention is to provide a system and method of storing spent nuclear fuel that affords adequate heat removal capabilities from a stored canister during flood conditions, including "smart flood" conditions.

These and other objects are met by the present invention which in one aspect is a system for storing spent nuclear fuel comprising: a shell forming a cavity for receiving a canister of spent nuclear fuel, at least a portion of the shell positioned below grade; and at least one inlet ventilation duct extending from an above grade inlet to a below grade outlet at or near a bottom of the cavity; the inlet ventilation duct connected to the shell so that the cavity is hermetically sealed to ingress of below grade fluids.

By providing an inlet ventilation duct that extends from above grade to the cavity at a point below grade, the radiation shielding properties of the subgrade can be utilized for the spent fuel canister without obstructing the ventilation of the canister in the cavity with ambient air. When loaded with a hot spent fuel canister, cool ambient air will enter the above grade inlet, travel through the inlet ventilation duct, and enter the cavity preferably, at or near its bottom. Heat from the spent fuel will warm the cool air causing it to rise within the cavity. The heated air will then exit the cavity via an outlet ventilation duct located in either a lid or connected to the shell. Thus, below grade storage of the spent nuclear fuel canister is facilitated while affording adequate heat ventilation for the spent fuel canister.

In some embodiments, it is preferable that the system further comprise a bottom plate, the bottom plate, the shell, and the at least one inlet ventilation ducts forming an integral structure. It may also be preferred that two substantially S-shaped inlet ventilation ducts be provided.

In order to prohibit the incoming cool air from being heated in the inlet ventilation ducts, some embodiments will further comprise a means for insulating the inlet ventilation ducts from the shell. It further preferred in some embodiments that a major portion of the shell be positioned below grade, and that the shell be positioned sufficiently below grade so that when a canister of spent nuclear fuel is positioned in the cavity, the entire canister is below grade.

In another aspect, the invention is a method of storing spent nuclear fuel comprising: providing a below grade hole; providing a system comprising a shell forming a cavity for receiving a canister of spent nuclear fuel, at least a portion of the shell positioned below grade, and at least one inlet ventilation duct extending from an inlet to an outlet at or near a bottom of the cavity, the inlet ventilation duct connected to the shell; positioning the apparatus in the hole so that the inlet of the inlet ventilation duct is above grade and the outlet of the inlet ventilation duct into the cavity is below grade; filling the hole with engineered fill; and lowering a spent fuel canister into the cavity.

In some embodiments, the method will also preferably comprise the steps of lowering the canister into the cavity until the entire canister is below grade and placing a lid on a top of the shell, the lid comprising at least one outlet ventilation duct forming a passageway from at or near the top of the cavity to an ambient atmosphere. During ventilation of the canister in this embodiment, cool air will enter the cavity via

the inlet ventilation duct, the cool air will be warmed by heat from the walls of the canister and the shell when the canister is in the cavity, and warm air will exit the cavity via the outlet ventilation duct.

It is preferred that a small clearance exist between side walls of the canister and the shell when the canister is in the cavity. In other embodiments, the method may further comprise the step of positioning the canister atop support blocks positioned on a floor of the cavity, an inlet air plenum being created between the floor of the cavity and a bottom surface of the canister, wherein an outlet air plenum exists between the lid and a top surface of the canister. In some cases, it may be desirable to take affirmative measures to segregate the cool air entering the cavity via the inlet ventilation duct from the warm air exiting the cavity via the outlet ventilation duct.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top perspective view of a prior art VVO.

FIG. 2 is a side cross sectional view of an underground VVO according to an embodiment of the present invention having a spent fuel canister positioned therein.

FIG. 3 is a perspective view of the underground VVO of FIG. 2 removed from the ground.

FIG. 4 is a bottom perspective view of an alternate embodiment of a lid to be used with the underground VVO of FIG. 2.

FIG. 5 is a perspective view of an array of underground VVO's according to an embodiment of the present invention stored at an ISFSI.

FIG. 6 is a side cross sectional view of area VI-VI of FIG. 2.

FIG. 7 is a top view of the underground VVO of FIG. 2 removed from the ground and with the spent fuel canister removed from the cavity and the lid removed.

FIG. 8A is a schematic cross-sectional view of an underground VVO according to an embodiment of the present invention having a first alternative configuration of the inlet and outlet ventilation ducts.

FIG. 8B is a schematic cross-sectional view of an underground VVO according to an embodiment of the present invention having a second alternative configuration of the inlet and outlet ventilation ducts.

FIG. 8C is a schematic cross-sectional view of an underground VVO according to an embodiment of the present invention having a third alternative configuration of the inlet and outlet ventilation ducts.

FIG. 8D is a schematic cross-sectional view of an underground VVO according to an embodiment of the present invention wherein the body of the underground VVO is substantially flush with the ground.

FIG. 8E is a schematic cross-sectional view of an underground VVO according to an embodiment of the present invention wherein the body of the underground VVO is substantially flush with the ground and having an alternative configuration of the inlet and outlet ventilation ducts.

FIG. 9 is a top perspective view of an integral structure for storing spent nuclear fuel according to an embodiment of the present invention.

FIG. 10 is a schematic of the integral structure of FIG. 9 lowered into a below grade hole and positioned atop a base.

FIG. 11 is a schematic of the arrangement of FIG. 10 wherein the below grade hole is being filled with soil.

FIG. 12 is a schematic illustrating the arrangement of FIG. 10 wherein the below grade hole is completely filled with soil.

FIG. 13 is a schematic illustrating the arrangement of FIG. 12 wherein a spent fuel canister is loaded in the integral structure and a lid positioned thereon.

