

(12) UK Patent Application (19) GB (11) 2 054 218 A

(21) Application No 8018511
 (22) Date of filing 5 Jun 1980
 (30) Priority data 53627U
 (31) 53627U
 (32) 29 Jun 1979
 (33) United States of America (US)
 (43) Application published 11 Feb 1981
 (51) INT CL³ G05F 1/46 // H01J 27/00
 (52) Domestic classification G3U 211 215 BB
 (56) Documents cited GB 1294782
 (58) Field of search G3R G3U
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(54) Neutron generator control system

(57) A neutron generator tube 41 is provided with a neutron output control system which operates by monitoring the target beam current I_B and compares a function of this current with a reference voltage level (in operational amplifier 44) to develop a control signal V_G used in a series regulator (FET 1) to control the replenisher current of the neutron generator tube. The tube is described in use in a neutron well logging system.

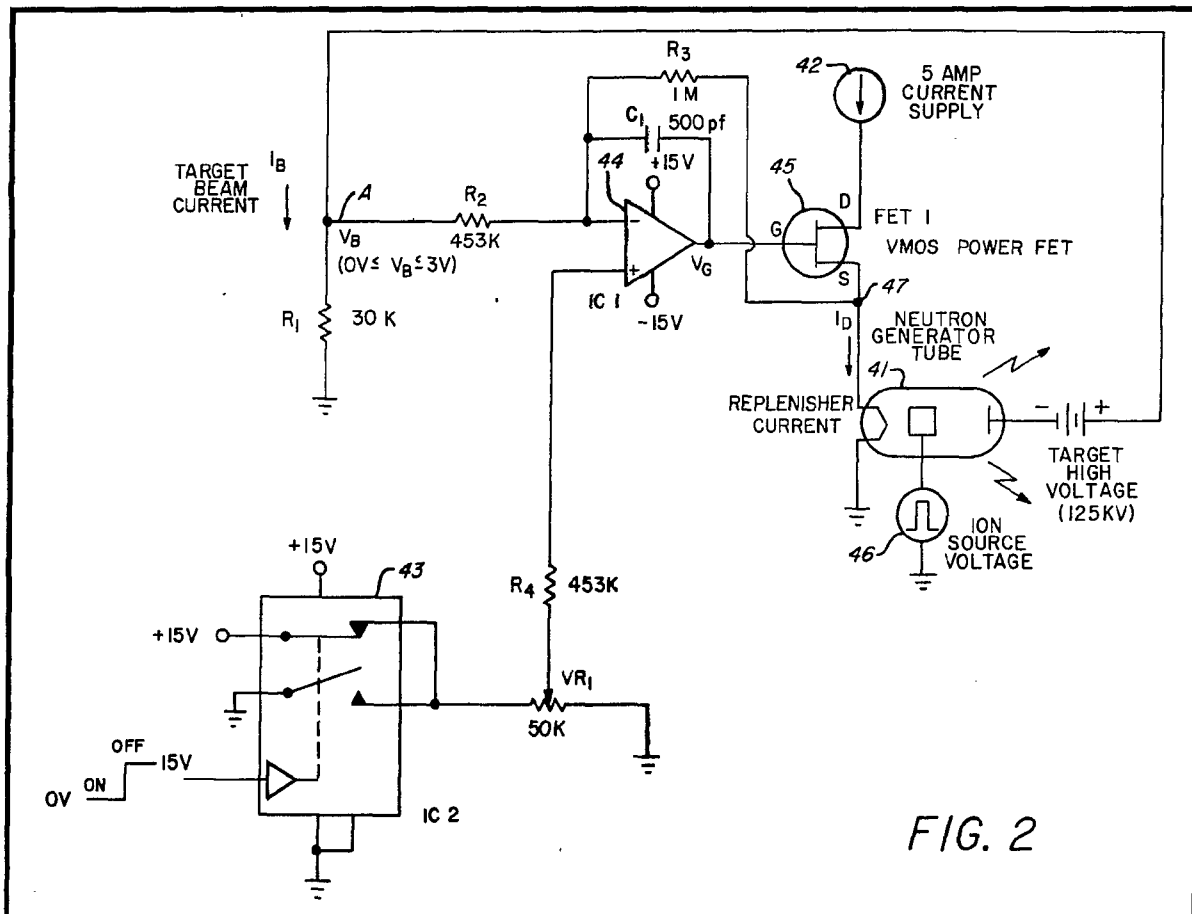


FIG. 2

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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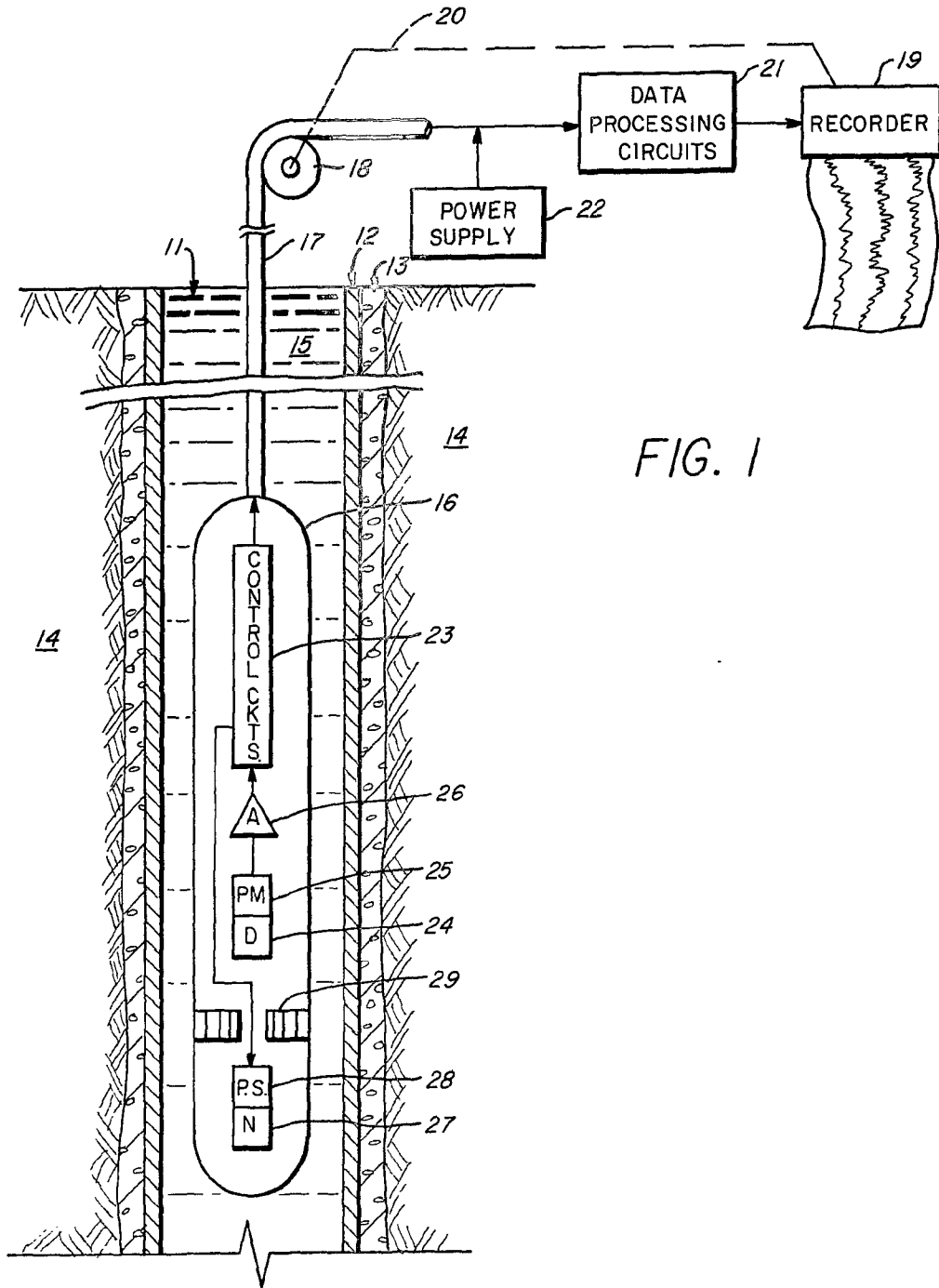


