

[54] **BONE MINERAL ANALYZER**

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[51] Int. Cl. **G01t 1/20**

[58] Field of Search **250/71.5 S, 83.3 D**

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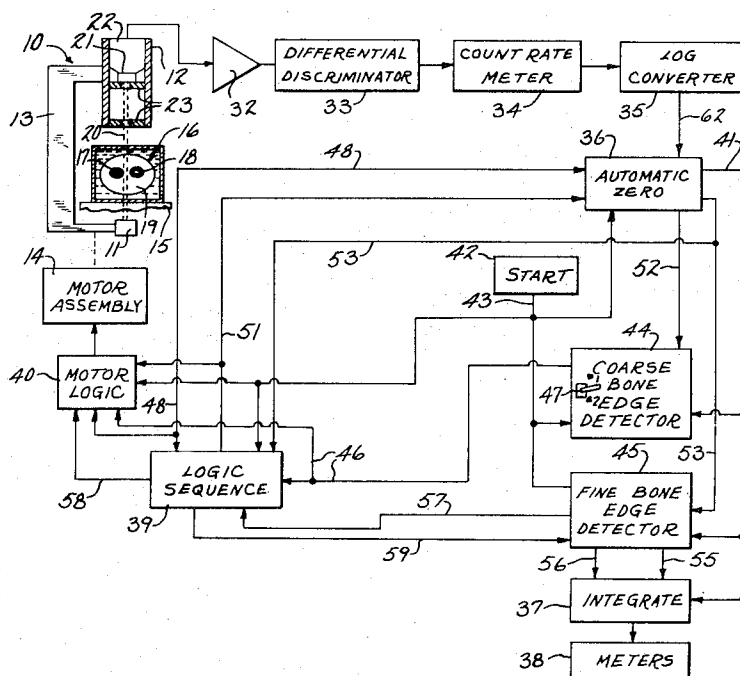
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ABSTRACT

A bone mineral analyzer includes a radioactive photon source and a spaced detector secured to a holder movable along a transverse scanning line. A tissue-covered bone is held in a tissue equivalent cover to produce a constant thickness profile with a photon scanning beam selectively absorbed by the bone and the tissue and tissue equivalent. A dual speed motor moves the holder at a rapid search speed to locate the bone and hold the beam in fixed relation to the tissue and tissue equivalent cover for establishing and storing a tissue reference signal. A slow scan speed is established for scanning the bone and establishing a bone-tissue signal. Corresponding logarithmic signals are subtracted and integrated over the width of the bone to produce a bone mineral related output which drives digital meters. A selection switch interconnects a logic circuitry to permit selection between a pair of bones spaced in a common tissue. Timing circuits improve the characteristic response of the system. Calibration for the digital reader is connected to the output side of the integrator to permit calibration adjustment without disturbing the signal in the integrator.

57 Claims, 8 Drawing Figures



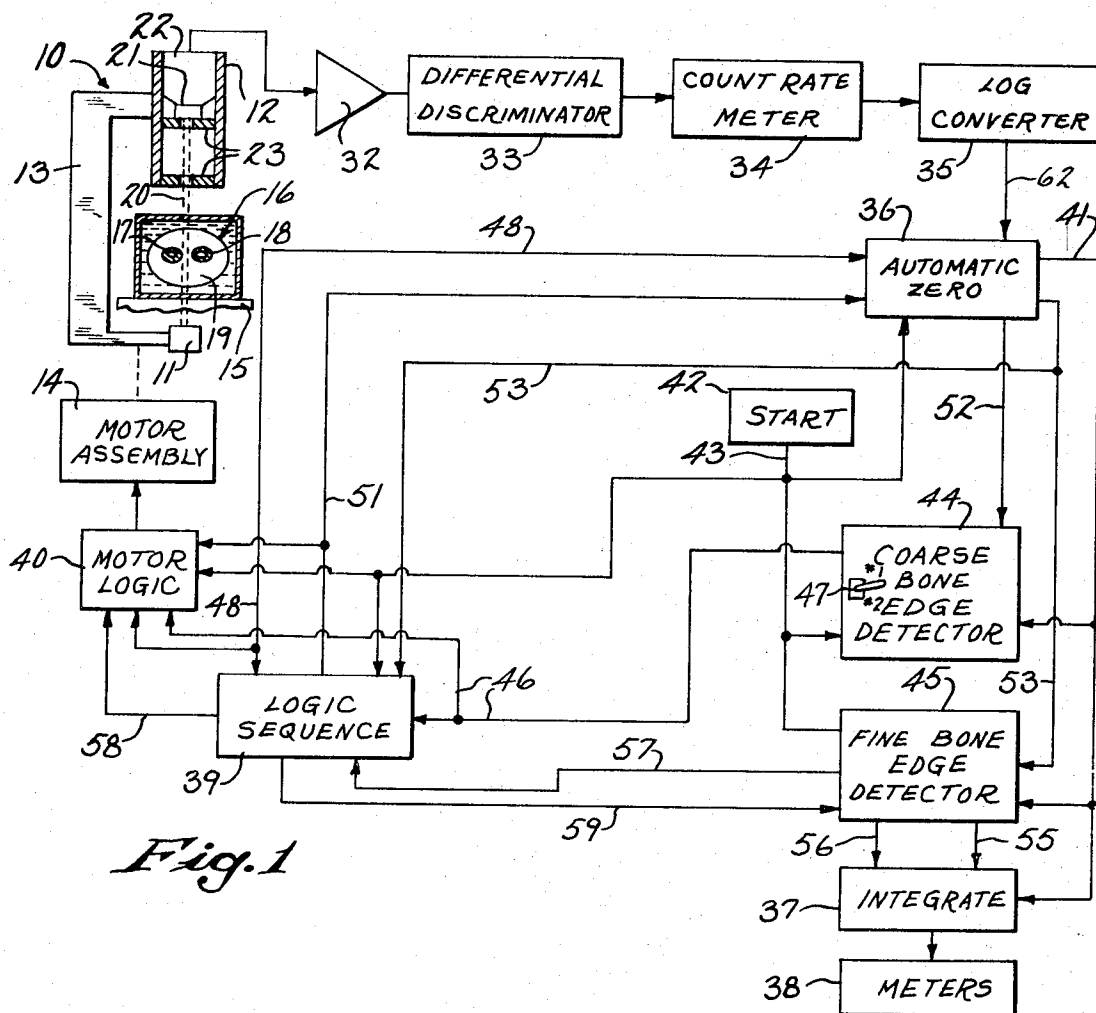


Fig. 1

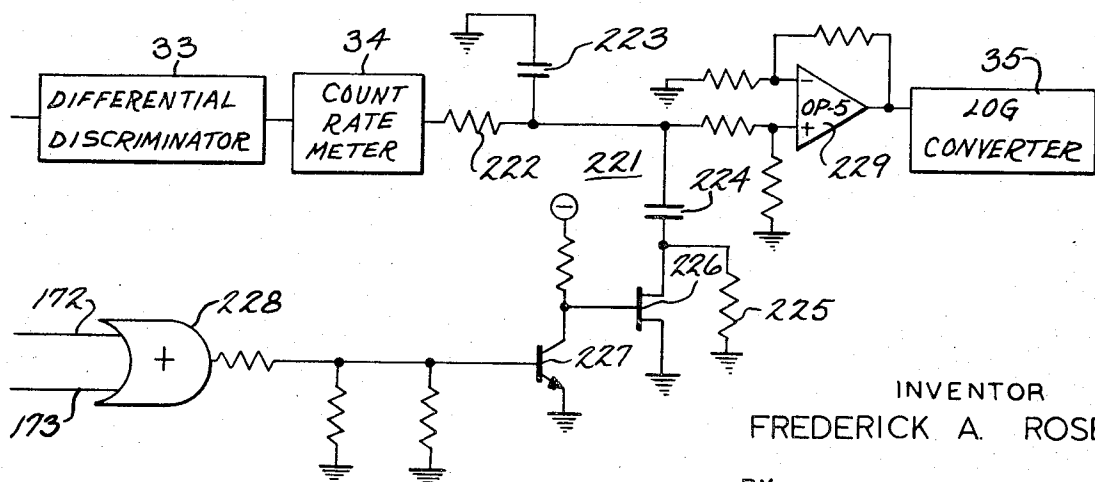


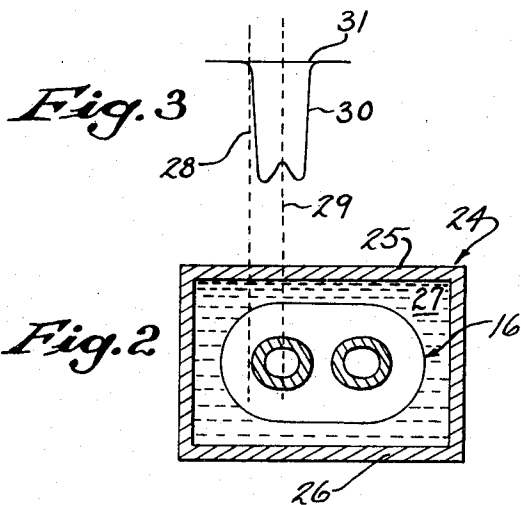
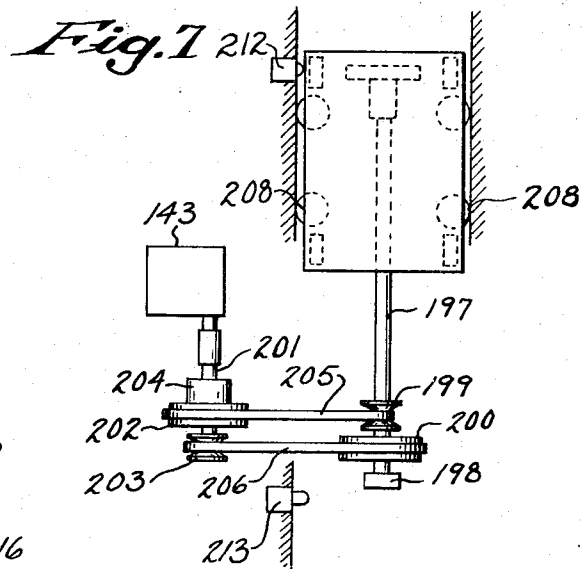
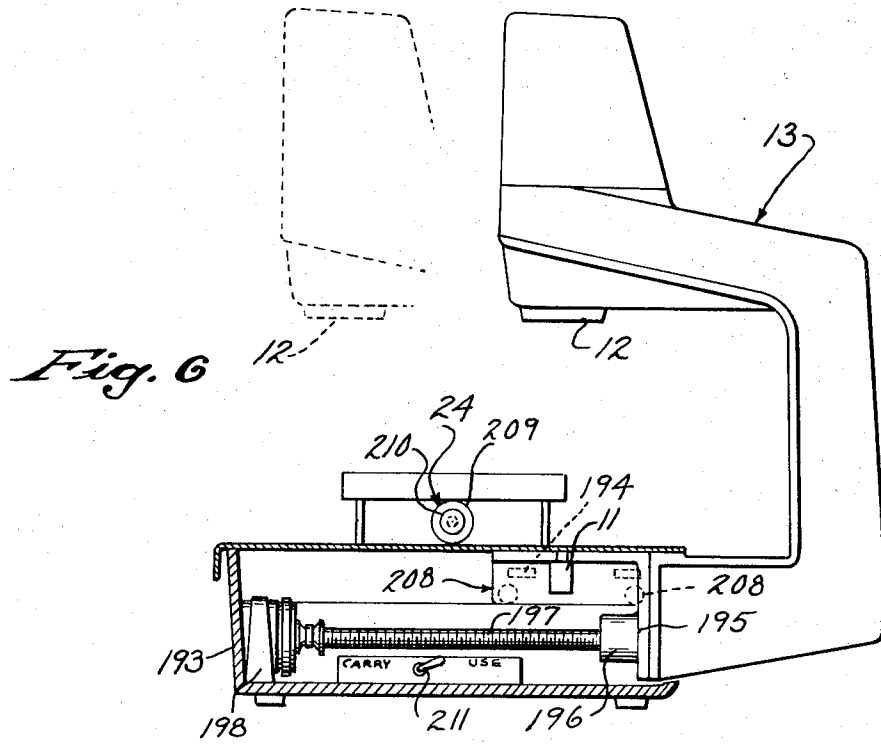
Fig. 8