FIG. 14 is a schematic view of an integral structure according to an embodiment of the present invention having an alternative configuration for the inlet and outlet ventilation ducts.

FIG. 15 is a schematic view of an integral structure for storing low heat spent fuel according to an embodiment of the present invention free of inlet ventilation ducts.

#### DETAILED DESCRIPTION OF THE DRAWINGS

Referring to FIGS. 2 and 3, underground VVO 20 is illustrated according to a first embodiment of the present invention. Underground VVO 20 is a vertical, ventilated dry spent fuel storage system that is fully compatible with 100 ton and 125 ton transfer casks for spent fuel canister transfer operations. Underground VVO 20 can be modified/designed to be compatible with any size or style transfer cask. Underground VVO 20 is designed to accept spent fuel canisters for storage at an Independent Spent Fuel Storage Installation "ISFSI" in lieu of above ground overpacks (such as prior art VVO 2 in FIG. 1). All spent fuel canister types engineered for storage in free-standing and anchored overpack models can be stored in underground VVO 20.

As used herein the term "canister" broadly includes any spent fuel containment apparatus, including, without limitation, multi-purpose canisters and thermally conductive casks. For example, in some areas of the world, spent fuel is transferred and stored in metal casks having a honeycomb grid-work/basket built directly into the metal cask. Such casks and similar containment apparatus qualify as canisters, as that term is used herein, and can be used in conjunction with underground VVO 20 as discussed below.

Underground VVO 20 comprises body 21, base 22, and removable lid 41. Body 21 is constructed of concrete, but can be constructed of other suitable materials. Body 21 is rectangular in shape but can be any shape, such as for example, cylindrical, conical, spherical, semi-spherical, triangular, or irregular in shape. A portion of body 21 is positioned below grade so that only top portion 24 protrudes above grade level 23. Preferably, at least a major portion of the height of body 21 is positioned below grade. The exact height which top portion 24 of body 21 extends above ground level 23 can be varied greatly and will depend on a multitude of design considerations, such as canister dimensions, radioactivity levels of the spent fuel to be stored, ISFSI space limitations, geographic location considering susceptibility to missile-type and ground attacks, geographic location considering frequency of and susceptibility to natural disasters (such as earthquakes, floods, tornadoes, hurricanes, tsunamis, etc.), environmental conditions (such as temperature, precipitation levels), and/or ground water levels. Preferably, top portion 24 of body 21 is less than approximately 42 inches above ground level 23, and most preferably approximately 6 to 36 inches above ground level 23.

In some embodiments, it may even be preferable that the entire height of body 21 be below grade (illustrated in FIGS. 8D and 8E). As will be discussed in more detail below, when the entire height of body is below grade, only the top surface of the body will be exposed to the ambient air above grade.

Referring still to FIGS. 2 and 3, body 21 forms cylindrical cavity 26 therein (best shown in FIG. 3). While cavity 26 is cylindrical in shape, cavity 26 is not limited to any specific size, shape, and/or depth and can be designed to receive and store almost any shape of canister without departing from the spirit of the invention. While not necessary to practice the invention, it is preferred that the horizontal cross-sectional size and shape of cavity 26 be designed to generally corre-

spond to the horizontal cross-sectional size and shape of the canister-type that is to be used in conjunction with that particular underground VVO. More specifically, it is desirable that the size and shape of cavity 26 be designed so that when a spent fuel canister (such as canister 70) is positioned in cavity 26 for storage, a small clearance exists between the outer side walls of the canister and the side walls of cavity 26.

Designing cavity 26 so that a small clearance is formed between the side walls of the stored canister and the side walls of cavity 26 limits the degree the canister can move within the cavity during a catastrophic event, thereby minimizing damage to the canister and the cavity walls and prohibiting the canister from tipping over within the cavity. This small clearance also facilitates flow of the heated air during spent nuclear fuel cooling. The exact size of the clearance can be controlled/designed to achieve the desired fluid flow dynamics and heat transfer capabilities for any given situation. In some embodiments, for example, the clearance may be 1 to 3 inches. A small clearance also reduces radiation streaming.

Two inlet ventilation ducts 25 are provided in body 21 for providing inlet ventilation to the bottom of cavity 26. Inlet ventilation ducts 25 are elongated substantially S-shaped passageways extending from above grade inlets 27 to below grade outlets 28. Above grade inlets 27 are located on opposing side walls of top portion 24 of body 21 and open to the ambient air above ground level 23. As use herein, the terms ambient air, ambient atmosphere, or outside atmosphere, refer to the atmosphere/air external to the underground VVO, and include the natural outside environment and spaces within buildings, tents, caves, tunnels, or other man-made or natural enclosures.

Below grade outlets 28 open into cavity 26 at or near its bottom at a position below the ground level 23. Thus, inlet ventilation ducts 25 provide a passageway for the inlet of ambient air to the bottom of cavity 26, despite the bottom of cavity 26 being well below grade. Vent screens 31 (FIG. 3) are provided to cover above grade inlets 27 so that objects and other debris can not enter and block the passageways of inlet ventilation ducts 25. As a result of the elongated S-shape of inlet ventilation ducts 25, above grade inlets 27 cease to be a location of elevated dose rate that is common in free-standing above ground VVOs. While below grade outlets 28 are illustrated as being opening near the bottom of the walls of cavity 26, below grade outlets 28 can be located in the floor of cavity 26 if desired. This can be accomplished by appropriately reshaping inlet ventilation ducts 25 and forming an opening through bottom plate 38 and into cavity 26. In such an embodiment, base 22 can be considered part of the body 21 through which the inlet ventilation ducts 25 extend.