FIG. 1

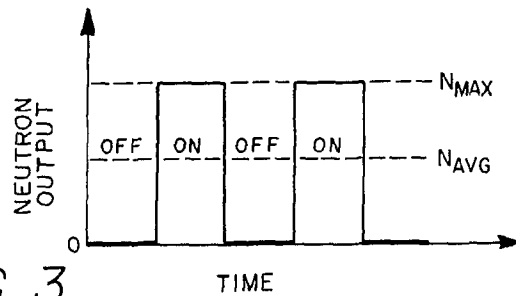


FIG. 3

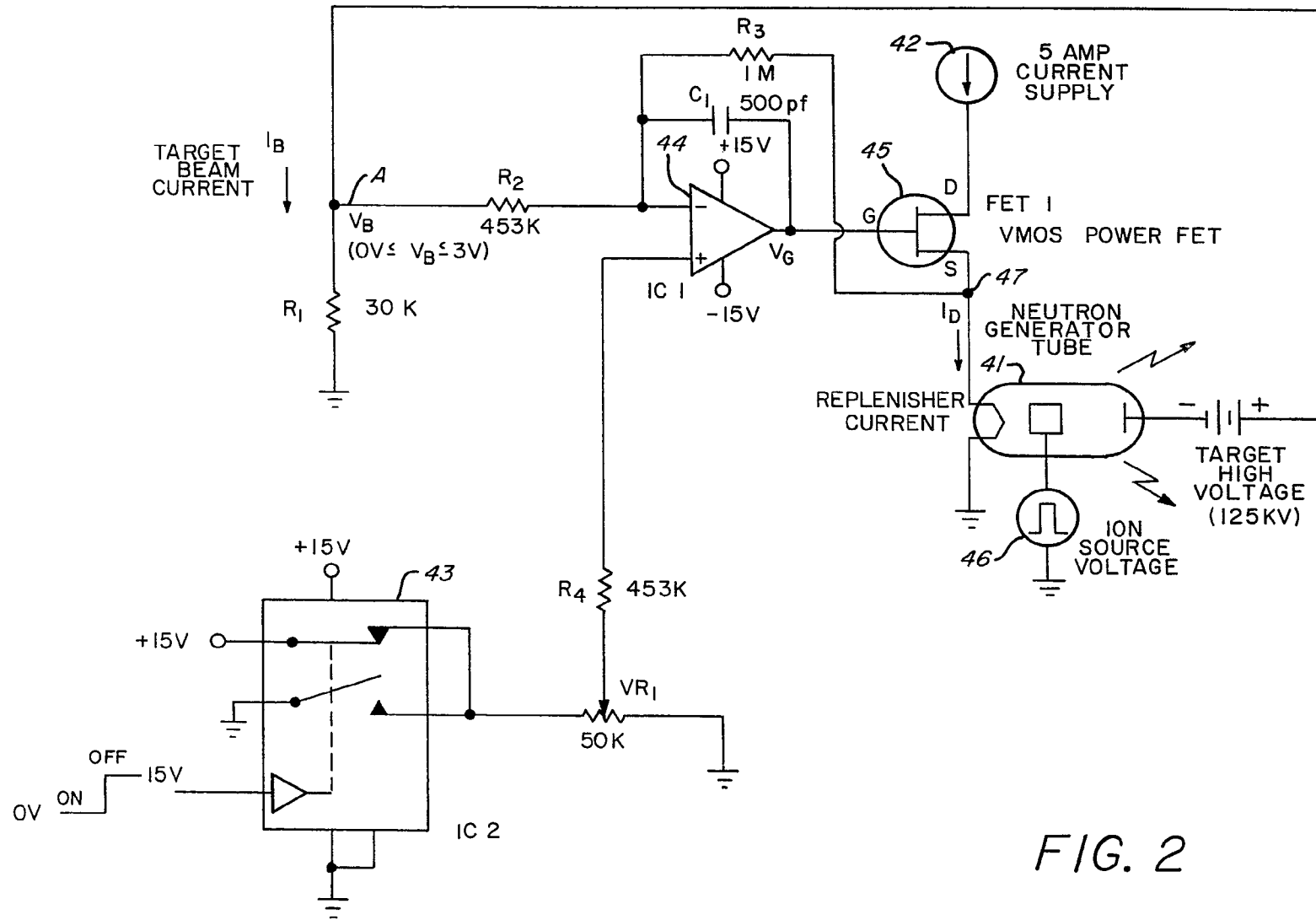


FIG. 2

SPECIFICATION

Well logging neutron generator control system

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This invention relates to neutron well logging and more particularly to means for controlling the neutron output of a neutron generator tube used in neutron well logging.

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In recent years pulsed neutron well logging has become a commercially important well logging technique. Pulsed neutron techniques have been utilized for measuring the thermal neutron lifetime or thermal neutron decay

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time of earth formations in the vicinity of a well borehole, for making activation analyses of elemental constituents of the earth formations in the vicinity of the well borehole, for making porosity measurements of the earth

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formations in the vicinity of the well borehole and for making inelastic neutron scattering measurements for fast neutrons. In each of these well logging techniques the pulsed neutron source used to generate neutron pulses

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for the physical measurements has typically been an evacuated tube, deuterium-tritium accelerator type source. Such sealed off or closed and evacuated tube neutron sources generally comprise an outer envelope of glass,

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metal or some other vacuum encapsulation material, such as ceramic, which houses therein the elements of the neutron generator tube. The tube elements generally comprise a target which is electrically insulated at a high

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voltage potential, a source of ions which may be accelerated onto the target by its high voltage potential and a pressure regulator or replenisher element which may be used to stabilize or control the amount of pressure of

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gas within the evacuated outer envelope. Gas pressures of about 10^{-2} mm Hg. are typical for the operation of these tubes.

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The replenisher or pressure regulator of neutron generator tubes generally comprises a heater element which is surrounded by a surface which is capable of absorbing or emitting gas molecules of the gas filling the evacuated tube envelope as a function of its

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temperature. The capability of such a surface for emitting or absorbing gases in the tube envelope is controlled by the temperature of a heating element associated with it. When the heating element is elevated in temperature, the surrounding gas impregnated surface is

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encouraged to dispel absorbed gases by thermal emission. When the heating element is cooled, the surrounding surfaces associated with it are encouraged to absorb gases from the atmosphere inside the evacuated tube