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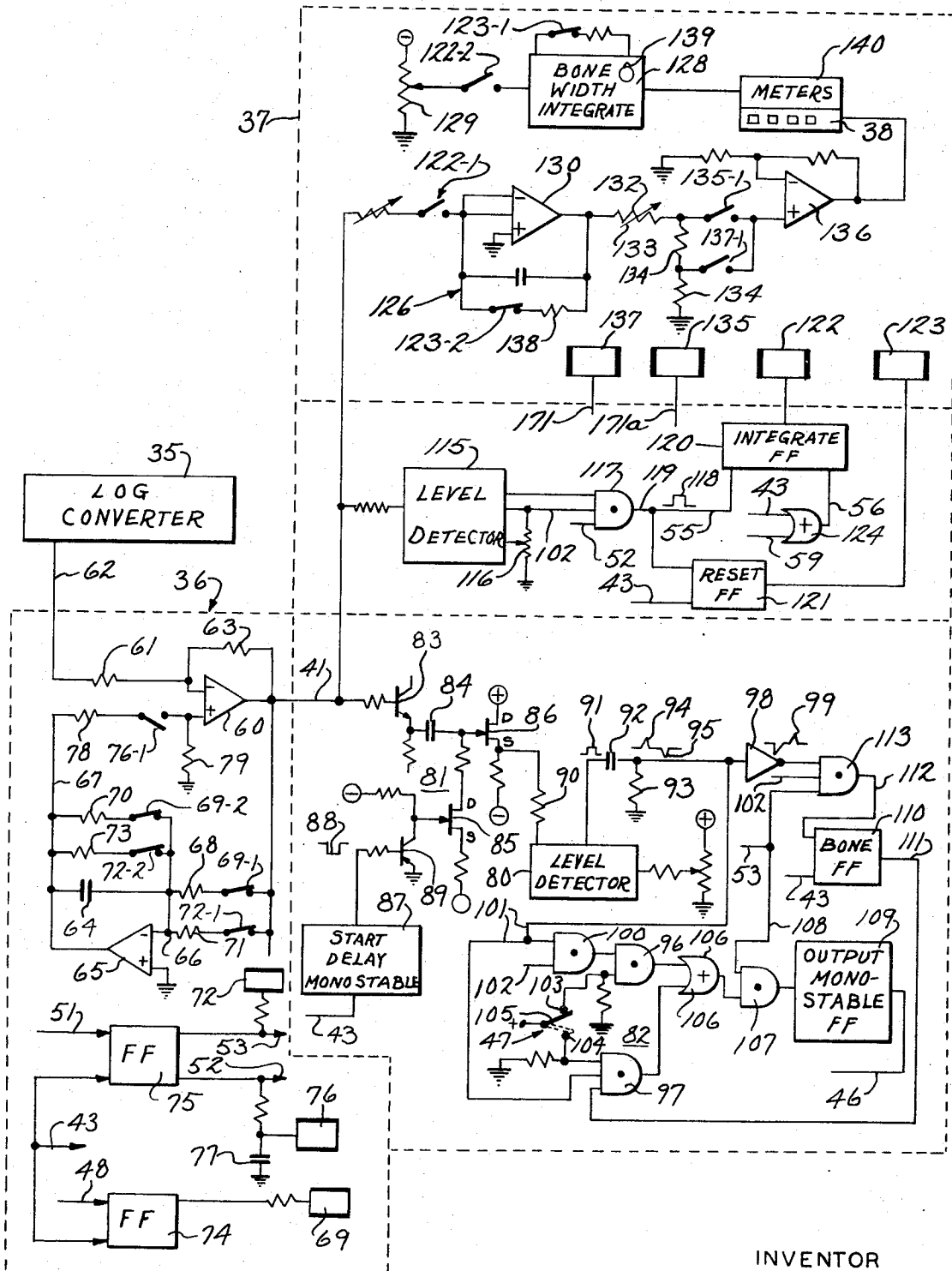


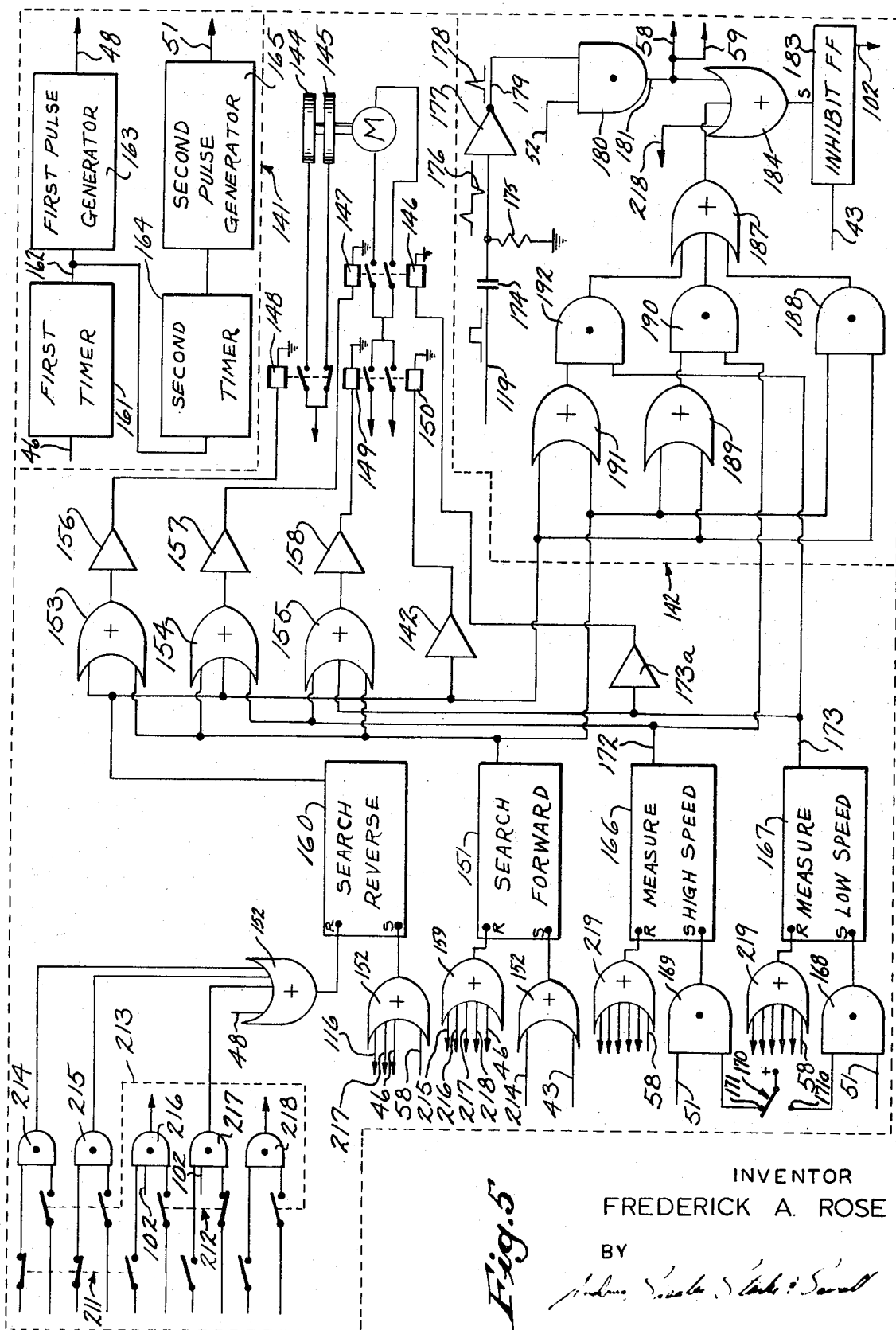
Fig. 4

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BONE MINERAL ANALYZER

BACKGROUND OF THE INVENTION

This invention relates to a bone mineral analyzer for determining the bone mineral content of a tissue covered bone.

The determination and analysis of the mineral content of a bone has been employed in the diagnoses and treatment of certain diseases and conditions related to bone demineralization. In the field of geriatrics, osteoporosis and osteomalacia require in vivo analysis of the mineral content of the bones. Dangerous conditions resulting from drugs, stress, pregnancy and lactation can also be analyzed and monitored if accurate bone mineral content can be detected. Generally, the prior art has employed radiographic analysis of a tissue covered bone for in vivo analysis or alternatively the excision, ashing and weighing of a bone sample for in vitro analysis. Both systems have very distinct disadvantages in practical application, particularly for in vivo determinations. In radiographic analysis, the bone mineral content is not readily determined with any high degree of accuracy and precision because of the effect of the soft tissue and the scattering of the radiation source and the like. Generally, the depletion of bone mineral has degenerated so greatly before a radiographic method discloses the condition, that a highly dangerous condition exists at the time of detection. Thus, an osteoporosis condition will generally have degenerated to such a state that a spontaneous fracture is imminent before the bone mineral depletion is readily detected by a radiographic method. Further, a relatively high degree of skill is required to properly conduct and analyze the results.

A highly improved method of determining the bone mineral content has recently been developed and is generally disclosed in an article entitled "Precision and Accuracy of Bone Mineral Determination By Direct Photon Absorptiometry" by John R. Cameron, Richard B. Mazess and James A. Sorenson, which was published in "Investigative Radiology" in the May-June 1968 edition Vol. 3, No. 3. As more fully disclosed in such article a monochromatic radionuclide source such as Iodine 125 or Americium 241 establishes a highly collimated photon beam which is intercepted by a collimated scintillation-detector-pulse height analyzer. The beam absorption characteristic of tissue is substantially different than the absorption characteristic of the bone. Further, the beam absorption characteristic of the bone is directly related to the amount of mineral in the bone, defined by an equation related to the logarithm of the ratio of the tissue absorbed beam intensity and the bone absorbed beam intensity. The tissue covered bone or limb is immersed in a liquid such as water which has an absorption characteristic essentially like that of the tissue to define an artificial profile having a constant thickness including a tissue equivalent specimen and a bone specimen which is scanned by movement of the beam across the covered bone. By integrating the logarithm of a tissue reference signal and a bone-tissue signal over the width of the bone and taking the difference, an accurate and precise method of determining the bone mineral content was obtained. The signals can be recorded for manual or automatic computation. For example, the signals were recorded on paper tape for subsequent computer calculation and in a further

development, internal calculation of the logarithmic curve was provided. The operator located the beam from one to three millimeters from the edge of the bone and then manually adjusted an average base line value to a zero position by reading of a meter and adjustment of a suitable control in the detection system. Thereafter the scanner was engaged and the beam was moved across the limb at a selected scanning speed with means responsive to interception of the onset and terminal end of the bone for automatically calculating the logarithmic integral of the resulting absorption curve and the displaying of the results upon suitable digital meters.

Although the apparatus and method provides reliable results, practical disadvantages, particularly from a clinical consideration, remain in the application of such apparatus and method. The total tissue covering a bone will vary from person to person and for any given water equivalent immersion body a corresponding difference in thickness equivalent material will occur.

As the output is dependent on the difference between the tissue reference signal and the bone-tissue signal, the apparatus must be established to maintain a constant reference or alternatively, as suggested in the paper, a base line reference signal must be inserted into the system to compensate for the variations. Further, the activity of the source of a radioactive source will generally decrease with time resulting in a somewhat difference characteristic. Consequently, in the prior art method, a new base line was manually introduced into the instrument for each measurement made by visual reading and zeroing of the level from which the bone signal was taken.

Although the absorption method provides a highly and very distinct improvement over earlier methods, the control of the operator particularly in initially setting the reference base line in order to establish the proper level of detection introduces a source of distinct error and requires a reasonable degree of skill to properly carry out the method of scanning. Further, movement of the tissue covered bone during the scanning will of course affect the results and, consequently, the time to execute a single pass is desirable as small as possible.

SUMMARY OF THE INVENTION

The present invention is particularly directed to a bone mineral analyzer employing the variable absorption characteristics of an essentially monoenergetic beam energy as disclosed in the above development and in particular provides an automatic instrumentation of the apparatus to virtually eliminate the operator variability and permit rapid, reliable and accurate output readings. Generally, in accordance with a particularly novel aspect of the present invention the analyzer is constructed with a beam producing means and a detection means constructed to establish an output response related to a selected essentially monoenergetic energy portion of a scanning beam and including an automatic reference signal means connected to the detection means for actuating a signal storage means to establish a tissue reference or base line signal proportional to the intensity level of the beam received while the beam is aligned with a tissue equivalent specimen. In a preferred and novel construction, a signal storage

means includes a capacitor connected to the output of the detection means by a difference amplifier. The capacitor is connected through suitable switching means to the output of the difference amplifier at two different time constants to permit rapidly charging the capacitor to an approximate final value and to more slowly charge the capacitor to a final value. After storing of the reference signal the charged capacitor is connected as an input to the amplifier with the signal generated while scanning the bone portion and directly establishes an output related to the difference for subsequent computation to determine the bone mineral content. The latter dual charging time is particularly significant in connection with a further novel aspect of the present invention in which a beam means is moved relative to the tissue equivalent covered bone member at a relatively fast search speed, with the interception of the beam means by the bone locating the bone and then a scanning beam is moved at a relatively slow scan speed to scan the bone. In the combination, the capacitor may be charged to the approximate value during the rapid search and charged to a final value after location of the bone and alignment with tissue equivalent material. The dual speed search and scan is of particular practical significance in a clinical instrument for in vivo determination to permit rapid and convenient measurement of a patient's bone. Thus, the beam means will rapidly locate the bone and then slowly scan the bone to permit adequate response by absorption of the beam, such that a plurality of scans of the same bone portion may be taken and averaged to make a more accurate determination. The beam means may include a single beam to locate and scan the bone, or may include a separate locating beam and separate scanning beam.

A particularly practical apparatus has been constructed employing a count rate meter to produce an analog output proportional to a radioactive beam source. The statistical nature of the output of radioactive sources would generally make the use of a count rate meter difficult because of the response characteristic when operating with the dual speed rapid search and slow scan construction. In accordance with a further aspect of the present invention the count rate meter is selected to have a rapid response with a variable time constant means connecting the count rate meter into the circuit. During the rapid search mode a relatively small time constant is employed to allow response to interengagement of the beam means and the bone edge after which the time constant is made large to compensate for errors which would otherwise be introduced as a result of the statistical nature of the scanning beam.

The automatic drive control of the present invention also permits accurate location of the scanning beam slightly spaced from the bone edge while establishing the tissue reference signal to more accurately reflect the thickness and composition of the tissue material covering the bone and thereby increase the accuracy of the determination.

In accordance with a further important practical aspect of the present invention the apparatus includes presettable bone selection means whereby the beam may scan two or more laterally spaced bones in a common tissue and select which of the two bones will be

analyzed. Generally, bone selection logic means are provided with a manual input to determine the bone to be selected and with the logic means interconnected such that the output of the first bone logic means enables the second bone logic means for operation when the second bone is desired. As applied to the fast search and slow scan, the drive means is interconnected to maintain the rapid search mode until the proper bone has been selected.