Above grade inlets 27 are located in the side walls of body 21 at an elevation of about 10 inches above ground level 23. However, the elevation of above grade inlets 27 is not limiting of the present invention. The inlets 27 can be located at any desired elevation above the ground level, including level/flush therewith, as shown in FIGS. 8D and 8E. Elevating above grade inlets 27 substantially above the ground level 23 helps reduce the likelihood that rain or flood water will enter the cavity 26. It is noted that for ISFSI's in flood zones, flood-water can possibly rise more than a foot above ground level and, thus, enter cavity 26 via inlet ventilation ducts 25. However, as discussed below with respect to FIG. 6, underground VVO 20 is specifically designed to deal with the worst flood conditions in a safe and effective manner.

While above grade inlets 27 are preferably located in the side walls of body 21, the above grade inlets are not limited to such a location and, if desired, can be located anywhere on the body, including for example in the top surface (or any other



surface) of the body. Further examples of possible locations for above grade inlets 27 on body 21 are illustrated in FIGS. 8A-8E.

Referring still to FIGS. 2 and 3, inlet ventilation ducts 25 have a rectangular cross-sectional area of about 6 inches by 40 inches. However, any cross-sectional shape and/or size can be used, such as for example, round, elliptical, triangular, hexagonal, octagonal, etc. Additionally, while the shape of inlet ventilation ducts 25 is an elongated substantially S-shaped passageway, a multitude of shapes can be used that still achieve acceptable dose rates at the above grade inlets 27. For example, rather than an elongated S-shape, the inlet ventilation duct can extend from the above grade inlet to the below grade outlet in a zig-zag shape, a tilted linear shape, a general L-shape, or any angular, linear, or curved combination. The exact shape, size, and cross-sectional configuration of the inlet ventilation duct is a matter of design preference and will be dictated by such factors, such as thickness of the body of the VVO, radioactivity level of the spent fuel being stored in the cavity, temperature of the spent fuel canister, desired fluid flow dynamics through the ducts, and placement of the above grade inlet vents on the body (i.e., whether the above grade inlet vents/opening are located on the side walls of the body, its top surface, or some other surface of the body). Further examples of possible shapes for inlet ventilation ducts 25 are illustrated in FIGS. 8A-8E.

Inlet ventilation ducts 25 are preferably formed by a low carbon steel liner. However, inlet ventilation ducts 25 can be made of any material or can be mere passageways formed into concrete body 21 without a lining.

As best illustrated in FIG. 3, cavity 26 is formed by thick steel shell 34 and bottom plate 38. Shell 34, bottom plate 38, and inlet ventilation ducts 25 are preferably made of a metal, such as steel, preferably low carbon steel, but can be made of other materials, such as stainless steel, aluminum, aluminum-alloys, plastics, and the like. Inlet ventilation ducts 25 are seal joined to shell 34 and bottom plate 38 to form an integral/unitary structure 100 (shown in isolation in FIG. 9) that is hermetically sealed to the ingress of below grade water and other fluids. In the case of weldable metals, this seal joining may comprise welding or the use of gaskets. Thus, the only way water or other fluids can enter cavity 26 is through above grade inlets 27 or outlet ventilation ducts 42 in lid 41. As will be discussed below with respect to FIGS. 9-15, the integral structure itself is an invention and can be used to store spent nuclear fuel without the use of body 21.

An appropriate preservative, such as a coal tar epoxy or the like, is applied to the exposed surfaces of shell 34, bottom plate 38, and inlet ventilation ducts 25 in order to ensure sealing, to decrease decay of the materials, and to protect against fire. A suitable coal tar epoxy is produced by Carbolite Company out of St. Louis, Mo. under the tradename Bitumastic 300M. In some embodiments of the underground VVO of the present invention, a bottom plate will not be used.

Concrete body 21 surrounds shell 34 and inlet ventilation ducts 25. Body 21 provides non-structural protection for shell 34 and inlet ventilation ducts 25. Insulation 37 is provided at the interface between shell 34 and concrete body 21 and at the interface between inlet ventilation ducts 25 and concrete body 21, thus maintaining the bulk temperature of the concrete within FSAR limits. Insulating shell 34 and inlet ventilation ducts 25 from concrete body 21 also serves to minimize the heat-up of the incoming cooling air before it enters cavity 26. Suitable forms of insulation include, without limitation, blankets of alumina-silica fire clay (Kaowool Blanket),

oxides of alumina and silica (Kaowool S Blanket), alumina-silica-zirconia fiber (Cerablanket), and alumina-silica-chromia (Cerachrome Blanket).

Insulating inlet ventilation ducts 25 from the heat load of spent fuel in cavity 26 is very important in facilitating and maintaining adequate ventilation/cooling of the spent fuel. The insulating process can be achieved in a variety of ways, none of which are limiting of the present invention. For example, in addition to adding an insulating material to the exterior of the shell 34 and inlet ventilation ducts 25, it is also possible to insulate inlet ventilation ducts 25 by providing a gap in concrete body 21 between cavity 26 and inlet ventilation ducts 25. The gap may be filled with an inert gas or air if desired. Moreover, irrespective of the means used to provide the insulating effect, the insulating means is not limited to being positioned on the outside surfaces of shell 34 or inlet ventilation ducts 25 but can be positioned anywhere between cavity 26 and inlet ventilation ducts 25.

