

PATENTS-US--A270682

DE 82011753

S.N. 270, 682 (79)
S-54, 593
RL-8090
filed 6-4-81

NTIS PC A02/MF A01

PATENTS-US--A270682

DE82 011753

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MASTER

THERMIONIC SWITCHED SELF-ACTUATING REACTOR

SHUTDOWN SYSTEM

By: Donald M. Barrus, USA
4821 Alexandria Lane
San Jose, Calif. 95129

Charles D. Shires, USA
1066 Wilsham Drive
San Jose, Calif. 95132

William A. Brummond, USA
4608 Almond Circle
Livermore, Calif. 94550

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THERMIONIC SWITCHED SELF-ACTUATING REACTOR
SHUTDOWN SYSTEM

Background of the Invention

The invention described herein arose under
5 Contract No. DE-AT03-76SF71032 between the United States
Department of Energy and the General Electric Company.

The invention relates to control systems for
nuclear reactors, and, more particularly, to a
self-actuated control system responsive to temperature
10 increase or over-power conditions of a reactor.

The use of control systems to regulate the
reactivity of a nuclear reactor by varying the location of
control (neutron absorber) elements or rods with respect to
the reactive core is well known. With a view toward the
15 possibility of an emergency condition arising, as by an
unexpected drop in coolant flow, increase in temperature,
or rise in reactivity, such control systems include
arrangements for "scramming" the control rods, i.e., for
rapid insert of the absorber elements into the core to
20 quickly shut down the reactor.

With the advent of the liquid metal fast breeder
reactor (LMFBR) and the Gas-Cooled Fast Reactor (GCFR), a

need for faster, less complex, more reliable control rod scram or shutdown systems has become apparent, whereby the reactivity of the reactor can be quickly shut down.

More recent efforts have been directed to the
5 desirability of utilizing secondary or alternate control systems of the self-actuating type which would make an LMFBR or GCFR inherently safe. Such alternate or self-actuating systems provide control without reliance on the primary reactor control system or plant operators,
10 while being capable of actuation by the plant operators. These efforts have resulted in systems which sense the reactor flow rate and actuate when the flow drops below a predetermined level, measure the temperature of the coolant and actuate when the temperature exceeds a specified point,
15 or measure the flux or reactivity level of the reactor and actuate when the reactivity exceeds a specified level. The following exemplifies various operator-actuated and/or self-actuated prior art control systems.

U. S. Patent No. 4,158,602 issued June 19, 1979,
20 to L. E. Minnick discloses a self-actuating scram system triggered by a loss of primary coolant flow which supports the absorber rods above the reactor core region. A loss of primary coolant flow causes a decrease in the supporting pressure on the absorber rods allowing the rods to fall
25 into the core region, thus scramming the reactor.

U. S. Patent No. 3,359,172 issued December 19,
1967, to C. S. Olsson discloses a reactor shutdown system employing an electromagnet-operated valve to terminate coolant flow. Absorber rods, normally suspended above the
30 core, will fall into the core region upon loss of coolant flow.

U. S. Patent No. 2,931,763 issued April 6, 1960, to J. A. Dever discloses a control apparatus incorporating electromagnetically held control rods. The control rods are released upon a signal initiated within an ionization 5 chamber. Electron tubes conduct sufficient current to retain the control rods as long as the neutron flux remains below a predetermined level.

U. S. Patent No. 2,781,308 issued February 12, 1957, to E. C. Creutz et al discloses a neutronic reactor 10 control system in which voltage produced by an ionization chamber effects release of absorber rods from an electromagnetic latching mechanism.

U. S. Patent No. 3,940,309 issued February 24, 1976, to F. Imperiali discloses a self-actuated scram 15 system utilizing electromagnetic means to suspend and release absorber material into the reactor core region.

U. S. Patent No. 2,867,727 issued January 6, 1959, to H. Welker et al discloses a neutron-sensing device in which neutrons, penetrating a semiconductor, create 20 electron-hole pairs which produce a voltage which can be monitored.

U. S. Patent No. 4,085,004 issued April 18, 1978, to J. C. Fletcher et al discloses a control device for a nuclear thermionic power source. Actual neutron flux is 25 compared to a linear function of current supplied by a thermionic converter.

U. S. Patent No. 3,970,007 issued July 20, 1976, to J. R. Klein discloses a neutron detection device utilizing uranium hydride as a neutron sensor. Radiation 30 causes the uranium hydride to fission, releasing heat and

hydrogen gas. The gas pressure breaks a normally closed circuit causing activation of a safety device.