In a preferred construction of a bone mineral analyzer, a single scanning beam is employed to locate the bone and to scan the bone with the output of a beam detection means connected to a differential discriminator to transmit the pulses of the radioactive beam source within the selected monoenergetic range and establish an input to a count rate meter. The output of the count rate meter is connected to the dual time constant circuit. A difference amplifier and a logarithmic converter are connected in series between the dual time constant circuit and an integrating means. The output of the difference amplifier is also connected to the storage capacitor through the dual time constant circuit and the capacitor in turn is selectively connected to the input of the difference amplifier. A coarse bone edge detector is provided to respond to initial engagement of the scanning beam and the bone is operable through a logic sequence control which includes the bone selection means to connect the capacitor to the amplifier with the short time constant and to establish alignment of the scanning beam with the tissue equivalent specimen for establishing a reference or base line signal. A fine bone edge detector is connected into the circuit to respond to the second engagement of the scanning beam and the bone and is operable to actuate an integrating means for simultaneously integrating the output of the amplifier and separately integrating a constant signal until the beam disengages the trailing edge of the bone. The output of the integration means are connected to digital readout meters to provide a direct corresponding readout.

In accordance with a further aspect of the present invention, the integration and readout means store the readout as a signal and include calibration adjustment means to permit changing of the unit count with a count established in the readout means without changing the integrated signal. A standard unit may then be mounted in the apparatus and when scanned should produce a known reading. If the readout means do not read properly, the calibration control is adjusted to produce the proper readout, for the corresponding standard signal. The bone member is then immediately mounted in the apparatus and one or more scans made to produce a direct readout of the mineral content.

The present invention thus provides a highly improved bone mineral analyzer which will permit accurate and precise determination of the bone mineral content either in vivo or in vitro conditions and which is particularly adapted for clinical use.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings furnished herewith illustrate the preferred constructions of the present invention in which the above advantages and features are clearly disclosed as well as others which will be readily understood from the description of such illustrated embodiments.

In the drawings:

FIG. 1 is a block diagram illustrating the several components of a preferred embodiment of a bone mineral analyzer constructed in accordance with the teaching of the present invention;

FIG. 2 is a schematic illustration of the cross section of a limb mounted within a tissue equivalent cover for analysis by the bone mineral analyzer of FIG. 1;

FIG. 3 is a typical curve illustrating the bone mineral content of a limb such as illustrated in FIG. 2;

FIG. 4 is a schematic circuit of a referencing circuit, a bone detecting circuit and integrating circuits in a preferred construction;

FIG. 5 is a schematic block diagram illustrating the logic sequence and motor logic control as shown in block diagram in FIG. 1;

FIG. 6 is a view diagrammatically illustrating a drive mechanism for moving of the beam across the scanning paths;

FIG. 7 is a view taken generally on line 6—6 of FIG. 5; and

FIG. 8 is a schematic circuit diagram illustrating an alternative construction of a portion of the circuit shown in FIG. 4.

GENERAL DESCRIPTION

Referring now to the drawings and particularly FIG. 1, a bone mineral analyzer according to a preferred embodiment of the present invention is shown including a movable scanner 10 comprising a radiation beam producing source 11 and an aligned detector assembly 12 that are rigidly coupled by a U-shaped support assembly 13 for unitary movement by a drive motor assembly 14. The scanner 10 is preferably constructed in accordance with the construction shown in the copending application of Robert Burkhalter and George L. Congdon entitled LIMB HOLDER POSITIONER FOR BONE MINERAL ANALYZER Ser. No. 83,945, filed Oct. 26, 1970 which was filed on the same day as this application and is assigned to the same assignee. The assembly 13 is generally shown as a U-shaped arm member which moves transversely over a support area 15 upon which a tissue covered limb 16 is supported. In the illustrated embodiment of the invention, the limb 16 is shown including a pair of transversely spaced bones 17 and 18 within a common body tissue 19, such as a forearm which includes the radius and the ulna. Source 11 establishes a beam 20 including a selected essentially monoenergetic energy, which is absorbed at one level by a unit thickness of the body tissue and at a distinctly different level by the bone. Beam 20 is directed toward the detector assembly 12 and the output is a signal related to the received selected energy. Source 11 preferably consists of a monochromatic, low energy photon source, generally within a range of 20 to 80 kev, such as Iodine 125 which has a 27.3 kev tellurium K x-ray from electron capture or Americium 241 which has a 59.6 kev gamma ray, with the energy level selected in accordance with the size of the bone being measured and the total bone tissue cover. The detector assembly 12 may consist of any suitable radiation detector responsive to the selected monoenergetic energy of the beam and which, if other energy forms are present, can discriminate between the energy of interest and background radiation. Thus, the source 11 and detector 12 are selected to produce a monoener-

getic output response. For example, with the above operative sources, the detector assembly 12 may comprise a collimated thallium activated sodium iodide, NaI (TI), scintillation crystal detector 21 which is aligned with the source to detect the source radiation and which is coupled to a photomultiplier tube 22 for producing an electrical output signal which is a function of received radiation. A commercially available detector assembly 12 which has been successfully employed is a Harshaw Chemical Company Model No. 25HC3M/-X568-029-87. This device includes the thallium activated sodium iodide crystal which produces light pulses proportional to the received energy and the photomultiplier tube 22 which produces an electric output signal function related to the light pulses. A pair of lead plates 23 each about 5 mm thick and spaced apart about 4 cm and each having apertures aligned on a common axis with the photon source provides for detector collimation.

For purposes of source collimation, the source may be contained in a thin walled stainless steel tube (not shown) approximately 1 cm long and 3 mm in diameter. The tube may be disposed in a 3 mm hole drilled in a lead cube with the end of the cylinder approximately 5 mm below the surface of the cube.

The mineral content of a bone is a function of the logarithm of the ratio of the beam intensity transmittance after passage through a given thickness of tissue and tissue equivalent material (I_0) to the intensity of the beam (I) after passage through an equal thickness of bone mineral plus tissue and, as more fully described in the previously identified article, the mineral content can therefore be conveniently determined by subtracting the difference of the log signals, integrated over the width of the selected bone.

To establish a constant profile for a measurement, the tissue covered bone or limb 16 is placed in a suitable holder 24 having parallel top and bottom walls 25 and 26 and which is filled with a material having the same beam absorptive characteristics as the tissue, such as water 27. As will be discussed more fully hereinbelow, measurements are made with the beam 20 aligned with the tissue specimen comprising tissue 19 and tissue equivalent material 27 as at line 28 to establish a tissue reference signal and with the beam 20 moving across the bone and thus passing through the bone 17, tissue 19 and tissue equivalent material 27 as at line 29 of FIG. 2 to establish a bone-tissue signal. The logarithm of the signals are established and as shown in FIG. 3 the area between the bone-tissue signal curve 30 ($\ln I$) and the base line or tissue reference signal 31 ($\ln I_0$) indicates the mineral content of the bone 17.

In the embodiment of the invention shown in FIG. 1, the output of the photomultiplier tube 22 of detector 12 is amplified by an amplifier 32 and transmitted to a receiving means including a differential discriminator 33 which only transmits the detected energy pulses within a selected range and in particular pulses representing the monoenergetic gamma rays of interest. A count rate meter 34 is coupled to the differential discriminator 33 to produce an analog output which is proportional to the transmitted monoenergetic beam intensity received and transmitted by the detector 12. A logarithmic converter 35 receives the output

of count rate meter and converts the same into a logarithmic function so that bone mineral content can be determined in accordance with the logarithmic ratio discussed above. While those skilled in the art will appreciate that the components illustrated in block form in FIG. 1 and discussed briefly hereinabove may take a wide variety of specific forms, certain specific examples which could be employed to provide a satisfactory apparatus, include an Oretic Model 485 amplifier, an Oretic Model 406-A differential discriminator, an Oretic Model 441 count rate meter, and a Philbick-Nexus 4350 Log Converter.

The output of the logarithmic converter 35 is connected to an automatic zero sequence and referencing circuit 36 to selectively establish a tissue reference signal related to the beam absorption by the tissue specimen and to subsequently transmit the difference of such tissue reference signal and a bone-tissue signal which is established as the beam 20 scans the selected one of the bones 17. An integration means 37 is selectively connected to the circuit 36 and integrates said difference output and establishes an output directly related to the bone mineral content. A readout means 38 is connected to the integration means 37 to display the bone mineral content.

Referring still to FIG. 1, in the preferred embodiment of the invention the output of the log converter 35 is also connected through circuit 36 to actuate a logic sequence circuit 39 and a motor logic circuit 40 to control the movement of the beam 20, via a lead 41 which also coupled the output of circuit 36 to the integration means 37.

A start signal unit 42 such as a push button unit establishes a start signal at a start line 43 connected to initiate the operation of the motor assembly 14 in a search forward mode to drive the scanner 10 toward the bone being measured and to condition the logic circuit 39 for operation. The line 43 of start signal unit 42 is also connected to the automatic referencing circuit 36 as well as a coarse bone edge detector circuit 44 and a fine bone edge detector circuit 45 to provide movement of the beam 20 in accordance with interception of the beam 20 by the bone. As shown in FIG. 3, the magnitude of the signal level decreases with the interception of beam 20 by the leading edge of the bone 17 being measured. The coarse edge detector 44 is responsive to such decrease to provide a start analysis signal at a line 46 which is connected to the logic sequence circuit 39 and the motor logic circuit 40. Where the analyzer is constructed to scan the limb containing two bones, as shown in FIG. 1, the coarse bone edge detector includes a selection switch control 47 which internally establishes the response to provide a start analysis signal only when the selected bone is sensed.

The motor logic circuit 40 will, upon receipt of the start analysis signal, cause the motor assembly 14 to operate in a search reverse mode until the logic sequence circuit 39, which is also actuated by the start analysis signal, provides, after a predetermined delay, a start analysis delay signal at a first delay control line 48 whereupon the motor stops and holds the scanner 10 in a position wherein the source 11 and detector assembly 12 are approximately 2 to 3 mm outside of the bone as shown at line 28 in FIG. 3. The start analysis delay signal line 48 is also connected to the referencing circuit

circuit 36 which becomes operative to establish the zero reference signal for producing curve 31, as shown in FIG. 3.

After a selected time delay during which circuit 36 completes setting of the base line reference signal, the logic sequence circuit 39 provides a second start analysis delay signal at a line 51. Line 51 is connected to the motor logic circuit 40 to begin operating in its forward measurement mode whereby the scanner 10 begins moving toward the bone to be measured. Line 51 is also connected to the referencing circuit 36 to internally connect the stored tissue reference signal within circuit 36 to be subtracted from the signal received from the log converter 35 and therefore establish an output at an average value of zero during the initial forward measurement mode.

The referencing circuit 36 also establishes interlocking signals to the coarse and fine edge detectors via lines 52 and 53 which, upon the completion of the referencing, disables the coarse edge detector 44 and enables the fine edge detector 45. The interlock signal at line 54 of reference circuit 36 is also connected to enable the logic sequence circuit 39.

When the onset of the bone is again sensed, a change of magnitude of the output signal of circuit 36 occurs. The fine bone edge detector circuit 45 is now actuated and provides an integrate start signal at a line 55 to the integration circuit or means 37 which then begins integrating the signal from circuit 36 to provide the integral of the area between the curves 30 and 31 in FIG. 3 and correspondingly energizes the readout meter 38. When the trailing edge of the bone is detected, the fine bone edge detector circuit 37 initiates the generation of a reset signal which is coupled via a reset line 56 to the integrating circuit 37 which then terminates the integration, as follows. A signal is transmitted via a line 57 to the logic sequence circuit 39 to establish an end of measurement signal which is transmitted via a line 58 to the motor logic circuit 40 to switch the motor drive from its forward measure mode to a reverse mode in which the scanner 10 is returned to its initial position. The logic sequence circuit 39 also produces a signal at a line 59 which is connected back to the fine bone edge detector to generate the signal at line 56.

In addition, a bone width may be determined by integrating a constant level signal over the distance traveled by the scanner 10 between the rise and fall of the signal provided by the fine bone edge detector circuit 45 which indicates the leading and trailing edges of the bone being measured.

ZERO SEQUENCE AND REFERENCING CIRCUIT

Generally, a particularly novel zero sequence and referencing circuit 36 is shown in FIG. 4 constructed to provide computation of the difference of the tissue reference signal and the bone-tissue signal. The circuit 36 includes a first operational amplifier 60 having an inverting input connected by a resistor 61 to a line 62 for receiving the input signal from the log converter 35. The output of the amplifier 60 is connected by a feedback resistor 63 of a value corresponding to the input resistor such that the output signal is equal to and the inverse of the input signal.

The output of amplifier 60 is connected via output line 41 to the edge detectors 44 and 45 and to the in-

tegration means 37, and is also connected internally to charge a signal storage capacitor 64, as follows.

The capacitor 64 is connected across a second operational amplifier 65 and particularly between an inverting input terminal 66 and the output line 67. A first time constant resistor 68 connects the input terminal 66 to the output line 41 in series with a set of normally closed contacts 69-1 of relay 69. A related feedback resistor 70 is connected in parallel with capacitor 64 by a second set of normally closed contacts 69-2 of relay 69. The resistors 68 and 70 are of an equal resistance such that the signal at line 67 is equal and the inverse of the signal at terminal 66. Further, the resistor 68 in series connected with capacitor 64 is selected to establish a relatively short charging time constant, e.g., 0.1 seconds.

A second time constant resistor 71 similarly connects the terminal 66 to line 41 via a set of normally closed contacts 72-1, of a disconnect relay 72. A second feedback resistor 73, of a resistance equal to that of resistor 71, is connected across capacitor 64 by a second set of normally closed contacts 72-2 of relay 72. The resistor 71 establishes a relatively long charging time constant, e.g., 2.0 seconds. Relays 69 and 72 are controlled by a pair of corresponding flip-flop circuits 74 and 75, each having a reset input connected to the start line 43 of the apparatus start unit 42 of FIG. 1. The relays 69 and 72 are de-energized when the circuits 74 and 75 are reset.

The flip-flop 74 has its set terminal connected to the first delay signal line 48 to open contacts 69-1 and 69-2 during the final averaging to establish a tissue reference signal in capacitor 64.

The flip-flop 75 has its set terminal connected to the second delay signal line 51 to open contacts 72-1 and 72-3 and thereby disconnect the capacitor 64 from the operational amplifier 60 and store the signal in capacitor 64.

