

[54] METHOD AND APPARATUS FOR
PROGRAMMING LIQUID SCINTILLATION
SPECTROMETERS

[75] Inventors: Joseph R. Toman, Naperville;
Edmund Frank, Chicago, both of Ill.

[73] Assignee: Packard Instrument Company, Inc.,
Downers Grove, Ill.

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[52] U.S. Cl. 250/369, 250/71.5 R

[51] Int. Cl. G21h 5/00

[58] Field of Search 250/106 SC, 71.5 R

[56] References Cited
UNITED STATES PATENTS

3,188,468	6/1965	Packard	250/106 SC
3,437,812	4/1969	Packard	250/106 SC
3,499,149	3/1970	Cavanaugh, Jr.	250/106 SC
3,271,574	9/1966	Dawson et al.	250/106 SC
3,246,156	4/1966	Frank et al.	250/106 SC
3,571,596	3/1971	Frank	250/106 SC

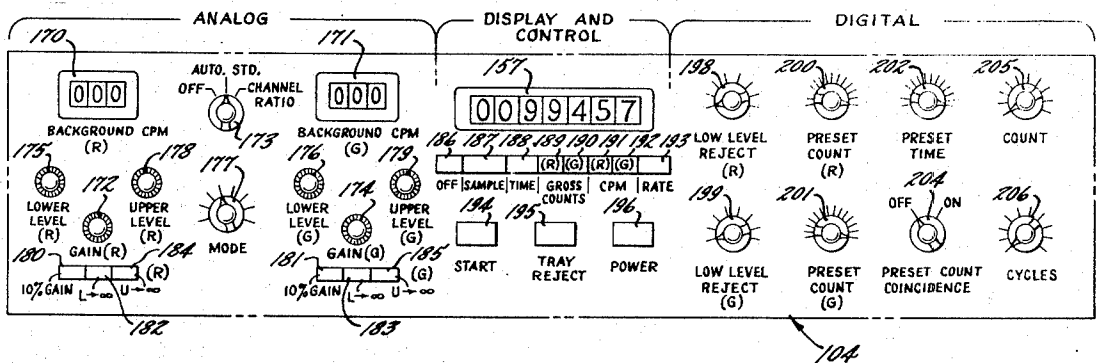
3,604,935	9/1971	Nather	250/106 SC
3,560,744	2/1971	Jordan	250/106 SC

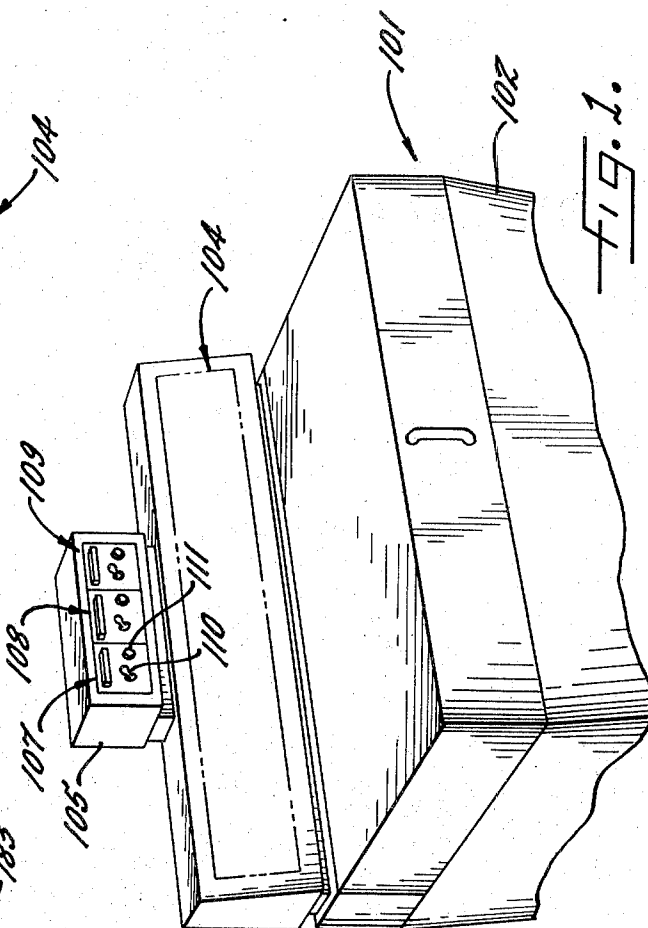
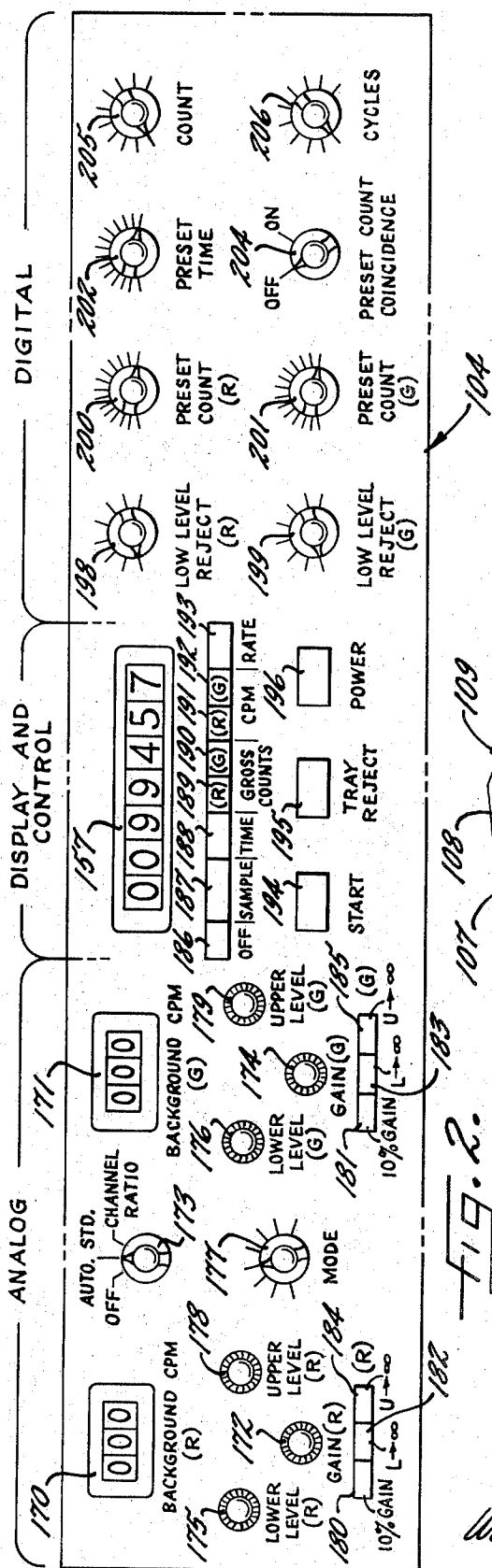
Primary Examiner—James W. Lawrence
Assistant Examiner—B. C. Anderson

[57] ABSTRACT

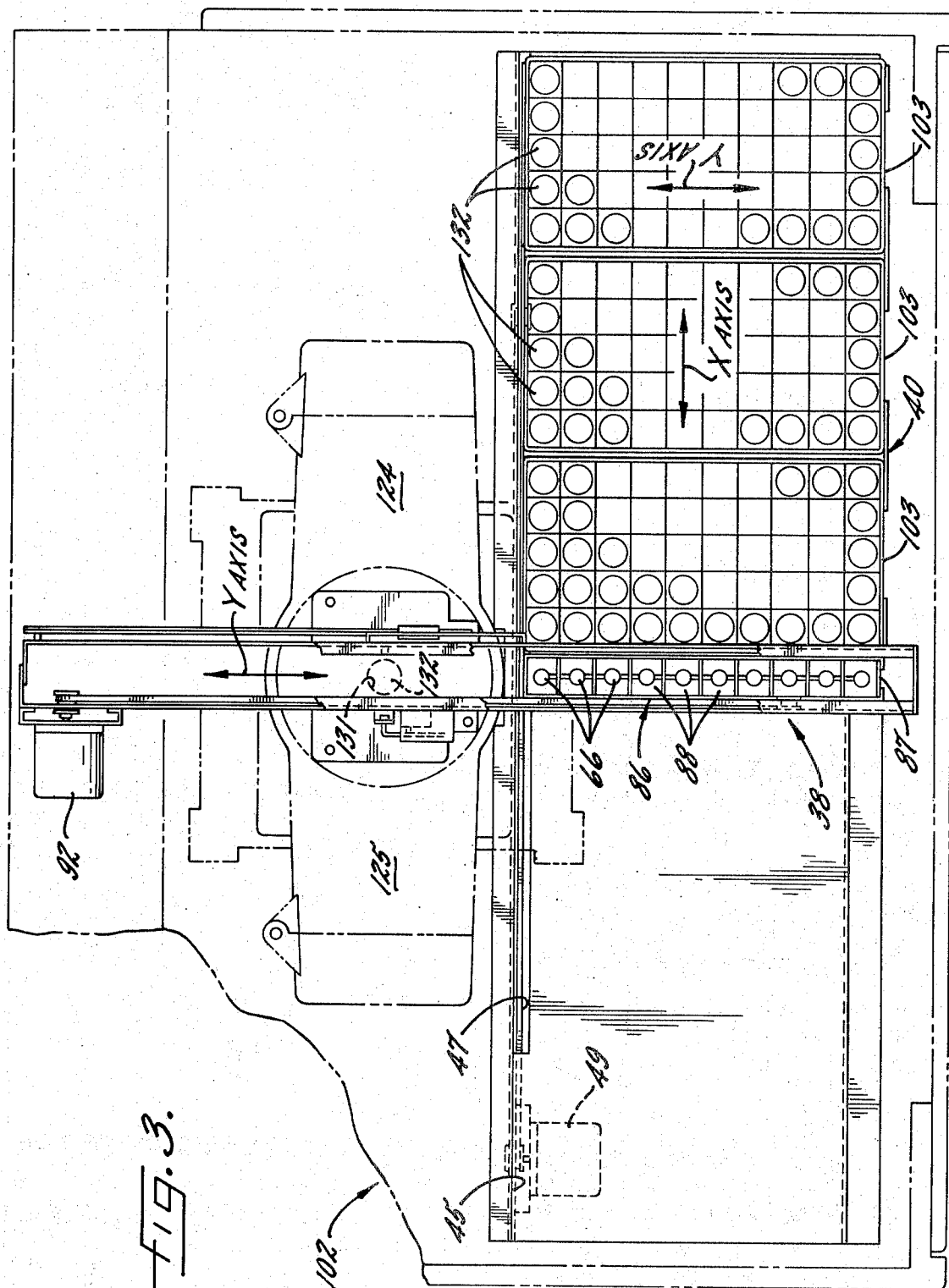
In an automatic scintillation counting device adapted to detect and measure the radioactivity of a multiplicity of samples supplied in trays or other sets, provisions are made for automatically changing one or more of the analog counting parameters, or analog-plus-digital parameters, for each set. The changes are effected automatically as each sample set comes into counting position, thereby permitting unattended automatic counting of samples requiring entirely different counting parameters. At the analyst's option, two or more sets may be counted under conditions established for one of the sets. Provisions are also made for retaining the operation of the master, or front panel, control when it is unnecessary to vary the counting program parameters for particular sets.

9 Claims, 18 Drawing Figures

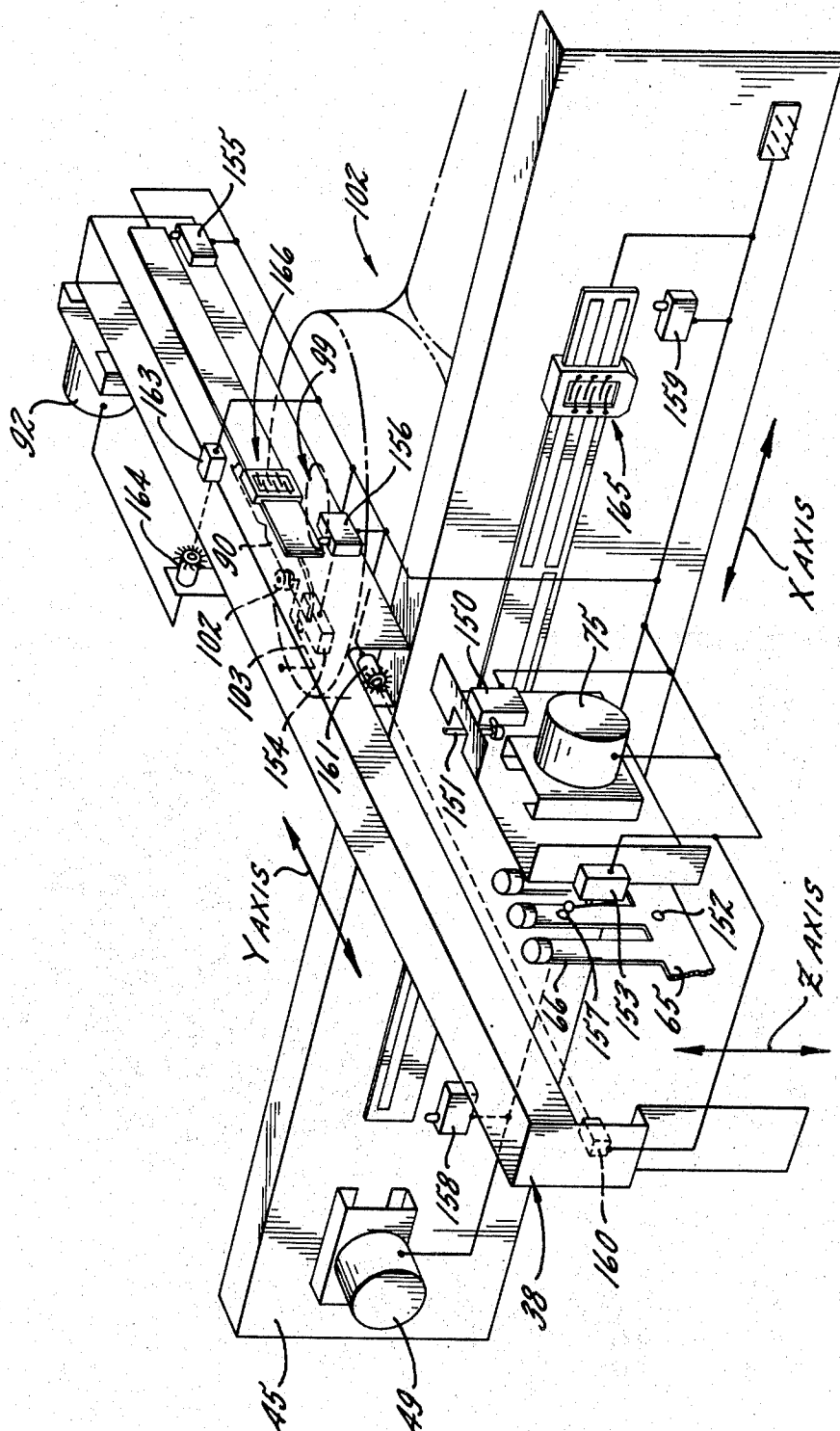




INVENTORS.
 JOSEPH R. TOMAN,
 EDMUND FRANK
 BY
 Wolfe, Hubbard, Seyditz, Voit & Osann, Ltd.
 ATTORNEYS.

