

- [54] SYSTEM FOR REMOTE CONTROL OF UNDERGROUND DEVICE**

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- [52] U.S. Cl..... 340/15; 102/22; 102/70.2 R;
176/39; 340/16 C

- [51] **Int. Cl.²** **F42D 3/00**

- [58] **Field of Search**..... 340/5 R, 16 C, 15; 102/18, 102/22, 19.2, 23, 70.2 R; 176/39, DIG. 4

- ## [56] References Cited

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- [57]
- ABSTRACT**

ABSTRACT

A system for remote control of an underground device, particularly a nuclear explosive, which includes means at the surface of the ground for transmitting a seismic signal sequence through the earth having controlled and predetermined signal characteristics for initiating a selected action in the device, and apparatus located with or adjacent to the underground device which produces electrical signals in response to the seismic signals received at the device together with means for comparing these electrical signals with the predetermined signal characteristics and means for initiating a selected action.

- ### 4 Claims, 12 Drawing Figures

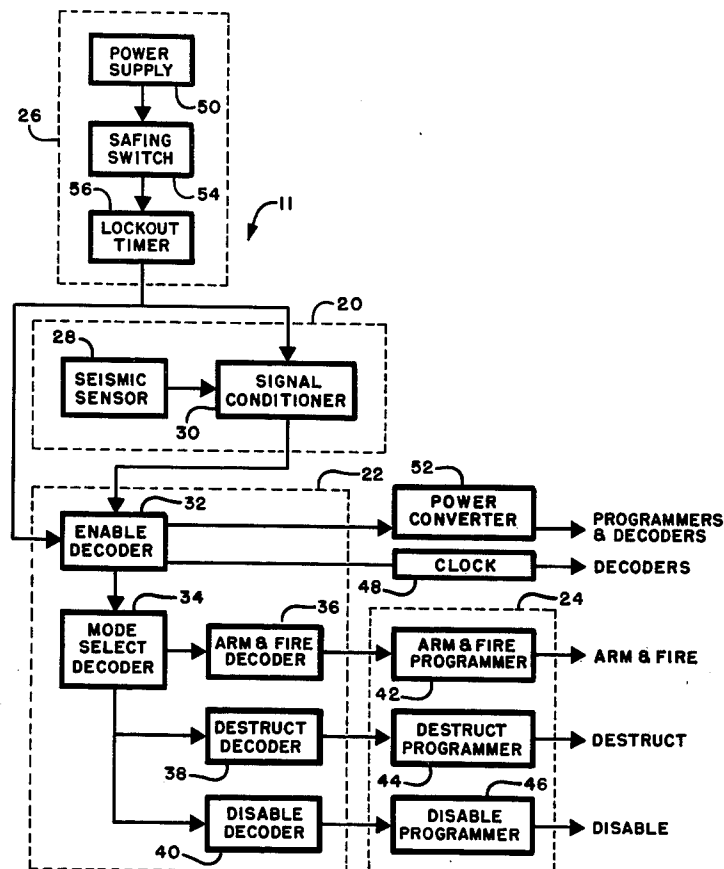


FIG. 2

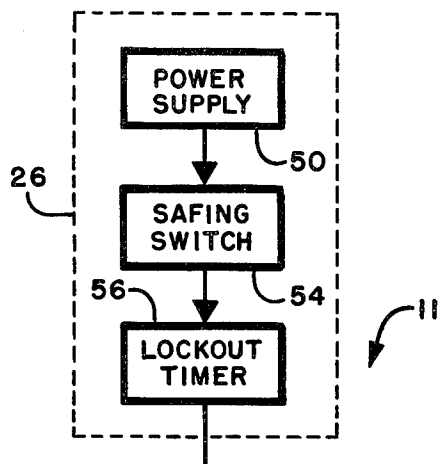


FIG. 1

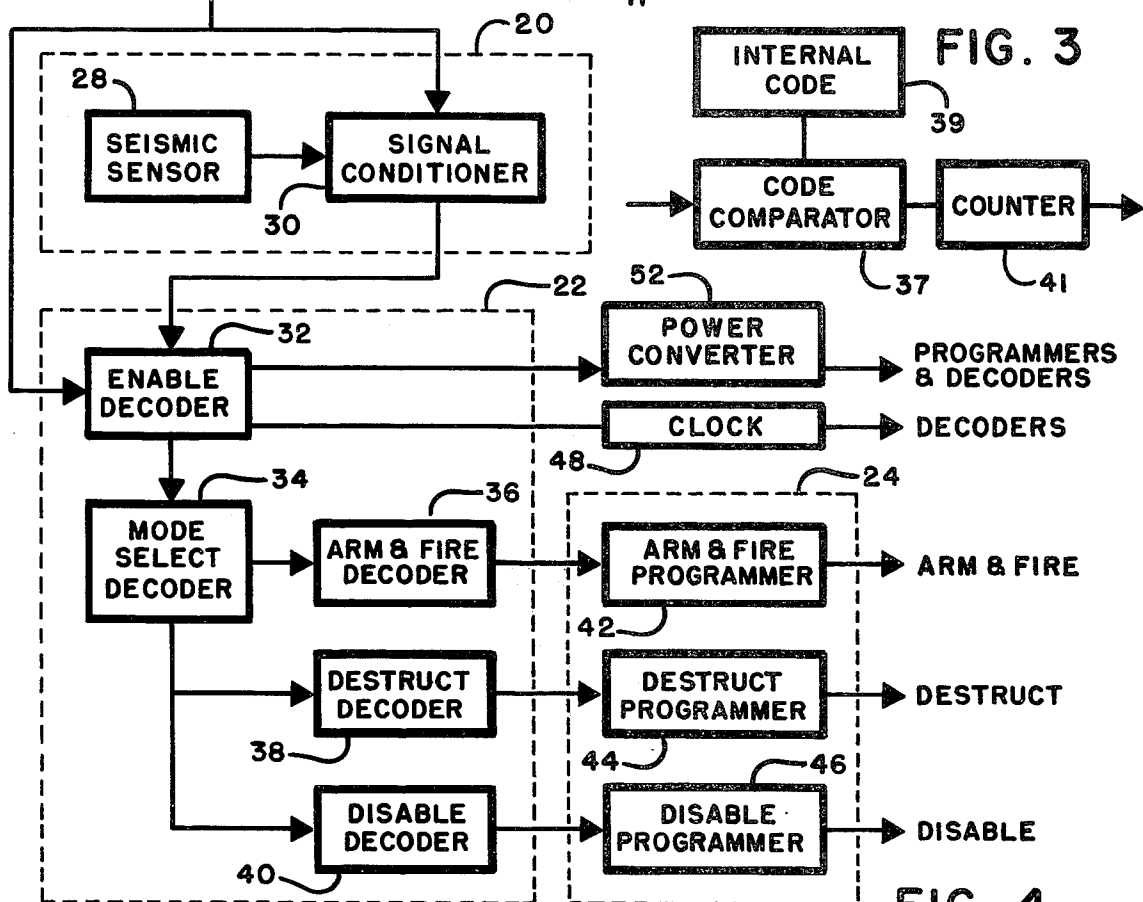
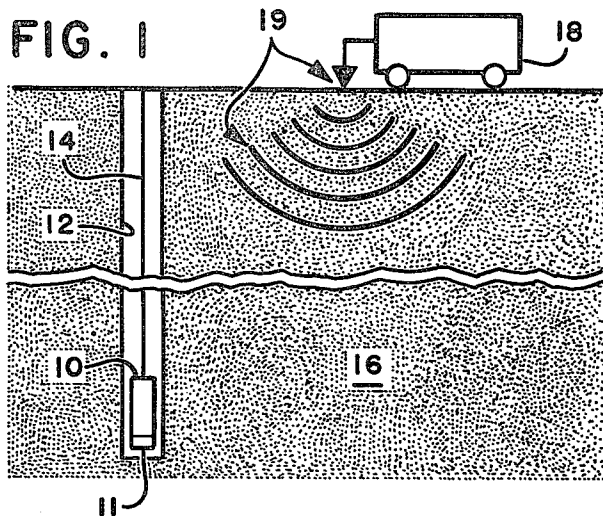
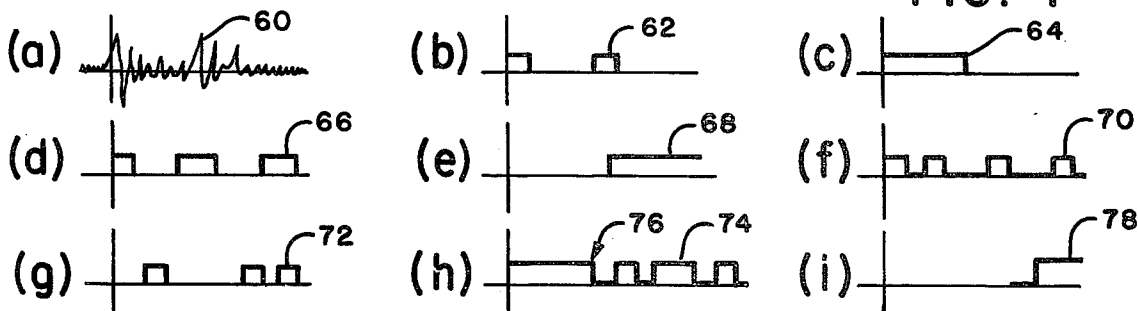