U. S. Patent No. 3,177,124 issued April 6, 1965, to D. T. Eggen et al discloses a reactor control device triggered by the melting of a solder joint. Upon experiencing an increase in neutron flux a layer of uranium abutting the solder joint begins to heat the joint until it melts, releasing absorber material.

U. S. Patent No. 2,904,487 issued September 15, 1959, to J. J. Dickson discloses a reactor control system employing a temperature responsive transducer actuated by heat generated from a uranium strip. Neutron flux causes the uranium strip to fission and heat a bimetallic transducer which generates an automatic control signal.

Thus, while various approaches have been developed for reactor control, a need still exists for a simple self-actuated control system which is failsafe, reliable, testable in the core at shutdown, resettable and capable of actuating upon sensing either the initiation of a transient coolant temperature increase event or a transient over-power (increased reactivity) event, as well as being capable of actuation by plant operators. The above-cited art fulfills certain of these requirements in various ways, but involves complex apparatus and is not fully responsive to both or either of these reactor conditions by use of simple control apparatus.

Related Application

The present invention is in the same general field of art as U. S. Application Serial No. _____ (DOE Case S-54,592), filed _____, 1981, and assigned to the assignee of this application.

Summary of the Invention

It is an object of the present invention to provide a self-actuated control system for nuclear reactors.

It is a further object of the invention to provide 5 a self-actuated shutdown system for a reactor which is responsive to coolant temperature increase and/or over-power (increased reactivity) conditions of the reactor.

A further object of the invention is to provide a self-actuating reactor shutdown system, particularly 10 applicable for liquid metal cooled fast breeder reactors (LMFBR) and gas-cooled fast reactors (GCFR).

Another object of the invention is to provide a self-actuated shutdown system for a reactor which utilizes 15 a thermionic switched electromagnetic latch arrangement responsive to reactor neutron flux changes and to reactor coolant temperature changes.

Another object of the invention is to provide a thermionic switched, electromagnetic latched self-actuating reactor shutdown system which utilizes a thermionic diode 20 for actuating the electromagnetic latch for releasing absorber elements into a reactor core.

The self-actuating shutdown system (SASS) of the present invention, which utilizes a thermionic sensing device, acts directly to cause release (scram) of the 25 control rod (absorber element) without a reference or signal from the main reactor plant protection and control systems. The thermionic trigger or switch acts in conjunction with, but independent of, the plant control and protective system and therefore provides separate and 30 redundant reactor shutdown capability for selected off-normal conditions.

To optimize both the temperature and neutron flux effects, the invention utilizes two separate detectors which are tailored to their specialized positions and functions, as follows:

5 1. Self-actuation in response to a temperature increase of the reactor coolant occurs by heating of a thermionic sensor to a selected set trigger point by the coolant as it emerges from fuel assemblies adjacent to the SASS and impinges on the sensor mounted above the reactor
10 fuel assemblies. As the reactor coolant temperature increases, the temperature of the thermionic sensor is raised to a point where it conducts current (changes from a high impedance to a very low impedance) generating the signal used for shutdown.

15 2. Self-actuation in response to reactor neutron flux increase is achieved by placing the thermionic sensor near the reactor core or flux region. The thermionic sensor is made responsive to the reactor flux by the attachment of uranium, or other material which heats from neutron bombardment, to its emitter or by enclosing the emitter of the sensor inside a blanket of these materials.
20 When the reactor neutron flux is increased, the uranium or other heating material responds by heating the thermionic sensor to the selected trigger point where it conducts
25 current generating a shutdown signal.

The present invention broadly encompasses a self-actuated reactor shutdown system wherein an electromagnetically actuated latch mechanism retains the control rod (neutron absorber element) in a ready or cocked position exterior of the reactor core region, and upon an increase in coolant temperature beyond a selected point and/or upon an increase in neutron flux (over-power) beyond a selected point, a thermionic device connected

5 electrically to the electromagnetic latch mechanism is heated so as to conduct current which effects a short-circuit of the electromagnet causing same to lose holding power which releases the control rod to drop by gravitational force into the reactor core causing shutdown of the reactor. The thermionic device may, for example, constitute a thermionic diode connected electrically in parallel with the electromagnet.