When the start signal is received at line 43, each of the flip-flop circuits 74 and 75 are reset to close the relay contacts and connect the output signal of the amplifier 60 to the inverting terminal 66 of the operational amplifier 65 through the paralleled resistors 68 and 71. In addition, because the input resistances equal the feedback resistances of the amplifier, the voltage at the output terminal or line 41 is the inverted duplicate of the log converter signal appearing at input line 62 and the signal appearing on conductor 67 is the inverted duplicate of the output signal and therefore equal to the log signal appearing at line 62. Capacitor 64 will also be charging through resistor 68 which is substantially smaller than 71. This will be the condition of automatic circuit 36 as the scanner 10 moves toward the bone to be measured.

When the bone edge is sensed, the coarse bone edge detector circuit 44 provides the start analysis signal at the line 46 of FIG. 1 and actuates the logic sequence and motor logic circuits 39 and 40 as previously described to back the scanner 10 away from the bone 17 until the logic sequence circuit 39 provides the start analysis delay signal at line 48 which stops the motor and sets the flip-flop 74 to open relay 69 and now connects capacitor 64 in circuit through resistor 71. Because of the shorter time constant of resistor 68, capacitor 64 will have assumed substantially its final charge prior to the opening of relay contacts 69-1 and

69-2. The time constant of resistor 71 and capacitor 64 is long compared to the statistical fluctuations in the count rate due to source fluctuations and hence the average count rate is now accurately determined in the circuit and accumulated on the capacitor 64. As a result, when relay 69 opens, the time required for the charge on capacitor 64 to assume its final value is relatively short compared with the time that would be required for 64 to charge from a fully discharged condition. Thus, because capacitor 64 has been substantially fully charged through resistor 68 to provide a relatively short time constant, only final averaging is required through the resistor 71 when relay 69 is open.

After a second delay during which the final value is fully set in the capacitor, e.g., approximately 6 seconds in the preferred embodiment, the logic sequence circuit provides the start analysis signal twice delayed at the lines 51, which sets the zero sequence flip-flop 75 to open relay 72 and thereby disconnect capacitor 64 from amplifier output line 41.

The setting of flip-flop circuit 75 energizes a relay 76 which is connected to the opposite side of the circuit 75 in parallel with a relatively short time delay capacitor 77. Relay 76 includes a set of normally open contacts 76-1 which connect the output line 67 of amplifier 65 and capacitor 64 to the non-inverting input of the amplifier 60. A series resistor 78 is connected in line 67 and a grounding resistor 79 is connected to the non-inverting input of amplifier 60. Upon the opening of relay 72 and the closing of relay 76, the amplifier 60 is connected as a differential amplifier with the input equal to the output of the log converter 35 appearing at line 62 less the voltage stored in capacitor 64 appearing at line 67. Initially, the signals at its terminals, i.e., from the log converter 34 and from capacitor 64, will both be related to the tissue reference specimen so that the output at line 41 will assume an average value of zero. Therefore, when the scanner is in position with the beam 20 aligned with tissue and tissue equivalent material at line 28 in FIGS. 2 and 3, the base line count rate and the output of the automatic zero circuit will be effectively zero. This is represented by the line 31 of FIG. 3.

The sequence flip-flop 75 also provides the interlocking signals at the two lines 52 and 53 which are connected to condition the logic sequence unit 39 and the bone edge detectors 44 and 45 for selective operation before and after completion of the referencing.

The initial resetting of circuit 75 by the start signal at line 43 establishes a signal at line 53 and removes the signal from line 52. In this mode, the coarse edge detector 44 is enabled and the fine edge detector 45 and logic sequence circuit 39 are disabled, as presently described. On the other hand, when zero sequence flip-flop 75 is set by the start analysis twice delayed signal of line 51, the zero sequence complete signal appears at line 52 to tell other portions of the apparatus that the zero sequence is complete and a measurement is in progress. These signals are employed to condition the apparatus for the generation of appropriate signals by certain portions of the device during a measurement, as previously described.

Those skilled in the art will appreciate that while in the preferred embodiment the base line is set at zero, it can also be set at some other convenient value which

would then be suitably taken into account by the integrator means 37.

COARSE BONE EDGE DETECTOR CIRCUIT

It will be recalled that the coarse edge detector circuit is operative to provide a start analysis signal when the beam 20 of scanner 10 originally encounters the bone 17 being measured. This circuit 44 is shown in FIG. 4 to include a level detector 80 and a level detector input circuit 81 connected to the output of the referencing circuit 36 to selectively transmit the output signal appearing at line 41. Detector 80 is connected to a bone selection circuit 82 including switch 47 and controls the generation of the start analysis signal at line 46 when the proper bone intercepts the beam 20 of scanner 10.

The level detector input circuit 81 includes a transistor 83 connected as an emitter follower with the output signal of circuit 36 applied to its base and its emitter connected to a coupling capacitor 84, the other side of which is selectively returned to ground through a field effect transistor 85. A second field effect transistor 86 is connected as a source follower with its gate also connected to the other side of the capacitor 84 and its source connected to the level detector 80. Transistor 86 has a very high input impedance and transmits the voltage on the capacitor to level detector 80 without loading the input circuit. The field effect transistor 85 is used to switch the impedance on the output side of the capacitor and therefore the signal transfer to the field effect transistor 86. When the field effect transistor 85 is on the impedance of the transistor is low and hence the time constant of the coupling capacitor 84 and the resistance inserted by the transistor 85 is relatively short and the signal is effectively by-passed to ground with the gate of transistor 86 set to zero, corresponding essentially to the base line. When field effect transistor 85 is off, the impedance is very substantial and typically 10^9 ohms and hence the time constant is very long and the voltage signal of the absorption curve at line 41 of the bone is transmitted to detector 80.

Transistor 85 is controlled by the start signal from the start unit 42 which is connected by line 43 to a start monostable multivibrator 87, the latter provides a negative going square wave signal 88 to the base of transistor 89 whose collector is connected to the gate of field effect transistor 85. The negative pulse drives transistor 89 fully on and the voltage at the collector raises and turns on field effect transistor 85. The time constant for the capacitive coupling from input transistor 83 and therefore line 41 is short and the voltage level at the gate of field effect transistor 86 is set to the reference zero which appears at line 41. When the start-delay pulse of multivibrator 87 falls, transistor 89 turns off and consequently turns off field effect transistor 85. Since the time constant of capacitor 83 is now long, the bone absorption signal from circuit 36 is transmitted through field effect transistor 86 and a resistor 90 to the input terminal of level detector 80, which may be of any suitable type, such as a Schmitt-trigger.

Level detector 80 is set to become operative at a voltage representing interception of the edge of the bone or bones being scanned. In the preferred embodi-

ment of the invention previously described, the particular logarithmic converter 35 induced 2 volts per decade of count rate change and the level detector threshold was set at about 0.3 volts below the "off" voltage at the source of field effect transistor 86. The output of the level detector 80 is a square wave 91 with the leading and trailing edges corresponding to the interception of the beam 20 by the onset and termination bone edges. A capacitor 92 and a resistor 93 form a differentiating circuit connected to detector 80 to produce a positive pulse 94 at the leading edge of the bone and a negative pulse 95 at the trailing edge thereof. The output of the differentiating circuit is connected to a first bone logic unit 96 and a second bone logic unit 97 of the selection circuit 82 and which units are selectively conditioned for response, by the selection switch unit 47, to a positive pulse signal. The output of the differentiating circuit is also connected to an inverter 98 to invert said signals and particularly produce a signal 99 representing the trailing edge of the first bone 17. The output of the inverter 98 is connected to disable the second bone logic unit 97 until the trailing edge pulse 99 of the first bone is established.

In the bone selection circuit 82, the logic unit 96 is a three input AND gate having one terminal connected to a signal lead 100 from the differentiating circuit and producing an output when the first bone leading edge pulse 94 appears on conductor 100, if the first bone has been selected by proper setting of switch 47 to establish a proper input at a second input line 101 and an interlock signal from the logic sequence circuit 39 is simultaneously applied to a line 102 connected to the third input of gate 96. The latter indicates the absence of error signals so that a measurement may be properly made, as described hereinafter.

The selector switch unit 47 has a bone-1 terminal 103 connected to the second input of the first AND gate 96 and a bone-2 terminal 104 connected to one input of a second bone logic unit 97 shown as a three input AND gate 97. A common contact arm 105 of switch unit 47 is positioned to supply power to one of the terminals 103 and 104 and thereby condition the corresponding gate 96 or 97 for response. The outputs of AND gates 96 and 97 are connected to the inputs of an OR gate 106 whose output is connected as one input of a third two input AND gate 107, whose other input 108 is connected to line 53 of circuit 36 and receives a signal when the zero sequence setting operation has not been completed by the zero sequence or referencing circuit 36. As a result, an output from the coarse bone edge detector 45 will be prevented after the completion of the zero sequence setting operation and a measurement is in progress.

If only a single bone is present or the first of a pair of bones is to be measured, the selector switch unit 47 will be placed in its bone-1 terminal as illustrated by full lines in FIG. 4. In this position, the AND gate 96 will provide an output signal when the leading edge of the bone is sensed in response to the pulse signal 94 at line 100 and the interlock signal at line 102. As a result, a signal will be provided by the OR gate 106 to one input of the AND gate 107 whereby an output actuating signal will be provided if the reference circuit interlock signal is also present at line 53. An output monostable flip-flop 109 is connected to the output of the AND

gate 107 and the start analysis line 46 of the coarse bone edge detector 46 thus provide a start analysis signal when the leading edge of the first bone is sensed, no measurement is in process and no error signals are present.

If the second bone 18 is to be measured and consequently the first bone is to be disregarded, the selector switch unit 47 is placed in its bone-2 position with arm 105 engaging contact 104 to condition gate 97 for operation. As a result, when the leading edge pulse 94 of the first bone appears on conductor 101, AND gate 96 will be disabled as a result of removal of the signal from unit 47 so that it will not provide an output signal to OR gate 106. The AND gate 97 which provides the other input to OR gate 106 is also disabled as a result of the start signal at the line 43 from unit 42, as follows. A bone flip-flop circuit 110 has its reset input connected to line 43 and an output line 111 connected to gate 97. The reset of circuit 110 removes the signal from line 111 at commencement of the operation and the OR gate 106 and the AND gate 107 will be disabled so that no start analysis signal will be generated in response to the initial pulse 94 whereby the various circuits dependent upon the start analysis signal to commence operation will remain inactive even though the scanner 10 is traversing the first bone.

The bone flip-flop circuit 110 has its set input connected by a line 112 to a three input AND gate 113 whose inputs are coupled to the output of an inverter 114, the reference circuit interlock signal line 54 and the logic sequence interlock line 102. Since a signal will be present at line 102 if there are no error signals and at line 54 when the zero sequence is in process, the bone flip-flop 110 is set by the inverted trailing edge pulse 95 of the first bone which appears as pulse 99 at the gate 113. The flip-flop 110 transmits a corresponding signal via line 111 to gate 97 and conditions the gate for operation in response to a positive logic signal at the third input which is connected to line 100. Consequently, when the leading edge pulse generated by interception of beam 20 by the second bone appears on conductor 100, the AND gate 97 will be enabled and provides an output to the OR gate 106 so that the start analysis signal will be generated. In this manner, the motor assembly 14, logic sequence circuit 39 and related elements are actuated to provide the measurement of the second bone by the start analysis signal at line 46, generally in the manner discussed hereinabove with respect to FIGS. 1 and 3.

FINE BONE EDGE DETECTING CIRCUIT AND INTEGRATION CIRCUITS

It will be recalled that after the start analysis signal is generated, the motor assembly 14 will reverse and move the scanner 10 to a position 2-3 mm outside the bone as shown at line 28 in FIG. 3, whereupon the logic sequence circuit 39 will generate a start analysis delay signal at line 48 which will stop the motor assembly 14 and commence the zero sequence operation of the referencing circuit 36. After the zero sequence setting operation has been completed, the logic sequence circuit 39 will generate a start analysis signal twice delayed at line 51 which will cause the motor assembly 14 to begin moving the scanner 10 in its measure forward direction. The fine bone edge detecting circuit 45

is coupled to receive the signal at line 41 from the referencing circuit 36 and is operative to commence integration by the integrating circuit 37 when the edge of the bone to be measured is intercepted a second time by beam 20 of the scanner 10.

The fine bone edge detecting circuit 45 includes a level detector circuit 115, which may also take any convenient form such as a Schmitt-trigger circuit. The level detector 115 is coupled to line 41 of circuit 36 to receive the output signal from the circuit 36 which, it will be recalled, will be a voltage proportional to the logarithm of the beam absorption of the scanner 10 as it traverses the bone and will be set at an average value of zero before the bone is encountered. The level at which detection is made by detector 115 is determined by the setting of a potentiometer 116 which, in the preferred embodiment of the invention, is set at minus 0.3 volts similar to detector 80. The output of the level detector 115 is coupled to one input of an AND gate 117 which is also coupled to receive the zero set complete signal from line 52 of circuit 36 and a logic interlock signal from line 102 of circuit 39. Thus, gate 117 will be enabled to provide a bone edge signal 118 at its output line 119 when the signal at line 41 of circuit 36 reaches a predetermined value as a result of appropriate signals at lines 52 and 102 indicating proper circuit operation to that time. The bone edge signal 118 is a positive signal which is connected by line 55 to set an integrate flip-flop 120 and to reset a reset flip-flop 121 to condition circuit 37 to initiate an integrating operation.

The integrate flip-flop 120 and the reset flip-flop 121 are coupled to operate relays 122 and 123, respectively, in the integrating circuit 37. As will be discussed more fully hereinbelow, an integrating operation can commence when relay 122 is energized and relay 123 is de-energized. The starting signal line 43 is connected to the set input of reset flip-flop 121 to actuate relay 123 and close sets of contacts 123-1 and 123-2 to reset the integrators 128 and 130 respectively. The starting signal line 43 is also connected to one side of the OR gate 124 to terminate the integration by resetting the integrate flip-flop 120 and hence de-energize relay 122 and open relay contacts 122-1 and 122-2.