Body 21, along with the integral steel unit formed by bottom plate 38, shell 34, and ventilation ducts 25, are placed atop base 22. Base 22 is a reinforced concrete slab designed to satisfy the load combinations of recognized industry standards, such as, without limitation, ACI-349. Base 22 is rectangular in shape but can take on any shape necessary to support body 21, such as round, elliptical, triangular, hexagonal, octagonal, irregularly shaped, etc. While using a base is preferable to achieve adequate load supporting requirements, situations can arise where using such a base may be unnecessary.

Referring back to FIG. 2, underground VVO 20 has a removable ventilated lid 41. Lid 41 is positioned atop body 21, thereby substantially enclosing cavity 26 so that radiation does not escape through the top of cavity 26 when canister 70 is positioned in cavity 26. When lid 41 is placed atop body 21 and spent fuel canister 70 is positioned in cavity 26, outlet air plenum 36 is formed between the top surface of canister 70 and lid 41. Outlet air plenum 36 is preferably a minimum of 3 inches in height, but can be any desired height. The exact height will be dictated by design considerations such as desired fluid flow dynamics, canister height, VVO height, the depth of the cavity, canister heat load, etc.

Lid 41 has four outlet ventilation ducts 42. Outlet ventilation ducts 42 form a passageway from the top of cavity 26 (specifically from outlet air plenum 36) to the ambient air so that heated air can escape from cavity 26. Outlet ventilation ducts 42 are horizontal passageways that extend through side wall 30 of lid 41. However, the outlet ventilation ducts can be any shape or orientation, such as vertical, L-shaped, S-shaped, angular, curved, etc. Because outlet ventilation ducts 42 are located within lid 41 itself, the total height of body 21 is minimized.

Lid 41 comprises a roof 35 made of concrete. Roof 35 provides radiation shielding so that radiation does not escape from the top of cavity 26. Side wall 30 of lid 41 is an annular ring. Outlet air plenum 36 helps facilitate the removal of heated air via outlet ventilation ducts 42. In order to minimize the heated air exiting outlet ventilation ducts 42 from being siphoned back into inlet ventilation ducts 25, outlet ventilation ducts 42 are azimuthally and circumferentially separated from inlet ventilation ducts 25.

Ventilated lid 41 also comprises shear ring 47. When lid 41 is placed atop body 21, shear ring 47 protrudes into cavity 26, thus, providing enormous shear resistance against lateral forces from earthquakes, impactive missiles, or other projectiles. Lid 41 is secured to body 21 with bolts (not shown) that extend therethrough.

While not illustrated, it is preferable that duct photon attenuators be inserted into all of inlet ventilation ducts **25** and/or outlet ventilation ducts **42** of underground VVO **20**, irrespective of shape and/or size. A suitable duct photon attenuator is described in U.S. Pat. No. 6,519,307, Bongrazio, the teachings of which are incorporated herein by reference.

Referring now to FIG. 4, an embodiment of a lid **50** that can be used in underground VVO **20** is illustrated. Lid **50** contains similar design aspects as lid **41** and is illustrated to more fully disclose the aforementioned lid design aspects. Lid **50** has four horizontal outlet ventilation ducts **51** in side wall **52**. Shear ring **54** is provided on the bottom of lid **50** to fit into cavity **26**. Bolts **18** are used to secure lid **50** to tapped holes in the top of body **21**.

While the outlet ventilation ducts are illustrated as being located within the lid **50** of underground VVO **20**, the present invention is not so limited. For example, outlet ventilation ducts can be located in the body of the underground VVO at a location above grade. This concept is illustrated in FIGS. 8A-8E. If the outlet ventilation ducts are located in the body of the underground VVO, the openings of the outlet ventilation ducts to the ambient air can be located in the body's side walls, on its top surface, or in any other surface. Similar to when the outlet ventilation ducts are located in the lid, the outlet ventilation ducts can take on a variety of shapes and/or configurations when located in the body of the underground VVO itself. As with the inlet ventilation ducts, the outlet ventilation ducts are preferably formed by a low carbon steel liner, but can be made of any material or can be mere passageways formed into concrete body **21** or lid **41** without a lining. In all embodiments of the present invention which have both inlet and outlet ventilation ducts, it is preferred that the outlet ventilation duct openings be azimuthally and circumferentially separated from the inlets of the inlet ventilation ducts to minimize interaction between inlet and outlet air streams. There is no limitation on the shape and style of lid used in conjunction with underground VVO **20**.

Referring back to FIG. 2, soil **29** surrounds body **21** for almost the entirety of its height. When spent fuel canister **70** is positioned in cavity **26**, at least a major portion, if not the entirety, of canister **70** is below grade. Preferably, the entire height of canister **70** is below grade in order to take full advantage of the shielding effect of the soil **29**. Thus, soil **29** provides a degree of radiation shielding for spent fuel stored in underground VVO **20** that can not be achieved in above-ground overpacks. Underground VVO **20** is unobtrusive in appearance and there is no danger of underground VVO **20** tipping over. Additionally, underground VVO **20** does not have to contend with soil-structure interaction effects that magnify the free-field acceleration and potentially challenge the stability of an above ground free-standing overpack.

Referring to FIG. 6, area VI-VI of FIG. 2 is illustrated in detail. FIG. 6 illustrates design aspects that are important to ensure that underground VVO **20** can successfully withstand flood conditions without adverse impact. Support blocks **32** are provided on the bottom surface (formed by plate **38**) of cavity **26** so that canister **70** can be placed thereon. Support blocks **32** are circumferentially spaced from one another (shown in FIG. 7). When canister **70** is loaded into cavity **26** for storage, the bottom surface **71** of canister **70** rests on support blocks **32**, forming an inlet air plenum **33** between the bottom surface **71** of the canister **70** and the bottom surface/floor of cavity **26**. Support blocks **32** are made of low carbon steel and are preferably welded to the bottom surface of the cavity **26**. Other suitable materials of construction include, without limitation, reinforced-concrete, stainless steel, and other metal alloys.