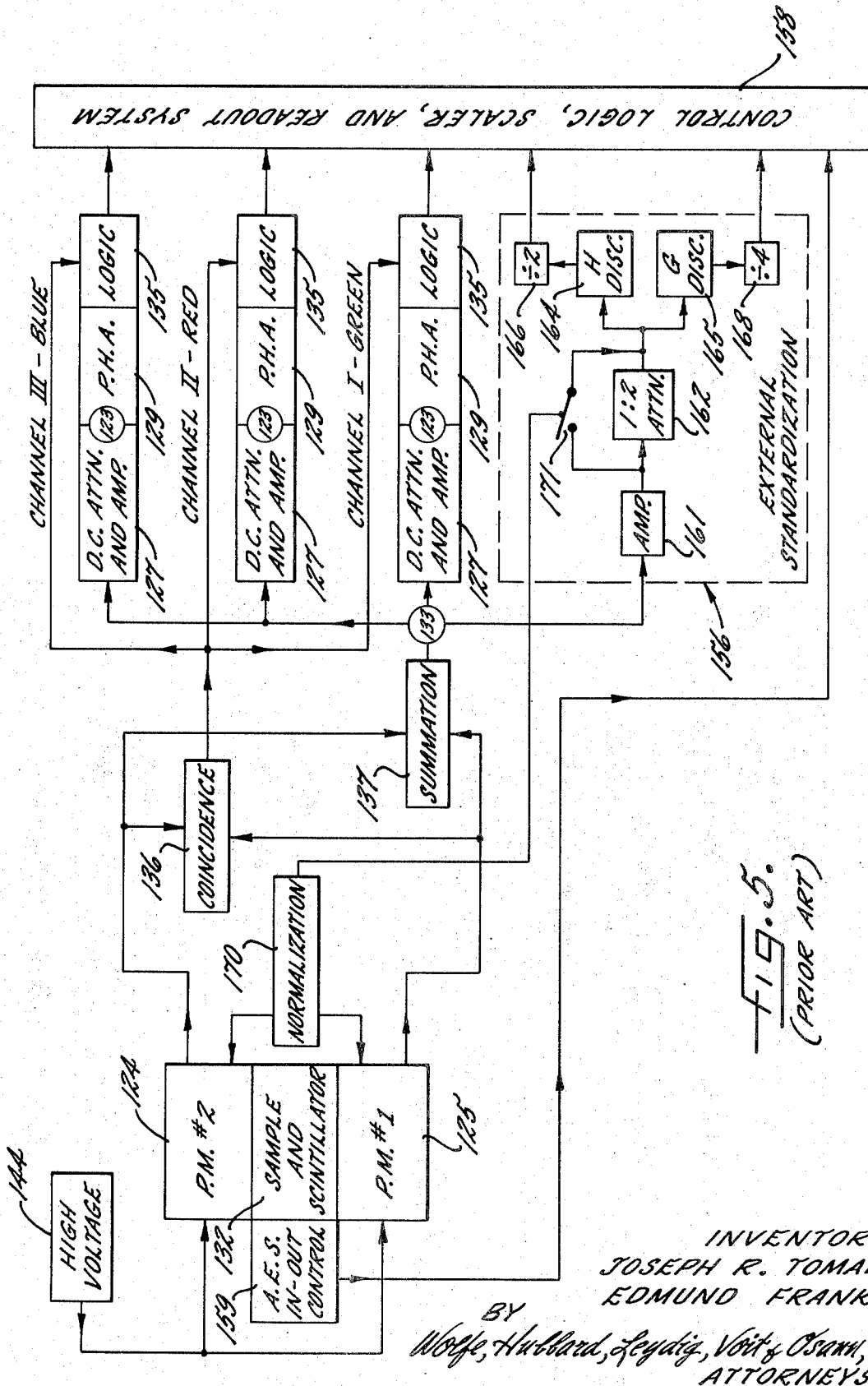


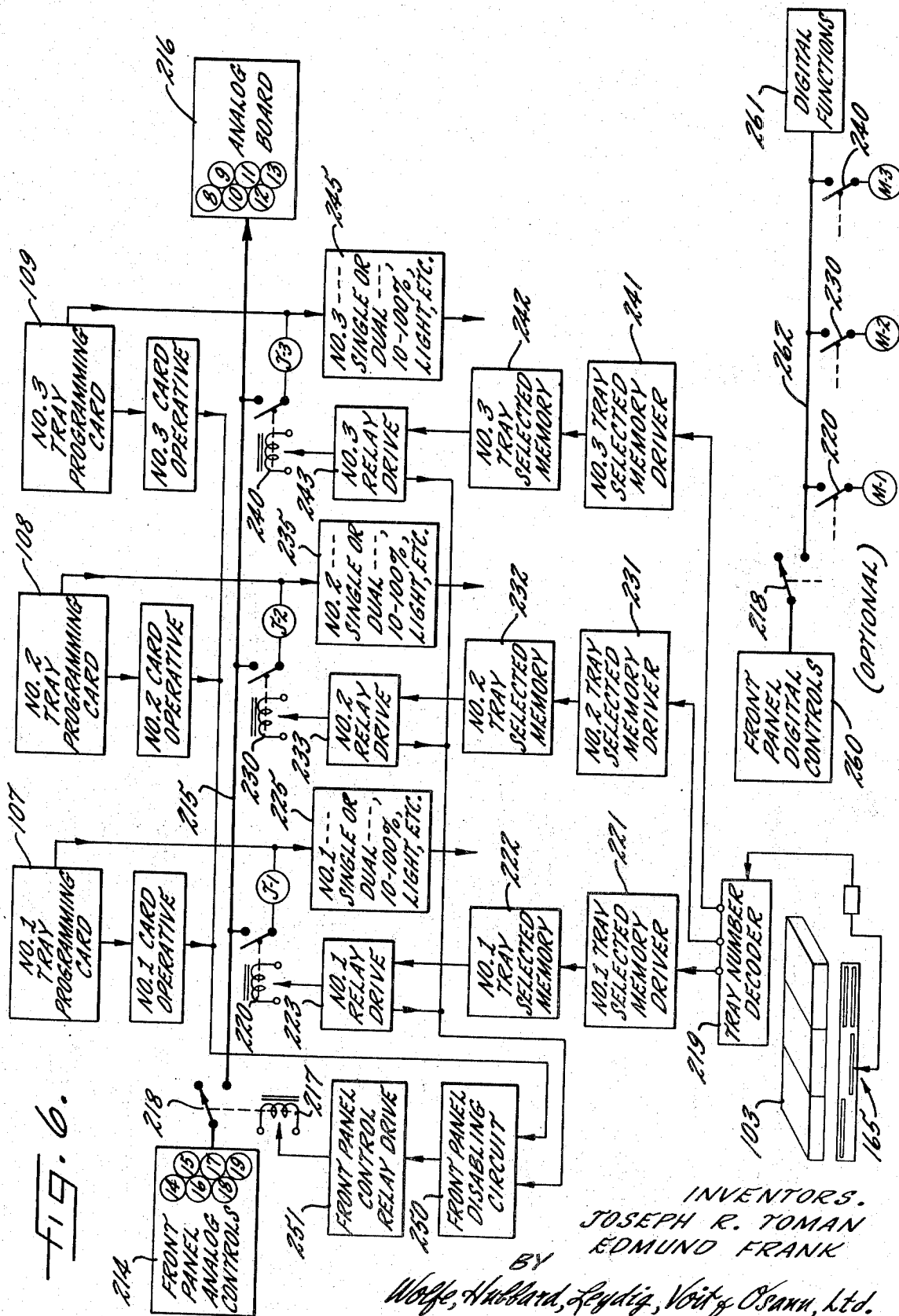
INVENTORS.
 JOSEPH R. TOMAN
 EDMUND FRANK
 BY
 Wolfe, Hubbard, Leydig, Voigt & Osann, Ltd.
 ATTORNEYS.



INVENTORS.
JOSEPH R. TOMAN
EDMUND FRANK

BY
Wolfe, Hubbard, Leydig, Voigt & Osann, Ltd.
ATTORNEYS.





INVENTORS.
JOSEPH R. TOMAN
EDMUND FRANK

BY
Wolfe, Hubbard, Lydick, Voigt & Osann, Ltd.
ATTORNEYS.

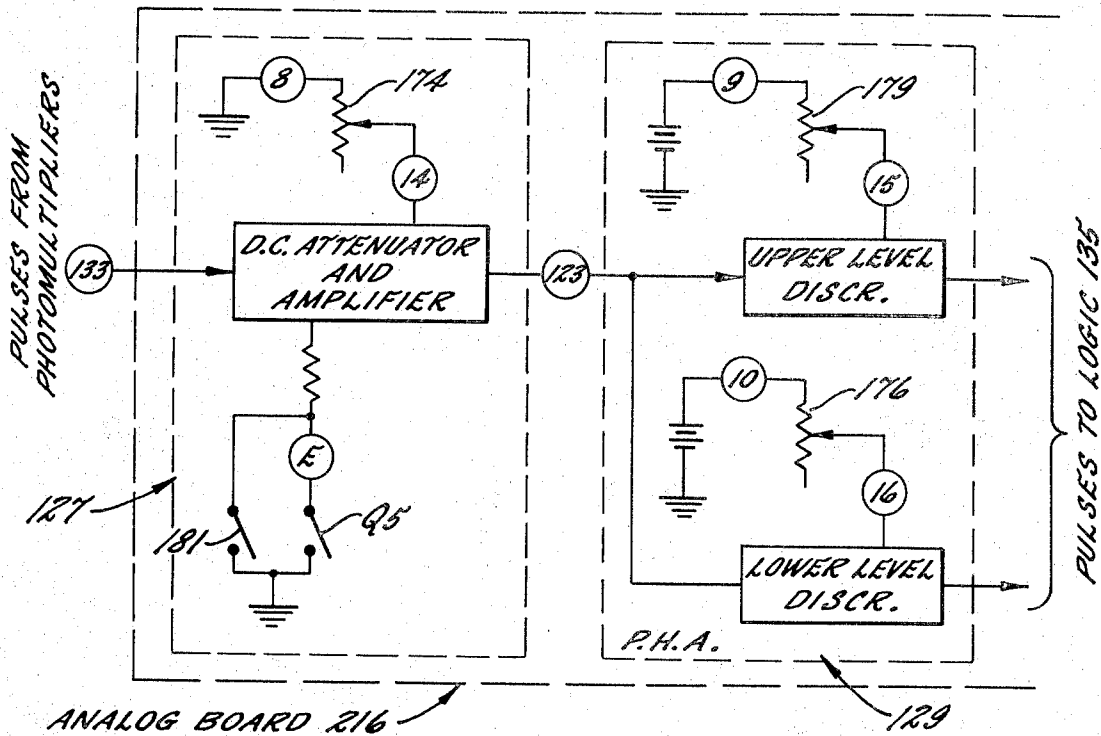


Fig. 7.

INVENTORS.
JOSEPH R. TOMAN
EDMUND FRANK
BY
Wolfe, Hubbard, Leydig, Voigt & Osann, Ltd.
ATTORNEYS.

Fig. 8a.

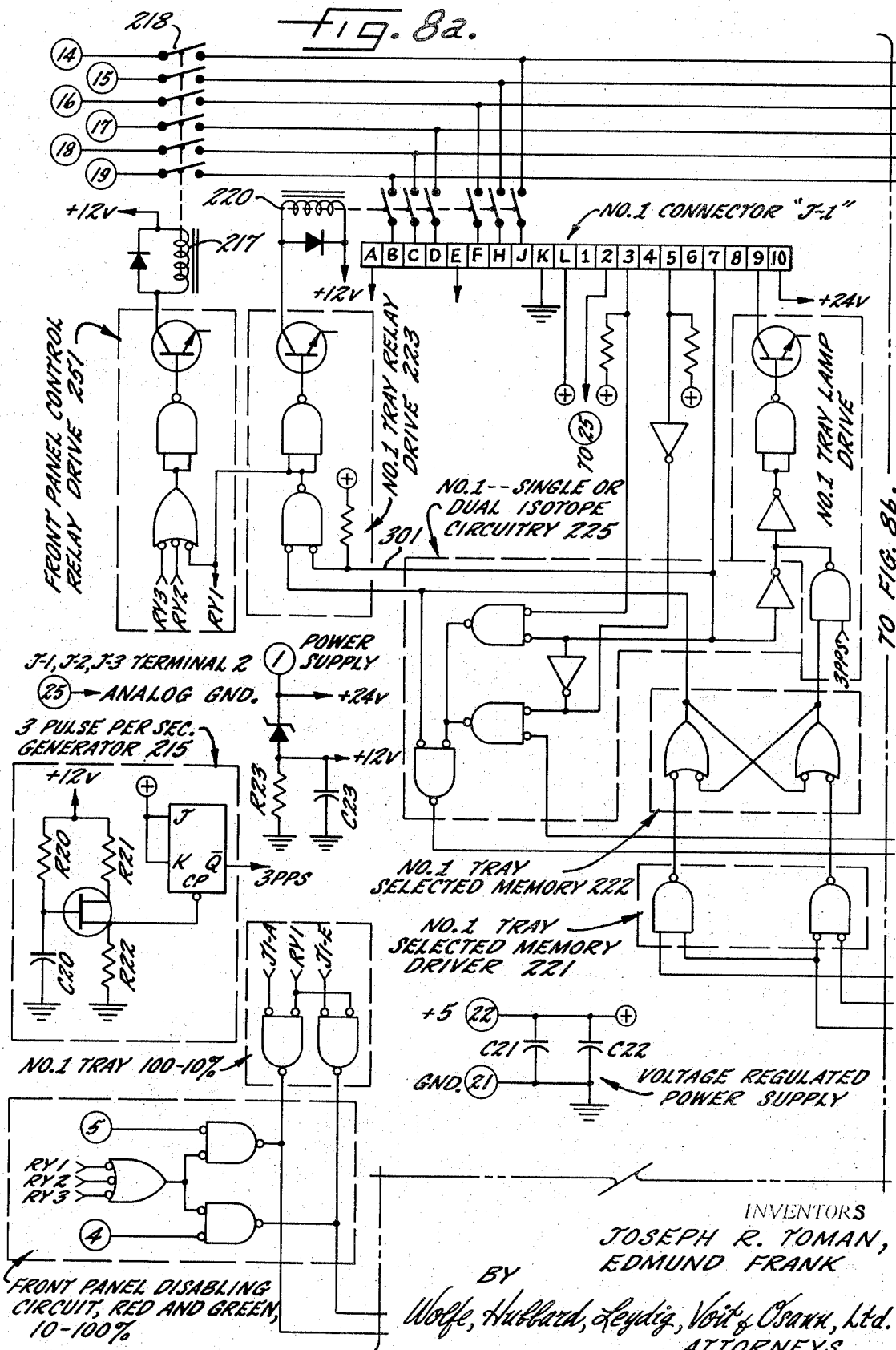


Fig. 8b.