Brief Description of the Drawings

10 Figures 1A and 1B illustrate, in partial cross-section, an embodiment of a SASS positioned within a reactor core fuel bundle in accordance with the invention;

Figure 2 is a view of the Fig. 1 embodiment taken along the lines 2-2 of Fig. 1;

15 Figure 3 is a cross-sectional view of an embodiment of a thermionic diode in accordance with the invention taken along the line A-A of Fig. 4;

Figure 4 is a view of the diode taken along the line B-B of Fig. 3; and

20 Figure 5 schematically illustrates an embodiment of an electric circuit interconnecting the electromagnet and the thermionic switch means with an external power supply.

Detailed Description of the Invention

25 The present invention is directed to a self-actuated reactor shutdown system (SASS). While the invention is particularly applicable for use in a liquid

metal fast breeder reactor (LMFBR), it can be utilized in other types of reactors, such as the gas-cooled fast reactor (GCFR). A SASS is defined as a control rod system that can scram the reactor automatically without either a signal from an external control circuit or an operator action. Initiation of the scram in accordance with the present invention is entirely from direct sensing of coolant temperature and/or an over-power condition.

Particular requirements of a SASS are as follows:

- 10 1. It must be capable of operating automatically.
2. It must be fail-safe, such that no malfunction of the SASS can cause a hazardous condition.
- 15 3. It must not impose excessive restrictions on normal operation of the reactor.
4. It must have as little as possible adverse effect upon plant availability.
5. It must contribute substantially to the overall safety of the reactor.

The SASS of this invention satisfies each of the above requirements and employs an electromagnetic latch mechanism and a thermionic diode to activate a control rod scram without a signal from the reactor operating control system. The use of electromagnetic latch mechanisms to retain absorber elements such that during normal operation the control rod is held above the reactor core and is dropped into the core upon release of the latch mechanism by gravitational force on the absorber element, are known in the art as pointed out above. While the present invention utilizes this known principal of operation, the invention also incorporates the use of a thermionic device which is responsive to high coolant temperature and/or high

neutron flux (over-power) conditions of the reactor. The diode functions to control an electromagnet which, in turn, releases the absorber element, whereby the SASS of this invention provides a system responsive to both coolant 5 temperature and neutron flux.

The SASS incorporating the present invention cannot be overridden by external control either from operators or plant control systems with the intent to hold off a scram. Further, the SASS of this invention is able to be restored 10 to operational or cocked condition only by deliberate operator action, and only when the reactor conditions have been corrected and will permit reactivation. In addition, the SASS of this invention is responsive to scram signals generated by the plant protective systems.

15 Referring now to Figs. 1A and 1B, a SASS incorporating the present invention is illustrated. As known in the art and illustrated in the drawings, the control rods or elements of the SASS are positioned within a fuel bundle containing a plurality of fuel rods or 20 assemblies. The fuel bundles are located in the core of the reactor, while the control rod or neutron absorber element of that bundle is maintained in a location exterior of the reactor core region under normal reactor operating conditions. As shown in Figs. 1A-1B and 2, the SASS or 25 control assembly generally indicated at 10 is positioned centrally within a fuel bundle composed of a plurality of reactor fuel rods or assemblies 11. The control assembly 10 is encased in guide tube 12 which extends through the reactor core region indicated at 13 and secured in the core 30 at the lower end of the guide tube as known in the art. Guide tube 12 is provided at the lower end 14 with a plurality of coolant inlet openings 15 through which reactor coolant under pressure is directed upwardly as indicated by the flow arrows. Movably located within the

upper end 16 of guide tube 12 are an absorber assembly (control rod) 17 and a main driveline assembly 18, which are spaced from the inner surface of the guide tube so as to provide for coolant flow therebetween as indicated by flow arrows. Absorber assembly 17, containing neutron absorbing material as known in the art, is provided with a plurality of openings 19 in the lower and upper ends thereof to allow coolant to flow therethrough, as indicated by flow arrows. Secured to the upper end of absorber assembly 17 is a magnet armature 20 which cooperates with an electromagnet 21 secured to the main driveline 18 to retain the absorber assembly in its ready or cocked position exterior of core region 13 as shown, when electromagnet 21 is energized. Positioned in guide tube 12 below the core region 13 is a control assembly snubber or kinetic energy absorbing means 22 which retards the downward movement of the absorber assembly 17 after it passes into the core region.