The bone edge signal 118 at line 119 is a positive going DC signal which will be up for the duration that the scanner 10 traverses the bone being measured. As will be discussed in greater detail hereinbelow, the fall of the signal 118 will be employed by the logic sequence circuit 39 to generate an end of measurements signal at the line 59 shown in FIGS. 1 and 3, which is connected to the OR gate 124 to also reset integrate flip-flop 120. In this manner, after the traverse of the bone being measured has been completed, the relay 122 will be opened, terminating the integration operations.

The integrating circuit 37 includes a bone mineral integrating circuit 126 coupled to the output line 41 of the circuit 36 through normally open relay contacts 122-1 of relay 122 and a resistor 127 to receive the signal. A bone width integrating circuit 128 is also connected through a set of normally open relay contacts 122-2 of relay 122 to a constant voltage source represented by a potentiometer 129. Circuits 126 and 128 may be identical and accordingly circuit 128 has

been illustrated in block form for the sake of brevity. It will be understood that except for the fact that the bone mineral integrating circuit 126 is coupled to integrate the automatic zero output signal while the bone width integrating circuit 128 is coupled to integrate a constant voltage, the circuit components and method of operation of the two circuits may be otherwise identical.

The illustrated integrating circuit 126 includes an operational amplifier 130 having its input connected by contacts 122-1 and resistor 127 to line 41. A capacitor 131 is coupled between the inverting terminal and the output terminal of amplifier 30. As those skilled in the art will appreciate, the output voltage of the operational amplifier 130 is equal to the integral

$$-\frac{1}{R_{127}C_{131}} \int V_{41} dt,$$

and is stored in the capacitor 131. The signal V_{41} is equal to the difference between the tissue reference signal shown as the log curve 31 and the bone-tissue signal shown as the log curve 30 and therefore the integral is equal to the difference of such curves 30 and 31 and therefore equal to the bone mineral content.

The integration circuit 126 may be provided with the usual calibration by the variable resistor 127 connected to the input side of the circuit. In accordance with the present invention, a calibration resistor 132 is connected to the output side of circuit 126 and provided with an external control element 133, as diagrammatically shown in FIG. 1, to permit output calibration for a given signal on capacitor 131. This permits adjustment and calibration of the readout means or meter 38 with a single scan, as more fully developed hereinafter.

Because the system according to the preferred embodiment of the invention can be driven in a high speed or low speed mode, i.e., 1 mm per second or 2 mm per second to compensate for the output of source 11 with time, a scale factor must be introduced into the signals provided to the meter 38. For this reason, a voltage divider consisting of equal resistors 134 are connected and coupled between the resistor 132 and ground. A relay 135 controls relay contacts 135-1 which are connected to the junction of resistor 132 and the one resistor 134 and connect the bone mineral voltage to the input of an operational amplifier 136. A relay 137 includes normally open relay contacts 137-1 connected to the junction of resistors 134 to provide one-half of this bone mineral voltage to amplifier 136. Relay 135 is controlled by a motor low signal which is provided from the motor logic circuit when the device is in its low speed mode and relay 137 is controlled by a motor high signal from the motor logic circuit when the device is in its high speed mode. The operational amplifier 136 is connected as a voltage follower to provide a high input impedance to the voltage divider resistors 134 and low output impedance to the meter 38 which gives the actual indication to the operator. The meter 38 is diagrammatically shown as a digital panel type meter which establishes a visual numerical display proportional to the signal on the capacitor 131, and therefore the mineral bone content when operated as described.

The integrate reset relay 123 includes a set of normally open contacts, relay contacts 123-2, which are

connected in series with a resistor 138 across capacitor 131 to shunt and reset the capacitor when the start signal at line 43 sets the reset flip-flop circuit 121. This dumps the charge previously stored on capacitor 131 in preparation for a new integrating operation. The reset flip-flop 121 is reset by the bone edge signal 118 to open the contacts 123-2 when an integrating operation commences. Contacts 123-1 remain open after the termination of the integrating operation so that the charge on capacitor 131 is retained until the next start signal is received, for purposes of calibrating the meter 38.

The bone width integrator 128 is similarly constructed and connected to the potentiometer 129 by the contacts 122-2 of start integration relay 122. The integration 128 will also include a calibration control element 139 to set the circuit to the output side and to thereby properly actuate a similar meter 140.

MOTOR LOGIC AND LOGIC SEQUENCE CIRCUITS

The logic sequence circuit 39 includes a start analysis responsive channel or circuit 141 for generating the first delayed start analysis signal at line 48 and subsequently the second delay start analysis signal at line 51. In addition, an inhibit and end of measurement channel or circuit 142 is provided for generating an end of measurement signal at line 59, and the inhibit interlock signal at lines 102 for controlling logic elements of FIG. 4, as more fully discussed hereinafter.

The scanner drive assembly 14 includes a reversible motor 143 having its drive shaft connected to drive arm 13 through suitable clutches 144 and 145, arranged with separate relay or relays controlling each of the modes of the motor. The motor 143 is a two speed reversible type such as that sold by Bodine and identified as type KYC-26-T3A1. The two speeds are used to attain the measurement or scan speeds such as 1 mm per second for low speed scans and 2 mm per second for high speed scans. This speed change is set by energizing either a low speed motor relay 146 or a high speed motor relay 147, each of which includes the related contacts 146-1 and 147-1 connecting the motor to the incoming supply lines. The clutches are used to obtain a gross speed change from 1 or 2 mm per second scan speed to 1 cm per second search speed. One of the two clutches 144 and 145 is engaged at all times by using a common actuator including a double throw high speed clutch relay 148 connected so that when relay 148 is energized, the clutch 144 connects motor 143 to drive the output shaft and arm 13 at 1 cm per second search speed while the clutch 145 connects motor 143 to drive arm 13 at the lower scan speed when this relay 148 is de-energized. The direction of motor operation is controlled by forward and reverse motor relays 149 and 150, respectively.

The motor logic circuit 40 includes a search forward flip-flop 151 having a set signal connected by an OR gate 152 to line 43 of start unit 42 and an output line similarly connected, when the flip-flop is set, to energize the high speed clutch relay 148, the high speed motor relay 147 and the forward motor relay 149 through the respective OR gates 153, 154 and 155, and associated amplifiers 156, 157 and 158. The scanner 10 is thus driven in the forward direction and at high speed until the leading edge of the first bone 17 to be mea-

sured intercepts the beam 20. The coarse bone edge detector circuit 45 will then provide the signal at line 46 which is connected to the reset terminal by an OR gate 159 of the search forward flip-flop 151 and upon receipt of the signal de-energizes the high speed clutch relay 148, the high speed motor relay 147, and the forward motor relay 149 and the motor will stop its forward traverse.

A search reverse flip-flop 160 is similarly connected to control gates with a set input connected to the line 46 to provide a reverse drive speed at an output line connected to energize high speed clutch relay 148, the high speed motor relay 147 and the reverse motor relay 150 similar to the output of flip-flop 151 so that the motor 143 operates at high speed in its reverse mode. The reset terminal of the flip-flop 160 is similarly connected to the logic sequence circuit 39 and particularly line 58. The several AND gates to the flip-flops 151 and 160 permit interlocking signals related to the position of the scanner arm assembly to prevent operation if the arm has not moved properly for any reason, as hereinafter described.

Referring again to the channel 141 of the logic sequence circuit 39, the start analysis signal line 46 from the coarse bone edge detection circuit 45 is connected to a first delay generator 161 whose output line 162 is coupled to a first output pulse generator 163, whereby a start analysis delay signal will be generated at line 48 after a predetermined time delay. The signal at line 48 is provided to the flip-flop 74 of the referencing circuit 36 for initiating the zero sequence function and in addition is provided to the motor logic circuit 40 to reset the search reverse flip-flop 159. This de-energizes the motor drive circuit, whereby the scanner 10 and particularly beam 20 will be in its zero mode or at rest. The period of the first delay generator 161 is such that the scanner will come to rest in a position that is 2 - 3 mm outside of the bone as shown at line 28 in FIG. 3, and remains at rest for a predetermined period.

The output signal of the first pulse generator 163 is connected to a second delay generator 164 whose output is coupled to a second output pulse generator 165 whereby after a second time delay, the start scan analysis signal will be generated at the line 51. The period of the second delayed generator 165 establishes the above rest period of beam 20 and is selected to be sufficiently long to permit the automatic zero sequence circuit to complete the automatic zero setting function; e.g., 6 seconds.

The twice delayed signal at line 51 is connected to actuate a measure high speed flip-flop 166 or measure low speed flip-flop 167 by corresponding dual input AND gates 168 and 169 which are selectively conditioned for operation by a two position speed selector switch 170 having a high speed contact 171 connected to gate 169 and a low speed contact 171a correspondingly connected to the other gate 168. The contacts are also connected to correspondingly energize the relays 135 and 137 of circuit 37, shown in FIG. 4. If measure high speed flip-flop 166 is energized, a signal will be generated at the output line 172 which is connected to gates 154 and 155 to the high speed motor relay 147 to drive the motor at high speed in a forward direction, or if measure low speed flip-flop 167 is energized, the signal will be generated at its output line 173

which is similarly connected to gate 155 and to relay 146 via an amplifier 173a to actuate the low speed motor relay 146 to drive the motor for low speed operation.

The beam 20 is therefore moved forwardly toward bone 17 at a relatively slow scan speed. When the beam 20 is again intercepted by the bone, the fine bone edge detector circuit 45 will provide a generally square wave bone edge signal 118 for the period that the bone intercepts the beam 20.

The square wave signal functions to initiate the integration and will also be applied to the end of measurement circuit or channel 142 of logic sequence circuit 39. A differentiating circuit consisting of a capacitor 174 and a resistor 175 is connected to line 119 of circuit 45 whereby a negative pulse signal 176 is provided to the input of an inverter 177 upon the decrease in the level of the square wave signal. As a result, a signal 178, indicating that the trailing edge of the bone 17 has been passed, is provided at the output line 179 of inverter 177. Line 179 is connected as one input to a two input AND gate 180, the other input of which is connected to the line 52 of automatic zero circuit 36 for receiving a completion signal indicating that a measurement is in progress. Accordingly, the AND gate 180 provides an end of measurement signal at the output line 181 if a measurement is in progress and after the trailing edge of the bone being measured has been passed by the beam 20 of scanner 10.

The signal at line 181 is connected via the line 58 to reset the measure high speed flip-flop 166 and the measure low speed flip-flop 167 and to set the search reverse flip-flop 160. As a result, a signal appears at the output line of flip-flop 160 to actuate the high speed clutch relay 148, the high speed motor relay 147 and the reverse motor relay 150. This places the motor 143 in its high speed reverse mode for rapid movement of the scanner 10 to its home position, whereupon the clutch and motor relays will be de-energized by a limit switch 182.

The end of measurement signal line 59 of circuit 39 is also connected as one input to the two input OR gate 124 in the fine bone edge detector circuit 45 to reset the integrate flip-flop 120 whereby the relay contacts 122-1 open to terminate the integrating operation. Relay contacts 123-1 will remain open, however, to retain the charge on the integrating circuits.

It will be further recalled that the coarse bone edge detector circuit 44 will not provide the start analysis signal at line 46 unless an inhibit not signal is received from circuit 39. This signal is provided by an inhibit flip-flop circuit 183 which is reset by the initial start signal of unit 42 and set by the end of measurement signal at line 181 which is connected as one input to a three input OR gate 184.

The other two inputs of gate 184 are connected to interlocks to set the flip-flop 183 and disable the apparatus if erroneous operation occurs.

In addition, an input signal is generated to the OR gate 184 at a terminal if scanner 10 is out of position as indicated by operation of a limit switch logic circuit which is described in connection with the drive assembly. A multiple input OR gate 187 is connected to the third input of OR gate 184 to indicate error signals in the motor logic circuit 40.

The setting of the logic flip-flop circuits 151, 160, 166 and 167 in the motor logic circuit 40 should be such that the motor and clutch relays will be in either a zero mode, that is, when the scanner is at rest, a search forward mode, during which the scanner traverses forward at 1 cm per second, a search reverse mode, during which the scanner traverses in a reverse direction at 1 cm per second, measure high speed mode in which the scanner moves forward at 2 mm per second and measure low speed mode in which the scanner moves forward at 1 mm per second. An error signal will occur if these flip-flop circuits are set in such a manner that inconsistent modes of operation are indicated and produce a signal at an input of gate 187. Specifically, these error signals include the appearance at the output of a two input AND gate 188 connected to the outputs of search reverse flip-flop 160 and search forward flip-flop 151 to transmit a signal to gate 187 and thus to gate 184 if the flip-flops are simultaneously set. Similarly, the outputs of the search forward flip-flop 151 and/or the search reverse flip-flop 160 are connected to an OR gate 189, the output of which is connected as one input to AND gate 190. The high speed measure flip-flop 166 is connected as a second input to the AND gate 190 to disable the apparatus if both a search and measure flip-flop are set. The measure low speed flip-flop 167 and the search reverse flip-flop 160 and the search forward flip-flop are similarly connected to an OR gate 191 and an AND gate 192 to produce a disable signal if such flip-flops are simultaneously set. Thus, when the motor logic flip-flops 151, 160, 166 and 167 are set in such a manner that more than one machine mode is indicated, the gate 184 produces a signal to set the inhibit flip-flop 183 and a signal will be generated which resets the device and sends the scanner back to its home position.

The flip-flop 183 thus provides an interlock permitting operation of the apparatus in a manner to accurately drive the scanner 10 to measure the beam absorption characteristics.