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envelope. The amount of gas present in the tube envelope controls the amount of gas present in the ion source and hence, the capability of the ion source to produce positively charged ions of gas for acceleration

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onto the target material.

In a typical neutron generator tube operation, the gas present in the evacuated envelope may be either deuterium gas or a mixture of deuterium and tritium gas. The target material is impregnated with tritium. Thus when

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deuterium ions are formed in the ion source and accelerated onto the target by its high voltage potential, the electrostatic Coulomb repulsion between the ions being accelerated

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and the nuclei of the tritium atoms is overcome and nuclear fusion takes place. This produces the unstable isotope helium 5 which immediately decays by the emission of an approximately 14 MEV monoenergetic neutron

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characteristic of this decay.

A problem which has been associated with the use of such neutron generator tubes in well logging has been that the output of the neutron generator falls off as a function of

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time as the tritium in the target material is effectively used up by the nuclear reactions and by heating of the target. Also high voltage power supply voltage variations, replenisher heater current variations and ion source

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emission capability can cause neutron output to vary.

For most well logging operations it is highly desirable that during a given logging run the neutron output of the tube remain constant

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and also as high as possible. High output is desirable to promote the nuclear interactions sought to be measured by the well logging technique in use. Consistency of the neutron output is desirable to promote measurement

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consistency and to avoid systematic errors. In accordance with the present invention, there is provided a control system for controlling the output of a closed generator tube

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having a target material, an ion source, and a replenisher pressure regulator, said system comprising means for monitoring the average target current of said tube and for developing a signal representative thereof, means for comparing a function of said average target

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current representative signal with a reference signal and for developing a control signal representative of the comparison of said signals, and control means responsive to said control signal voltage for controlling current flow to the replenisher of said tube as a function thereof.