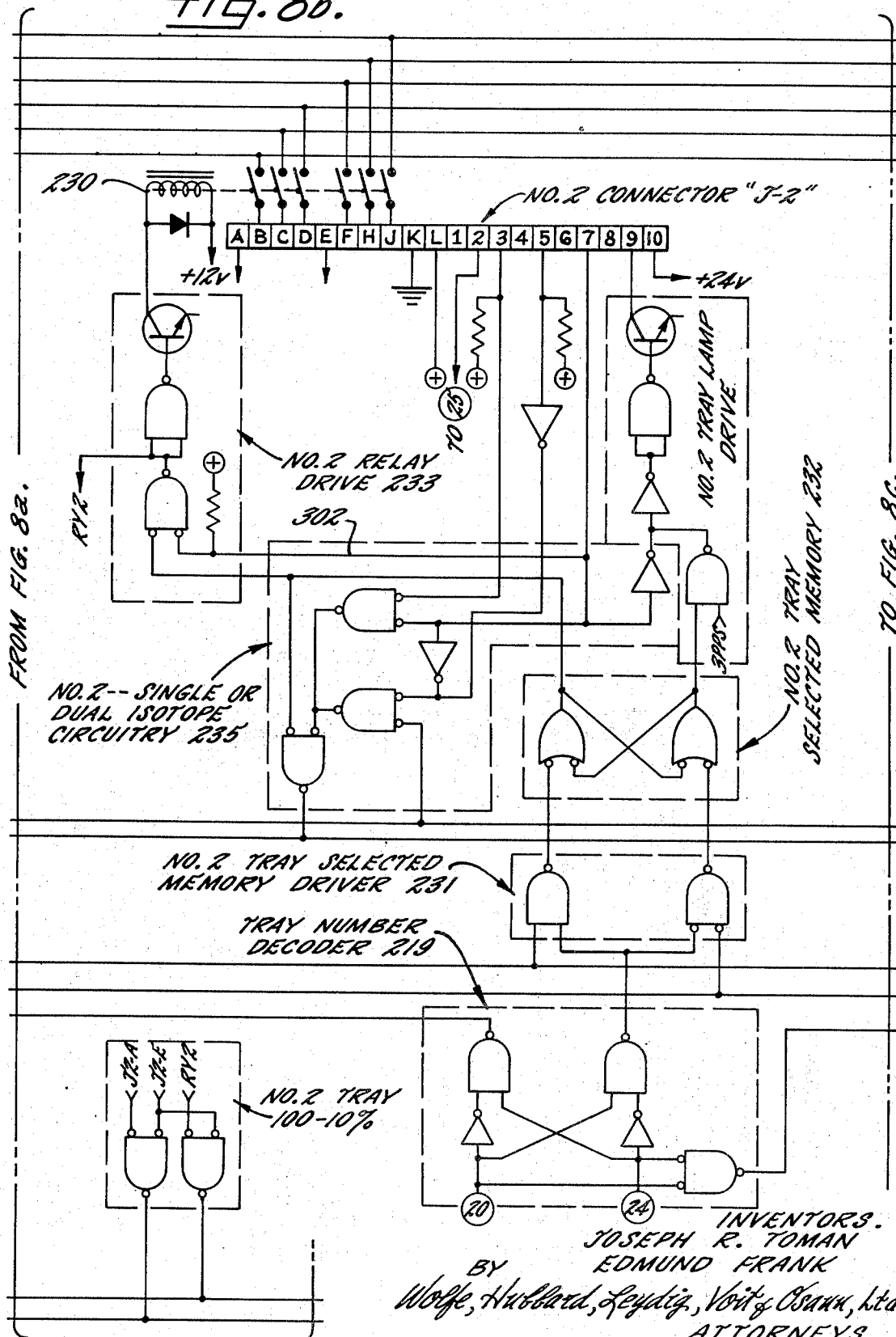
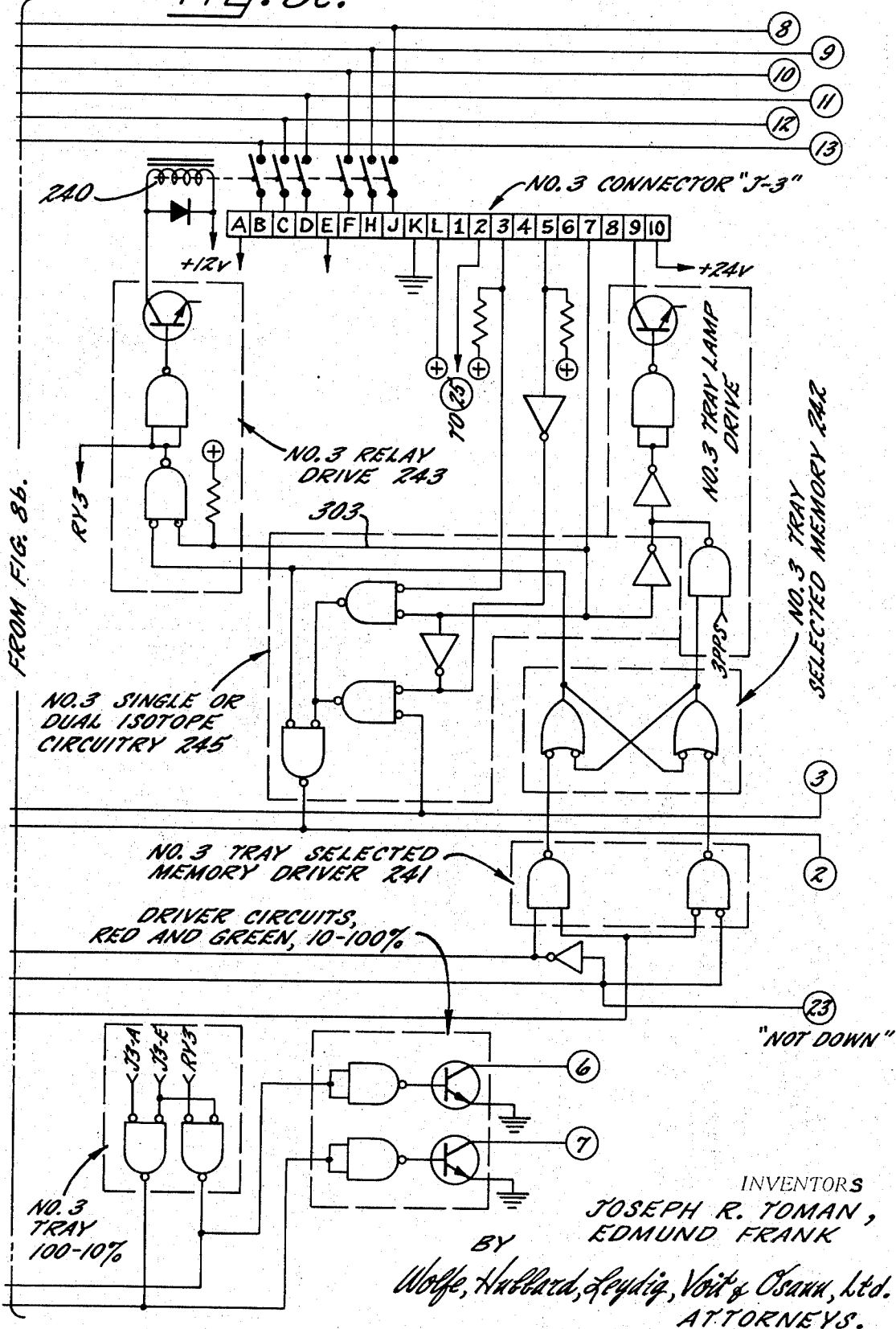


Fig. 8c.



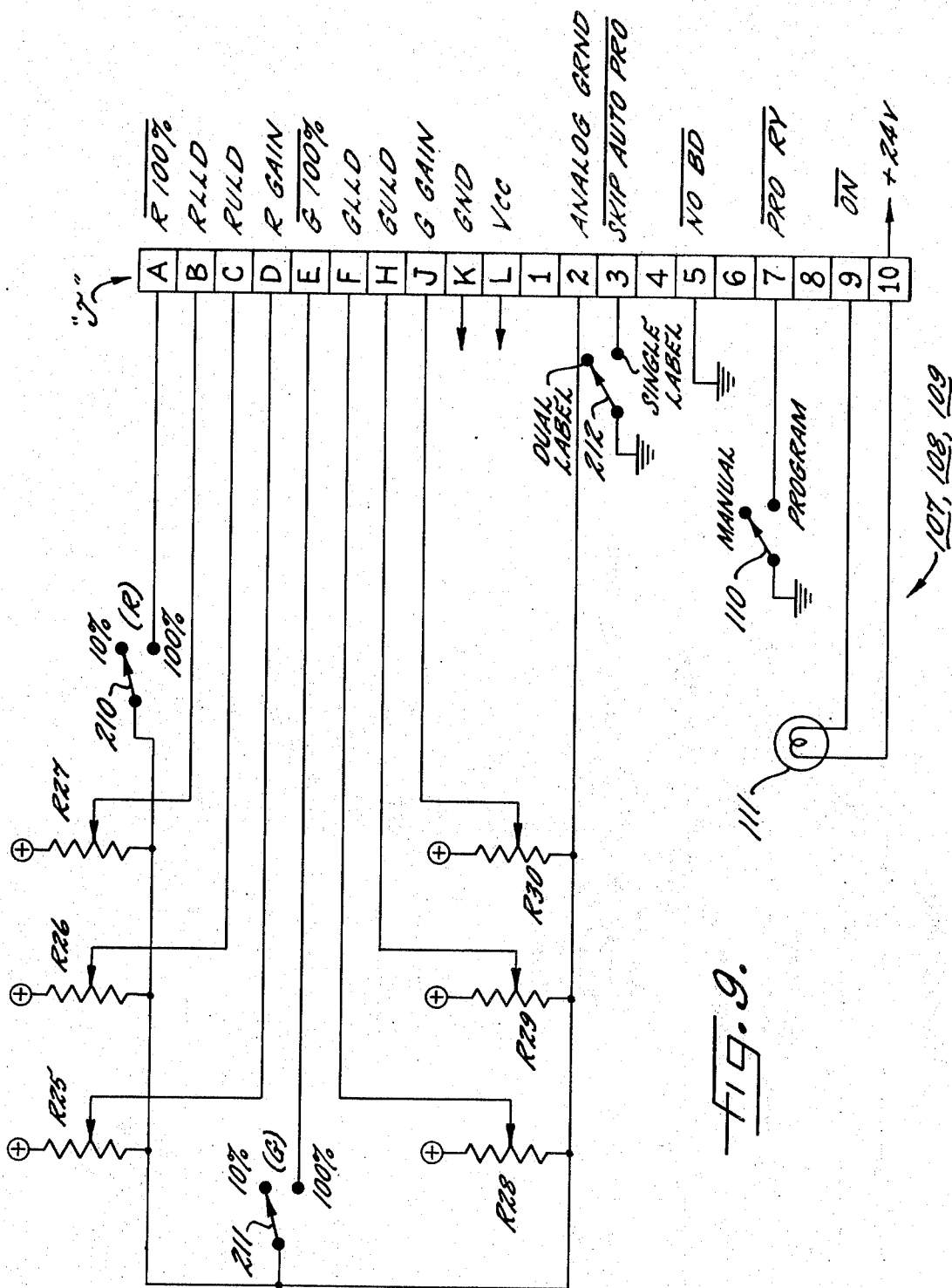


FIG. 9.

INVENTORS
 JOSEPH R. TOMAN,
 EDMUND FRANK
 BY
 Wolfe, Hubbard, Leydig, Voigt & Osann, Ltd.
 ATTORNEYS.

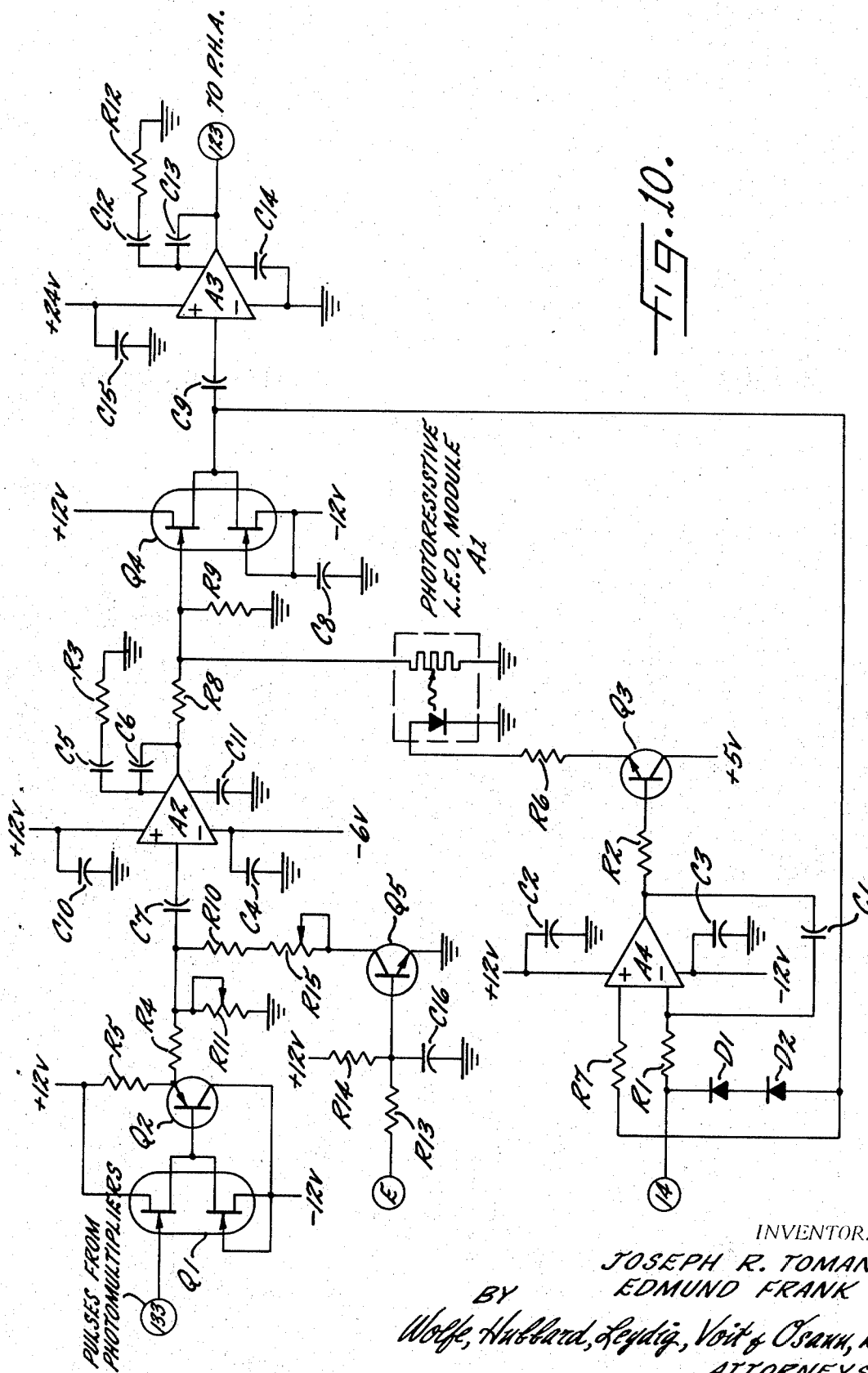
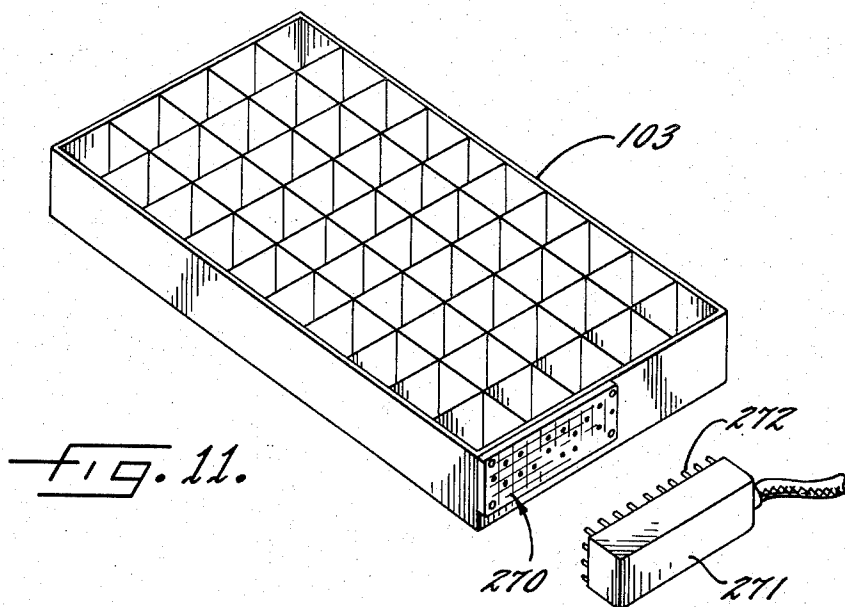


FIG. 10.

INVENTORS
 JOSEPH R. TOMAN,
 EDMUND FRANK
 BY
 Wolfe, Hubbard, Leydig, Voigt & Osann, Ltd.
 ATTORNEYS.



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◎ CARD	BACK- GROUND SUB.	COUNT EFF.	LOW LEVEL REJECT (R)	LOW LEVEL REJECT (G)	PRESET COUNTS (R)	PRESET COUNTS (G)	PRESET COUNT COINC.	PRESET TIME	◎ COUNT
1	1	OFF	OFF	OFF	.1	.1	OFF	.1	1
2	2	AUTO STD.	10	10	.2	.2	ON	.2	2
3	4	CH. RATIO	20	20	.4	.4		.4	3
4	8		40	40	1	1		1	4
5	16		100	100	2	2		2	5
6	32		200	200	4	4		4	6
7			400	400	10	10		10	7
8			1000	1000	20	20		20	8
9					40	40		40	9
10					100	100		100	∞
					200	200		200	
					400	400		400	
					1000	1000		1000	
◎					OFF	OFF		OFF	◎

FIG. 12.

INVENTORS
JOSEPH R. TOMAN
EDMUND FRANK

BY
Wolfe, Hubbard, Lyndig, Voit & Osann, Ltd.
ATTORNEYS.