FIG. 4



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SYSTEM FOR REMOTE CONTROL OF UNDERGROUND DEVICE

BACKGROUND OF INVENTION

Explosives and particularly nuclear explosives because of their relatively small size are being used or considered for use for stimulation of natural gas or oil reservoirs, in-situ oil shale retorting, copper and other mineral leaching, geothermal, waste disposal, excavation, and other applications. In each of these applications, one or more explosives are positioned underground at some desired depth and location and then detonated. The placement of the explosive in its underground location may require the drilling or otherwise excavating a chamber for receiving the explosive and then the emplacement of the explosive in the chamber. This is most often done by drilling a well into the earth to a desired depth and then lowering the explosive at the end of an appropriate cable to this depth. When the explosive is emplaced, the "well hole" is plugged and back-filled to prevent, in the case of nuclear explosives, radioactive material leakage to the surface and atmosphere.

In order to achieve controlled operation of the explosive, a set of control cables was required which was capable of maintaining electrical contact between the explosive in its underground cavity and surface initiating apparatus. These downhole control cables may be extremely costly, especially as the depths of explosive emplacement increase. Increased depth requires longer control cables which must operate at increasing pressures and temperatures with increasing depth. In addition, the downhole control cables often present difficulties due to this pressure and temperature environment in which they must be used and also because during the emplacement and back-filling operations cables may be inadvertently damaged or even severed. Any attempts to prevent such damage adds to the time and cost required to utilize the underground explosive. It would thus be desirable to provide a control system for an explosive, particularly a nuclear explosive, which did not require direct, physical or electrical connection with the surface so that the only contact required would be the wire rope, pipe or other means of support utilized to lower the explosive into its cavity.

SUMMARY OF INVENTION

In view of the above, it is an object of this invention to provide a control system for an underground device, particularly a nuclear explosive having no direct electrical control connection to the surface.

It is a further object of this invention to provide a control system for an underground device which is responsive to induced seismic signals from the surface to the device.

It is a still further object of this invention to provide an underground device control system which is capable of inducing a selected one of multiple actions from seismic signals induced at the surface.

It is a further object of this invention to provide a seismic signal controlled nuclear explosive which includes inherent safing devices.

Various other objects and advantages will appear from the following description of the invention and the most novel features will be particularly pointed out hereinafter in connection with the appended claims. It

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will be understood that various changes in the details, and arrangements of the parts, which are herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art.

The invention comprises means for producing a desired seismic signal at the surface together with apparatus located with an underground device which includes means for producing electrical signals proportional to the seismic signals received at the device, means for analyzing the electrical signals and decoding the same, and means for initiating an action in the device responsive to the analyzed signal.

DESCRIPTION OF DRAWING

The invention is illustrated in the accompanying drawing wherein:

FIG. 1 is a somewhat diagrammatic presentation of a nuclear explosive or other device in an underground location and the surface control equipment;

FIG. 2 is a block diagram of the control apparatus located with the nuclear device underground;

FIG. 3 is a detail of a portion of the control apparatus shown in FIG. 2; and

FIGS. 4a through i are diagrammatic representations of portions of a typical control sequence and electrical signals for the apparatus shown in FIGS. 2 and 3.