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The neutron output of a neutron generator tube is a function of the target current of the tube. The target current, in turn, is a function of the target high voltage, the ion source

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voltage and the replenisher heater current. In an embodiment of the present invention, to be described herein, the target high voltage is at a fixed value, and the ion source voltage is pulsed at a given repetition rate and pulse

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width. By varying the replenisher heater current and hence its heater element temperature, the average neutron output of the tube is controlled. In this preferred embodiment of the present invention, the target beam current

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is monitored, converted to a voltage signal and compared to a reference voltage. An error voltage developed from this comparison is used to control the replenisher current in such a manner that the replenisher current is automatically adjusted to maintain a constant value of the average target beam current corresponding to the reference voltage. A circuit for accomplishing this in said embodiment may be described as a series regulation replenisher current control circuit. Such a circuit may be used to vary the replenisher heater current or even turn off the replenisher current completely. The circuit provides advantages over prior art control circuits for controlling neutron generator tubes in that improved regulation of the replenisher current is accomplished and a relatively simple circuit using few parts is required for this. The replenisher current regulating circuit also has a smaller power consumption than those known in the prior art and is capable of operating at temperatures of up to 200°C. An additional feature of the control circuit is the remote turn on or off capability of the replenisher heater current with relatively low power COSMOS logic level voltages.

Said embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram illustrating a well logging system in accordance with the present invention and utilizing a pulsed neutron generator;

Figure 2 is a schematic circuit diagram illustrating a replenisher current control system in accordance with the present invention; and

Figure 3 is a schematic diagram illustrating the neutron output of a neutron generator tube controlled in accordance with the present invention as a function of time.

Referring initially to Fig. 1 a well logging system embodying the present invention is illustrated schematically. A well borehole 11 is lined with a steel casing 12 and filled with a borehole fluid 15. The steel casing 12 is cemented in place by a cement layer 13 and effectively seals off earth formations 14 from communication with the borehole 11 except in instances where the steel casing and cement layer are perforated for oil production. A fluid tight, hollow body member or sonde 16 is suspended in the borehole 11 by a well logging cable 17 of the usual armored cable type known in the art. The logging cable 17 communicates electrical signals to and from the sonde to surface equipment.

At the surface, the well logging cable 17 passes over a sheave wheel 18 which is electrically or mechanically linked, as indicated by the dotted line 20, to a well logging recorder 19. This linkage enables measurements made by the downhole sonde 16 to be

recorded as a function of borehole depth by the recorder 19. Signals from the well logging cable 17 are provided to surface data processing circuits 21 which process measurement data to provide information which is supplied to the recorder 19 for recording as a function of borehole depth. Power supply 22, located at the surface, supplies power for the operation of the downhole equipment on cable 17 conductors.

In the downhole sonde 16 equipment is provided for making pulsed neutron measurements. While not shown in the schematic drawing of Fig. 1 it will be understood that appropriate power supplies in the downhole instrument convert power source 22, power supplied from the surface into the necessary operating voltages for the equipment in the downhole sonde 16. Control circuits 23, which will be described in more detail subsequently, provide control functions for a neutron generator tube 27 and a high voltage power supply 28 associated therewith and which are located near the lower end of the sonde. Neutron shielding material 29 which may consist of alternate layers of iron, paraffin, cadmium and borated foils or the like is provided to shield the neutron generator 27 from the remainder of the instrumentation within the downhole sonde 16.

A gamma ray detector in the form of a scintillation crystal 24 of thallium activated sodium iodine or the like is optically coupled to a photomultiplier tube 25. This provides for detecting gamma radiation originating in the earth formations in the vicinity of the borehole and resultant from neutron bombardment by the neutron generator 27. As is well known in the art the impingement of gamma rays upon the detector crystal 24 produces light flashes therein whose intensity is proportional to the energy of the gamma ray producing the scintillation. The photomultiplier tube 25 is optically coupled to the detector crystal 24 and amplifies the light flashes produced by the detector crystal 24 and converts them to electrical voltage pulses whose amplitude is proportional to the intensity of the light flashes. These electrical signals are further amplified in an amplifier 26 and conducted into the control circuit electronics 23 portion of the tool where they are appropriately supplied to conventional cable driving circuits (not shown) for transmission to the data processing circuits 21 located at the surface of the earth.