SCANNER DRIVE ASSEMBLY

The mechanical portions of the apparatus are schematically illustrated in FIGS. 6 and 7 to include the scanner 10 which includes the generally U-shaped arm 13 for supporting the detector assembly 12 at its upper end. The lower end of arm 13 is received within a hollow, generally rectangular housing 193 which is suitably slotted to permit movement of arm 13 between its full and phantom positions shown in FIG. 5 with limit switches mounted adjacent the path of the lower end of arm 13 to insure proper position of the arm. The source 11 is rigidly secured to an integral plate portion 194 extending forwardly from the lower end of arm 13 to place source 11 in direct alignment with and below the detector 12. In addition, the arm 13 includes a vertical end plate 195 which carries a fixed nut 196 for threadably engaging a drive screw 197. The other end of the drive screw 197 is mounted for rotation in a bearing 198 and carries a first relatively small spindle 199 and a second relatively large spindle 200. The motor 143 has its output shaft 201 operable to be coupled to a first relatively large spindle 202 or a second relatively small spindle 203 by a clutch assembly 204 which includes clutches 144 and 145. Spindle 202 is

coupled to the spindle 199 by a belt 205 and when coupled to the motor output shaft 201 will rotate the screw 197 at a speed such that the scanner 10 will move at 1 cm per second. The spindle 203 is coupled to the spindle 200 by a belt 206 and when coupled to the motor output shaft 201 will rotate the screw 197 at a speed which will move the scanner 10 at the 2 mm per second speed. The scanner 10 may be driven at 1 mm per second speed by shifting the motor from its high speed mode to its low speed mode, as previously, and with the spindle 203 coupled to the motor output shaft 201.

The scanner 10 may be mounted for movement in the housing 193 in any convenient manner such as by vertical track and roller units 207 disposed to the opposite sides of the housing 193 and horizontally disposed track and roller units 208 formed in the sides of said housing.

In operation, a standard profile member 209 having a known absorption characteristic is mounted in the scanner 10. The member 209 is formed with an annular recess 210 which is filled with an appropriate liquid or the like which simulates the absorption characteristic of the bone. A single scan is made and the readout on the digital meters 38 and 140 compared with the standard. If the readings do not agree, the calibration control 133 is adjusted to insert the proper reading. As the integral signal is stored in capacitor 131 and the calibration means 132 is connected to the output side of such capacitor 131, movement of control 133 can provide a direct correct calibration.

The limb 16 is then mounted with the holder 24 in the scanner 10, with the bone selection switch 47 and speed selection switch 170 preset to provide the desired movement of beam 20.

The start unit 42 is actuated and the scanning beam 20 moves over the limb 16 and the timing means automatically establishes the predetermined timed coordination between the operation of the drive assembly, the referencing circuit, the bone detecting circuits, the integrating means and the interrelated computing circuits.

The illustrated motor assembly further includes a plurality of diagrammatically illustrated limit switches interconnected in the logic drive circuit of FIG. 5 for selectively automatic positioning the scanner arm 13.

As shown in FIG. 6, a selector switch 211 is mounted on the front of the assembly to permit initial positioning of the arm 13 in either the extended or scan start shown in full line in FIG. 6 or the retracted carry position similar to the finish scan position shown in phantom in FIG. 6. The start or use position is detected by scan limit switch 212 and the carry position by a carry limit switch 213. The limit switches 211 - 213 are connected in the motor logic circuit of FIG. 5 through a plurality of AND gates 214, 215, 216, 217 and 218. Gates 214 and 215 are two input gates connected to establish the carry logic signal, with one input connected to the carry contacts of the selector switch 211 and the other input connected to the carry limit switch 213. The gates 216 and 217 are three input gates and are similarly connected to the selector switch 211 and to the scan or use limit switch 212 and additionally to the flip-flop 183 and particularly line 102. Gate 218 is connected to scan contacts of the selector switch 211 and to the limit switch 213.

In summary, gate 214 provides a signal if the operator actuates the selector switch 211 to the carry position but the related limit switch is not activated whereas gate 215 provides a signal when the limit switch is activated. Gate 216 provides a signal if the operator sets the switch 211 to the use position for establishing a scan operation, the use limit switch 212 is not activated and the scan signal appears at the control flip-flop line 102, whereas the related gate 217 provides a signal when the use switch 212 is activated. The final gate 218 indicates an actuation of the start button without the arm retracted for scanning a bone as indicated by actuation of the carry limit switch. The outputs of the several gates 214 - 218 are connected to the several coupling OR gates 152 to the forward and reverse flip-flops 151 and 160, as shown by the input lines corresponding to the numbers of the gates 214 through 218, inclusive, and all gates 214 - 218 are similarly connected to the separate reset terminals of the gates 166 and 167 through OR gates 219. The logic switch gate 218 is also connected to the second input of the gate 184 to control the control or inhibit flip-flop 183.

ALTERNATE EMBODIMENTS OF THE INVENTION

FIG. 8 shows an alternate embodiment of the invention wherein a novel count rate meter addition circuit 221 is inserted between the count rate meter 34 and the log converter 35 to increase accuracy of response where the source establishes a random monoenergetic energy.

It has been found that one of the chief contributors to error in scanners employing radioactive sources is the statistical nature of the emission from such sources. If the count rate meter 34 is made fast enough to easily detect the edges of a bone when scanning at 1 mm per second, large errors may be generated. When making absorptometric measurements such as these, it is desirable to have the medium being scanned absorb a relatively large amount of the original beam so that the absorption curve will be well defined. If, however, the absorption is too great, the counting rate must be averaged over a longer time period to obtain accurate results because the final calculations involves taking the logarithm of the count rate and the logarithm of zero is minus infinity. In other words, if during the time over which the count rate is averaged, the radioactive source because of its statistical nature happens to be putting out fewer gamma photons, the conversion to a logarithm may result in a disproportionately large contribution to the final integral, since fluctuations above and below the mean value do not cancel each other in magnitude.

In order to remedy this situation, the count rate meter 34 is selected with a relatively fast response time. The circuit 221 includes a low pass filter consisting of a resistor 222 and a capacitor 223 which is connected to the output of the count rate meter 34 and its impedance values are such as to give a rise time sufficiently short (e.g., 0.05 seconds) to allow detection of the bone edge during rapid search. A second capacitor 224 is connected between resistor 222 and ground in series with a resistor 225, and in a parallel path in series with the drain-source impedance of a field effect

transistor 226 whose gate is coupled to the collector of a control transistor 227. Resistor 225, which is relatively large relative to resistor 222, has little influence in grounding capacitor 224 but provides a current path through which the voltage across the capacitor can be established at approximately the correct value during the search forward operation and prevent generation of undesirable transients when the transistor is switched on. The base transistor 227 is connected by an OR gate 228 to receive a measurement mode signal which is present when either the measure high speed forward flip-flop 166 or the measure low speed flip-flop 167 of the motor logic circuit 40 are set (see FIG. 4). It will be recalled that one of these two flip-flops will be set when a scan measurement is being made and will therefore be reset during initial scanner movement. Accordingly, transistor 227 and field effect transistor 226 will be off prior to the initiation of a measurement. Since the impedance of the field effect transistor 226 is very high and resistor 222 is very large, capacitor 223 is effectively out of circuit until transistor 226 is turned on and the time constant of the circuit as a whole is governed by the resistance of resistor 222 and the capacitance of capacitor 223. When a measurement mode signal occurs during a measuring operation, transistor 227 will be turned on and turn on field effect transistor 226, and thereby grounding the lower end of the capacitor 224. The time constant of the circuit is now provided by resistor 222 and the sum of capacitors 223 and 224. This new time constant is chosen to be large enough to control the logarithmic errors introduced by statistical fluctuations in the radioactive source.

In this manner, the time constant of the output of the count rate meter 34 is made relatively short during the search mode, so that the bone edge may be readily detected during forward search and is made relatively long during the measurement mode so that the statistical variations of the radioactive source will not introduce substantial errors.

The output of the count rate meter 34 may be coupled to the log converter by an operational amplifier 229 which is connected as a voltage follower.

It has been determined that a substantial source of error in performing in vivo measurements is movement of the subject. For example, the radius of an adult human male is about 1.5 cm in diameter so that an arm movement of only 1 mm introduces an error in measurement of approximately 7 percent. Accordingly, the integrating circuit 37 may be provided with memory and averaging means for averaging a plurality of bone-tissue signal measurements made in several sequential scans. In addition, the motor logic circuit 40 may be provided with automatic cycling means for returning the scanner 10 to the reference position outside of the bone being measured after each of a predetermined number of measurements until a plurality of measurement scans have been performed. In this manner, not only will the effects of subject movement be minimized, but the effects of the statistical nature of the source will also be further reduced.

In the illustrated embodiment, the timing and control means is interconnected to automatically establish a complete sequence in response to operation of the start unit 42. Within the broader aspect of this invention, such means may of course be modified to require rou-

tine operations such as actuation of a further push button type control. For example, rather than having the second delayed pulse at line 51 which is generated after establishing of the reference signal actuate the motor 143 to establish a slow scan, the apparatus could be constructed to maintain the stopped condition and illuminate a lamp when the slow scan would normally be initiated. A second or continuing unit would be manually actuated to start the slow scan. The operator would merely actuate the initial start unit, wait for the light, and then actuate the continuing button with the apparatus completing its sequence in the same manner as previously described. The modified apparatus would provide the automatic referencing and storing function as well as other functions subject to operator variability.

Further, the scanning beam 20 provides the dual functions of searching for and locating the bone and of scanning the bone to establish the tissue reference signal and the bone-tissue signal. If desired, separate beams may be employed as part of a total beam means to provide the various functions. For example, a separate search beam may be provided which is similar to or different from a scanning beam. Any beam employed must, of course, be able to detect the interception by the bone.

As those skilled in the art will further appreciate, many of the functions performed by the structure enumerated in the description of the preferred embodiment of the invention may be performed by other apparatus as well. For example, digital techniques may be employed where analog systems have been described. Although the referencing for the base line is shown with a period in which the beam 20 is held stationary, the sensing of the tissue equivalent specimens and storage of the signal can be made with a continuous scan movement by appropriate controlled timing and scanning movement. Further, the apparatus could be construed to provide for the automatic referencing of the base line during the initial forward search movement by appropriate locating controls related to the physical construction of the scanner and the means to hold the limb to actuate the referencing circuit during the initial forward movement. In addition, the tissue reference signal could be subtracted from the measurement quantity after separate integration of the signals has taken place rather than before with apparatus having means for setting the reference base line in a sample-and-hold circuit, integrating this value for the same length of time as the measurement signal, and then subtracting the results of the two integrations. The tissue reference signal could then be established before or after the bone-tissue signal is obtained. Another method of cancelling the reference count rate is to introduce this signal into the log converter 34 in such a way as to shift the converter's reference current so that the output is zero.

Further, the width of the measured bone may be established by a clock-driven digital accumulator or the like by a suitable timing means responsive to the pulse signals previously described which correspond to the onset and termination of the penetration of said bone by said beam. This would avoid the necessity of calibrating the bone width readout means. A similar digital accumulation (integration) could be performed

on the bone mineral portion by applying the output of the automatic zero circuit to a voltage-to-frequency converter.

The present invention thus provides a highly improved bone mineral analyzer which is particularly adapted for clinical instrumentation and which can be operated by personnel with minimal skill.

Various modes of carrying out the invention are contemplated as being within the scope of the following claims, particularly pointing out and distinctly claiming the subject matter which is regarded as the invention.

I claim:

1. A bone mineral analyzer for determination of the mineral content of a bone surrounded by a tissue cover, said analyzer comprising

scanning means including a beam detection means and a beam producing means establishing a penetrating beam means directed to said detection means, said beam means including a scanning beam with a selected essentially monoenergetic energy portion selectively absorbed at one absorption level per unit thickness by said bone in accordance with the mineral content of the bone and at another different absorption level per unit thickness by the tissue cover, said scanning means establishing an output proportional to absorption of said selected monoenergetic portion of the scanning beam,

support means including an absorbent tissue equivalent material located to cover said tissue-covered bone and defining an artificial profile for a non-bone tissue reference specimen and a bone-tissue specimen,

drive means to establish relative movement between said beam means and support means and thereby effect scanning of a selected portion of said specimen including the non-bone and bone specimens,

bone edge sensing means connected to said detection means for sensing the interception of said beam means by said bone,

signal receiving means connected to said detection means, said signal receiving means including automatic referencing means responsive to predetermined alignment of said scanning beam and the tissue reference specimen to establish a tissue reference signal and including control means responsive to said bone edge sensing means and connected to said drive means for determining bone scan movement of said beam during which said beam is intercepted by said bone, to establish a bone-tissue signal related to beam absorption by the bone-tissue specimen throughout said bone scan movement, and

readout means for comparing said tissue and bone-tissue signals to establish a bone-related output functionally related to the absorption of said beam by the bone of said tissue-covered bone.

2. The bone mineral analyzer of claim 1, wherein said beam is an essentially monochromatic energy beam of emitted radiant energy and said detection means comprises a collimated detector associated with said receiving means to establish output energy pulses in accordance with the relative level of the emitted radiant energy,

discriminating means to transmit energy pulses within a selected range, and
means to establish a pulse signal output related to the average of the pulses per unit of time.

3. The bone mineral analyzer of claim 1, including means associated with said control means and said bone edge sensing means and responsive to alignment of said beam means and the leading edge of the bone to align said scanning beam with said reference specimen in preselected spaced relation to the bone,

logarithmic converting means connected to receive said signals,

storage means to store said tissue reference signal, and integrating means having input means connected to said logarithmic converting means and to said storage means and establishing an output equal to the difference between the integrals of said signals, and said readout means being connected to said integrating means.

4. The bone mineral analyzer of claim 1 including logarithmic conversion means to convert the signal output of the detection means to the logarithm thereof,

storage means to store the signal during said alignment of the scanning beam with said reference specimen to establish said tissue reference signal, and

integrating means to effectively integrate said signals over the width of the bone and establish the difference between said integrations to produce said bone-related output.

5. The bone mineral analyzer of claim 4 wherein said storage means is a capacitive means and a resistive means connects said capacitive means to the conversion means, and

switch means responsive to the predetermined alignment of said scanning beam with the tissue reference portion to increase the time constant of the capacitive and resistive means to charge the capacitive means to an approximate value at a short time constant compared to fluctuation in the scanning beam and to a final value at a relatively long time constant.