DETAILED DESCRIPTION

As indicated in FIG. 1, a conventional or nuclear explosive or other device 10 (hereinafter referred to as a nuclear explosive as this is to what the present invention is principally directed) and its appropriate control system 11 may be emplaced together in a shaft or tunnel 12 by a lowering and support cable or line 14 at some desired depth in the earth 16. The shaft 12 may, after emplacement, be back-filled and plugged in an appropriate manner to minimize or prevent release of radioactive material to the surface. It will be apparent that additional nuclear explosives and control systems may be emplaced at varying depths in the same shaft 12 or in additional shafts with each being controlled in a similar manner. A surface control system 18 may be located on the surface of the earth and utilized to produce a predetermined sequence or otherwise modulated coded seismic signals through the earth, as indicated by the arrow and seismic "waves" 19, for receipt by nuclear explosive 10 and its control system 11.

The nuclear explosive 10 may be any nuclear device or explosive with suitable arming, firing, safing and the like subsystems associated therewith for the usual and safe operation thereof. These subsystems include the necessary power supplies, timing circuits and switching circuits to either arm and fire the nuclear device when appropriate, or to disable or even destruct the device without a nuclear detonation should such seem desirable because of some malfunction of equipment or other events. As the present invention is not directed to these aspects of the nuclear explosive, further description of the same is not provided herein.

The surface control system 18 may include any appropriate arrangement of control circuits and devices which will produce some desired pattern or sequence of seismic signals which are coded to indicate some selected action or operation of the nuclear explosive 10, such as the arming and firing, disabling or destruction thereof. The control system 18 will include one or more appropriate transponders which are capable of produc-

ing the desired coded seismic signal, for example a plurality of explosives or a frequency generator suitably coupled to the earth. The explosives may be initiated in a desired sequence at programmed time intervals to produce a plurality of seismic signals or pulses of sufficient amplitude to be detected by the nuclear explosive 10 at its emplaced location. The frequency generator(s) may be programmed so as to produce pulse sequences of different single frequencies, variable or multiple frequencies, and/or variable intervals and durations. The seismic signals generated must be of sufficient amplitude to be distinguishable from any background noise or other seismic disturbances at the location of the nuclear explosive 10. In addition, it may be desirable to provide a seismic listening device within the surface control system 18 which may monitor the background seismic noise and signals at its location to insure the background noise is at a low level at the time selected for utilization of the nuclear explosive 10 to minimize the chance of background seismic signals interfering with communication between the surface control system 18 and the nuclear explosive 10. However, the system may be designed such that should interference occur, it may only necessitate the retransmission of the command signal. Explosive transponders may include charges of dynamite or other high explosives, which may each include about 1 to 20 pounds of explosive material, buried in separate holes at an appropriate depth near the surface, such as from 10 to 20 feet deep, with innerconnecting primer cord and the like while the frequency seismic signal generator may be an electromechanical vibrator mechanism such as is commonly used in seismic exploration and mapping of subterranean geological formations. The seismic signal generator may be a stationary unit or a truck or tractor mounted mobile unit such as the Vibroseis system used by Seismograph Services Corporation or other similar systems.

The control system 11 shown in FIG. 2 which is located with the nuclear explosive 10 includes a seismic detector portion 20, a decoding portion 22 and a programmed action initiation portion 24, as well as a safing portion 26. Each of these portions interacts with the others so as to cause the nuclear explosive 10 to respond with some appropriate action as determined by the coded seismic signals produced at the surface by surface control system 18. Each of the portions are shown with various devices or circuits to provide a function or operation which will enable the operation of the control system. It will be understood that other subfunctions, devices or circuits may be substituted for many of these described and shown to provide a variation in operation within the scope of this invention and that those shown are merely by way of example. Also, each of the various devices or apparatus may utilize conventional and well known apparatus selected to provide the desired operation and coaction.