The neutron output of a neutron generator tube 27 of Fig. 1 is illustrated in Fig. 3 as a function of time. In the illustration of Fig. 3 a pulsed neutron mode of operation of the neutron generator tube is contemplated. The high voltage power supply is on at all times in the system and bursts or pulses of neutrons are produced by applying voltage pulses illustrated at 46 of Fig. 2 to the ion source. The

neutrons are produced by the neutron generator tube 27 as previously described. Voltage pulses 46 of a predetermined amplitude and duration are applied to the ion-source of the neutron generator tube 41. In this manner the neutron output of the tube may be made to vary as indicated in Fig. 3. That is to say, the neutron output will rapidly increase from essentially zero to N_{max} , the maximum value of neutron output of which the generator tube is capable when a given magnitude voltage pulse is applied to the ion source. During this time an average value N_{avg} will be emitted. In this manner a very rapid build up or pulse of neutron output from the generator tube 27 is accomplished as a function of time. Removing the voltage pulse from the ion source returns the neutron generator tube to the quiescent value of neutron output which is essentially zero.

For typical well logging operations the on-time of the neutron generator tube in pulsed mode will usually not exceed a duty cycle of approximately 5–10% of its operating cycle. That is to say, the neutron generator tube will generally only be on from 5–10% of the time and the off periods of Fig. 3 will occupy approximately 90–95% of its time in a typical well logging operation. Neutron pulse durations of approximately 50 microseconds duration and repetition rates of from 1000–10,000 pulses per second are typical for pulsed neutron well logging techniques.

The neutron generator control system operates to maintain the average value N_{avg} of the neutron output at a constant or predetermined value for the duration of a well logging run. Obviously such a system cannot replace tritium in the tube which is used up in generating the neutron output. Long term deterioration of the neutron output is unavoidable in generator tubes which provide only deuterium in the replenisher. Tubes having a deuterium and tritium mixture can avoid such long term neutron output deterioration.

The need for short term control of neutron output arises from the relationship between the replenisher current and the neutron output, which is a complicated function. Very small changes in the replenisher current can cause very large changes in the neutron output. By monitoring the target current (which is related to the neutron output) and correcting the replenisher current to hold the target current constant, the neutron output may be stabilized for short term variations such as could occur during a well logging job.

Alternatively, it should be noted that the neutron generator 27 could be operated continuously for certain types of well logs. In such a case the values N_{avg} and N_{max} would be the same value. In this instance the control system would maintain approximately a constant neutron output from the neutron generator 27 for the duration of a well logging job.

Referring now to Fig. 2 a portion of the control circuitry 23 of Fig. 1 having to do with the control of the neutron output from a neutron generator tube is illustrated in more detail, but still schematically. Point A of the circuit is connected to the low side of the target high voltage power supply (which may typically be negative 125 kilovolts). The neutron generator tube 41 target beam current (which is sampled at Point A) flows to ground through resistor R_1 generating a voltage V_B at Point A which is related to the neutron output of the generator tube. The sampled voltage at Point A is used to regulate the drain current I_D of the VMOS power field effect transistor 45 (labelled FET1). This current is also the replenisher current of the neutron generator tube 41, and is sampled at point 47.

A variable resistor VR1 establishes a reference voltage for controlling the average neutron output of the generator tube 41. The setting of variable resistor VR1 is determined by the transfer characteristics of the VMOS power FET 45 and the relationship between the replenisher current and the neutron output of the generator tube. In general, the transfer characteristics will vary with each FET and generator tube. For the purpose of this description it will be assumed that the desired neutron output is obtained when the average target beam current is 100 microamperes and the replenisher current is 3 amperes. These are typical values encountered in the operation of neutron generator tubes in well logging usage. In this case, the variable resistor VR1 is adjusted until the replenisher current is 3 amperes and the target current is 100 microamperes giving a reference voltage V_B at Point A, of 3 volts. This voltage establishes the average operating point of the neutron generator tube 41.

