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ROUTINE TESTING AND CALIBRATION PROCEDURES
FOR MULTICHANNEL PULSE ANALYZERS AND
GAMMA - RAY SPECTROMETERS

By
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November 1, 1963

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A B S T R A C T

Procedures for the routine calibration of gamma-ray scintillation spectrometers and multichannel pulse-height analyzers are presented. A standard laboratory scintillation spectrometer, designed for the application of recently developed computer data processing techniques, is described in detail. The performance specifications required of all electronic components in this application are discussed. In particular, the performance specifications for multi-channel pulse-height analyzers are treated at length, and simple laboratory tests are described which will determine the performance specifications of an analyzer. These tests include live-timer accuracy, zero and ADC stability with count rate, ADC linearity, and long-term system stability.

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ROUTINE TESTING AND CALIBRATION PROCEDURES FOR MULTI-CHANNEL PULSE ANALYZERS AND GAMMA-RAY SPECTROMETERS

by

D. F. Crouch and R. L. Heath

I. Introduction

The techniques of scintillation spectrometry are presently being applied to a variety of problems in routine radiation measurement. These techniques require the use of highly sophisticated electronic systems and methods for data reduction. In view of the complexity of the equipment and the performance requirements necessary for successful digital data processing, the application of these techniques in routine laboratories will require the standardization of measurement techniques and of calibration and testing procedures for determining and maintaining the performance of spectrometer systems.

A major difficulty has been the lack of a well-defined set of performance specifications for electronic equipment necessary for this type application. In many cases, a potential purchaser of equipment may be unable to write pertinent specifications on a pulse-height analyzer or associated equipment and/or not be able to determine if a particular system meets his requirements. The development of pulse-height analyzers, spectrometer systems, and data analysis techniques at this laboratory has resulted in the production of a standard laboratory gamma-ray scintillation spectrometer system for routine laboratory use. Calibration procedures and performance tests for multichannel pulse-height analyzers have been developed to aid in the design, purchase, and maintenance of these systems.

The purpose of this brief report is to present a detailed description of the gamma-ray scintillation spectrometer in general use for routine applications. This spectrometer is designed for use of computer data processing techniques for the analysis of complex gamma-ray spectra. For this reason the performance specifications are somewhat more restrictive than might be necessary for less accurate measurements. All systems presently in use include perforated paper tape read-in and read-out devices and incorporate arithmetic circuitry to permit addition and subtraction of one spectrum from another and simple multiplication to perform analysis of complex spectra by successive subtraction techniques. Comprehensive catalogues of pulse-height spectra of individual nuclides are available for use on all machines in the form of perforated paper tape.

To permit computer techniques to be applied to the reduction of data from all analyzers in the laboratory all components of the system have been standardized. Calibration and performance tests on

a typical spectrometer system will be described in detail. This includes the detector, H.V. supply, shield, amplifier, and pulse-height analyzer with all accessory data processing devices. In addition to the description of analyzer testing procedures, routine calibration procedures for the spectrometers will be presented.

II. Description of Scintillation Spectrometer System

A. Detector and Associated Auxiliary Equipment

1. Detector: The standard size scintillation detector adopted for most precision gamma-ray spectrometry is the 3" x 3" NaI cylinder. Arguments for the choice of this size detector and illustration of the effects of detector size are given on page 11 of Ref. 1. In general, detectors to be used for precision quantitative work are fabricated in this laboratory. A diagram of a typical laboratory scintillation unit is shown in Fig. 1. For more routine measurements, some use has been made of commercial scintillation detector units. Typical energy resolution for both types of detectors is from 7.5% to 8.0% for the Cs^{137} photo-line. A drawing of a typical 3" x 3" commercial scintillation unit is shown in Fig. 2. The main difference between the laboratory

Fig. 1 - Laboratory Scintillation Detector Unit

Fig. 2 - Typical Commercial Scintillation Detector

1. R. L. Heath, Scintillation Spectrometry - Gamma-ray Spectrum Catalogue, IDO-16408 (1958).

and commercial detectors is in the amount of material surrounding the crystal. Because of the large amount of material on the top of the can in the commercial unit, quantitative applications require that the following parameters be determined:

- 1) distance from the top of the crystal to the top of the can so that accurate source distances can be established, and
- 2) effective absorption of can and packing above crystal so that precise absorption corrections can be made if the detector is to be used for quantitative measurements (particularly for low-energy photons).