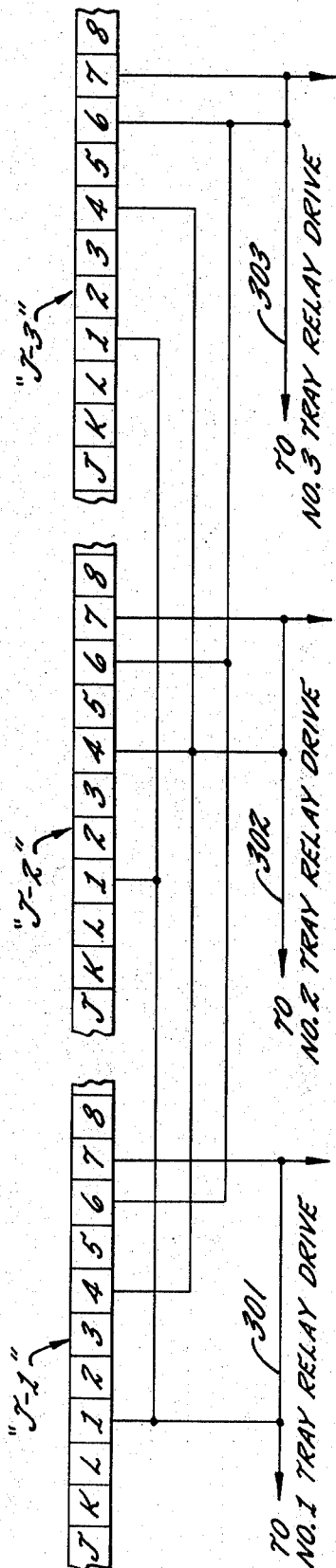


FIG. 13.

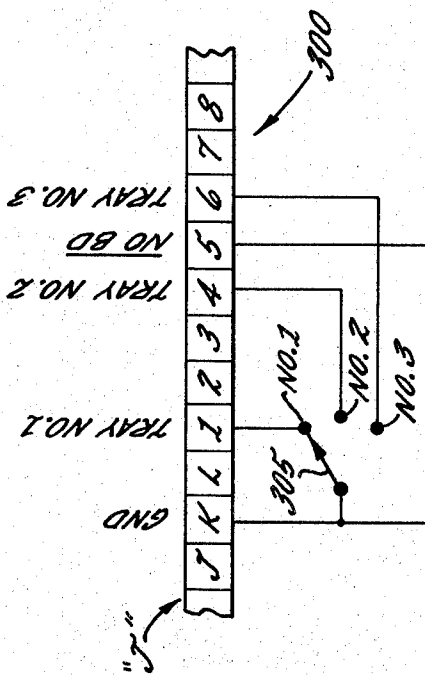


FIG. 14.

INVENTORS
JOSEPH R. TOMAN
EDMUND FRANK

BY
Worfe, Hubbard, Leydig, Voigt & Osann, Ltd.
ATTORNEYS.

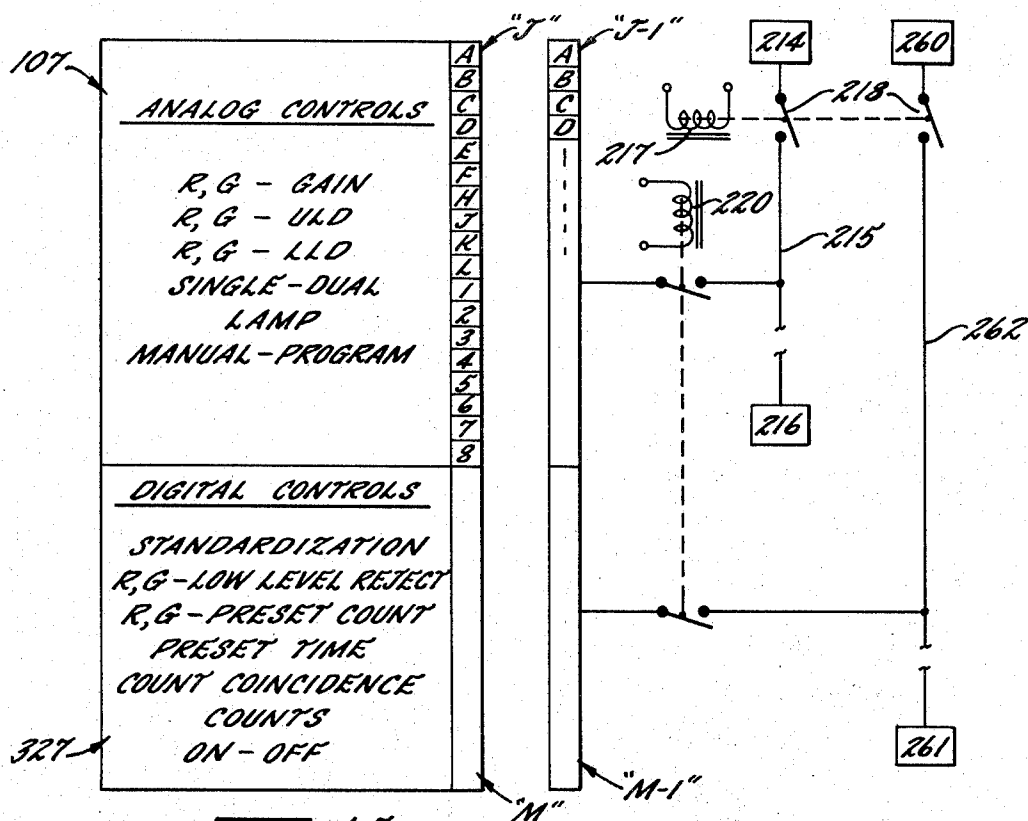


FIG. 15.

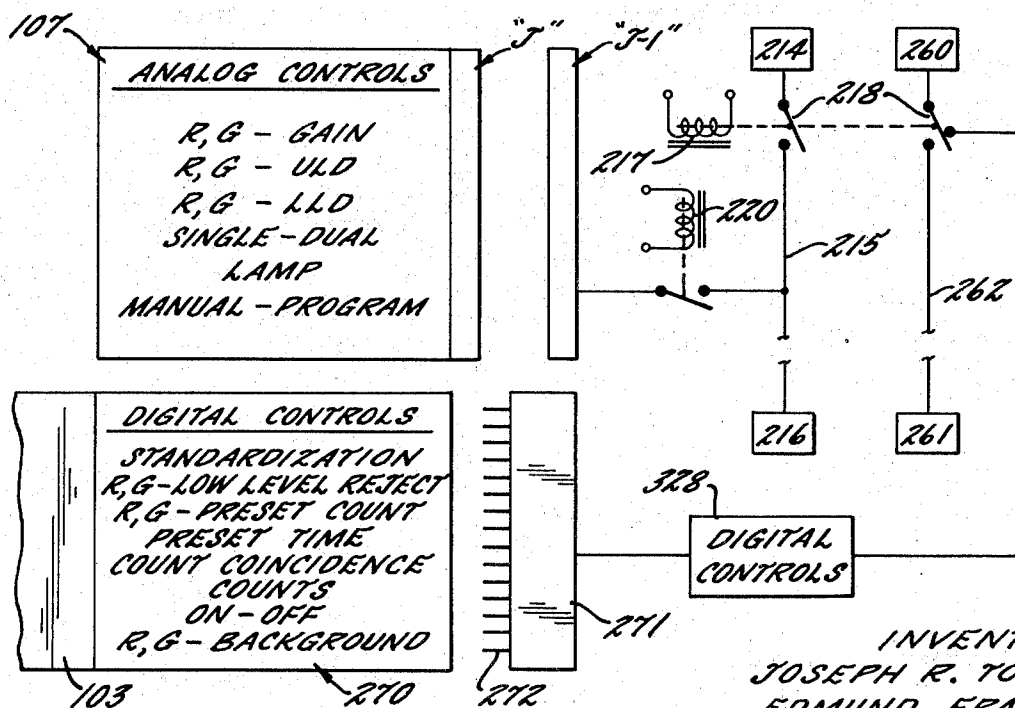


FIG. 16.

INVENTORS
JOSEPH R. TOMAN
EDMUND FRANK

BY
Wolfe, Hubbard, Seyditz, Voigt & Osann, Ltd.
ATTORNEYS.

METHOD AND APPARATUS FOR PROGRAMMING LIQUID SCINTILLATION SPECTROMETERS

CROSS REFERENCE TO RELATED APPLICATIONS AND PATENTS

Packard	U.S. Pat. No. 3,114,835	
Packard	U.S. Pat. No. 3,188,468	
Cavanaugh	U.S. Pat. No. 3,499,149	
Bristol	Ser. No. 629,462	filed Apr. 10, 1967
Frank	Ser. No. 27,405	filed Apr. 10, 1970
Frank et al.	Ser. No. 27,406	filed Apr. 10, 1970
Frank	Ser. No. 27,411	filed Apr. 10, 1970

SUMMARY AND BACKGROUND

This invention relates to automatic scintillation counting, and more particularly concerns the provision of a fully automated system for radioactive detection and measurement of a multiplicity of samples where the samples are divided into different sets that require different counting parameters.

Equipment for automatically detecting and measuring the activity levels of radioactive samples has reached a high level of development. With state-of-the-art scintillation spectrometers and their fully-automatic auxiliaries it is now possible to place a batch of samples into a spectrometer apparatus and have the apparatus function unattended to detect and measure the radioactivity, correct for inherent errors, and print out the results on a computer-print-out sheet or on magnetically or mechanically-readable records.

There is, however, one limitation of many such automatic spectrometers. Customarily a laboratory will have one spectrometer which is used by a number of researchers or research teams. Each researcher generates a set or series of samples which, for optimum scintillator accuracy, may require a particular set of predetermined counting program parameters or conditions. For example, different radionuclides may be used, the activity levels may differ by orders of magnitude, or two or more radionuclides may be present. It is customary in such circumstances for each researcher to alter the various counting condition controls for his or her set of samples, and then either restore or re-set the controls for the next set. This necessarily creates the possibility of human error by incorrectly adjusting the various function controls and, from an inconvenience standpoint, prevents unattended overnight or over-weekend automatic counting.

Accordingly, an object of the invention is to provide a simple, fully automatic, system for changing the scintillator counting program parameters — either analog or analog-plus-digital — for each set of samples. A related object is to provide replacement program-control modules so that each researcher can adjust the module's controls once for his or her project, and thereafter be assured that the same program parameters are being used for counting all the project's samples. An overall object is to provide an automatic scintillation counting device, including automatic sample handling and transferring equipment, capable of changing one or more — or all — counting program parameters for each set of samples, and in which the changing is effected in response to the particular set of samples being (individually) counted.

Other and further objects include: provisions for counting two or more sets under program counting conditions established for one of the sets; for retaining the standard "master," or "front panel," controls when

it is unnecessary to vary the programs for particular sample sets; and for utilizing various improved sub-components for the system.

In the ensuing description, the system of the invention is applied to an exemplary liquid scintillation spectrometer, including sample handling and transferring equipment, for automatically processing a multiplicity of radioactive samples. The samples are transferred in sets to a sample counting zone for individual counting. It will be appreciated, however, that this type of scintillator and transfer equipment is exemplary only, and that the "sets" need not be defined by discrete trays or magazines, but may simply be regions or portions of a single magazine or of a belt-fed sample transferring mechanism, all of which are well known in the art.

BRIEF DESCRIPTION OF DRAWINGS

Other objects and advantages of the invention will become apparent as the following description proceeds, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a fragmentary overall perspective of a liquid scintillation spectrometer embodying the invention, including front panel and program controls;

FIG. 2 is a front elevation of the front panel on the spectrometer of FIG. 1;

FIG. 3 is a top plan view showing the overall arrangement of a sample changing apparatus and associated detection and counting mechanisms, as employed in the spectrometer of FIG. 1;

FIG. 4 is a perspective showing, in somewhat stylized or schematic form, certain of the electrical components, wiring, and connections on the sample changing apparatus of FIG. 3;

FIG. 5 is a diagrammatic block-and-line representation of an illustrative prior art multiple channel scintillation spectrometer capable of embodying the present invention;

FIG. 6 is a diagrammatic, stylized, block-and-line representation of a programming system of the invention, including optional provision for programmed digital control;

FIG. 7 is a diagrammatic, more detailed, block-and-line representation of the pulse height analyzer ("P.H.A.") component of the spectrometer of FIG. 5, illustrating certain of the connector points associated with the invention;

FIGS. 8a, 8b, and 8c, in conjunction, are a diagrammatic detailed block-and-line representation of the tray program control circuitry of the invention;

FIG. 9 is a wiring diagram of a single tray programming card for interconnection into the control circuitry of FIG. 8;

FIG. 10 is a wiring diagram of the d.c. attenuator and amplifier ("D.C.ATTN & AMP") component of the spectrometer of FIG. 5;

FIG. 11 is a perspective of an alternative embodiment of the invention, with provisions for both analog and digital program selection of the spectrometer;

FIG. 12 is a front view of an illustrative program card for the alternative embodiment of FIG. 11.

FIG. 13 is a diagrammatic partial schematic representation of a modified FIG. 8 circuit for use when it is desired to program several trays from a single tray programming card;

FIG. 14 is a diagrammatic partial schematic representation of a "dummy" tray programming card for use with the circuit of FIG. 13;

FIG. 15 is a schematic block and-line representation of one form of system for providing digital as well as analog program control; and

FIG. 16 is a similar schematic of an alternative form of system for digital and analog control.

While the invention is susceptible of various modifications and alternative forms, a specific embodiment thereof has been shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that it is not intended to limit the invention to the particular form disclosed, but, on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the invention as expressed in the appended claims.

THE ENVIRONMENT OF THE INVENTION

Before treating the present invention in detail, it will be helpful first to consider briefly the prior art background or environment. In radioactivity measurements, it is the most frequent objective to determine the rate at which decay events in an isotope present in a radioactive source occur, this rate generally being expressed as counts per unit time, e.g., counts per minute. The quantity of a particular isotope present in a radioactive source is in general proportional to the rate of decay events produced by that isotope, such rate being termed the "activity level" of the source. As a generalization, the decay events or radiation emanations from a radioactive source are, for purposes of measurement or counting, converted into corresponding voltage or current pulses which can then be counted. The pulses may be counted for a predetermined time, or a predetermined number of pulses may be counted, the ratio of counted pulses to the elapsed time period being indicative of the activity level. In some instances the voltage pulses may be fed to a direct-reading or recording rate meter which indicates the activity level.

GENERAL ORGANIZATION AND OPERATION OF SPECTROMETER

The spectrometer illustrated diagrammatically at 101 in FIG. 1 includes a radioactive source 132 (FIGS. 3, 5), disposed in operative relationship to one or two light-responsive detectors or proportional transducers 124, 125 (FIGS. 3, 5). The transducers serve to convert radiation from decay events within the source 132 into corresponding electrical signals, e.g., voltage pulses, the transducer may be any one of a variety available in the art, such for example as a photomultiplier tube observing a sodium iodide (thallium activated) crystal which converts radioactive decay events from gamma-emitting isotopes into light flashes. Regardless of the particular type of detector and transducer employed, it should have a proportional characteristic, i.e., each voltage pulse will be substantially proportional to the energy of the decay event which produces it.

The voltage pulses so derived by the detector or transducers 124, 125 are, however, of relatively low amplitude. It is impractical, if not impossible, to discriminate these pulses on the basis of differences in their amplitudes and to count or measure their rate of occurrence. Accordingly, and with reference to FIG. 5, the pulses from the transducers 124, 125 (FIGS. 3, 5)

are passed through one or more "channels," each comprising a linear amplifier 127 and a pulse height analyzer ("P.H.A.") 129. Because the pulses received by the analyzer 129 have been amplified and thus occupy a fairly wide spectrum of amplitudes, the analyzer selects only those pulses which lie above or below certain pre-selected amplitudes, and passes them to a final indicating device such as a rate meter or a scaler, the latter being shown at 157 (FIG. 2). By adjusting the amplitude band or "window" of pulse amplitudes passed by the analyzer 129, the background pulses (resulting either from spurious radiation, cosmic rays, or noise in the transducer) is substantially reduced, so that the count received by the scaler is comprised principally of pulses resulting from the activity of the source being measured. The background pulses to a large extent have amplitudes that fall outside the acceptance band of the analyzer after the latter has been adjusted. The background count passed by the analyzer may, of course, be measured for a given time interval with no radioactive source present, and then subtracted from subsequent scaler counts received with radioactive sources present.

Because the pulses applied to the input of the analyzer 129 have amplitudes substantially proportional to the energy of corresponding decay events in the source 132, the analyzer may be adjusted successively to pass bands of pulse amplitudes, and the energy spectrum of the decay events in an isotope thus plotted. Once that spectrum has been measured, or is known, the analyzer 129 may be set to pass an amplitude band or window in which a fairly large proportion of all pulses derived from the isotope decay events are passed and counted, yet in which the background or spurious pulses passed to the scaler are relatively few.