The seismic detector portion 20 may include a seismic sensor 28 and a signal amplifying and conditioning circuit 30. Seismic disturbances or movements may be measured down to the very low frequencies and amplitudes with variable reluctance detectors commonly known as geophones. Conventional geophones utilize a magnet and a coil movable with respect to each other to provide a signal at the same frequency and proportional amplitude to any seismic movement sensed by the geophone. Standard geophones are manufactured

in a variety of types with sensitivities ranging to 0.3 v/in/sec or higher. One example of such commercially available geophones is the Model HS-1 from Geospace, Houston, Texas. The signal conditioning circuit 30 may include appropriate band pass amplifiers to filter out undesirable frequencies and threshold detectors or voltage discriminators to reduce background noise. In addition, the signal conditioner 30 may include appropriate circuit elements responsive to the particular seismic signature produced by the transponder utilized with the surface control system 18, e.g., an explosive transponder(s) produces a burst of broadband seismic noise at programmed intervals which is filtered and attenuated by the earth during transmission while the frequency transponder produces a single frequency which is varied and/or interrupted in a controlled manner. For example, signals of the latter type may be detected as the simultaneous presence of one frequency (f_1) and the absence of another (f_2). The signal conditioner 30 may produce a pulse or set of pulses corresponding to a particular seismic signal or signature depending upon the signature and the preselected coded information included therewith and the response which is desired, as well as the particular decoding circuitry utilized in decoding portion 22.

The resulting pulse or the like sequence generated by the signal conditioner 30, as determined by the controlled coded seismic signal produced at the surface, is then compared by the decoding portion 22 against a stored code to insure the seismic signals received by the seismic detector portion 20 are authentic and determine the action which was selected at surface. The decoding portion 22 thus may include an enable decoder 32 which makes an initial determination of the authenticity of the seismic signals sensed by seismic detector 20 and, if these initial signals do match the predetermined code stored in enable detector 32, the additional portions of the coded signal are coupled to a mode or action select decoder 34. The mode select decoder 34 determines the action to be taken from an additional coded portion of the coded seismic signal and, depending on the action desired, couples the still remaining portion of the coded signal to either the arm and fire decoder 36 or the destruct and disable decoders 38 and 40. The decoders 36, 38 and 40 compare the coded signals transmitted thereto against a stored code to insure that they constitute an authentic command before initiating the desired action. The coded signal selected and transmitted by the surface control system 18 may contain, for example, timed information in the form of seismic pulses or signals such that the first bits of information in a certain timed relationship received by seismic detector 20 and identified by the enable decoder 32 serves as a prefix to distinguish against background noise thereby avoiding unnecessary cycling and conserving power, the next portion of the signal as compared in mode select decoder 34 serves as an address and identifies the desired action, and the remaining portion as compared by the decoders 36, 38 and 40 serves as the authentication for the particular action commanded. These decoders may include any appropriate electronic or electromechanical comparators or coded switches to provide this operation.

The decoders 36, 38 and 40, after determining the authenticity of the signal and the desired action to be taken, may produce a signal or series of signals or pulses or transmit additional portions of the coded seis-

mic signal to initiate the desired action in the programmed portion 24 by corresponding arm and fire programmer 42, destruct programmer 44 or disable programmer 46. These programmers may be provided with a stored program of actions to be taken to carry out the selected nuclear explosive action. For example, the arm and fire programmer 42 may produce or transmit a series of pulses or signals which carry out the necessary sequence of events to fire the nuclear explosive. The destruct programmer 44 may produce signals which will initiate conventional chemical explosives, or the like, within the nuclear explosive to destroy the nuclear explosive. The disable programmer 46 may activate a safing mechanism which will irrevocably disable the nuclear explosive thereafter precluding the arming and firing of the nuclear explosive. These programmers may be interlocked or otherwise used in conjunction with appropriate safing devices to preclude accidental nuclear detonation, disablement, or destruction. The programmers may include electronic, electromechanical or mechanical timers, counters, switches and other conventional devices appropriate to a particular nuclear explosive system.

FIG. 3 illustrates a typical decoder circuit arrangement which may be used for any of the decoders 36, 38 and 40. The decoders may include a code comparison circuit 37 which is coupled to an internal code storage circuit 39 which, if the comparison indicates an authentic command to produce a desired action, a counter circuit 41 may be initiated to produce a desired series of pulses to carry out this action or the code comparison may produce a series of pulses counted by counter 41 which will produce an output pulse or pulses should the count reach a preset level.