Support blocks **32** also serve an energy/impact absorbing function. Support blocks **32** are preferably of a honeycomb grid style, such as those manufactured by Hexcel Corp., out of California, U.S.

Support blocks **32** are specifically designed so that bottom surface **71** of canister **70** is lower than top **74** of below grade outlets **28** (FIG. 2) of inlet ventilation ducts **25**. Preferably, support blocks **32** are designed so that bottom surface **71** of canister **70** is about 2 to 6 inches below top **74** of below grade outlets **28**. However, any desired height differential can be achieved through proper design. By supporting canister **70** in cavity **26** so that its bottom surface **71** is lower than top **74** of below grade outlets **28**, underground VVO **20** will provide adequate cooling to canister **70** under even the most adverse flood condition, which is colloquially referred to as a "smart flood." A "smart flood" is one that floods the VVO so that the water level is just high enough to block airflow through the inlet ventilation ducts **25** completely. In other words, the water level is just even with top **74** of the below grade outlets **28**.

However, underground VVO **20** can adequately deal with the "smart flood" condition because the bottom surface **71** of the canister **70** is situated at a height that is below top **74** of below grade outlets **28**. As a result, if a "smart flood" was to occur, the bottom of the canister **70** will be in contact with (i.e. submerged in) the water. Because the heat removal efficacy of water is over 100 times that of air, a wet bottom is all that is needed to effectively remove heat and keep the canister **70** cool. The deeper the submergence of canister **70** in the water, the cooler canister **70** and its contained fuel will remain. As the water in cavity **26** is heated by the bottom of canister **70**, the water evaporates, rises through cavity **26** via annular space **60**, and exits cavity **26** via the outlet ventilation ducts. Thus, the canister cooling action changes from ventilation air-cooling to evaporative water cooling.

In one embodiment, below grade outlets **28** of inlet ventilation ducts **25** will be 8 inches high by 40 inches wide and inlet air plenum **33** is 6 inches high. This provides a height differential of 2 inches.

It should be noted that the height differential design aspect of underground VVO **20** that is detailed in FIG. 6 can also be incorporated into free-standing above ground casks and VVOs to deal with "smart flood" conditions, independent of the other features of underground VVO **20**. Thus, this concept is an independent inventive aspect of the present application. When incorporated into above ground VVOs, the inlet ventilation ducts should be designed so that radiation can not escape to the surrounding environment from the inlet ventilation ducts. This is a threat because the canister will be below the inlet duct's opening into the storage cavity. In this embodiment, the inlet ventilation ducts will be shaped so that a line of sight does not exist to the canister in the storage cavity from the ambient air. For example, the inlet ventilation ducts can comprise a portion that is L-shaped, angled, S-shaped, or curved.

Moreover, while the height differential design aspect of FIG. 6 is achieved using support blocks **32**, it is also possible to practice this aspect of the invention without support blocks **32**. In such embodiments, canister **70** will be positioned in cavity **26** and rest directly on the floor of cavity **26**. However, the use of support blocks **32** is desirable because of the creation of air inlet plenum **33** and because the use of support blocks **32** helps prohibit debris and dirt from getting trapped at the bottom of cavity **26**.

Referring now to FIGS. 8A-8E, examples of alternative configurations of the outlet ventilation ducts and the inlet ventilation ducts in an underground VVO according to the

present invention are schematically illustrated. Much of the detail, and some structure, has been omitted in FIGS. 8A-8E for simplicity with the understanding that any or all of the details discussed above with respect to underground VVO 20 can be incorporated therein. Like numbers are used to identify like parts with the exception of alphabetical suffixes being used for each embodiment.

It should be noted that, in addition to the configurations of the inlet ventilation ducts and the outlet ventilation ducts illustrated in FIGS. 8A-8E, a multitude of other configurations, combinations, and modifications can be incorporated into the present invention. Some of these details are discussed above. Additionally, the outlet ventilation duct configurations of any of the illustrated embodiments can be combined with any of the illustrated inlet ventilation duct configurations, and vice versa.

In all embodiments of the present invention, it is desirable that the heated air exiting the outlet ventilation ducts 42 be prohibited from being siphoned back into the inlet ventilation ducts 25 (i.e., keeping the warm outlet air stream from mixing with the cool inlet air stream). This can be accomplished by in a number of ways, including: (1) the positioning/placement of the inlets 27 on the underground VVO 20 with respect to the outlets of the outlet ventilation ducts 42; providing a plate 98 or other structure that segregates the air streams (as exemplified in FIGS. 8A and 8C-8E); and/or (3) extending the inlet ventilation ducts 25 to a position away from the outlet ventilation ducts 42.

As a result of the heat emanating from canister 70, cool air from the ambient is siphoned into inlet ventilation ducts 25 and into the bottom of cavity 26. This cool air is then warmed by the heat from the spent fuel in canister 70, rises in cavity 26 via annular space 60 (FIG. 6) around canister 70, and then exits cavity 26 as heated air via outlet ventilation ducts 42 in lid 41.

Referring now to FIGS. 5, ISFIs can be designed to employ any number of underground VVOs 20 (or integral structures 100) and can be expanded in number easily to meet growing needs. Although underground VVOs 20 are closely spaced, the design permits any cavity to be independently accessed by cask crawler 90 with ease. The subterranean configuration of underground VVOs 20 greatly reduce the height of the stack structures created during loading/transfer procedures where transfer cask 80 is positioned atop underground VVO 20.