LIQUID SCINTILLATION AND COINCIDENCE MONITORING

In spectrometry involving isotopes which produce radiation particles having relatively low penetrating power, namely alpha and beta particles, and particularly with samples or sources of low activity levels, the detector or transducer preferably includes a solution of liquid scintillator into which the radioactive substance (sample) is added. Light flashes in this solution, resulting from decay events in the isotope, are transmitted to a photosensitive electrical device, preferably a photomultiplier tube. Because such photomultiplier tubes are to an undesirable degree prone to produce spurious voltage pulses due to "dark noise current" which is primarily caused by thermally induced electron emission, it has been common practice to employ "coincidence monitoring" in order to preclude counting of these spurious voltage pulses. Such a liquid scintillation spectrometer with coincidence monitoring, and intended primarily for work with alpha and beta radiation isotopes, is diagrammatically illustrated in FIG. 5.

Referring to FIG. 5, the radioactive source is shown at 132 as a sample of isotope-containing substance dissolved or suspended in a liquid scintillator, the latter being in a container having light-transmissive walls. Aromatic ethers are commonly employed as solvents, although numerous other solvents are known in the art. Any one of numerous commercially obtainable scintillators or fluorescent materials is also dissolved in the solvent for the purpose of converting the radiant energy resulting from a decay event (for example, an

alpha or beta decay event) into light energy. Finally, the sample includes the radioactive material, which is or contains a radionuclide or isotope to be measured. The emission energy spectra of the different radionuclides may vary greatly, each having a characteristic known spectrum. Such spectral characteristics are fully described in the scientific literature.

Where the maximum beta energy of the radionuclide is relatively low, typified by tritium (maximum beta energy of 0.018 mev.), carbon-14 (0.15 mev.), and up to phosphorus-32 (1.71 mev.) or so, the light flashes in the scintillator solution are relatively weak, although proportional in intensity to the energy of the decay events which produce them. It is for this reason that a very sensitive light-to-voltage transducer, such as a relatively high gain photomultiplier tube, is employed, and coincidence monitoring is utilized to reduce the effects of noise pulses therein.

Referring more specifically to FIG. 5, the spectrometer there illustrated includes a pair of photomultipliers as transducers 124, 125 which are placed contiguous with, or adjacent to, the sample 132 and energized from a variable high voltage source 144. The photomultipliers 124 and 125 serve the respective functions of providing pulses to be analyzed and pulses to "monitor" or gate the first pulses when both photomultipliers simultaneously respond. The outputs of photomultipliers 124, 125 may, if desired, be preamplified through preamplifiers, not shown, if the output from the respective photomultipliers is insufficient, but with present day (1971) high gain photomultipliers such preamplifiers may frequently be omitted.

In order to reduce the number of thermal noise pulses in the photomultipliers, the sample 132, the photomultipliers 124, 125, and the optional preamplifiers are advantageously all located within a cooled chamber or freezer, diagrammatically illustrated at 102 (FIG. 1).

The outputs of the photomultipliers 124, 125 or of their associated preamplifiers, are coupled to one or more "channels," each composed of an (optional) attenuation unit and amplifier 127, a pulse height analyzer 129, and a logic circuit 135, one channel for each radionuclide in the sample. The photomultiplier output pulses are thus amplified to a predetermined extent, and passed to the pulse height analyzers 129, each of which provides a discriminated input signal for a suitable logic circuit 135 which, for example, may simply be an AND gate, which feeds into a control logic, scaler (scaler 157 on FIG. 2), and readout system 158 (on FIG. 5). Additional channels may be provided to accommodate additional channels for simultaneously counting a sample containing more than two different radionuclides, as explained below.

When a decay event (for example, a beta emission) occurs in the sample 132, a light scintillation is produced that is simultaneously detected by both photomultipliers 124, 125. Correspondingly, electrical signal pulses proportional in amplitude to the energy of the decay event (i.e., the amount of light observed by the respective photomultipliers) are fed to one or more of the pre-selected channels ("Channel I," "II," or "III" in FIG. 5), and amplified by the amplifiers 127 in that selected channel. These pulses are then analyzed in pulse height analyzer 129 which passes only a selected band of pulses. The analyzers 129 preferably are constructed and adjusted to pass all received pulses which exceed a predetermined low amplitude, that is, to serve

as lower level discriminators ("L.L. DISC." in FIG. 7) and may (but need not) restrict the upper amplitude of passed pulses, i.e., as upper level discriminators ("U.L. DISC.").

As will be explained below in connection with coincident counting, only when the analyzer 129 and the coincidence circuit 136 provides coincident, or simultaneous, input pulses to the AND gate in the logic circuit 135 does the latter produce an output pulse which is controlled by the system 158 (i.e., scaler 159 in FIG. 2). If, on the other hand, coincident inputs are not present at the AND gate, any pulse from the pulse height analyzer 129 is blocked from, and therefore not counted by, the scaler system. By way of example, when a thermal pulse is generated in either one of the photomultipliers, coincident input pulses will not be received by the coincident circuit 136 and presented at the AND gate of logic circuit 135, and hence no count will be recorded by the scaler 157 (FIG. 2). This is so even if the thermal pulse is within the amplitude band or window being passed by the analyzer.

MULTIPLE LABELED MEASUREMENTS AND MULTIPLE CHANNEL CIRCUIT

As further shown in FIG. 5, the liquid scintillation and coincidence monitoring circuit may be adapted to detect, isolate, and measure the radioactivity emanating from a plurality of radionuclides within a single sample, the operations associated with each nuclide being performed simultaneously. The circuit of FIG. 5, for this purpose, includes one or more additional counting channels "II" and "III" (FIG. 5), each composed of an attenuator and amplifier unit 127, pulse height analyzer 129, logic circuit 135 (connected to the pulse height analyzer 129), and a scaler system 158, and if desired, even more such channels. Multiple channel units are adapted for the independent measurement of the activity levels of two or more isotopes which are simultaneously present in a single source or sample, or which are present individually in mixed sources or samples; circuits and techniques for such detection and measurement are described, for example, in Packard '835.

Very briefly, in multiple channel radioactivity detecting and measuring spectrometers, the output from the photomultipliers 124, 125 (FIG. 5) is fed simultaneously to a plurality of channels, each containing an attenuation unit, an amplifier, a pulse height analyzer, and associated logic and scaler apparatus. In each channel the attenuation unit and/or amplifier amplify the pulse by an amount or factor which is different from that in the other channel or channels. If the spectral peaks of the respective radionuclides are separable, counting and monitoring of pulses from one radionuclide may be effected independent of pulses contributed by the other or others; if the spectral peaks overlap, computation may be required to determine the activity attributed to each radionuclide. Multiple channel circuits thus are capable of simultaneously measuring the activity levels of each of several different radionuclides provided each radionuclide has a different characteristic energy spectrum.

SUMMATION-TYPE MEASUREMENT CIRCUIT

Although in some scintillation circuits only one of the photomultipliers 124, 125 is used for detecting scintillations (the other serving only to exclude signals from the

first photomultiplier that do not correspond to a scintillation), a more efficient coincident counting circuit, generally termed a summation-type circuit (as shown in FIG. 5) allows both photomultipliers 124,125 to observe the sample and to deliver a usable output signal corresponding to each decay event. In effect, a summation-type circuit adds algebraically the simultaneous output pulses of the two photomultiplier tubes 124,125 so that the input to the attenuation units and amplifiers is double the amplitude that can otherwise be obtained. Advantages of the summation circuitry are set forth in Bristol Ser. No. 629,462.

As shown in FIG. 5, the summation circuit utilizes the photomultipliers 124,125 positioned to observe the sample 132 as in the arrangement of FIG. 3. Again, preamplifiers may be used, and the assembly of sample, photomultipliers, and preamplifiers may be positioned in a refrigerated zone, not shown. Output pulses delivered by the photomultipliers 124,125 are both fed to a coincidence circuit 136 and to a summation circuit 137. The coincidence circuit 136 may typically comprise an amplifier and a pulse forming network associated with each line from one of the photomultipliers, with the pulse forming networks feeding into an AND gate which delivers an output signal only when signals from the photomultipliers 124,125 are simultaneous. The summation circuit 137 illustratively comprises a pair of preamplifiers and a summing amplifier to sum the signal pulses received from the photomultipliers. Thus, coincident pulses from the photomultipliers are effectively doubled in amplitude by the summation circuit 137 while non-coincident pulses corresponding to thermal noise in one of the photomultipliers remain at the initial level.

Further in the circuit of FIG. 5, the output signals from the summation circuit 137 are fed to the pulse height analysis channels, of which three such channels are shown in the drawing. Each such channel comprises an attenuation unit and amplifier 127, a pulse height analyzer 129, and a logic circuit 135. Thus, all of the pulses from the summation circuit 137 are received by each pulse height analysis channel, although the only pulses transmitted from the corresponding logic unit will be those coincident pulses of proper amplitude which pass through the "window" established by the pulse height analyzer for that pulse height analysis channel.

Coincidence counting, that is, the rejection of non-coincident pulses caused by thermal noise in the photomultipliers or in their associated preamplifiers, is obtained by feeding the output from the coincidence circuit 136 to the logic circuit 135 associated with each pulse height analysis channel. Thus, only those signals from photomultipliers 124,125 which are generated simultaneously will open the AND gate in the logic circuit 135 and permit registration of the signal by the scalers.

As indicated in FIG. 5, two or more pulse height analysis channels may be utilized to count simultaneously a sample containing two or more radionuclides, the method of using the summation-type circuit of FIG. 5 corresponding generally to that more fully set forth in Packard '835.

TYPICAL PHOTOMULTIPLIER ARRANGEMENT

The structure and operation of typical photomultipliers and their associated circuitry have been fully de-

scribed, as for example in Packard '835 and in Bristol Ser. No. 629,462, and accordingly their principles are well understood. However, to provide a background for an understanding of the circuitry constituting the present invention, a brief description of photomultipliers and their operation will be presented.

When a decay event, for example, a beta emission from a radionuclide, occurs in the sample (132 of FIG. 5) it produces a light scintillation which is simultaneously detected by a photosensitive cathode, in one or both photomultiplier tubes 124,125. As the light rays impinge upon the cathode, electrons proportional in number to the energy of the light are emitted. The emitted electrons are attracted to the first dynode in the photomultiplier, which is at a higher voltage with respect to the cathode, thus producing by bombardment still more electrons which are in turn attracted to the next higher potential dynode. This process continues until the electrons reach the final element in the photomultiplier, the anode, the thus cause current flow through, and voltage pulses across, an output load resistance (not shown). These voltage pulses are sent to an output transformer (not shown) and appear at the input to the attenuation units and amplifiers of FIG. 5.

In order to simplify the ensuing discussion, isotope decay events will be referred to by way of example as beta decay events or beta emissions. It will be understood, however, that alpha and gamma radiation may be considered in the same way, even though, particularly in the case of gamma radiation, there may be mono-energetic spectra involved in some instances.

SPECTRAL DISTRIBUTIONS AND OPTIMUM COUNTING CONDITIONS

It is well known that beta-emitting isotopes produce decay events which individually involve energies spread over a fairly wide range or spectrum. Each isotope has its own characteristic spectrum with a known maximum energy. A small proportion of the decay events have relatively high and low energies, while the majority have energies in the middle region between the upper and lower limits, the distribution being skewed rather markedly toward the lower limit. For a given gain of the transducer which forms a source of voltage or current pulses proportionally related to the energies of the decay events, the amplitude spectrum of the pulses corresponds to the energy spectrum of the decay events.

In the following discussion it is assumed, except as otherwise stated for explanatory or elaborational purposes, that the sample contains only a single radionuclide species. For a parallel discussion involving multiple-labeled samples, reference may be made to Packard '835.

If there were no spurious counts caused by thermal noise or background radiation, and if there were no quench effects (to be described presently), detecting all of the counts from a sample over a predetermined time period would provide a reading of sample activity in absolute units of counts per unit time. In practice however this is infeasible for a number of reasons, most important of which is the presence of low level background noise and high level background radiation, both of which generate spurious pulses that are indistinguishable from the actual decay-produced pulses, particularly at low and high levels of pulse height.

The effects of high and low level noise are customarily minimized by employing amplitude discriminators as pulse height analyzers to reject all pulses below a predetermined minimum amplitude and all pulses above a second, higher, predetermined amplitude. Thus, in FIG. 5, amplitude discriminators in the pulse height analyzers (e. g., 129), reject all pulses having an amplitude below a predetermined minimum and all pulses having an amplitude above a predetermined maximum. The region of accepted pulses is termed the window, and it will be evident that the width of the window determines the fraction of the total spectrum that is counted by the radiation detecting and measuring apparatus.

A given spectrometer may be provided with two or more windows, particularly when used for counting and measuring multiple-labeled samples. Additionally, and for reasons which will appear below, the spectrometer may have an external standardization circuit 156 (FIG. 5) including one or more integral channels, that is, amplification channels such as those including G-to-infinity ("G. DISC." 165 on FIG. 5) and H-to-infinity ("H. DISC." on FIG. 5) discriminators. The effective window is from a predetermined amplitude G or H, respectively, and all pulses above that level are transmitted. Such integral windows are especially valuable in connection with the use of external standards to compensate for quenching effects.

QUENCHING AND QUENCHING COMPENSATION

As suggested by the discussion of the counting window, the counts per minute indicated by a scaler (e.g., scaler 157 of FIG. 2) will be substantially less than the activity of the sample expressed as disintegrations per minute. The proportionality factor relating sample activity (in disintegrations per minute) to the measured counts per minute is termed the counting efficiency, and is invariably less than 100 percent. Counting efficiencies of less than 100 percent are due mainly to three factors: limitations of equipment, the deliberate exclusion of a portion of the count by adopting the window technique, and quench.

The last element, quench or quenching, is chiefly of two types. Chemical quenching results from the presence of ingredients in the sample and scintillator (132 of FIGS. 3,5) will interfere with the conversion of beta particles to light scintillations; organic compounds having a nitro group are particularly serious offenders in this respect. Color quenching is the attenuation or diminution of the brightness of a scintillation caused by colored or color-absorbing ingredients in the sample and scintillator.

The effect of either type of quenching is identical, and results in an apparent diminution of pulse height as measured by a photomultiplier or as transmitted through a pulse height analysis channel. Systems and techniques have been devised for compensating for quench effects, as will be explained subsequently.

INTERNAL STANDARD

Perhaps the earliest technique of quench compensation is by the use of an internal standard, that is, the procedure of determining the activity of a sample in a scintillator, adding to the sample a known amount of the same radionuclide as a standard, re-determining the activity, and computing the unquenched activity of the

original sample from the ratio of the difference in the two measurements and the expected difference based on the known activity of the standard. On the assumption that quenching will be constant for similar samples, the activity measured for all such samples can then be corrected to allow for quench and other factors which reduce counting efficiency.

EXTERNAL STANDARD — STRAIGHT COUNT

The technique of internal standardization is rather cumbersome and laborious; it is slow, the original sample is invariably contaminated by the standard, there is opportunity for technician error, and frequently different standards must be used with different samples where the samples have widely differing activities. To avoid these limitations, the technique of external standardization has been developed, and for more complete description of external standardization reference may be made to Packard '468, Cavanaugh '149, or Bristol Ser. No. 629,462.

Briefly, for external standardization, a sample is first counted alone, a high energy gamma-emitting source producing scintillations by Compton interaction is placed near the sample, and the two re-counted together. By relating the actual change in measured counts to the expected change produced by the external standard (as determined by previously counting the external standard in the presence of an unquenched standard), the un-quenched activity of the sample can then be computed.

By one technique, known as the straight count method ("AUTO. STD." position of the knob 173 of FIG. 2), determining the change in counts produced only by the external standard at any predetermined window or infinity channel (e.g., the G-to-infinity channel, via the G.DISC. 165 of FIG. 5) it is possible to compute the effect of quenching on the sample. A series of samples having the same known activity is made up, containing progressively increased amounts of an ingredient known to produce quenching. Advantageously, these samples contain the same scintillator, solvent, and radionuclide as the "unknown" samples. These samples are then counted in the presence of the external standard and a counting efficiency curve is plotted. Then, using the same channel or channels that were employed in preparing the curve to count the pulses produced by the external standard in the presence of an unknown sample, the curve yields a numerical value for the counting efficiency. When this efficiency is divided into the measured activity of the unknown sample counted in the absence of the external standard, the quotient is the true activity of the sample in disintegrations per minute.

NET EXTERNAL STANDARD RATIO

A further improvement of the technique of external standardization entails the use of two channels ("CHANNEL RATIO" position of the knob 173 of FIG. 2), rather than one, to determine the amount of quenching of radiation produced by the external standard. This technique, known as the net external standard ratio procedure, is particularly adaptable to the automatizing of external standard quench determinations.