Operational amplifier 44 is connected as an inverting voltage gain circuit with the gain determined by the ratio R_3/R_2 . The output voltage V_G of the operational amplifier 44 is applied to the gate of the field effect transistor 45. This gate voltage controls the drain current I_D of the field effect transistor 45 which is supplied from a 5 ampere current supply 42. This drain current is sampled at point 47 and fed back through resistor R3 to establish the operating conditions of the operational amplifier 44 as previously described. The non-inverting input of the operational amplifier 44 is connected to the voltage setting provided by variable resistor VR1 through resistor R_4 . This voltage applied to the non-inverting input of the operational amplifier 44 plus the voltage developed across R_1 determines the output voltage of the operational amplifier 44.

If the average value of the neutron output N_{avg} begins to decrease below the operating value as determined by the setting of VR1, the target beam current will decrease. This will cause the voltage V_B to decrease. When

V_B decreases, this causes the output voltage V_G of the operational amplifier 44 to increase. The increased voltage output V_G of the operational amplifier 44 causes the replenisher current I_D to increase. The increase in replenisher current I_D tends to increase the target beam current as sampled at Point A.

If the neutron output of the generator tube 41 begins to increase above predetermined average operating value N_{avg} , the target beam current will increase. This causes the voltage V_B across resistor R_1 to increase. When V_B increases, this causes the output voltage V_G of the operational amplifier 44 to decrease. The decrease of V_G , the gate voltage on field effect transistor 45, causes the replenisher current I_D , as sampled at point 47, to be reduced. This in turn reduces the output of the neutron generator tube 41 by cooling the replenisher heater element.

A solid state switching integrated circuit 43 is used to apply and remove a control voltage source (0-15 volts) to variable resistor VR_1 . When the control voltage source is removed from the variable resistor VR_1 , the voltage applied to the non-inverting input of operational amplifier 44 goes to zero volts. When zero volts is applied to the non-inverting input of the operational amplifier 44, the voltage output of the operational amplifier is reduced sufficiently to insure that the field effect transistor 45 is completely turned off. This interrupts the replenisher current I_D completely and effectively reduces the output of the neutron generator tube 41 to zero.

CLAIMS

1. A control system for controlling the output of a closed generator tube having a target material, an ion source, and a replenisher pressure regulator, said system comprising means for monitoring the average target current of said tube and for developing a signal representative thereof, means for comparing a function of said average target current representative signal with a reference signal and for developing a control signal representative of the comparison of said signals, and control means responsive to said control signal voltage for controlling current flow to the replenisher of said tube as a function thereof.

2. A system as claimed in claim 1, wherein said control means comprises an active circuit element placed in a series circuit with the replenisher pressure regulator of said tube.

3. A system as claimed in claim 2, wherein said active circuit element is capable of completely turning off current flow to said replenisher.

4. A system as claimed in claim 3, wherein said control means comprises a field effect transistor having a source, a gate and a drain.

5. A system as claimed in any preceding claim, wherein said comparing means comprises an operational amplifier and means for summing said target current voltage representative signal and a voltage signal representative of the replenisher current of said tube to form a summation signal and for comparing said summation signal and said reference signal in said operational amplifier to provide said control signal.

6. A control system as claimed in claim 1 and substantially as herein described with reference to Fig. 2 of the accompanying drawings.

7. A well logging system for conducting neutron well logging operations, comprising a fluid tight hollow body member sized and adapted for passage through a well borehole and housing therein, a radiation detector for detecting radiation emanating from earth formations in the vicinity of the well borehole in response to neutron irradiation thereof, and a closed neutron generator tube having a target material, an ion source and a replenisher pressure regulator, and a control system therefore as claimed in any preceding claim.

Printed for Her Majesty's Stationery Office
by Burgess & Son (Abingdon) Ltd.—1981.
Published at The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.