An embodiment of a method of using underground VVO 20 to store spent nuclear fuel canister 70 will now be discussed in relation to FIGS. 2-5. Upon being removed from a spent fuel pool and treated for dry storage, spent fuel canister 70 is positioned in transfer cask 80. Transfer cask 80 is carried by cask crawler 90 to a desired underground VVO 20 for storage. While a cask crawler is illustrated, any suitable means of transporting transfer cask 80 to a position above underground VVO 20 can be used. For example, any suitable type of load-handling device, such as without limitation, a gantry crane, overhead crane, or other crane device can be used.

In preparing the desired underground VVO 20 to receive canister 70, lid 41 is removed from body 21 so that cavity 26 is open. Cask crawler 90 positions transfer cask 80 atop underground VVO 20. After transfer cask 80 is properly secured to the top of underground VVO 20, a bottom plate of transfer cask 80 is removed. If necessary, a suitable mating device can be used to secure the connection of transfer cask 80 to underground VVO 20 and to remove the bottom plate of transfer cask 80 to an unobtrusive position. Such mating devices are well known in the art and are often used in canister transfer procedures. Canister 70 is then lowered by cask crawler 90

from transfer cask 80 into cavity 26 of underground VVO 20 until the bottom surface of canister 70 contacts and rests atop support blocks 32, as described above.

When resting on support blocks 32, a major portion of the canister's height is below grade. Most preferably, the entirety of canister 70 is below grade when in its storage position. Once canister 70 is positioned and resting in cavity 26, lid 41 is placed over cavity 26, substantially enclosing cavity 26. Lid 41 is oriented atop body 21 so that shear ring 47 protrudes into cavity 26 and outlet ventilation ducts 42 are azimuthally and circumferentially separated from inlet ventilation ducts 25 on body 21. Lid 41 is then secured to body 21 with bolts. As a result of the heat emanating from canister 70, cool air from the ambient is siphoned into inlet ventilation ducts 25 and into the bottom of cavity 26. This cool air is then warmed by the heat from the spent fuel in canister 70, rises in cavity 26 via annular space 60 (FIG. 6) around canister 70, and then exits cavity 26 as heated air via outlet ventilation ducts 42 in lid 41.

Referring now to FIG. 9, an integral structure 100 for storing spent nuclear fuel is illustrated according to an embodiment of the invention. Integral structure 100 is essentially a combination of shell 34, inlet ventilation ducts 25, and bottom plate 38 of underground VVO 20 without the concrete body. Integral shell 100 can be used to store canisters of spent nuclear fuel without the addition of the concrete body. Therefore, some embodiments of the present invention will be the integral structure 100 itself.

Shell 34, bottom plate 38, and inlet ventilation ducts 25 are preferably formed of a metal, such as low carbon steel. Other suitable materials include, without limitation, stainless steel, aluminum, aluminum-alloys, plastics, and the like.

Inlet ventilation ducts 25, bottom plate 38, and shell 34 are seal welded at all junctures to form a unitary structure that is hermetically sealed to the ingress water and other fluids. The only way water or other fluids can enter cavity 26 is through inlets 27 or top opening 101 of shell 34. The height of shell 34 is designed so that a canister of spent fuel can be positioned within cavity 26 so as not to protrude from top opening 101. There is no limitation on the height to which shell 34 can be constructed. The exact height of shell 34 will be dictated by the height of the spent fuel canister to be stored therein, the desired depth (below grade) at which the canister is to be stored, whether the outlet ventilation ducts are in the lid or integrated into the shell 34, and/or the desired height of the outlet air plenum that is to exist during canister storage.

FIGS. 10-13 illustrate a process of using integral structure 100 to store a spent fuel canister at a below grade position at an ISFSI, or other location, according to one embodiment of the present invention. It should be noted that the any of the design and/or structural details discussed above with respect to underground VVO 20 can be incorporated into integral structure 100, such as, for example, the use of vent screens, variable configurations of the inlet and outlet ducts, clearances, the use of an insulation, etc. However, in order to avoid redundancy, a discussion of these details will be omitted with the understanding that any or all of the details of underground VVO 20 are (or can be) incorporated into the storing methods and apparatus of integral structure 100, and vice versa.

Referring to FIG. 10, a hole 200 is first dug into the ground 210 at a desired position within the ISFSI and at a desired depth. Once hole 200 is dug, and its bottom properly leveled, base 22 is placed at the bottom of hole 200. Base 22 is a reinforced concrete slab designed to satisfy the load combinations of recognized industry standards, such as ACI-349. However, in some embodiments, depending on the load to be supported and/or the ground characteristics, the use of a base may be unnecessary.

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Once base 22 is properly positioned in hole 200, integral structure 100 is lowered into the hole 200 in a vertical orientation until it rests atop base 22. Bottom plate 38 of integral structure 100 contacts and rests atop the top surface of base 22. If desired, the bottom plate 38 can be bolted or otherwise

secured to the base 22 at this point to prohibit future movement of the integral structure 100 with respect to the base 22. Referring to FIG. 11, once integral structure 100 is resting atop base 22 in the vertical orientation, soil supply pipe 300 is moved into position above hole 200. Soil 301 is delivered into hole 200 exterior of integral structure 100, thereby filling hole 200 with soil 301 and burying a portion of the integral structure 100. While soil 301 is exemplified to fill hole 200, any suitable engineered fill can be used that meets environmental and shielding requirements. Other suitable engineered fills include, without limitation, gravel, crushed rock, concrete, sand, and the like. Moreover, the desired engineered fill can be supplied to the hole by any means feasible, including manually, dumping, and the like.