As pointed out above, the direct holding of a reactor control (absorber) rod by an electromagnet secured to the end of a control drive similar to the apparatus of Figs. 1A and 1B thus far described is known. In operation of the apparatus thus far described, the electromagnet 21 is lowered by the driveline 18 to contact the magnet armature 20 on the top of the control rod or absorber assembly 17, and the electromagnet 21 is energized by application of electrical current from a power source, whereby the assembly 17 is attracted to the electromagnet and is withdrawn from the core region 13 by driveline 18 and positioned in its ready or cocked location above the core region as shown. Release (scram) of the absorber assembly 17 is obtained by reducing the holding power of the electromagnet 21. For example, such release may be obtained by a known method where the reactor undergoes a thermal transient and the coolant is heated above normal

thereby heating the electromagnet to a calibrated curie point, causing the magnet to release the control rod. Release via the curie point approach is effective but slow.

The main driveline 18 is actuated by a
5 mechanically driven system supported on the reactor top shield. A variety of such mechanical drive systems are known, such as electrically driven racks and pinions, roller nut and ball nut screws. The driveline 18 is usually sealed by bellows that allow the linear movement to
10 be translated through the reactor containment boundary.

Release of the absorber element 17 in accordance with the present invention provides a substantially higher speed of response and involves a thermionic device such as one or more thermionic diodes illustrated in Figs. 3 and
15 4. The thermionic device is attached electrically in parallel with the electromagnet and when the device conducts it shorts the electromagnet current causing it to lose its holding power.

The thermionic switched electromagnetic latch of
20 the present invention as illustrated in Figs. 1A and 1B consists of a flux sensing thermionic switch 23 located above and electrically connected in parallel, as described hereinafter, with the electromagnet 21 and a temperature sensing thermionic switch 24 mounted on main driveline 18 above the top of guide tube 18. Note that Fig. 2 illustrates three switches 24 positioned around driveline 18. Thermionic switch 24 is also connected electrically in parallel, as hereinafter described, with electromagnet 21 and is located above the coolant outlet 25 of the fuel
25 assemblies 11 so that heated coolant indicated by the flow arrows passing through coolant outlet 25 is directed onto temperature sensing switch 24. A neutron shield 26 for
30 flux sensing thermionic switch 23 is positioned about the

switch by a neutron shield drive rod 27 operatively connected to the drive mechanism, not shown, for operating the main driveline 18 described above. Neutron shield 26, for example, may be constructed of material such as
5 depleted uranium. Main driveline 18 is provided with a plurality of coolant outlets 28 such that coolant from inlet 15 passes underpressure up through guide tube 12, through openings 19 and around absorber assembly 17, around electromagnet 21, around thermionic switch 23, upwardly
10 through main driveline 18, and exits via coolant outlets 28.

The flux sensing thermionic switch 23, which can be electrically identical to temperature sensing switch 24, is located within the control assembly 10 so that it will not in direct contact with high temperature coolant from
15 the fuel assemblies 11.

As shown in Fig. 2., a plurality of temperature sensing thermionic switches 24 can be placed around or along the driveline 18, or the switches 24 can be supported on extensions or arms over the fuel assembly coolant outlets 25. Also, ducts may be provided to direct the
20 coolant flow from outlets 25 onto the temperature sensing thermionic switch 24.

It is within the scope of this invention to utilize a plurality of flux sensing thermionic switches 23 within the control assembly 11 to provide for redundancy, set point, and position adjustment. Also, the flux sensing thermionic switch 23 can be placed in a different location than that illustrated, if needed, to more accurately adjust the detection ability.

30 The thermionic switches 23 and 24 of the Figs. 1A and 1B control assembly are embodied in Figs. 3 and 4 as a thermionic diode indicated generally at 30. The diode 30

consists of a sealed container 31 having therein an emitter 32 and a collector plate 33 separated by a gap 34, with a uranium blanket 35 positioned around emitter 32 which causes heating of diode due to neutron flux, and a quantity 5 of thermionic material 36 located within sealed container 31. Emitter 32 and collector plate 33 are connected to an electrical potential, as illustrated in Fig. 5, via electrical leads 37 and 38, respectively, which extend through insulators 39 in container 31. The uranium blanket 10 35 may be replaced by a quantity of uranium attached to the emitter 32.

By way of example, the diode 30 may be constructed of the following material: container 31 is of stainless steel; emitter 32 is of molybdenum, with a diameter of 15 0.750 in. and wall thickness of 0.050 in.; collector plate 33 is of molybdenum, with a diameter of 0.450 in. and wall thickness of 0.10 in.; gap 34 is in the range of 0.10 in.; uranium blanket 35 has a wall thickness of 0.10 in.; thermionic material 36 may be cesium or other metallic 20 vapors at operational temperatures. The electric leads 37 and 38 are of copper; and the insulators 39 are of alumina.