The distance from the top of the crystal to the top of the can is generally ascertained by making a contact radiograph with a Tm^{170} radioisotope camera. A print of a typical radiograph of a commercial detector is shown in Fig. 3.

Fig. 3 - X-ray Photograph of Commercial Scintillation Detector Used to Locate Position of Crystal

The effective absorption of the packing and can above the crystal can be estimated from the spectrum of an isotope that has both an x-ray (or low-energy gamma ray) and a high-energy gamma ray. For example, the ratio of x-ray photopeak counts to gamma-ray photopeak counts in a Cs^{137} spectrum obtained with a given detector may be compared with the ratio obtained with a "thin window" detector. The observed difference may then be used to calculate the thickness of absorbing material between source and detector. A detailed description of the method along with sample calculations appears in Appendix I.

2. Detector Base and Source Holder: The scintillation detector is normally mounted in the phototube base shown in Fig. 4. A schematic showing the usual wiring diagram for the base is given in Fig. 5. The voltage distribution between photo cathode, screen, and dynodes obtained with this arrangement has been found to give good resolution and count-rate shift characteristics for most DuMont 6393 and RCA 8054 photomultipliers. Generally, a total voltage of -750 volts to -1100 volts is used with the bleeder network shown. Negative

QUANTITIES SHOWN ARE FOR ONE ASSEMBLY

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REQ'D.— 1

MAT'L — BRASS
REQ'D — 1

MAT'L. — BRASS
REQ'D. — 1

MAT'L. --- BRASS
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Fig. 4 - Diagram of Photomultiplier Base Assembly

Fig. 5 - Wiring Diagram for Phototube

high voltage is generally used to reduce input noise problems. To prevent deterioration of the photocathode from accidental leakage to ground, the detector assembly is operated at cathode potential through a 20 Megohm resistor as shown. If any possibility of grounding the detector assembly exists, positive high voltage should be used.

Fig. 6 is a photograph of the standard source holder arrangement used for routine measurements. The usual source-detector distance is 10 cm from the top face of the crystal, although additional shelves can be inserted for the measurement of low intensity sources. It should be pointed out that error in the quantitative results will increase as the source-detector distance is reduced. In high precision experiments, where photon scattering from the source holder may be significant, the source holder arrangement shown in Fig. 7 is used. Detailed engineering drawings of these two

arrangements are presented in Figures 8 and 9.

3. Source Mounting: Sources for routine analysis are mounted on 3.25" x 2.50" paper board cards with a 1" diameter hole in the center. Scotch tape or mylar is used to cover and mount the source material. Metal source holders are avoided in order to minimize Compton scattering from the source holder.

4. Beta Absorbers: In order to prevent the entry of beta particles from beta decay sources into the detector, beta absorbers are usually inserted between detector and source. Both References 1 and 2 discuss the effects of beta absorbers on the spectra. Beryllium is used for this purpose to minimize bremsstrahlung production. The beta absorber is normally placed on top of the detector as shown in Fig. 6.

5. Detector Shielding: A technique known as "graded shielding" is used to minimize the effect of photoelectric interaction in the shield. A sketch of the standard detector shield is shown in Fig. 10. Outside dimensions of the shield are 40" square by 37" deep. The shield has 4" walls with 2" of lead on the bottom and top, and is usually constructed

2. R. L. Heath, "Scintillation Spectrometry - The Experimental Problem," Proceedings on Applications of Computers to Nuclear and Radiochemistry, NAS - NS 3107, page 93 (October 18-19, 1962).

Fig. 6 - Photograph of Standard Source Holder Assembly Showing Absorber Location

Fig. 7 - Photograph of Special Source Holder Assembly

of 2" x 4" x 8" lead bricks. For this reason, the top of the shield is supported by a 1/2" Fe plate. The inside of the shield is lined with 30-mil Cd and 15-mil Cu sheets in that order. A general discussion of the effects of shield size and construction materials is given in References 1 and 2.