Referring to FIG. 12, soil 301 is supplied to hole 200 until soil 301 surrounds integral structure 100 and fills hole 200 to a level where soil 301 is approximately equal to ground level 212. Soil 301 is in direct contact with the exterior surfaces of integral structure 100 that are below grade. When hole 200 is filled with soil 301, inlets 27 of inlet ventilation ducts 25 are above grade. Shell 34 also protrudes from soil 301 so that opening 101 is slightly above grade. Therefore, because integral structure 100 is hermetically sealed at all junctures, below grade liquids and soil can not enter into cavity 26 or inlet ventilation ducts 25. Support blocks 32 are provided at the bottom of cavity 26 for supporting a stored spent fuel canister.

Referring to FIG. 13, once hole 200 is adequately filled with soil 301, a canister 70 of spent fuel 70 is loaded into cavity 26 of integral structure 100. The canister loading sequence is discussed in greater detail above with respect to FIG. 5. Canister 70 is lowered into cavity 26 until it rests on support blocks 32. As discussed above with respect to FIG. 6, support blocks 32 and outlets 28 of integral structure 100 are specially designed to deal with "smart flood" conditions. Canister 70 rests on support blocks 32, forming an inlet air plenum 33 between the bottom of canister 70 and the floor of cavity 26 (which in this case is bottom plate 38).

When canister 70 is supported on support blocks 32, the entire height of canister 70 is below ground level 212. This maximizes use of the ground's radiation shielding capabilities. The depth at which canister 70 is below ground level 212 can be varied by increasing or decreasing the depth of hole 200. Once canister 70 is supported in cavity 26, lid 41 is placed atop shell 34, thereby closing opening 101 and prohibiting radiation from escaping upwards from cavity 26. Outlet air plenum 36 is formed between the bottom surface of lid 41 and the top of canister 70.

Lid 41 comprises outlet ventilation ducts 42. Outlet ventilation ducts 42 form passageways from outlet air plenum 36, through lid 41, to the ambient air above ground level 212. Outlet ventilation ducts 42 do not have to be provided in lid 41, but can be formed as part of the integral structure 100 if desired. This will be discussed in greater detail below with respect to FIG. 14.

Referring still to FIG. 13, when integral structure 100 is used to store spent nuclear fuel canister 70, the radiation shielding effect of the sub-grade is utilized while adequately facilitating cooling of canister 70. The cooling of canister 70 is facilitated by cool air entering inlet ventilation ducts 25 via above grade inlets 27. The cool air travels through inlet ventilation ducts 25 until it enters cavity 26 at or near inlet air

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plenum 33 via below grade outlets 28. Once the cool air is within cavity 26 it is warmed by the heat emanating from canister 70. As the air is warmed, it travels upward along the outer surface of canister 70 via annular space 60 until the air enters outlet air plenum 36. As the air travels upward through annular space 60 it continues to remove heat from canister 70. The warmed air then exits cavity 26 via outlet ventilation ducts 42 and enters the ambient air. This natural convective cooling flow repeats continuously until the canister 70 is adequately cooled.

Referring now to FIG. 14, an alternative embodiment of an integral structure 200 is illustrated. Integral structure 200 is used to store a spent fuel canister in manner similar to that of integral structure 100 discussed above. While much of the structure is identical to that of integral structure 100, integral structure 200 further comprises outlet ventilation ducts 42 seal welded directly to shell 34. The outlet ventilation ducts 42 can be formed out of any of the materials discussed above with respect to the inlet ventilation ducts 25. As a result of the outlet ventilation ducts 42 being part of integral structure 200, lid 41 can be free of such ducts. The cooling process of canister 70 remains the same.

FIG. 15 illustrates an integral structure 300 according to another aspect of the present invention. Integral structure 300 is similar in many respect to that of integral structures 100 and 200 in its design and functioning. However, integral structure 300 is specifically designed to store canisters 70 holding low heat spent fuel. When a canister 70 is giving off low heat, for example in the magnitude of 2-3 kW, it is not necessary to supply inlet ventilation ducts to supply cool air to cavity 26. Therefore, the inlet ventilation ducts are omitted from integral structure 300. Integral structure 300 comprises only outlet ventilation ducts 42, which act as both an inlet for the cooler air and an outlet for the warmer air.

While outlet ventilation ducts 42 of integral structure 300 are seal welded to shell 34, it is possible for the outlet ventilation ducts to be located in the lid 41 if desired. Moreover, the concept of eliminating the inlet ventilation ducts for low heat load canister storage can be applied to any of the underground or above ground VVO embodiments illustrated in this application, specifically including underground VVO 20 and its derivatives.

While the invention has been described and illustrated in sufficient detail that those skilled in this art can readily make and use it, various alternatives, modifications, and improvements should become readily apparent without departing from the spirit and scope of the invention. Specifically, it is possible for the entire underground VVO and/or integral structure of the present invention to be below grade, so long as the inlet ventilation ducts and/or outlet ventilation ducts open to the ambient air above grade. This facilitates very deep storage of spent fuel canisters.

What is claimed is:

1. A system for storing spent nuclear fuel comprising:
  - a shell forming a cavity, the shell having an open top end, a hermetically closed bottom end, a height and an opening in a side wall of the shell;
  - a canister storing spent nuclear fuel positioned in the cavity, the cavity having a horizontal cross-section that accommodates no more than one of the canister;
  - an inlet ventilation duct having an inlet opening, the inlet ventilation duct connected to the shell so as to enclose the opening of the shell, the inlet ventilation duct forming a hermetically sealed passageway from the inlet opening to the opening of the shell, the hermetically sealed passageway excluding the cavity; and

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the opening of the shell positioned at a first vertical height above the bottom end of the shell and the inlet opening positioned at a second vertical height above the bottom end of the shell, wherein the second vertical height is greater than the first vertical height.