Again inviting attention to FIG. 4, and particularly to the external standardization circuit 156, the channels for determining quenching effects of radiation from the

external standard are selected at two levels, preferably each above the maximum activity level of any beta-emitting radionuclide in the sample. Thus, one channel including the H. DISC. 164 is H-to-infinity while the other channel through the G. DISC. 165 is G-to-infinity. For practical purposes, it is preferable that the total number of counts provided by the external standard on an unquenched blank be in the ratio of 2:1 from the G-to-infinity channel and the H-to-infinity channel. Otherwise stated, with an external standard and an unquenched blank, the G-to-infinity channel will record twice as many counts as the H-to-infinity channel.

When quenching occurs the spectral curve relating counts per minute to pulse height will be displaced to a new position, and the ratio of counts received by each of the two infinity channels will no longer be the same. This change of ratio provides a versatile procedure for compensating against the effects of quenching.

For the net external standard ratio procedure the same type of calibration curve may be used as was employed in the straight count method. For convenience it is preferable that the ratio of the counts through the G-to-infinity and the H-to-infinity channels be converted by an arbitrary factor to unity, so that a change in the ratios provides an immediate quantitative indication of the degree of quenching. Also, it is usually more convenient to employ the ratio of H-to-infinity to G-to-infinity, rather than vice versa.

Suitable circuitry for utilizing the net external standard ratio technique has been described in detail, as for example in Cavanaugh Ser. No. 541,721, and accordingly only a brief description as it applies to the present invention is here furnished. Turning to FIG. 5, an exemplary external standardization circuit, shown schematically as circuit 156, is therein depicted. The various logic units 135 feed into a control logic, scaler, computer, and readout system shown schematically as block 158. This system of block 158 also controls the operation of the automatic external standard placement mechanism, or in-out control 159, adapted to position the external standard near the sample 132 during a preselected period, e.g., 0.5 minutes, of automatic external standard counting in conjunction with the spectrometric analysis of each sample. The apparatus for effecting automatic external standardization in-out control, schematically shown as 159 in FIG. 5, is more fully exemplified in Packard '468.

As shown in FIG. 5, all pulses received by either or both photomultipliers 124,125 are summed in the summation circuit 137 and are fed to the three pulse height analysis channels I, II, and III as well as to the external standardization system 156. The pulse height analysis channels were described previously and no further description is warranted.

The external standardization system 156 is comprised of an amplifier 161, a 1:2 attenuation circuit 162, and a pair of discriminators, H-to-infinity discriminator 164 and G-to-infinity discriminator 165, the latter two being in parallel. These discriminators respectively pass pulses of heights greater than predetermined pulses of H and G, respectively. Additionally, the H-to-infinity discriminator (or pulse height analyzer) 164 is made adjustable so that it will pass exactly half as many counts (from the external standard irradiating an unquenched blank) as will the G-to-infinity discriminator 165. Further, to accommodate a more conveniently us-

able number of pulses, the H-to-infinity discriminator 164 is followed by a frequency divider 166 which divides the output pulses from H-to-infinity discriminator 164 by a factor of two, and the G-to-infinity discriminator 165 is followed by a frequency divider 68 which effects a division by four. Thus, inasmuch as pulses from the G-to-infinity discriminator 165 are divided by a factor twice as great as the pulses from H-to-infinity discriminator 164, both discriminators will ultimately deliver the same number of counts to the control logic, scaler, computer, and readout system 158 when the external standard irradiates an unquenched standard,

NORMALIZATION

Normalization (170 in FIG. 5) provides a system for restoring the photomultiplier tube or tubes to a predetermined normal, or standardized, operating characteristic, and has particular applicability to spectrometers using coincidence counting, summation-type circuitry, and/or external standardization.

In brief over-view, normalization permits the gain of a photomultiplier to be adjusted, and therefore returned to a predetermined normal condition, without necessarily altering the high voltage power input to the photomultipliers. It permits the photomultiplier or photomultipliers to be maintained at a constant gain level irrespective of the tendency of such gain to change with time.

In the schematic circuit of FIG. 5, a normalization circuit 170 is provided which is capable of altering the gain of each photomultiplier 124,125 (or associated circuitry) independent of the other photomultiplier. The circuit 170 includes a shunt switch 171 around the 1:2 attenuation unit 162 in the external standardization circuit 156, so that when one of the photomultipliers is rendered inactive, pulses from the other, active, photomultiplier will not be attenuated in the external standardization circuit 156. The pulses from the active photomultiplier will accordingly have the same amplitude as would the summed pulses from both photomultipliers 124,125 with the attenuation circuit 162 in operation.

To determine whether each photomultiplier is functioning normally or whether it has experienced a gain increase or decrease an external standard gamma emitter is inserted near an unquenched standard (containing a scintillator but having no activity). Then with one of the photomultipliers deactivated and with the 1:2 attenuation circuit 162 shorted out, counts are determined from both discriminators 164,165. If the active photomultiplier has experienced a gain increase or decrease, this will be reflected as a change in the ratio of counts detected by the H-to-infinity discriminator 164 to that detected by the G-to-infinity discriminator 165 (after multiplying by the factor of two to maintain the expected ratio at unity). By regulating or adjusting the output of the photomultiplier tube undergoing tests to establish a ratio as close as desired to unity, as described in Bristol Ser. No. 629,462, the photomultiplier will then have its gain restored to the desired gain.

By the same token, the procedure is repeated with the opposite photomultiplier engaged in circuit and with the previously normalized photomultiplier disengaged, and again the gain of the engaged photomultiplier is adjusted if necessary to restore the measured channels ratio to within a desired tolerance of unity. If the ratio obtained from each photomultiplier is within

the acceptable tolerances after normalization, it can be concluded that the gain of each photomultiplier tube will be at its normal, or design, level and that both of the tubes have substantially equal gains, i.e., are in balance. Under these conditions, the net external standard ratio from external standardization unit 156 will be a function only of the degree of quench within the sample and scintillator 132.

AUTOMATIC SAMPLE CHANGING APPARATUS (PRIOR ART)

The system of the invention was designed, and is particularly adapted for use with, an automatic changing apparatus for sample vials in which the vials are stored in movable trays. Each tray, and therefore all samples in the tray, may be counted according to one pre-selected program, and the program either maintained or changed for the next succeeding tray, depending upon the instructions of the analyst. In the automatic changing apparatus, either the front panel (FIG. 2) controls or the programming card (107, 108, 109, in FIGS. 1, 6) may be employed to vary the counting parameters.

In the changing apparatus (described in more detail in Frank Ser. No. 27,405, Frank et al. Ser. No. 27,406, and Frank Ser. No. 27,411) a rectilinear array of vials is indexed along an X-axis, rows of the array are indexed seriatim along a Y-axis, and the individual vials of the Y-axis indexed row are indexed seriatim past a counting station. Sensors are provided to override portions of the indexing mechanism if no sample vials are present in array rows or individual compartments.

Turning first to FIG. 3, there is shown a liquid scintillation apparatus 102 (within the assembly 101 of FIG. 1) housing a scintillation detector mechanism. A top opening 131 is provided in the scintillation detector mechanism for the insertion of sample vials 132 into the sample detector mechanism. Rectangular arrays of the sample vials 132 spaced in columns and rows along respective X and Y cartesian coordinates of the arrays are normally carried in trays 103 (see FIGS. 3, 4). The trays are preferably constructed in the manner described in greater detail in the Frank application Ser. No. 27,405. In turn, arrays of the trays 103 may be loaded onto the sample changing apparatus and manipulated as hereinafter described. In the illustrated embodiment it is contemplated that the sample vials 132 will carry a radioactive isotope-containing substance dissolved, suspended, or otherwise mixed in a liquid scintillation medium comprising a solvent and one or more of numerous commercially available scintillators or fluorescent materials, the sample vial having light-transmissive walls. Scintillations or light flashes may then be counted by the photomultipliers 124, 125 (FIGS. 3, 5) and other apparatus carried within the liquid scintillation detector mechanism, at a counting station provided for that purpose.

For aligning successive Y-axis rows of the sample vial array with a transfer station 38 (FIG. 4), first indexing apparatus is provided including a carriage 40 (best illustrated in FIG. 3), upon which the trays 103 may be manually placed, and which supports and moves the trays 103 along the X-axis. For supporting the carriage 40 and for allowing motion of the carriage 40 along the X-axis in the illustrated embodiment, guide brackets having front support rollers mounted thereupon are secured to the bottom front of the carriage 40, and for

supporting the rear of the carriage 40, rollers are provided which engage a track mounted upon the vertical rear wall of the apparatus, all as depicted in Frank et al. Ser. No. 27,406.

The carriage 40 may be driven in either direction along the X-axis by a carriage drive mechanism. An endless belt 47 is passed (FIGS. 3, 4) around an idler and a drive pulley. The pulley is rotated by a small servomotor 49 (FIG. 4) mounted on the vertical rear wall 45 of the apparatus. A top portion of the belt 47 is secured to a belt connecting a bracket (not shown), which is, in turn, connected to a carriage position switch. When the belt 47 is driven by the servomotor 49, connecting bracket, and position switch are moved in a direction parallel to the X-axis, and the carriage 40, which is secured to the carriage position switch 165, is moved in unison therewith.

Precise alinement of the carriage 40 (FIG. 3) with the transfer station 38 is accomplished by means of an X-axis positioning mechanism, as described in Frank et al. Ser. No. 27,406. Thus, the position of any given row of sample containers 132 may be accurately aligned with the transfer station 38.

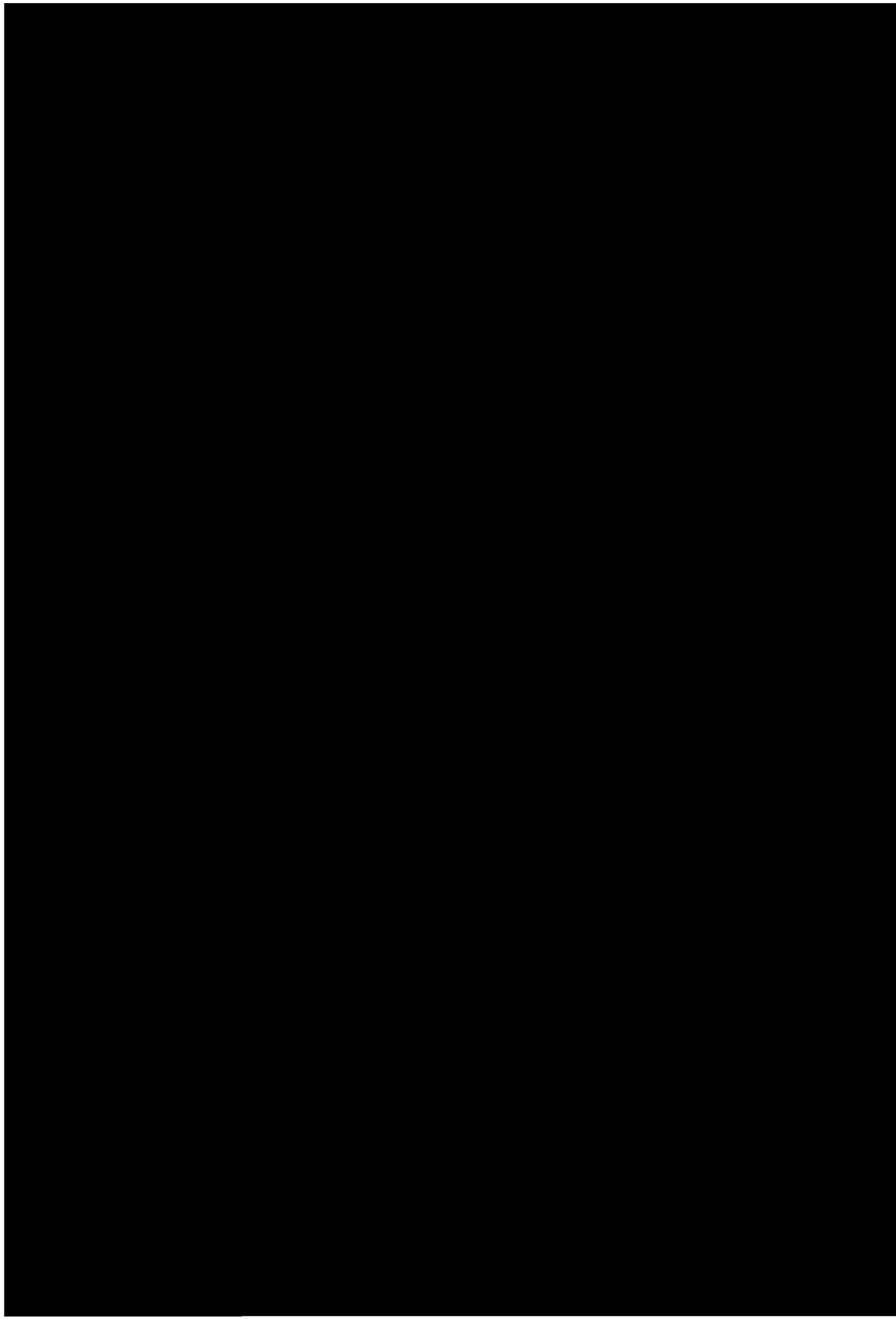
Indexing apparatus is also included for indexing a row of containers along the Z-axis between the transfer station 38 and additional transfer means. In the illustrated embodiments, and as best seen in FIGS. 3 and 4, this indexing apparatus includes an elevating comb structure 65 having a plurality of teeth 66, which are adapted for insertion into and out of holes formed for that purpose in the bottom of the carriage 40 and sample vial-containing trays 103, respectively. By moving the comb 65 upwardly when a row of sample vials 132 is aligned with the transfer station 38, the vials 132 may be ejected upwardly from the tray 103. In the embodiment illustrated in the Frank et al. Ser. No. 27,406 application, the comb 65 is elevated by means of a Z-drive motor 75 (FIG. 4), the output shaft of which is connected to and drives a cam arm connected to the slide of a scotch gear arrangement for stepwise motion.

Pursuant to the Frank Ser. No. 27,411 application, the comb teeth 66 are elevated through the carriage holes and tray holes to lift and eject the vials 132 from the tray 103, and a row of vials 132 along the Y-axis is positioned accurately at the transfer station 38 immediately prior to the ejection of the vials 132 from the tray 103 by the comb tines 66.

The Z-axis, or vertical, motion of the comb 65 is guided by comb-mounted rollers, not shown, which operate in Z-axis oriented tracks, conveniently mounted on the apparatus structure, and by additional rollers mounted between the tines 66.

Indexing apparatus is also provided for indexing a row of containers along the Y-axis so that the containers (see Frank Ser. No. 27,405 for an exemplary tray construction) move past a loading station 131 in seriatim order for aligning the containers with the station. To this end, a Y-axis carriage 86 (FIG. 3) is disposed generally above the elevating comb 65 for motion along the Y-axis. The carriage includes a partitioned mobile conveyor or carriage 87 which contains a plurality of bottomless compartments 88 for receiving the Z-axis wheel indexed vials 132. Skirts are provided guiding the upwardly thrust vials 132 into the appropriate compartments.

When the vials 132 are introduced into the compartments 88, the conveyor or carriage 87 is moved along



DISPLAY AND CONTROL

Display and control functions are shown at the center of the front panel 104, and include a digital readout device 157, a series of readout selector switches 186 through 193, inclusive, and three main switches, namely START switch 194, TRAY REJECT switch 195, and POWER switch 196.

The various push button switches 186 through 193 are employed to select the on-line display shown by the visible digital readout display device 157. For example, when SAMPLE switch 187 is engaged, the device 157 displays the sample number; when TIME switch 188 is depressed the device shows the elapsed time in hundredths of a minute. Depressing the GROSS COUNTS switches 189 or 190 (for the "red" and "green" channels, respectively; see below) reveal the gross counts in each sample counting channel, while depressing either of the CPM switches 191, 192 (for the "red" and "green" channels, respectively) gives a display of net counts per minute in the selected channel, alternating with a display of the percent standard deviation. When the RATE switch button 193 is depressed a digital rate meter is connected into the display device 157 to show the instantaneous count rate.

The remaining three push button switches are self explanatory. The POWER switch 196 turns the system "on," the START switch 194 initiates automatic sequence of tray movements and counting operations; and the TRAY REJECT switch 195 rejects the entire counting program and moves all sample trays to the initial "home" position so that counting may again be initiated.