The thermionic material 36 is tailored to ionize at a selected temperature, for example, in the range of 1000°F to 1100°F. An electrical potential, from power 25 supply 40, such as 10 to 15 volts, is applied to the emitter 32 and collector plate 33 and when the ionization temperature of the thermionic material 36 is reached, due to reactor over-power conditions (high neutron flux) or coolant temperature, the material changes from high 30 resistance to low resistance thereby conducting more of the available current and, in effect, short-circuits the electromagnet 21 in Fig. 1A which is connected in parallel with the diode 30, via the control circuit illustrated in Fig. 5.

Figure 5 schematically illustrates an embodiment of an electric circuit interconnecting the electromagnet and the thermionic switch means with an external power supply. As shown, the thermionic switches or diodes 23 and 5 24 are connected in parallel with electromagnet 21 and to current limited, regulated D.C. power supply 40.

It has thus been shown that the present invention provides a self-actuating shutdown system (SASS) for nuclear reactors, particularly and LMFR, which is 10 responsive to low coolant flow and/or high neutron flux (over-power) conditions of the reactor. The SASS of this invention satisfies each of the requirements outlined above for such a system.

While a particular embodiment of the invention has 15 been illustrated and described, modifications will become apparent to those skilled in the art, and it is intended to cover in the appended claims all such modifications as come with the scope of the invention.

Abstract of Disclosure

A self-actuating reactor shutdown system incorporating a thermionic switched electromagnetic latch arrangement which is responsive to reactor neutron flux changes and to reactor coolant temperature changes. The system is self-actuating in that the sensing thermionic device acts directly to release (scram) the control rod (absorber) without reference or signal from the main reactor plant protective and control systems.

To be responsive to both temperature and neutron flux effects, two detectors are used, one responsive to reactor coolant temperatures, and the other responsive to reactor neutron flux increase. The detectors are incorporated into a thermionic diode connected electrically with an electromagnetic mechanism which under normal reactor operating conditions holds the the control rod in its ready position (exterior of the reactor core). Upon reaching either a specified temperature or neutron flux, the thermionic diode functions to short-circuit the electromagnetic mechanism causing same to lose its holding power and release the control rod, which drops into the reactor core region under gravitational force.