6. The bone mineral analyzer of claim 4 including a summing means having a first input means connected to said storage means and a second input means connected to said detection means to establish an integrating input signal equal to the difference of said tissue reference signal and said bone-tissue signal.

7. The bone mineral analyzer of claim 6 wherein said summing means is connected to the output of said conversion means.

8. The bone mineral analyzer of claim 1 wherein said beam producing means includes a radionuclide means establishing a random intensity supply,

said receiving means having a logarithmic convertor means to establish a logarithmic signal in accordance with a selected average pulse rate of said beam,

said referencing means including an automatic zero circuit means selectively connected to said convertor and having a capacitive storage means connected to the output of the zero circuit means in series with a variable resistance means to charge said storage means in accordance with said logarithmic signal,

resistance control means responsive to said alignment of the scanning beam with the tissue reference portion and adapted to actuate said resistance means to increase the resistance level and thereby increase the time constant whereby said storage means is charged to an approximate value at a short time constant compared to the statistical fluctuations in the signal arising from said source fluctuation and to the final value with a relatively long time constant.

9. The bone mineral analyzer of claim 8 wherein said zero circuit means includes an operational amplifier having a first input means connected to said convertor and a second input means selectively connected to said capacitive storage means and an output means selectively connected to the capacitive storage means in series with said resistance means,

switch means connected to the opposite sides of the capacitive means to connect said capacitive means to said operational amplifier, said switch means having a first input responsive to the starting of said beam means to connect the capacitive means to the operational amplifier in series with a minimum resistance and having a second input means to increase said resistance and thereby the time constant and a third input means to connect said capacitive means to said operational amplifier, and

a sequential timing means connected to said input means and responsive to alignment of said beam means with said bone to sequentially energize said input means.

10. The bone mineral analyzer of claim 8 wherein said drive means includes a variable speed drive motor means connected to said beam means to move said beam means across said specimen,

start means to actuate said drive motor means at a rapid feed speed to move said beam means to rapidly effect interception of the beam means by said bone portion, and

means responsive to predetermined interception of said beam means by said bone to establish a slow forward scan speed to slowly scan said bone-tissue specimen.

11. The bone mineral analyzer of claim 10 wherein said bone edge sensing means includes a coarse edge detection means and a fine edge detection means,

said coarse edge detection means being connected to control the drive means and the receiving means during said rapid forward movement and said fine edge detection means being connected to control the drive means and the receiving means during said scan movement.

12. The bone mineral analyzer of claim 8 wherein said automatic referencing means includes means establishing said alignment of the scanning beam and the tissue reference specimen for a predetermined minimum period in response to selected interception of said beam means by said bone and switching means connected to said resistance means to increase said resistance level within said minimum period.

13. The bone mineral analyzer of claim 12 wherein said automatic referencing means stops said scanning beam in alignment with an area of said tissue reference portion, and

said switching means is responsive to establishment of that alignment of the scanning beam and the tissue reference specimen to increase said resistance level.

14. The bone mineral analyzer of claim 1 including means connected to said automatic referencing means and directly establishing said predetermined alignment of the scanning beam and the tissue reference specimen in response to selected detection of said bone.

15. The bone mineral analyzer of claim 1 wherein said control means includes means responsive to said bone edge sensing means to align said scanning beam with said tissue reference specimen slightly spaced from an edge of the bone.

16. The bone mineral analyzer of claim 1 wherein said drive means includes timing means holding said scanning beam in stationary alignment with said tissue reference portion for a selected period to average the intensity of the scanning beam and store reference voltage and for moving said scanning beam forwardly to traverse said bone-tissue specimen at a selected scanning rate after said selected period.

17. The bone mineral analyzer of claim 1 wherein said drive means includes a variable speed drive motor means connected to said beam producing means to move said beam means across said specimen,

start means to actuate said drive motor means at a rapid feed speed to move said beam producing means to rapidly effect interception of said bone portion by said beam means, and

means responsive to selected interception of said bone by said beam means to establish a slow forward scan speed to slowly scan said bone-tissue specimen.

18. The bone mineral analyzer of claim 17 wherein said drive motor means is reversible and is operated in the reverse direction at said rapid feed speed response to the interception of an edge of said bone by said beam means and is thereupon operatively disabled to align said beam means with said tissue reference portion for a holding period and then is operated at said slow forward scan speed.

19. The bone mineral analyzer of claim 17 wherein said drive motor means includes a plurality of different slow scan speeds, and

said analyzer includes means to select different ones of those speeds in accordance with the power level of the beam producing means and to effect corresponding adjustment of the bone related output.

20. A bone mineral analyzer of claim 17 wherein a said bone edge sensing means including a coarse edge detection means and a fine edge detection means, said coarse edge detection means being connected to control the drive means and the receiving means during rapid forward movement and said fine edge detection means being connected to control the drive means and the receiving means during a bone scan movement.

21. The bone mineral analyzer of claim 20 wherein said coarse edge detection means includes a level detector,

an electronic capacitive coupling circuit connecting said level detector to the output of a logarithmic convertor and having means to vary the time constant of the coupling circuit,

means responsive to starting of said drive means to increase the time constant after a selected time period, level detection means associated with said fine edge detection means and connected to the logarithmic convertor, and

interlock means connecting said fine edge detection means to the output of the coarse edge detector to inhibit said fine edge detection means until said tissue reference signal is established.

22. The bone mineral analyzer of claim 20 wherein said fine edge detection means is connected to respond to the signal established by engagement of the beam with the bone,

said analyzer includes an inhibit means which holds said fine edge detection means off and which is responsive to establishing of said tissue reference signal to release said fine edge detection means, and

said readout means including an integrating means connected to said fine edge detection means and responsive to the interception of said beam means by the leading edge of said bone to initiate integration and to the interception of said beam means by the trailing edge of said bone to terminate integration.

23. The bone mineral analyzer of claim 22 wherein said fine edge detection means includes a level detector, and

said analyzer includes logic circuit means having a first input connected to said level detector and a second input connected to said inhibit means.

24. The bone mineral analyzer of claim 1 for analyzing a tissue covered bone including a first bone and a second bone spaced from the first bone within a common tissue cover, said analyzer including

a presettable selection means included in said drive means to control said drive means to respond selectively to interception of said beam means by the edge of a preselected one of said first and second bones and to actuate said receiving means to establish said bone-tissue signal.

25. The bone mineral analyzer of claim 24 having a detector establishing a first pulse in response to interception of said beam means by a bone and a second pulse of an opposite polarity in response to termination of interception of said beam means by a bone,

a first bone logic means connected to said detector and having a first output means connected to actuate said drive means,

a second bone logic means connected to said detector and connected to actuate said drive means,

a second bone control means connected to the detector and responsive to said second pulse to condition said second bone logic means for operation, and

said selection control means selectively enabling one of said logic means, whereby interception of said beam means by the leading edge of a preselected one of said first and second bones actuates said drive means.

26. The bone mineral analyzer of claim 25 wherein said detector includes a time-delay means operatively disconnecting said detection means for a selected period after starting of a scan cycle.

27. The bone mineral analyzer of claim 25 wherein said level detector includes a timing pulse means actuated by a search start signal,

a coupling capacitor connected to the detection means,

a triggered impedance switch means connected to said capacitor and to said timing pulse means to control the time constant of said coupling capacitor in response to the operation of the timing pulse means,

a high input impedance electronic switch connected to said capacitor,

a level responsive trigger circuit connected to the electronic switch, and

a differentiating means connected to the level responsive trigger switch to differentiate the output and establish said output pulses.

28. The bone mineral analyzer of claim 1 wherein said beam source is a radionuclide source establishing a monochromatic collimated gamma ray in the range of 20 to 80 kev,

said signal receiving means including a gamma ray detection means connected to a signal averaging means to establish an output signal proportional to the average gamma ray photons received per unit of time,

log conversion means to establish a logarithmic signal proportional to said output signal, and

an integrating means having input means connected to said conversion means to integrate the logarithmic signal, said integrating means having means to integrate said tissue reference signal and said bone-tissue signal and establish the difference therebetween to produce said bone mineral output signal.

29. The bone mineral analyzer of claim 1 wherein said support means includes a means defining a selected specimen support area, said drive means having a plurality of output speeds including at least one rapid search speed and one constant rate scan speed, means defining a first home position of said scanning means at which said beam is spaced from said bone support area,

start means actuating said drive means to move said beam means forward of the specimen support area at a rapid search speed,

said bone edge sensing means being responsive to interception of said beam by a bone of said tissue-covered bone to terminate said forward movement of the beam apparatus, and to retract and stop said scanning means to align the beam with said tissue equivalent cover, said receiving means having a signal storage means and establishing said reference signal in said storage means during the period said beam is stationary,

scan initiating means to initiate movement of said scanning means forwardly at said scan speed,

means responsive to the second interception of said beam by the bone of the tissue-covered bone to actuate said receiving means to establish said bone-tissue signal,

said receiving means including a summing means having a first input connected to said storage means for said tissue reference signal and having a second input connected to receive said bone-tissue

signal to establish an output related to said absorption characteristic of said bone, and

an integrating means connected to said summing means and to said readout means to establish a direct reading of said characteristic of said bone.

30. The bone mineral analyzer of claim 1 wherein said support means includes means defining a selected specimen support area, and in which said beam producing means includes a radioactive source emitting a gamma ray scanning beam as said scanning beam,

said drive means for said beam means including a plurality of output speeds including at least one rapid search speed and one constant rate scan speed, said beam means having a first home position spaced from said support area,

start means actuating said drive means to move said beam means toward the specimen support area at a rapid search speed to locate the bone of said tissue-covered bone and to move said scanning beam over said bone at a substantially slower scan speed, said detection means including a gamma ray beam amplifying detector to establish a train of pulses,

a count rate meter connected to said beam detection means and having a rapid response to establish a signal proportional to the intensity of the gamma ray pulses,

a logarithmic convertor, and

coupling means connecting the count rate meter to the logarithmic convertor and having a first resistance capacitance circuit with means to vary the time constant between a small time constant selected to establish accurate detection of the bone edge during the rapid search and a large time constant selected to compensate for logarithmic errors associated with the statistical fluctuation in the radioactive source during the scan speed.

31. The bone mineral analyzer of claim 30 wherein said resistance-capacitance circuit includes a coupling resistor connected to the output of the count rate meter,

a first capacitor connected in series with the resistor to a reference potential,

a second capacitor,

a switch means connected in series with said second capacitor and in parallel with said first capacitor, and

means responsive to establishment of said scan speed to establish a measurement mode signal and to actuate and close said switch means and connect said second capacitor in circuit.

32. The bone mineral analyzer of claim 31 wherein said switch means includes a field effect transistor connected in series with said second capacitor,

a resistor in parallel with said field effect transistor, and

a switching transistor connected to hold said field effect transistor off and responsive to establishment of said measurement mode signal to turn said transistors on.

33. The bone mineral analyzer of claim 30 having a differential discriminator means coupled to the beam detection means and to the rate meter to transmit pulses within a selected range.

34. The bone mineral analyzer of claim 1 having convertor means to establish an analog logarithmic signal

proportional to the detected intensity of the scanning beam,

said referencing means including a difference amplifier having a first input connected to said conversion means and having a second input, a signal storage means to hold said tissue reference signal, switching means selectively connecting said storage means to the output of the difference amplifier and to the second input of the difference amplifier,

said bone edge sensing means including a coarse edge detector connected to the output of the difference amplifier, and including a fine edge detector connected to the output of the difference amplifier,

a mineral content integrator connected to the output of the difference amplifier and having a start means connected to the output of the fine edge detector,

a second integrator having a preselected constant signal input means and a start means connected to the output of the fine edge detector,

a reversible drive motor means coupled to said beam producing means and having a first rapid drive feed connection and a second slow drive scan connection,

start means to establish the first rapid drive feed connection to rapidly move the beam means in a search mode,

a motor logic control means connected to said coarse edge detector circuit and operable to reverse the direction of the drive to retract the beam at said rapid drive feed connection a selected distance, timing means to hold the scanning beam slightly spaced from the bone edge for a selected time period and to then establish said scan connection of said motor means,

said fine edge detector actuating said integrators to integrate over the period said beam scans the bone, and

reset means responsive to termination of interception of the scanning beam by the bone to reverse said motor with said feed connection to rapidly return said beam means to the home position.

35. The bone mineral analyzer of claim 34 wherein said signal storage means is a capacitor connected in a feedback path of an operational amplifier,

said operational amplifier having an inverting input connected to the junction of said capacitor and a pair of parallel charging resistors, and

said switching means selectively connecting said resistors to the output of the difference amplifier to charge said capacitor with different time constants.

36. The bone mineral analyzer of claim 34 wherein said coarse edge detector includes a level detector, an electronic-capacitive coupling circuit connecting said level detector to the output of a logarithmic convertor and having means to vary the time constant of the coupling circuit,

means responsive to starting of said drive means to increase the time constant after a selected time period,

said fine edge detector includes a level detection means connected to the logarithmic convertor, and

interlock means connected to said fine edge detector to inhibit said fine edge detector until said tissue reference signal is established.

37. The bone mineral analyzer of claim 36 wherein said beam producing means establishes a random energy scanning beam, said analyzer including

a differential discriminator connected to said detection means to transmit a signal proportional to the detected energy of the scanning beam within a selected range,

a count rate meter,

first and second timing capacitors connecting said count rate meter to said convertor, and

means operably disconnecting one of said capacitors from the meter and responsive to said establishment of the scan speed for moving the beam over the bone-tissue specimen to connect the disconnected capacitor and thereby increase the time constant.