B. Electronic System

1. Linear Amplifier: In most spectrometers an external vacuum tube amplifier (ORNL type A-8) is used in the analyzer system rather than the amplifier supplied as an integral part of the commercial pulse analyzer. This amplifier has excellent overload characteristics and exhibits negligible bias shift at high input count rates. The output of the A-8 is a bipolar pulse which is the result of delay-line double differentiation. The integral linearity of this amplifier is better than 0.1%. Noise level on the normally used gain scale is approximately 0.25 volts for a 100 volt output. For use with multichannel analyzers, the output is attenuated such that an 80 volt output pulse will fall approximately in channel 250 (256 ramp position).

2. Digital Read-in and Read-out Equipment: Tally Model 424 Paper Tape Reader and Tally Model 420 Paper Tape Punch are used for paper tape

Fig. 8 - Source Holder Assembly Type I

Fig. 9 - Source Holder Assembly Type II

Fig. 10 - Detector Shield

the memory together with an end-of-word (typewriter space) code. No channel identification is used in order to reduce the read-out time. An end-of-message code is inserted for computer read-in, and tape-feed characters precede and follow all data. Fig. 11 illustrates this format.

In addition to the tape equipment, an IBM Output Typewriter is normally used for decimal read-out.

3. High Voltage Power Supply: High voltage to the photomultiplier is supplied by a high precision, adjustable power supply. Specifications on the power supply are 10 millivolt resolution, 0.005% stability per hour, 0.01% load regulation, and less than 5 millivolts ripple. During normal operation, shifts in photomultiplier gain are corrected by adjustment of the high voltage vernier. In this manner, non-linearities that might result from using the fine-gain vernier on the pulse amplifier are avoided.

A view of a typical analyzer system is shown in Fig. 12. In addition to the analyzer, HV power supply, and pulse amplifier, the usual system contains a total

read-in and read-out from the analyzers. Tape speed is approximately 60 characters per second. In the interest of promoting standardization of techniques, considerable attention has been given to the selection of a standard perforated tape data format. A form of the IBM eight-level perforated tape code was adopted for this purpose. An example of the tape format used is shown in Fig. 11. This format utilizes a 1-2-4-8 binary-decimal code in the first four punch levels. The 5th level is used for negative parity and the 6th level for zero. The presently used tape format for information contained in one channel requires 7 punch codes. Six binary-coded decimal codes are used to represent the six decimal digits in

Fig. 11 - Paper Tape Format

Fig. 12 - Multichannel Analyzer System

count scaler for monitoring the discriminator output of the amplifier and protective circuitry for monitoring over-voltage on the power bus and output of the phototube supply. These protective devices have been described in References 3 and 4.

4. Test Pulse Generator: Access to a stable, linear, mercury-relay type pulse generator is necessary for calibration and evaluation of the performance of analyzer systems. Since no pulse generator with precise amplitude control was commercially available, a simple inexpensive pulser has been designed especially for checking analyzer systems. Total cost of components for this pulse generator is about \$200. A schematic of the pulse generator is shown in Fig. 13. A photograph of the completed instrument can be seen in Fig. 14. To achieve the required precision, linear voltage control was attained by using a John Fluke Model 60A High Resolution Decade Potentiometer as the pulse amplitude control. Specifications for this potentiometer include a resolution of better than 0.0002% and linearity of $\pm 0.005\%$. Excellent voltage stability is attained by attenuating a 500 volt power supply voltage down to 200 millivolts for maximum output from the pulser. This voltage source is externally supplied by one of the high voltage power supplies normally used for photomultiplier high voltage. These supplies provide a very stable and ripple-free voltage. Selection of one of four capacitors permits adjustment of the decay time of the

3. K. F. Smith, "Overvoltage Protector for High Voltage Power Supplies," MTR-ETR Technical Branches Quarterly Report, 1st Quarter 1962, IDO-16781 (1962).
4. K. F. Smith, "Line Surge Protector," MTR-ETR Technical Branches Quarterly Report, 4th Quarter 1961, IDO-16760 (1962).