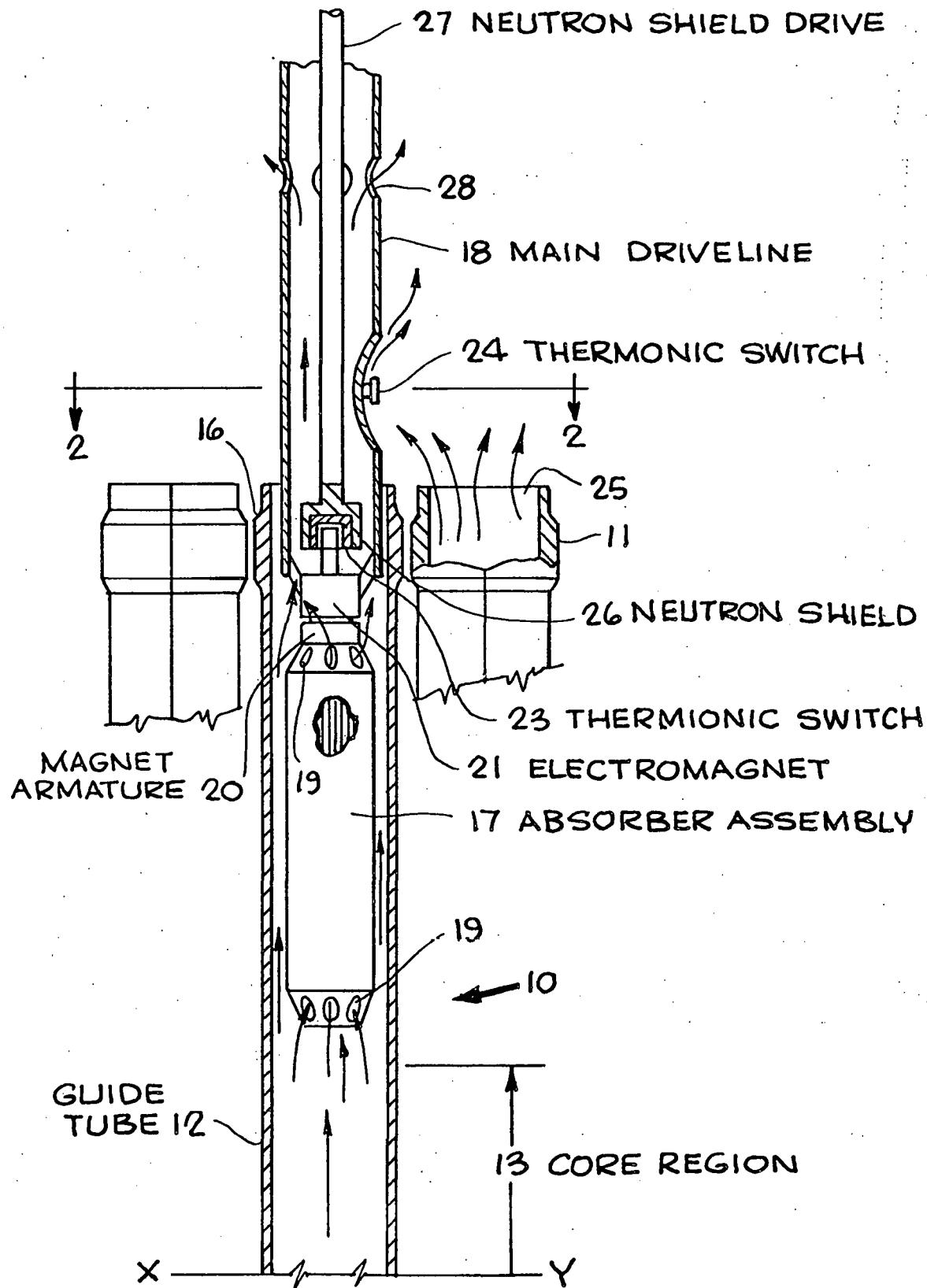


Fig. 1a

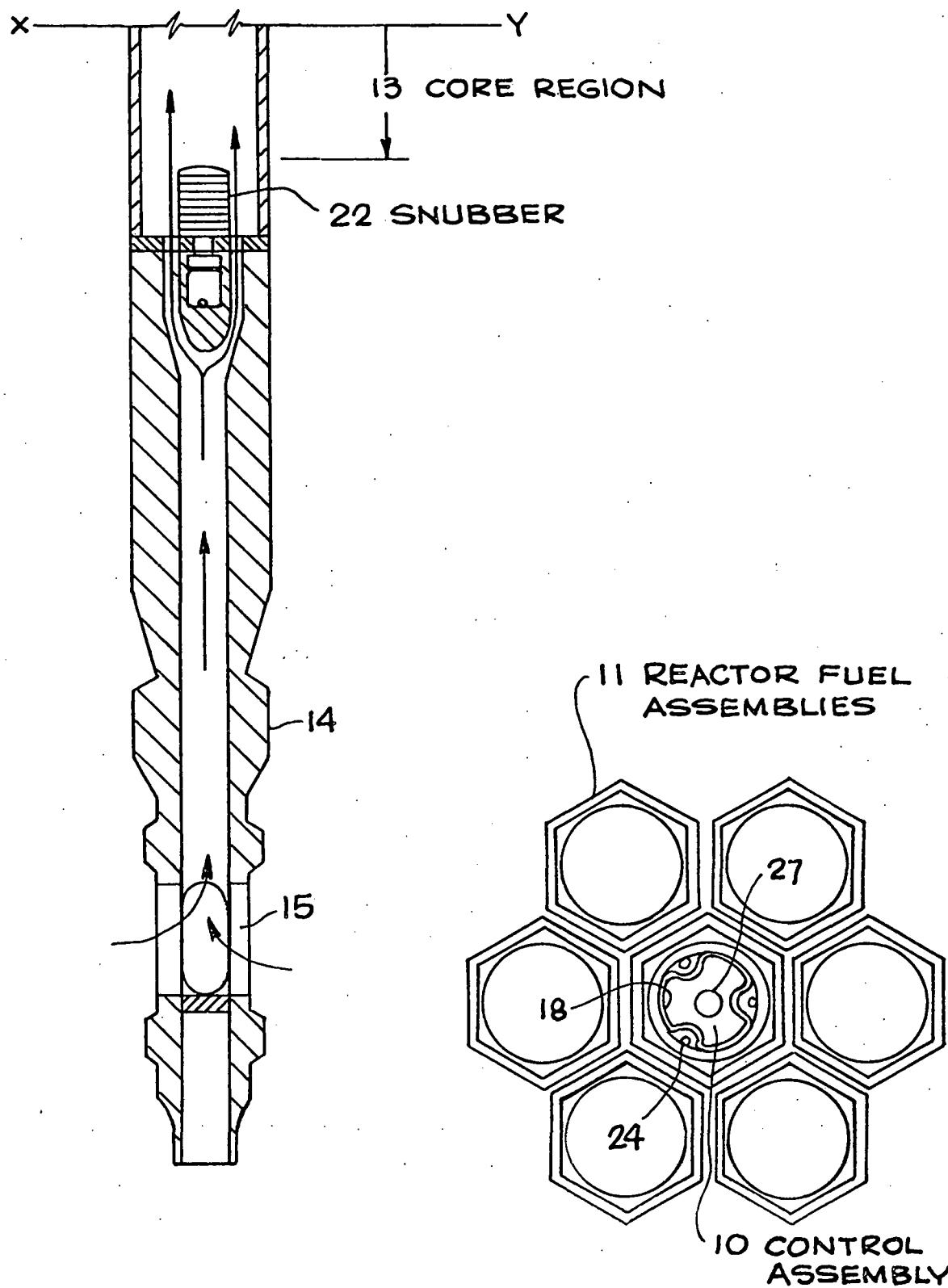