It will be apparent that any of the decoders and programmers may be provided with various timing gates and the like during which periods the proper seismic signals must be received by the seismic detector 20 in order to continue the precoded and preprogrammed sequence. If the received seismic signals do not correspond in the proper manner with these gate timers and the stored code, the entire decoder portion 22 and programmer portion 24 may reset to its initial condition to await a correct coded signal to thus minimize unnecessary cycling due to extraneous seismic signals or the undesired initiation of some action from such signals. With proper selection of codes and operations sequence, the device may be made virtually immune to extraneous or unauthorized seismic signals.

Additional control may be achieved using a suitable safing portion 26. The safing portion 26 may include a power supply 50, a safing switch or device 54, and an appropriate lockout timer 56. The safing switch 54 may be manually closed or enabled at the beginning of emplacement of the nuclear explosive 10 or it may include devices automatically actuated by the conditions to which the nuclear explosive 10 may be subjected, for example, the pressure and/or temperature which the nuclear explosive sees in the shaft 12 environment. In an underground nuclear explosive application, the temperatures may exceed 150°F while the pressures may exceed 1000 psi; the deeper the emplacement the higher the temperatures and pressures. The respective safing devices in safing switch 54 may be made sensitive to one or more of these conditions and automatically close only after the nuclear explosive 10 is safely emplaced at its intended location. The lockout timer

may be initiated by closing of the safing switch 54 and may be preset to allow a sufficient time for completion of emplacement and back-filling operations. When the timer has timed through its preset interval, the seismic detector portion 20 and the enable decoder 32 may be activated to await receipt of the appropriate seismic signals. When a seismic signal is received which includes the proper prefix signals, enable detector 32 may activate the power converter 52 which in turn is coupled to the remaining decoders, programmers and other circuitry of the control system. At the same time, a clock 48 may be activated to produce any required timing pulses for the control system. This activation of power converter 52 upon receipt of the proper prefix code minimizes the power requirements of the control system until the control operations are needed.

If it is desired, after the arm and fire code has been transmitted and received and the arming functions carried out, an additional signal may be required to fire the nuclear explosive from surface control system 18. A timer may enable a gate for a preset period of time during which time the fire signal must be sent and received or else the system may automatically reset itself. The firing signal may be routed directly to the nuclear explosive or it may be delayed for a preselected time period depending upon the desired operation objectives. When using multiple explosive devices underground, a precision timer in each nuclear explosive may be set for a different time delay which takes into account the difference in transit time of the seismic command signals to the respective explosive devices so as to provide a sequential detonation of the nuclear explosives, a simultaneous firing, or in any combination thereof.

FIGS. 4a through i illustrate a typical operation utilizing an explosive transponder type seismic signal and the various pulse sequences and operations which may be used in conjunction with this type of signal. Curve 60 illustrates a typical geophone output produced in response to two seismic pulses, while curve 62 represents corresponding pulses produced by the seismic signal conditioner 30. In this example, the seismic signal conditioning circuit 30 produces one pulse for each seismic signal in the same time sequence as the seismic signals are received and sensed by sensor 28. The decoder 32 may produce a given voltage output unless the decoder receives a preselected number of pulses sequentially in a given time period (such as four pulses, properly spaced, within a period of 20 seconds). If the required number of pulses arrive in this period, a NAND gate may drop to zero as indicated by the signal 64. The clock 48 is then initiated and begins to produce a series of pulses of given height and duration throughout the sequence of operation of the control system, as shown by curve 66. If an additional pulse is produced by the seismic signal conditioner 30 within a given time period after the enable detector 32 NAND gate drops to zero, the action select decoder 34 may open a gate, as indicated by curve 68, to either the arm and fire decoder 36 or to the destruct and disable decoder 38 and 40. The particular gate opened may be controlled by the timing of the signal or by multiple signals in a given period of time. This signal(s) serves as an address such that subsequent signals are routed to the appropriate decoder for code comparison. Curves 70 and 72 indicate typical curves or codes which may be stored in the internal code storage 39 of the decoder for the respective decoders 36, 38 and 40. The code comparator 37

may compare the pulses produced by the seismic signal conditioner 30 and those in the stored code circuit 39 with the level dropping from a given voltage to zero voltage everytime a signal and stored code are the same, such as shown by curve 74 for the internally stored code curve 70 and beginning at the point 76. If the code is authentic, as determined by the counter 41 reaching the predetermined number, a signal 78 may be generated to initiate the appropriate programmer 42, 44 or 46.