ANALOG SECTION

Analog functions of the circuit (FIG. 5) are, as noted earlier, regulated by the control knobs to the left of the front panel 104 (FIG. 2). On the depicted apparatus two pulse counting channels, I and II (FIG. 5), are provided, each optionally but desirably with variable gain and variable upper and lower discriminators. By convention, one channel is referred to as "green" and indicated by either green-colored indicia or by the letter "G" in parenthesis; the second channel is conventionally indicated as "red" or "R" in parenthesis. (A third channel, III, if provided, is conventionally designated "blue" or "B.")

More particularly, a six-position rotary "MODE" switch 177 selects one or more counting channels (FIG. 5) pre-set for optimum conditions to count particular radionuclides. For example, it is common to count radioactive hydrogen-3 (tritium), carbon-14, or phosphorus-32, or various combinations such as hydrogen/carbon, hydrogen/phosphorus, or carbon/phosphorus. Where only a single isotope is counted, only a single channel (FIG. 5) is used, while dual labeled samples require two channels. Additionally, the mode selector switch 177 may have positions which permit selection of the variable windows established by the variable gain and variable upper and lower level discriminator controls (e.g., 174, 179, and 176 for the "green" channel, and 172, 178, and 175 for the "red"). As indicated in FIG. 7, these optional variable controls operate potentiometers which control, respectively, the attenuation of the amplifier 127 and the upper and lower level discriminators of the pulse height analyzer 129 which feeds to the logic circuit 125 (FIG. 5).

For a complete description of the manner in which the potentiometers 176, 179 regulate the lower and upper level discriminators, reference is made to Packard '835. In the Packard '835 patent, the potentiometer wipers control the bias potential of a normally nonconductive amplifier, and only after the controlled bias is exceeded does the amplifier become conducting and permit the discriminator to transmit pulses having an amplitude exceeding the applied bias voltage. In a more preferred embodiment, a dual differential comparator (e.g., Fairchild A710 comparators, as shown in Fairchild catalog, Library of Congress Catalog Card 75-87311) is used, where the output pulse from the amplifier is compared with bias voltages from the upper and lower level discriminator controls.

As noted above, the optional variable gain-adjusting potentiometers 174, 172 (in "green" and "red" channels respectively) advantageously are employed to adjust the attenuation, and hence amplification, of the d.c. attenuator and amplifier circuits 127 (FIG. 5) in each amplification channel. However, for many purposes it is unnecessary to use variable gain, and should this be the case one or more fixed resistances may be employed, in which event the gain is adjustable.

Where adjustable gain is desired, the circuit of FIG. 10 has been found to afford the significant advantage of permitting remote direct current control of the amplification through each channel. Turning to FIG. 10, pulses from the photomultipliers 124, 125 (FIG. 5) are transmitted to a terminal junction 133 (FIGS. 5, 10) and enter the d.c. attenuator and amplifier circuit depicted in FIG. 10. After pulse shaping by a solid state device Q1 and an emitter follower Q2, and after amplification by an amplifier A2, followed by a field effect transistor Q4 and an amplifier A3, pulses are sent via the terminal junction 123 to the pulse height analyzers (129 on FIGS. 5, 7).

Attenuation control of the circuit of FIG. 10 is effected through two parameters, one continuously variable (or variable in small stepwise increments) and the other at two gain levels. First, a direct current control voltage applied at the terminal 14 (see also FIG. 7) effects analog control of circuit gain by regulating the output of a photoresistive pair comprising light emitting diode ("LED") and an associated photoresistor cell A1 connected to ground; the resistance of the photoresistor cell varies in relation to the amount of light from the diode, and this in turn is regulated by the magnitude of the voltage supplied to the terminal junction 14 by adjustment of the gain controlling potentiometer 174 (FIGS. 2, 7). To this end, the terminal junction 14 is connected in a direct current feedback circuit involving an amplifier A4, the photoresistive cell A1, and the field effect transistor Q4. Stabilization provided by the feedback circuit insures that the output voltage from the amplifier A4 is null when the feedback voltage equals the input voltage from the junction 14.

As noted above, the photo cell module A1 attenuates the main amplification system (including Q1, Q2, A2, Q4, and A3) by increasing or decreasing the resistance to ground. Another variable resistance, R11, similarly connected to ground, trims the resistance and insures that the gain is adjustable to a predetermined fixed level.

Additionally, provisions are included for providing for either 100 percent gain or 10 percent gain of the circuit of FIG. 10. To this end, a terminal E is included

in the circuit and is connected to a transistor Q5 serving as a switch; a signal to the terminal E closes the switch Q5 and closes a connection from the output of the emitter follower Q2 to ground via an adjustable calibration resistance R15. Thus, the signal to the terminal E from the "10 percent gain" push button 181 (or 180 in the "red" channel; see FIG. 2) indicates "not 100 percent," and thereby establishes 10 percent, rather than 100 percent, gain in the circuit of FIG. 10.

DIGITAL SECTION

Digital controls for both the red ("R") and green ("G") channels are at the right of the front panel 104 (FIG. 2). These knobs or switches are connected into the computer logic system and regulate the counting functions. In the exemplified embodiment, six such switches are provided, and their respective functions will be described seriatim.

The optional red and green LOW LEVEL REJECT controls 198, 199 for the red and green channels, respectively, select, for each counting channel, the minimum gross counts acceptable during the first minute of sample counting. If either reject setting is exceeded, the sample is retained for the full counting period. If neither reject setting is met, indicating a sample of low activity the sample is rejected after one minute of counting. Ordinarily these switches 198, 199 have positions corresponding to "off" and 10, 20, 40, 100, 200, 400, and 1,000 counts per minute.

The PRESET COUNT switches 200, 201 for the red and green channels determine the accumulated gross count when it is desired that the sample be counted to a preset number of counts. A determination is thus made of the length of time necessary to count the samples to reach that preset count. When the preset figure is reached, a printer associated with the readout system (158 in FIG. 5) prints out the length of time necessary to reach that count. (The PRESET TIME switch 202 causes the same functions if it is satisfied first, and overrides all preset count conditions.)

The PRESET COUNT COINCIDENCE switch 204, when in "on" position, is used for double label work. It causes the instrument to count until the preset count in both channels is reached before counting is stopped. Otherwise stated, the lower activity channel determines when counting is to terminate. (As noted above, the PRESET TIME switch 202 will terminate the counting if it is satisfied first.)

The PRESET TIME switch 202 determines the elapsed time, in increments of from one tenth to four hundred minutes, when counting is to terminate. The PRESET COUNT switches 200, 201 cause the same functions if they are satisfied first, and override all preset count conditions.

The COUNT switch 205 determines the number of times each sample is counted before the sample 132 is changed. Customarily, this switch 205 permits each sample to be counted up to nine times, or an infinity of times, before the sample changing mechanism converts to the next sample.

The CYCLES switch 206 determines the number of times the trays 103 (FIGS. 3, 6) are counted, and similarly can be set to count any number of times, from one to nine, or infinity.

THE SYSTEM OF THE INVENTION

Introduction

Apparatus and methods just described are able to perform virtually all of the analog and digital programming functions desired in an automatic spectrometer. They however have one limitation. When several different research projects are being conducted simultaneously in a laboratory equipped with only one spectrometer, and where the resulting samples have either different activity levels, or are tagged with different radionuclides, or for various other reasons require different analog or analog-plus-digital counting parameters, the spectrometer programming controls must be readjusted for each set of samples. Not only is this inconvenient, and represents a possible source of human error whenever adjustments are made, but it prohibits the fully automatic counting of different sets of samples where each set requires different analog, or analog and digital, parameters.

In accordance with one feature of the invention, a replaceable analog or analog-plus-digital program control module is provided for each set of samples so that counting of a particular set is effected by the spectrometer under conditions such that it is specially programmed for that particular set. Thus, a number of modules or cards containing discrete analog or analog-plus-digital programming controls are provided, one module for each set of samples, and a specific preselected program is employed as an incident to the counting of samples in that particular set. As a result, each sample set may be counted at optimum gain level and at optimum upper and lower level discriminator adjustments. As a concurrent result, the radionuclide or radionuclides in each set of samples may be counted under conditions optimum for the detection and measurement of activity of those samples.

In the preferred embodiment, described earlier, each set of samples is contained within a single sample-storage tray, and each tray is associated with a single tray programming card. Since the trays are advanced automatically into sample counting position, each tray brings its own associated tray programming card into operation, although if desired two or more trays may be counted with the program established for one of the trays.

Again in the preferred embodiment, the standard front panel digital and analog controls are retained in the spectrometer, and serve to control the counting program for all samples unless a unique set, or sets, of samples is to be counted. In that event, a special program is utilized only for the unique set or sets, with all other counting being programmed from the main, or front, panel.

In keeping with the invention, replaceable tray programming cards or modules are provided, one for each tray. The cards are provided with potentiometers and switches necessary to re-program the desired analog, or analog-plus-digital, function or functions. Should a particular tray programming card not be installed, or not be turned "on," programming is automatically governed by the front panel controls of the spectrometer.

In still another aspect of the invention, "dummy" tray program cards are provided. Installation of one of these dummy cards permits programming for the associated tray to be governed by the programming card corresponding to a different tray, rather than to the program established by the front panel controls.

Structural and operational details of the invention will be described hereinafter.

Tray Programming Cards

The tray programming modules or cards 107, 108, 109 (FIGS. 1, 6) by which the analog functions are set are plug-in modules and, in the depicted embodiment, serve to interdict the analog controls (FIG. 2) when the cards are: (a) inserted in the front panel housing 105 (FIG. 1), (b) properly activated by their respective front panel switches 110 (FIGS. 1, 9), and (c) appropriately selected by the selector mechanism 165 (FIGS. 4, 6).

A representative schematic circuit diagram for one such tray programming card 107, 108, 109 is depicted in FIG. 9, and attention is directed to that figure. As shown, each card includes a connector block "J" with a plurality of terminals designated "A" through "F" inclusive, "H," "J" through "L" inclusive, and "1" through "10" inclusive. These terminals correspond to the similarly designated terminals in the connectors "J" of the three sub-figures of FIG. 8.

On FIG. 9 the terminal descriptions are conventional; "(G)" stands for the "I" or "green" channel, that is, the channel associated with "(G)" on the front panel 104 (FIG. 2), while "(R)" is the "II" or "red" channel, again corresponding to the "(R)" designation on the front panel 104. "LLD" and "ULD" designate lower and upper level discriminators, respectively, and by corresponding adjustment of their associated potentiometers on the tray programming cards 107, 108, 109 (R27 for RLLD; R26 for RULD; R28 for GLLD; and R29 for GULD) perform the same functions as the corresponding lower and upper level discriminator potentiometers on the front panel 104 (FIG. 2) for the respective channels. Similarly, the potentiometers R25 and R30 control the RGAIN and GGAIN, and substitute for the red and green gain control potentiometer 172, 174 (FIG. 2) on the front panel 104 when the tray programming cards 107, 108, 109 are operative.

Regulation of gain, at either 100 percent gain or 10 percent gain, is effected by the switches 210, 211 associated with the "(R)" and "(G)" channels, respectively, and terminals "A" and "E," again respectively. Selection of dual label or single label counting, or in other words, the use of two or only one channel counting, is effected by the manual switch 212 associated with the "not SKIP AUTO PRO" terminal 3.

On each tray programming card is a front panel switch (110 on FIG. 9) that serves to activate the particular tray programming card when, but only when, that card has been selected by its associated tray selecting mechanism, i.e., the tray position readout switch 165 (FIG. 4) and the tray number decoder 214 (FIG. 8). When the switch 110 is closed the pilot light 111 is lit; when the tray programming card is selected, the pilot light 111 will pulsate at a rate of about three pulses per second to indicate that the particular tray programming card is in operation. The pilot light 111 appears on the front of each tray programming card 107, 108, 109 on the module or housing 105 of FIG. 1.

Exemplary System

An over-view of one embodiment of the system of the invention is best obtained with reference to FIG. 6. Functionally, the front panel analog controls 214 (corresponding to the gain controls 172, 174, the lower and upper level discriminator controls 175, 176, 178, 179) and the 100%-10% gain controls 180, 181 (FIG. 2) are normally connected through a main relay 217 and a main switch 218 via a symbolic conduit 215 to the ana-

log board 216 (also shown on FIG. 7). When the relay-operated switch 218 is in its closed position, the standard analog controls on the front panel 104 (FIG. 2) control the parameters on the analog board 216 (FIG. 7) associated with each counting channel (as shown on FIG. 5). When, however, the main switch 218 is in its open position, the front panel analog controls 214 are disengaged and the analog board 216 is controlled from a particular one of the tray programming cards 107, 108, 109, provided that particular card is then operative i.e., switch 110 is "on" (FIGS. 1, 9). When the card is operative, then in that event the potentiometers R25 through R30 are switched into the analog board circuit 216 (FIG. 6) via the local relay 220, and control the d.c. attenuator and amplifier circuit 127 and the upper and lower level discriminators in the pulse height analysis circuit 129.

The manner in which the front panel analog controls 214 (FIG. 6) are disengaged, or disconnected, from the analog board 216 is indicated schematically, for the "green channel," in FIG. 7. (Circled numerals in FIG. 7 (e.g. 8 and 14, 9 and 15, 10 and 16) correspond to the same-numbered circled numerals in FIGS. 6 and 8.) When the main relay 217 and main switch 218 (FIGS. 6, 8) are closed, the d.c. attenuator and amplifier 127 is controlled by the potentiometer 174; the upper level discriminator by the potentiometer 179, and the lower level discriminator by the potentiometer 176. However, when the main relay 217 and switch 218 are opened, these potentiometers 174, 179, 176 are disconnected from the circuit, and a new set of potentiometers is instead inserted. This new set, it will be recognized, consists of the potentiometers R28, R29, R30, respectively, on the program card 107 (FIG. 9); the insertion is effected by the automatic closing of the local relay 220 (FIGS. 6, 8).

In more detail, and with reference to the components of the "(G)" channel (depicted schematically in FIG. 7), the amount of attenuation and amplification of the d.c. attenuator and amplifier circuit 127 is, in front-panel-controlled normal operation, governed by the gain control potentiometer 174 (also shown on FIG. 2). By the same token, in the absence of operative tray programming cards the upper and lower level discriminators of the pulse height analyzer 129 (FIG. 7) are controlled by the front panel 179, 176 179, 176 (FIG. 2) respectively.

As depicted in the embodiment of FIG. 6, three tray programming cards 107, 108, 109 are provided, one for each tray 103 (FIG. 3). One such card is described elsewhere in conjunction with FIG. 9. Selection of the appropriate programming card 107, 108, or 109 is effected by a tray number decoder 219 which receives an appropriate binary signal from the tray selector circuitry, that is, the X-axis position readout switch 165 (FIG. 4) associated with the movement of the trays 103 along the X-axis, as described in conjunction with FIGS. 3 and 4. Binary numeral "one" signifies the presence of the first tray in counting position; "two" signifies the second tray; and "one-plus-two" the third tray.

The apparatus described herein is designed for three sample trays. If desired, sample changing systems may be employed which accommodate a larger or smaller number of trays, with the number of tray programming cards corresponding to the number of trays. Ordinarily, however, three trays, each with a capacity of 40 sample vials, suffice for most counting operations.

When the tray number decoder 219 receives the binary indication that a particular tray 103 is in position to have its samples 132 transferred to the counting well 131 (FIG. 3), and when a switch (not shown) in the counting well 131 (FIG. 3) indicates that a sample is in the counting position (thereby sending a "down" signal to the terminal 23 in FIG. 8c), the corresponding tray programming card, e.g. 107, is rendered operative. To this end, a signal is transmitted from the tray number decoder 219 to the corresponding No. 1 tray selected memory driver circuit 221 and then to the No. 1 tray selected memory circuit 222. The latter is a cross-coupled pair of negated NAND units (FIG. 8a), which store the signal and transmit it to the No. 1 relay drive circuit 223 to close a local relay 222 connecting the No. 1 tray programming card 107 into the symbolic conduit 215.

Two other operations occur at the same time. First, a signal is transmitted from the No. 1 relay drive circuit 223 to the front panel disabling circuit 250, which activates the front panel control relay drive 251 and opens the front panel control relay 217. This disengages the front panel analog controls 214 and thereby renders the analog board 216 subject to the control of the potentiometer on the No. 1 tray programming card 107 (see FIG. 9).