Fig. 1b

Fig. 2

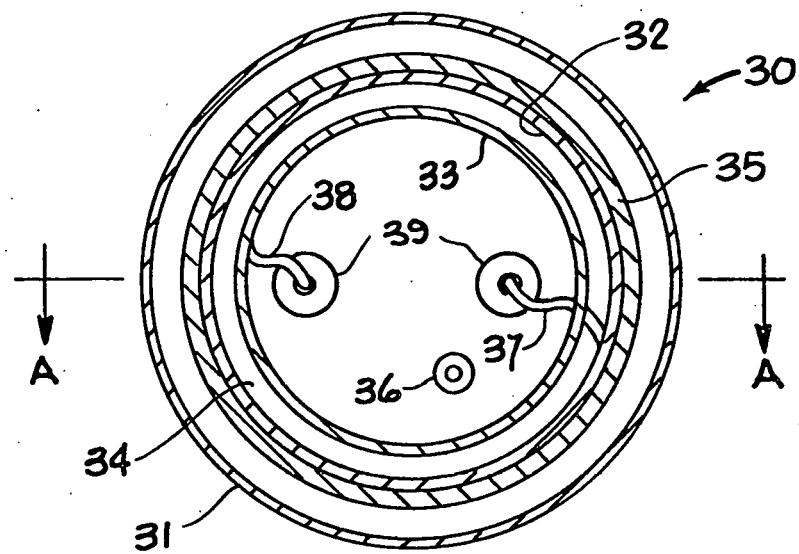


Fig. 4