The first group of signals which initiates the enable decoder 32 may serve as a time reference and start a gate timer to provide a series of gated intervals corresponding to the signal intervals of the code. Once started, the gate timer may run through a desired complete cycle and return to a reset condition. This gate interval may be arbitrarily chosen for a given system and may be, for example, on the order of 5 seconds. The minimum practical gate interval is determined by the maximum duration of the seismic signals, including reverberations, as received at the nuclear explosive 10. Reverberations will normally subside within 3 seconds. A generously long interval may be used since it may make little difference in a given type of operation whether the code transmission takes a few or many minutes to complete.

In this example, the gate timer may be started by an extraneous seismic signal, but it would simply run through one cycle and return to the reset position. Successful code transmission may be operated so as to require that the gate timer be in the reset position when the code is started. Such a condition may be determined by the seismic monitor at the surface control system 18 to make sure that the code is preceded by a period of minimal seismic activity for an interval corresponding to at least one cycle duration.

During each gate interval, the detector 28 may listen for the presence or absence of a seismic signal above threshold; the presence of a seismic signal constituting a "one" and the absence a "zero." Any subsequent code that does not agree with the stored code of the action decoder selected may be rejected and the system returned to the reset condition. Thus, the only penalty resulting from incorrect code or receipt of extraneous seismic signals during the process would be to start the cycle at the beginning. Any deliberate attempt at sequencing through codes by an unauthorized surface control system may be readily detected by the seismic monitor at the surface and because of the relatively slow rate of code acceptance, the unauthorized tampering could be traced and terminated before a significant percentage of the total code population could be transmitted. Additionally, the safing switch 54 and the lockout timer would preclude any response unless the subterranean conditions corresponding to safe emplacement are sensed and the lockout interval has passed.

If desirable, a capability may also be provided by which the nuclear explosive 10 would signal the surface control system 18 that the proper code has been re-

ceived and that the desired action had proceeded successfully to some given point. Such a signal might be generated by a small explosive charge or other type of seismic transponder in the vicinity of the nuclear explosive and be transmitted seismically back to the surface, as desired.

The control system of this invention permits the simpler and faster emplacement of a nuclear explosive by obviating the need for a downhole, electrical cable while also permitting the back-filling and stemming of the shaft 12 in an easier performed operation. The lack of electrical connection between the explosive device 10 and the surface provides a degree of protection from extraneous electrical signals which may damage or otherwise affect the system, such as from lightning or the like, and from electromagnetic pulses from detonations of nearby nuclear explosives which might be coupled via a cable. In addition, the system obviates the need for high-pressure and high-temperature resistant electrical connectors and cables. The absence of cable may also enable easier, faster or less expensive recovery of a nuclear explosive by reentry into the shaft 12 if required.

What is claimed is:

1. A system for controlling an action of a nuclear device such as exploding, disabling or destroying a nuclear explosive, contained within a chamber at a remote underground location and isolated from the surface by a column of back filled earth, from different sequences of seismic signal pulses produced at the surface of the ground comprising a plurality of explosives emplaced in the earth near the surface of the ground and laterally displaced from said column of back filled earth; and means located at the surface for individually detonating said explosives for producing a seismic signal from each detonation in a seismic signal pulse sequence having predetermined pulse sequence characteristics determined by the desired action and for transmitting the same through the earth; and control means located adjacent said nuclear device sensitive to said seismic signal pulses, including means for producing a corresponding sequence of electrical pulses in response to said sequence of seismic signal pulses; further means for comparing the identity of said electrical pulse sequence with predetermined pulse sequence characteristics determined by the desired action and stored in said further means; and additional means for initiating the desired action of said device in response to receipt of the appropriate pulse sequence characteristics.

2. The system of claim 1 including means located with said nuclear device for activating said apparatus after said device is emplaced in its underground location.

3. The system of claim 1 wherein said electrical pulse sequence producing means includes a geophone.

4. The system of claim 1 including means for preventing said initiating in response to receipt of other than said predetermined pulse sequence characteristics.

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