38. The bone mineral analyzer of claim 1 wherein said beam source includes a radionuclide element selected from Iodine 125 and Americium 241 and establishing a monochromatic collimated photon energy beam,

said detection means including a collimated crystal detector mounted in alignment with said beam and having a means to convert the photon energy absorbed by the crystal detector into a corresponding electrical signal,

said support means including a support having planar parallel surfaced clamp members to clamp the specimen to said support and thereby establish a corresponding constant total thickness of said clamp members, said tissue equivalent cover and said tissue-covered bone and having means to locate the specimen perpendicular to the clamp members,

said drive means having a holder to mount said beam producing means to move over said clamp members,

conversion means to detect the photons of said beam and establish an analog logarithmic signal proportional to the intensity of the detected scanning beam,

said referencing means including an automatic zero referencing difference amplifier having a first input connected to said conversion means and having a second input, a signal storage means to hold said tissue reference signal, switching means selectively connecting said storage means to the output of the difference amplifier and to the second input of the difference amplifier,

said bone edge sensing means including a coarse edge detector connected to the output of the difference amplifier and including a fine edge detector connected to the output of the difference amplifier,

a mineral content integrator connected to the output of the difference amplifier and having a start means connected to the output of the fine edge detector,

a second integrator having a preselected constant signal input means and a start means connected to the output of the fine edge detector,

a drive motor means coupled to said holder and having a first rapid drive feed connection and a second slow drive scan connection,

a motor logic control means connected to said coarse edge detector circuit and operable to reverse the direction of the drive to retract the holder a selected distance and hold the scanning beam spaced from the bone edge for a selected time period and to then establish said scan connection of said motor means, and said fine edge detector actuating said integrator to integrate over the period said beam scans the bone.

39. The bone mineral analyzer of claim 38 wherein said drive means includes a U-shaped holder having a pair of parallel spaced arms,

said beam producing means being mounted in the outer end of one of said arms with the beam means directed toward said second arm,

said detection means includes a collimated scintillation crystal detector mounted in said second arm in alignment with said beam means and having a photomultiplier to amplify scintillations due to the photons of said beam,

said support means including parallel surfaced clamp members including a housing wall and an overlying arm,

means to mount said holder to said housing with the first arm slidably mounted in said housing and the second arm spaced outwardly of said clamp members in alignment with said first arm,

said conversion means including a differential discriminator coupled to the photomultiplier to transmit the photon energy of a selected range,

a count rate meter connected to said differential discriminator to establish an analog signal proportional to the intensity of the photon beam, and

a logarithmic convertor connected to the count rate meter and to said automatic zero referencing difference amplifier.

40. The bone mineral analyzer of claim 38 wherein said difference amplifier includes an operational amplifier,

said switching means being connected to the opposite sides of the capacitive means to connect said capacitive means to said operational amplifier, said switching means having a first input responsive to the starting of said beam means to connect the capacitive means to the output of the operational amplifier in series with a minimum resistance and having a second input means to increase said resistance and thereby the time constant and a third input means to connect said capacitive means to the input of said operational amplifier, and

a sequential timing means connected to said input means and responsive to alignment of said beam means with said bone to sequentially energize said input means.

41. The bone mineral analyzer of claim 1 having a visual display means connected to said readout means, said display means including a signal storage means to store said output signal and a coupling means connected to establish a corresponding display, and

a calibration control means to vary the display of said display means for a given stored signal, said calibration control means being connected to the output of said signal storage means to permit calibration without varying of the signal in said

signal storage means and thereby permit calibration with a single pass operation.

42. The bone mineral analyzer of claim 41 wherein said display means includes an integration circuit means including a capacitor means forming said storage means, said calibration control means including an adjustable voltage dividing means connecting said integration circuit means to said display means to adjust the proportion of the signal in said capacitor applied to the display means and thereby, the display for a given stored signal.

43. The bone mineral analyzer of claim 1 having a digital readout means including a calibration reset means to adjust the readout magnitude per unit input and to simultaneously and correspondingly vary the output reading of an input established in said readout means.

44. The bone mineral analyzer of claim 1 including a housing having a planar support wall defining said support means,

a generally movable bracket having a first arm slidably mounted within said housing and an interconnected second arm overlying said first arm in spaced relation to said planar wall,

said beam producing means being mounted in one of said arms and establishing a scanning beam directed toward the opposite arm, and

said drive means being connected to position said bracket and including switch means for selectively establishing an extended start scan position for scanning operation and a retracted carry position.

45. The bone mineral analyzer of claim 1 having means to store said bone-related output, means to recycle said drive means to establish a series of said bone-related outputs, and

means to summate and average the bone-related outputs and display the average of said several scans.

said beam means and support means and thereby scanning a selected portion of said non-bone and bone portions, and

automatic referencing means connected to said detection means with said scanning beam aligned with the tissue reference specimen to establish a tissue reference signal related to the beam absorption and including a signal storage means responsive to the level of the output of said detection means to directly establish a signal in said storage means directly proportional to the level of the output of said detection means,

means to establish a bone-tissue signal related to beam absorption by the tissue-covered bone specimen, and

readout means to compare said signals over the total length of the bone scan and establishing a bone-related output related to the absorption of said beam by the bone mineral of said bone.

46. The bone mineral analyzer for in vivo determination of the mineral content of a bone surrounded by body tissue, said analyzer comprising

beam producing means to provide a penetrating beam that is absorbed by transmission through a unit thickness of bone at a bone absorption level determined by the bone mineral content and that is absorbed by transmission through a unit thickness of body tissue at a tissue absorption level

distinctly different from the range within which said bone absorption level varies according to bone mineral content,

drive means for causing relative lateral movement of said penetrating beam along a predetermined scanning path,

support means for supporting a tissue covered bone along said scanning path for transverse scanning by said penetrating beam, said support means including a tissue equivalent material having substantially the same beam absorption characteristics as body tissue, said material being located to provide said tissue covered bone with an artificial profile of a generally uniform depth to provide a tissue specimen comprising body tissue and tissue equivalent material but no bone and a bone specimen comprising said bone together with said body tissue and said tissue equivalent material,

beam receiving means for sensing the intensity of said beam after penetration of said beam through the specimen aligned therewith,

reference establishing means responsive to said beam receiving means for measuring the absorption of said beam during penetration of said beam through said tissue specimen,

bone detecting means operable while said beam scans along said scanning path for detecting the onset and termination of the penetration of said bone by said beam as a function of the corresponding changes in beam absorption sensed by said beam receiving means,

integrating means for measuring the integrated absorption of said beam sensed by said beam receiving means while said beam scans said bone specimen,

computer means for automatically calculating the mineral content of a predetermined unit volume of said bone as a function of the measurements performed by said reference establishing means and said integrating means, and

timing means for automatically providing predetermined timed coordination between the operations of said drive means, said reference establishing means, said bone detecting means, said integrating means and said computer means.

47. The bone material analyzer of claim 46 including bone size determining means for measuring the scanned width of said bone reference specimen as a function of the distance by which said scanning means moves between the onset and termination of bone penetration detected by said bone detecting means, and

said timing means automatically and selectively interconnects said bone size determining means to said computer means.

48. A bone mineral analyzer for determination of the mineral content of a bone, comprising

scanning means including a beam detection means and a beam producing means establishing a penetrating beam means directed to said detection means, said beam means including a scanning beam with a selected essentially monoenergetic energy portion selectively absorbed at one absorption level per unit thickness by said bone in accordance with the mineral content of the bone and

at another different absorption level per unit thickness by the tissue cover, said scanning means establishing an output proportional to absorption of said selected monoenergetic portion of the scanning beam,

support means including an absorbent tissue equivalent material located to cover said tissue-covered bone and defining an artificial profile having a non-bone tissue reference specimen and a bone-tissue specimen,

a variable speed drive means having start means to establish rapid relative forward search movement between said beam means and said support means, first motor control means responsive to selected interception of the beam means by said bone to actuate said drive means to terminate said forward movement for alignment of said beam with said tissue reference specimen for a selected period,

reference means responsive to the output of the detection means during said selected period to establish a tissue reference signal,

second motor control means connected to said variable speed drive means to actuate said drive means to establish a relatively low forward scan speed, and

means to establish a bone-tissue signal related to beam absorption by the bone-tissue specimen.

49. The bone mineral analyzer of claim 48 wherein said first motor control means aligns and holds said beam in fixed relation with said tissue reference specimen and with said beam spaced from the edge of the bone in the order of 3 millimeters.

50. The bone mineral analyzer of claim 48 wherein said reference means is actuated by said first motor control means, and said second motor control means is actuated by said reference means.

51. A bone mineral analyzer of claim 48 wherein said beam producing means includes a radioactive source and in which said scanning beam is a random intensity beam, said analyzer including

a count rate meter connected to said detection means and having a rapid response to establish a signal proportional to the intensity of the beam,

a logarithmic convertor,

coupling means connecting the count rate meter to the logarithmic convertor and having a resistance-capacitance circuit with means to vary the time constant between a small time constant selected to establish accurate detection of a bone edge during the rapid search and a large time constant selected to compensate for logarithmic errors associated with the statistical fluctuation in the radioactive source during the scan speed.

52. The bone mineral analyzer of claim 51 wherein said resistance-capacitance circuit includes a coupling resistor connected to the output of the count rate meter,

a first capacitor connected in series with the resistor to a reference potential,

a second capacitor,

switch means connected in series with said second capacitor in parallel with said first capacitor, and means responsive to initiation of low forward scan movement of said drive means to actuate and close said switch means and connect said second capacitor in circuit.

53. The bone mineral analyzer of claim 48 wherein said beam producing beam-establishes a random intensity scanning beam, said analyzer including

a first time constant means connected to said detection means for establishing a short time constant during said search movement and a long time constant for transmission of the signal to compensate for logarithmic errors associated with the statistical fluctuation in the radioactive source during the scan speed, and

a second time constant means connecting said reference means to said detection means for establishing a short time constant during the initial search movement and a long time constant during said selected period the tissue reference signal is established.

54. The bone mineral analyzer of claim 48 having a bone selection means for selectively actuating said beam means to select one of two bones spaced along the scan path in said tissue cover, said bone selection means including

signal forming means responsive to interception of said beam by the first bone to establish a first signal responsive to such interception, a second signal responsive to termination of such interception of said beam by said first bone, and a third signal in response to interception of said beam by the second bone,

a first bone logic circuit means connected to said signal forming means,

a second bone logic circuit means connected to said signal forming means,

input means to operably condition one of said logic circuit means to operate in response to the corresponding one of said first and third signals,

said first bone logic circuit means being connected to said second bone logic circuit means to transmit said second signal to said second logic circuit means to signal said second bone logic circuit means for operation, and

selectively actuated means connecting said first and second motor control means with said bone logic circuit means and to rapidly search for the selected bone and condition said second motor control means for operation in response to location of said selected bone.

55. A bone mineral analyzer for determination of the mineral content of one of two spaced bones surrounded by a common tissue cover, comprising

scanning means including a beam detection means and a beam producing means establishing a penetrating beam means directed to said detection means, said beam means including a scanning beam with a selected essentially monoenergetic energy portion selectively absorbed at one absorption level per unit thickness by said bone in accordance with the mineral content of the bone and at another different absorption level per unit thickness by the tissue cover, said scanning means establishing an output proportional to said selected monoenergetic portion of the scanning beam,

support means including an absorbent tissue equivalent material located to cover said tissue-covered bones and defining an artificial profile for a non-bone tissue reference specimen and a plurality of bone-tissue specimens,

signal receiving means connected to said detection means, said signal receiving means including referencing means connected to said detection means to establish a tissue reference signal related to the beam absorption of the non-bone tissue of the specimen and scan initiating means responsive to selected interception of said beam means by a bone to initiate scanning of said bone and to establish a bone-tissue signal related to beam absorption by the tissue-covered bone specimen, and control means including a presettable selection means to control said receiving means to respond to interception of beam means by a preselected one of the edges of the first bone and the second bone to establish a bone-tissue signal related to the corresponding bone of said two spaced bones.

56. The bone mineral analyzer of claim 55 having a detector establishing a first pulse in response to interception of said beam by a bone and a second pulse in response to termination of such interception of said beam by a bone,

a first bone logic means connected to said detector and having a first output means connected to actuate said drive means, a second bone logic means connected to said detector and connected to said detector to actuate said drive means,

a second bone control means connected to the detector and responsive to said second pulse to condition said second bone logic means for operation, and

said selection means selectively enabling one of said logic means, whereby interception of said beam means by preselected leading edge of one of said first or second bones actuates said control means.

57. A bone mineral analyzer for determination of the mineral content of a bone surrounded by a tissue cover, comprising

scanning means including a beam detection means and a beam producing means establishing a penetrating beam means directed to said detection means, said beam means including a scanning beam with a selected essentially monoenergetic energy portion selectively absorbed at one absorption level per unit thickness by said bone in accordance with the mineral content of the bone and at another different absorption level per unit thickness by the tissue cover, said scanning means establishing an output proportional to said selected monoenergetic portion of the scanning beam,

support means including an absorbent tissue equivalent material located to cover said tissue-covered bone and defining an artificial profile having a non-bone tissue reference specimen and a bone-tissue specimen,

drive means to establish relative movement between said beam means and support means and thereby scanning a selected portion of said non-bone and bone portions, and

automatic referencing means connected to said detection means with said scanning beam aligned with the tissue reference specimen to establish a tissue reference signal related to the beam absorption and including a signal storage means responsive to the level of the output of said detection means to directly establish a signal in said storage

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means directly proportional to the level of the out-
put of said detection means,
means to establish a bone-tissue signal related to
beam absorption by the tissue-covered bone
specimen, and

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readout means to compare said signals over the total
length of the bone scan and establishing a bone-re-
lated output related to the absorption of said beam
by the bone mineral of said bone.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,715,588 Dated February 6, 1973

Inventor(s) Frederick A. Rose

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 9, Line 52, after "also" delete
"being" and insert ---
begin ---;

Column 34, Line 38, beginning with Line 38
(CLAIM 45) delete the remaining portion of Claim 45, ending at Line 56.

Signed and sealed this 27th day of November 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

RENE D. TEGMEYER
Acting Commissioner of Patents