2. The system of claim 1 further comprising:

a lid positioned atop the shell so as to substantially enclose the open top end of the shell, the lid being non-unitary with respect to the shell; and

wherein the lid comprises an outlet ventilation duct forming a passageway from a top of the cavity to an ambient atmosphere.

3. The system of claim 1 further comprising an outlet ventilation duct forming a passageway from a top of the cavity to an ambient atmosphere.

4. The system of claim 3 wherein the outlet ventilation duct is hermetically connected to the shell.

5. The system of claim 1 further comprising a bottom plate, the shell positioned atop the bottom plate so that the bottom plate forms the hermetically closed bottom end, and wherein the bottom plate, the shell, and the inlet ventilation duct form an integral structure.

6. The system of claim 1 further comprising a concrete body surrounding the shell, the inlet ventilation duct extending through the concrete body.

7. The system of claim 1 further comprising a first of the inlet ventilation duct and a second of the inlet ventilation duct, wherein each of the first and second inlet ventilation ducts are substantially S-shaped.

8. The system of claim 1 further comprising means for insulating the inlet ventilation duct from the shell.

9. The system of claim 1 further comprising a base positioned below a grade, the shell and the inlet ventilation duct positioned atop the base.

10. The system of claim 1 further comprising:

a ground having a grade; and

wherein a major portion of the shell is positioned below the grade so that the opening in the side wall of the shell is below the grade, and the inlet opening is above the grade.

11. The system of claim 10 further comprising:

a lid positioned atop the shell so as to substantially enclose the open top end of the shell, the lid being non-unitary with respect to the shell; and

wherein an outlet air plenum is created between the lid and the canister, and an outlet ventilation duct that forms a passageway from the outer air plenum to an ambient atmosphere above the grade.

12. The system of claim 1 wherein the shell and the inlet ventilation duct are constructed of steel, the inlet ventilation duct being seal welded to the shell.

13. The system of claim 1 further comprising one or more support blocks located on a floor of the cavity.

14. The system of claim 1 further comprising:

a lid positioned atop the shell so as to substantially enclose the open top end of the shell, the lid being non-unitary with respect to the shell;

a first of the inlet ventilation duct and a second of the inlet ventilation duct, wherein each of the first and second inlet ventilation ducts are substantially S-shaped;

one or more support blocks located on a floor of the cavity; the lid secured to a top of the shell, the lid comprising an outlet ventilation duct;

a bottom plate; wherein the bottom plate, the shell, and the first and second inlet ventilation ducts form an integral structure;

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a concrete body surrounding the shell, the first and second inlet ventilation ducts extending through the concrete body;

means for insulating the inlet ventilation duct from the shell;

a ground having a grade;

the shell positioned sufficiently below the grade so that the entire canister is below the grade;

a base positioned below the grade, the shell and inlet ventilation duct positioned atop the base;

wherein the shell, the inlet ventilation duct, and the bottom plate are constructed of steel and seal welded together; and

wherein an outlet air plenum is created between the lid and the canister.

15. The system of claim 1 further comprising a lid positioned atop the shell so as to substantially enclose the open top end of the shell, the lid being non-unitary with respect to the shell.

16. The system of claim 1 further comprising:

the shell and the inlet ventilation ducts being constructed of metal; and

a concrete body surrounding the shell, the inlet ventilation duct extending through the concrete body.

17. A system for storing spent nuclear fuel comprising:

a shell forming a cavity, the shell having an open top end, a hermetically closed bottom end, a height and an opening in a side wall of the shell;

a multi-purpose canister storing spent nuclear fuel positioned in the cavity so that an annular space exists between the shell and the multi-purpose canister, the cavity having a horizontal cross-section that accommodates no more than one of the multi-purpose canister;

an inlet ventilation duct extending from an outside surface of the shell and having an inlet opening, the inlet ventilation duct connected to the shell so as to enclose the opening of the shell, the inlet ventilation duct forming a hermetically sealed passageway from the inlet opening into the annular space via the opening of the shell;

the opening of the shell positioned at a first vertical height above the bottom end of the shell and the inlet opening positioned at a second vertical height above the bottom end of the shell, wherein the second vertical height is greater than the first vertical height; and

wherein a line of sight does not exist through the hermetically sealed passageway from the inlet opening to the opening.

18. A system for storing spent nuclear fuel comprising:

a shell forming a cavity, the shell having an open top end, a hermetically closed bottom end, a height and an opening in a side wall of the shell;

a canister storing spent nuclear fuel positioned in the cavity, the cavity having a horizontal cross-section that accommodates no more than one of the canister;

an inlet ventilation duct having an inlet opening, the inlet ventilation duct connected to the shell so as to enclose the opening of the shell, the inlet ventilation duct forming a hermetically sealed passageway exclusive of the cavity that extends from the inlet opening into the cavity via the opening of the shell; and

the opening of the shell positioned at a first vertical height above the bottom end of the shell and the inlet opening positioned at a second vertical height above the bottom end of the shell, wherein the second vertical height is greater than the first vertical height.

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**19.** The system of claim **1** wherein the open top end of the cavity has a horizontal cross section through which the canister can pass.

**20.** The system of claim **17** wherein the open top end of the cavity has a horizontal cross section through which the multi-  
purpose canister can pass. 5

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**21.** The system of claim **18** wherein the open top end of the cavity has a horizontal cross section through which the canister can pass.

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