The second operation initiated by the operative status of the No. 1 tray programming card 107 is to activate a group of circuits shown symbolically as a circuit 225 in FIG. 6. This, in effect, represents the dual label selection switch 212 (FIG. 9) which determines whether counting is to be of a single labeled or a double labeled sample, the 10-100 percent gain selection switches 110, 210 (FIG. 9), and a front panel pilot light 111 (FIGS. 1 and 9) on each tray programming card. The panel light 111, supplied with d.c. by a three-pulse-per-second square wave generator 215 (FIG. 8a, including a unijunction transistor oscillator and a flip-flop serving as a square-wave pulse shaper) blinks when its associated programming card is operative, i.e., the existence of all three conditions of (a) the card being in place, (b) the card being switched "on" by the switch 110 (FIG. 9), and (c) the card being selected by the tray selector circuits.

Unless a card selected by the decoder 219 is operative, the analog parameters will continue to be governed by the front panel analog controls 214. By way of example, if the tray programming card 107 is either not in place on the front panel (as indicated electrically by the absence of a signal at the terminal 5 of the connector "J" in FIG. 8a), or if the switch 110 (FIG. 9) on the card 107 not be in the "on" position (as indicated by the absence of a signal at the terminal 7 on the connector "J"), the local relay 220 remains open and the main relay 217 remains closed. Parenthetically, appropriate AND gates in the circuits of FIG. 8 are responsive to the absence of the signals, and do not permit the local relay 220 to open unless both are received. If the tray programming card 107 is inoperative, the front panel analog controls 214 thus remain connected to the analog board 216.

Circuitry for the No. 2 and the No. 3 tray programming cards 108, 109 is similar to that discussed above in conjunction with the No. 1 tray programming card 107. For convenience, each of the circuit elements 220, 221, 222, 223, 225 (in the case of the No. 1 card 107) has been given the same number in FIG. 6, except

that for the No. 2 card 108 system the numbers are ten units higher, and for the No. 3 card system the numbers are twenty units higher. Thus, the relay 220 for the card 107 corresponds to the relay 230 for the card 108, and to the relay 240 for the card 109.

When counting of all the samples in the tray 103 has been completed—as indicated by a "not down" signal from the counting well 131 (FIG. 3) at the terminal 23 (FIG. 8c)—the tray position readout switch 165 then activates the tray number decoder 219 to disconnect the particular tray programming card associated with that tray and to connect the next succeeding programming card into the conduit 215. This is accomplished, for example, by the decoder 219 cancelling the signal to the No. 1 tray selected memory driver 221 and emitting a signal to the No. 2 tray selected memory driver 231, etc. The local relay 220 is thus opened and the local relay 230 closed. Thus, with all of the tray programming cards 107, 108, 109 switched on (by the front panel switch 110 as shown in FIG. 1 and 9), each tray is associated with—and only with—a particular tray programming card.

A complete circuit diagram for the systems schematically shown in FIG. 6 (except for the digital function controls, to be described hereinafter) is shown in FIGS. 8a, 8b, and 8c. In the diagram of the depicted embodiment the circuit elements are integrated solid state logic circuits, using conventional notation. Unless otherwise noted, all signals are either zero or plus five volts d.c.. Symbols on FIG. 8b are employed uniformly throughout all three subfigures of FIG. 8; as wiring diagrams and standard integrated circuit elements for these logic symbols are commonly available, no further description need be given.

Program Duplication

In the system described thus far, each sample tray 103 (FIG. 3) is associated with a particular tray programming card 107 (FIG. 9). A separate card must be provided for each tray, or else the program controls revert to those on the front panel (FIG. 2). There is no provision for counting two or more trays with the same programming card, or, in other words, for duplicating the program of one tray for a succeeding tray or trays.

On occasion it is desired to use a single programming card for more than one tray. To this end, and referring to FIGS. 13, and 14, a "dummy" programming card 300 (FIG. 14) is provided which has a connector "J" so that it can be plugged into the housing 105 (FIG. 1) on the spectrometer. Terminals on the connector "J" mate with the correspondingly designated terminals on the connectors "J" shown in FIG. 8. In the event one of the trays is to be counted with the parameters provided by another tray, the dummy card 300 is inserted into the housing 105 (FIG. 1) position corresponding to the former tray.

The dummy card 300 is provided with a multi-position switch 305 to permit selection of any one of the other tray programming cards. Unused terminals on the connector "J," in this case terminal "1," "4," and "6," are connected to the various positions on the switch 305, and a matrix, as shown in FIG. 13, is wired into the corresponding terminals of the connectors "J-1" through "J-3" of FIGS. 8a through 8c and to the indicated lines 301, 302, 303 leading to the respective tray relay drive circuits. Accordingly, it is unnecessary that a tray which is to be counted by the parameters

established by another tray physically follow that other tray in the counting sequence.

Optional Digital Programming

For more complete automation, various systems may be employed to alter the digital functions, as well as the analog functions, in response to each tray, or each set of samples. Thus, different pre-selected standardization modes, low level reject levels, pre-set count or pre-set time conditions, count coincidence conditions, and/or numbers of counts may be associated with each different tray. Effectively, this permits simple plug-in control of any or all counting parameters, much as though the entire (or substantially the entire) front panel 104 (FIGS. 1, 2) were to be re-programmed for each tray or series of trays.

To employ tray-controlled digital programming under either system, the front panel 104 digital controls 198 through 202, inclusive, and 204 through 206, inclusive, on FIG. 2, which normally control the control logic, scaler, and readout system 158 (FIG. 5) are provided with a switching mechanism to switch one or more of the digital controls out of circuit in response to the presence of a tray and an associated operative programming card. As indicated schematically in FIG. 6, the front panel digital controls 260 (described previously in conjunction with FIG. 2) connect through a schematic conduit 262 to the digital function board 261, corresponding in part to the control logic, scaler, and readout system 158 of FIG. 5. A main switch 218 in the conduit 262 is simultaneously operated by the same main relay 217 as used for analog controls, and correspondingly the main switch 218 is either closed or opened, as the case may be, in response to the presence of an operative tray programming card 107, 108, 109. By the same token, the local relays 220, 230, 240 used for the analog system connect or disconnect the digital controls (not shown in FIG. 6) corresponding to the digital controls 198 through 202 and 204 through 206 (FIG. 2) into or out of the main conduit 262.

It will be recalled that the control logic, scaler, and readout system 158 (FIG. 5) is programmed from the master digital controls on the front panel (FIG. 2) to adjust the sequence and parameters of the counting functions. The right-hand portion of the front panel 104 controls the "digital" operations associated primarily with the system 158 (FIG. 5); the controls at the left of the front panel 104 are associated with the "analog" functions of each of the counting channels (Channels I, II, III on FIG. 5); the central portion is concerned with displaying and controlling the results.

According to the first alternative system, and with reference to FIG. 15, an analog-plus-digital tray programming module is associated with each tray and comprises both an analog tray programming card 107 and a digital tray programming card 327, the former including a card connector "J" in the manner previously described in conjunction with FIG. 9. The digital tray programming card 327 is associated with a similar connector "M," and preferably is physically joined to the analog tray programming card 107. Consequently, when both the analog and digital cards 107, 327 (or a single card) are inserted into place in the housing 105 (FIG. 1), the card connectors "J," "M" mate with the corresponding spectrometer connectors "J-1," "M-1." The connector "J-1" is inserted into, or withdrawn from, the main conduit 215 which extends between the front panel analog controls 214 and the ana-

log board 216, as described earlier in conjunction with FIGS. 6 and 8, the switching is performed by the main relay 217 and the main switch 218 and by the local relay 220, all as described previously.

The digital tray programming card 327 includes a series of multiple-position switches corresponding in structure and function to certain of the digital controls on the front panel 104 (FIG. 2). Interconnection of the switches on the card 327 is effected by operation of the local relay 220, as described earlier in conjunction with FIG. 6. When so connected, the front panel digital controls 260 are disengaged from the circuit and instead the digital controls on the digital tray programming card 327 are engaged.

With the system of FIG. 15 any or all of the analog and digital functions may be chosen for each tray, or set of samples, and accordingly may be different from those parameters chosen for other trays. If, on the other hand, the front panel digital control functions are to be retained, an on-off switch on the digital tray programming card 327 (similar to the Manual-Program switch 110 (FIG. 9) for the analog card 107) serves to disengage the digital programming card 327 and restore digital programming control to the front panel 104.

A second alternative system for controlling analog-plus-digital functions or parameters is described schematically in FIG. 16, and exemplary embodiments are depicted in FIGS. 11 and 12. In this embodiment, instead of a digital tray programming card or module 327 (FIG. 15) associated with the analog tray programming card 107, a digital program-selection card 270 (FIGS. 11, 16) is affixed to the tray 103 itself. A sensor unit 271, with a series of microswitch elements 272 connected to appropriate digital control circuitry 328 (FIG. 16), senses the presence or absence of indicia, such as perforations, on the card 270, and adjusts the digital parameters fed to the digital function board 261. In this embodiment, analog functions are retained by an analog tray programming card 107 in the form of a module precisely as described earlier in conjunction with FIGS. 6, 8, 9.

With the embodiment of FIG. 16, the main relay 217 and the main switch 218 serve to switch the digital controls 328 into or out of the main digital conduit 262 between the front panel digital controls 260 and the digital function board 261 leading to the control logic, scaler, and readout system 158 (FIG. 5). Local relays for the digital controls are, in this case, unnecessary.

A suggested format for a digital parameter-selection card 270, which is removably attached to the tray 103, is shown in FIG. 12. The digital controllers on FIG. 2 which are to be tray-programmed—plus the standardization control switch 173 and the background count subtraction switches 170, 171 but not the cycles switch 206 (FIG. 2)—are associated with spaces on the card 270. Each digital function which is to be tray-programmed has a corresponding column on the card 270, and each alternative position of the controls has a corresponding row position on the card. Perforation of one region on the card 270 for each digital function permits the sensor unit 270 (FIG. 11) to detect the perforation and to transmit an appropriate signal to the digital controls 328 (FIG. 16) when the tray 103 and its attached digital parameterselection card 270 is moved in position against the sensor 271.

A variation of this second alternative may also be employed. Instead of sensing the appropriate analog tray programming control card 107,108,109 by the position of its associated tray (as earlier described in conjunction with FIGS. 3, 4), the digital program-selection card 270 may have "tray" position indications, as shown in FIG. 12. In this embodiment the sensor 271 (FIG. 16) itself indicates the particular tray being counted by transmitting the appropriate tray number to the tray number decoder 219 (FIG. 6), rather than employing a position readout switch 165 (FIG. 4). This procedure is best employed when the spectrometer 101 (FIG. 1) is designed to accommodate a large number of trays, as it avoids the progressively more complicated circuitry associated with detecting a particular tray should there be a large number of such trays.

SUMMARY

An important advantage of the present system is that a single spectrometer may be used by a number of researchers, each with a set of samples that, for optimum counting, requires a particular set of pre-set counting conditions. No manual change need be made in the analog settings for samples which require different counting conditions, and for this reason automatic counting of samples from different researchers may be accomplished overnight or over weekends, or at other times when the spectrometer is unattended. Similarly, errors are minimized in that each researcher, or each research project, may be assigned its own tray programming card, which thereby minimizes human error in setting up or adjusting the analog control for samples counted at different times.

The system of the invention has one significant feature, in terms of simplicity, that distinguishes it from many prior systems which allow analog program changes. Instead of replacing an entire amplification-discrimination channel, or other essentially complete sub-circuit, only the parameter controls are connected into, or disconnected out of, a circuit. Not only does this reduce the cost and complexity of the replaceable modules, but it minimizes circuit disturbances caused by replacement of an entire sub-circuit.

Although not shown in the drawings, the control logic, scaler, and readout system 158 (FIG. 5) may, if desired, be programmed to mark the count readout with an indication of the particular tray programming card being used in counting the particular sample or series of samples.

Exemplary values for electrical components of the various circuits described above are set forth in the tables below.

EXEMPLARY VALUES OF CIRCUIT COMPONENTS

FIG. 8

RESISTANCES		CAPACITANCES	
R 20	330 K	C 20	10 μf
R 21	750	C 21	1 μf 50 V.
R 22	47	C 22	100 μf 10 V.
R 23	1 K ½ W	C 23	10 μf 20 V.
Other Resistances			
Each		1 K	

EXEMPLARY VALUES OF CIRCUIT COMPONENTS

FIG. 9

RESISTANCES

R 25	1 K
R 26	1 K
R 27	1 K
R 28	1 K
R 29	1 K
R 30	1 K

EXEMPLARY VALUES OF CIRCUIT COMPONENTS

FIG. 10

SOLID STATE DEVICES		SOLID STATE DEVICES, CON'D.	
Q 1	U235	A 1	7800063 photo-cell I.E.D. module
Q 2	2N4126	D 1	1N914
Q 3	2N4401	D 2	1N914
Q 4	U235	CAPACITANCES	
Q 5	2N4401	C 1	0.1 μf
RESISTANCES		C 2	0.1 μf
R 1	47 K	C 3	0.1 μf
R 2	2.2 K	C 4	1.0 μf 25 V.
R 3	75	C 5	50 pf
R 4	2.0 K	C 6	27 pf
R 5	2.0 K	C 7	1.0 μf 25 V.
R 6	68	C 8	0.1 μf
R 7	47 K	C 9	1.0 μf 25 V.
R 8	6.65 K	C 10	0.1 μf
R 9	1 M	C 11	1.0 μf 25 V.
R 10	82.5	C 12	50 pf
R 11	10 K	C 13	27 pf
R 12	75	C 14	1.0 μf 25 V.
R 13	100	C 15	1.0 μf 25 V.
R 14	6.8 K	C 16	0.1 μf
R 15	100		

We claim as our invention:

1. In a scintillation spectrometer for automatically and sequentially handling and counting a multiplicity of radioactive samples, including
 - A. a sample counting zone,
 - B. means for counting said samples individually in said counting zone, including
 1. means responsive to radioactivity decay events for producing electrical pulses having an amplitude related to the energy of corresponding decay events,
 2. an amplification-discrimination channel receiving said electrical pulses, said channel having
 - a. an electronic amplifier for amplifying pulses from said event responsive means, and
 - b. upper and lower level discriminators for passing only a selected amplitude band of amplified pulses therethrough, and
 3. means for counting discriminated amplified signals as a measure of the number of said decay events,
 - C. a first analog parameter control for controlling at least one of (i) the gain of said electronic amplifier, (ii) said upper level discriminator and (iii) said lower level discriminator, and
 - D. means for transferring said multiplicity of samples in a plurality of sets to said sample counting zone for individual counting of samples, the improvement whereby at least one of the pulse amplifying amplifier parameters is programmed to effect counting of samples within each set at at least one predetermined analog parameter different from parameters for other sets, which comprises:
 - E. a replaceable analog parameter control having predetermined control settings and associated with an individual one of said plurality of sets,
 - F. means for determining the particular one of said sets then having its samples transferred to said sample counting zone, and

G. means responsive to said set determining means for disconnecting said first analog parameter control out of, and for connecting said replaceable analog parameter control into, said amplifier-discriminator channel.

2. Spectrometer of claim 1 including a plurality of said amplification-discrimination channels, wherein said first analog parameter control and said replaceable analog parameter control control at least one analog parameter in each of said channels.

3. Spectrometer of claim 1 wherein said replaceable analog parameter control controls said gain and both of said discriminators.

4. Spectrometer of claim 1 wherein said replaceable analog parameter control controls both said discriminators but not said gain.

5. Spectrometer of claim 1 wherein said replaceable analog parameter control additionally controls gain at 100 percent of gain and at 10 percent of gain.

6. Spectrometer of claim 1 including at least one additional replaceable analog parameter control associated with one of said sets and adapted to select the

replaceable analog parameter control associated with another of said sets.

7. Spectrometer of claim 1 including manual switch means on said replaceable analog parameter control for retaining analog parameter controls by said first analog parameter control.

8. Spectrometer of claim 1 including a separate replaceable analog parameter control associated with each one of said sets.

9. Spectrometer of claim 1 including a first digital parameter control for controlling at least one digital parameter of said sample counting means, a replaceable digital parameter control having predetermined control settings and associated with said replaceable analog parameter control, and means responsive to said connecting or disconnecting of said replaceable analog parameter control for disconnecting said first digital parameter control out of, and for connecting said replaceable digital parameter control into, said sample counting means.

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