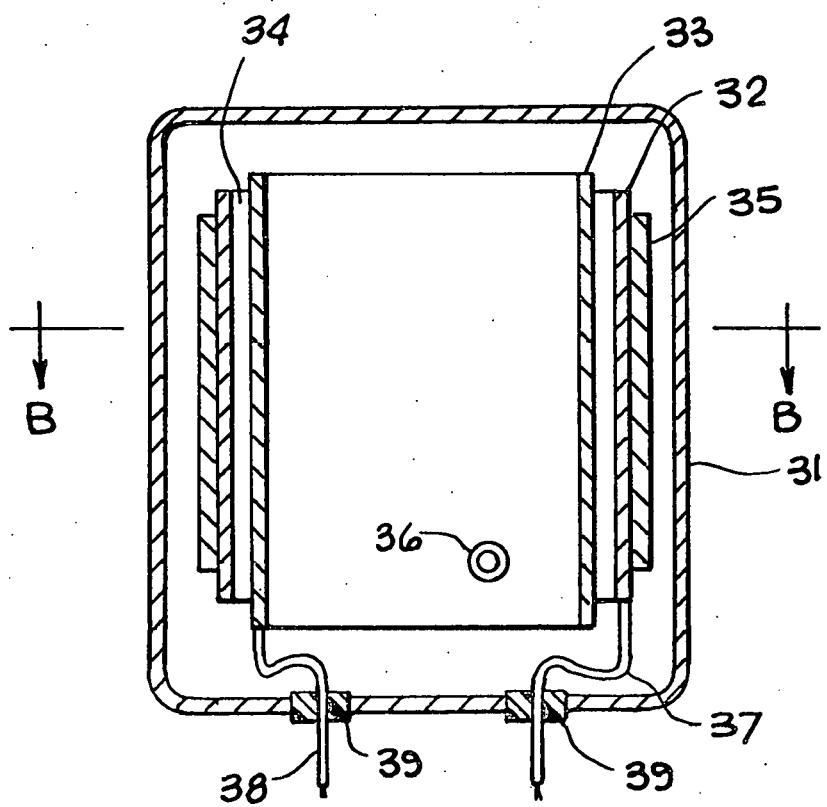


Fig. 3

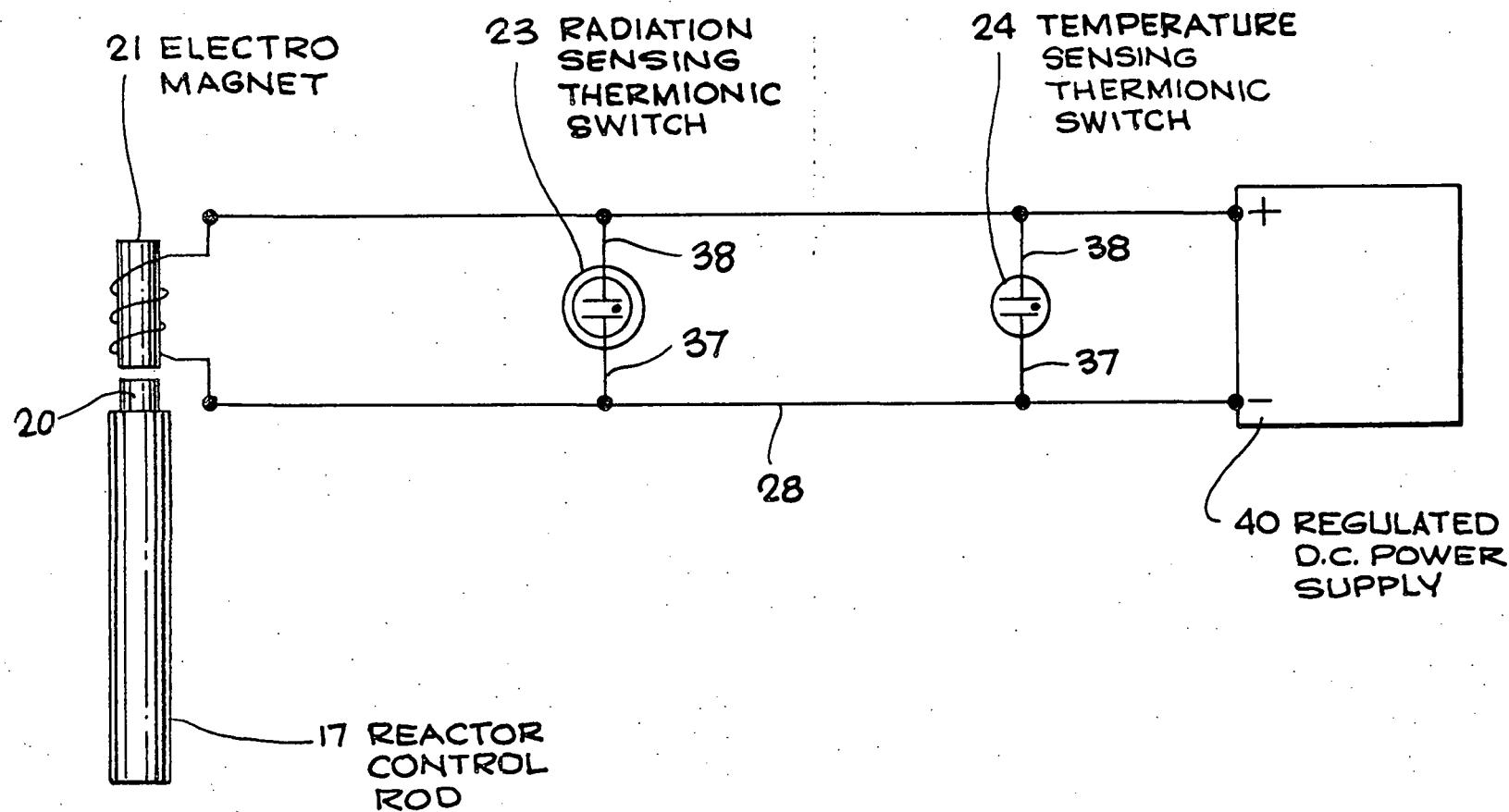


Fig. 5