Fig. 13 - Pulse Generator Schematic

Fig. 14 - Photograph of Precision Pulse Generator

outgoing pulse. A 10K composition pot permits adjustment of the rise time of the output pulse. These parameters are normally adjusted to give the same pulse shape at the output of the linear amplifier as a NaI detector.

To check linearity of the pulser, the d.c. voltage between the Fluke Potentiometer arm and ground was measured with a Leeds and

Northrup No. 7552 Slide-wire Potentiometer as a function of pulser amplitude vernier settings. On the scale used to check the pulser, the slide-wire bridge was accurate to 0.00001 volt. Typical calibration points are given below:

<u>Pulse Amplitude Setting</u>	<u>Voltage</u>
911.00	0.91100
511.00	0.51100
199.50	0.19951
49.50	0.04951

In addition, relay timing and RC constants were verified with an oscilloscope to ascertain that no charge build-up was occurring.

III. Performance Testing of Analyzer Systems

A. Use of the "Channel Profile"

1. Description and Interpretation of Channel Profile: The determination of the channel profile provides a precise method for determination of the pulse-height scale of an analyzer. The usual test for system stability and precision has been to record a particular pulse height in a channel and note how long the pulse height remains in the same channel. However, such a test in addition to not defining the sharpness of channel edges, adjacent channel interference, and effects of analyzer system noise and jitter, limits the channel number scale to an accuracy of ± 0.5 channel. The channel profile is obtained by observing the number of pulses stored in given channels for a given input pulse amplitude. The pulse amplitude is then increased by small known increments and these data plotted as a function of input pulse amplitude to define the channel edges.

2. Experimental Procedure for Obtaining Channel Profile: Initially, the pulse-height control of the pulser is adjusted so that the pulse will be recorded in a given channel, and the analyzer is switched to the analyze mode for a given time interval. The counts in all adjacent channels, the corresponding channel numbers, and the pulser setting are recorded. The analyzer memory is cleared, the pulse amplitude increased by a small increment, and the new pulse height analyzed for the same time interval as the former run. This procedure is continued until the pulse has been incrementally advanced through three or four channels. A sufficient number of experimental points should be taken in each channel such that channel edges and center will be clearly defined. A semi-log plot of channel counts versus pulser amplitude permits a "channel profile" to be sketched as shown in Fig. 15. At pulse heights where the channels overlap, two channel counts will normally appear on the graph for each pulser setting. This procedure is used to obtain profiles for several positions on the channel number scale.

Fig. 15 shows a typical window profile for a laboratory analyzer system. The amount of adjacent channel interference resulting from

Fig. 15 - Results of Channel Profile Measurement on Laboratory Spectrometer

of a given amplitude will be recorded. Ideally, a plot of this relationship should yield a straight line. Departure of this characteristic curve from a straight line is a measure of the linearity of the system. Integral linearity is defined as the ratio of the maximum deviation at any point to the pulse amplitude corresponding to full scale. This concept is illustrated in Fig. 16. The dotted diagonal line in this figure represents linear response and the solid line represents a measured characteristic curve. The voltage V_1 represents the true pulse height recorded by channel n_1 ; whereas, voltage V_2 is the pulse height that would be recorded by channel n_1 for a linear system. The integral linearity for Fig. 4 would be $V_2 - V_1 / V_{\max}$ where $V_{\max}$ is the maximum value on the pulse-height scale.

A good working definition for integral linearity of an analyzer system is the maximum deviation in any channel from a

system noise and jitter are readily indicated in a plot of this type. Typically, greater than 98% of all pulses should be recorded in one channel over at least one-third of a channel width.

In addition to indicating the precision and stability of the overall system, the channel profile can be used to determine pulse amplitude to an accuracy of better than ± 0.1 channel. For example, from Fig. 15 it can be seen that if a pulse is being recorded equally in two channels, the pulse is precisely on a channel edge. This principle will be incorporated in the following performance tests.

B. Test for Integral Linearity

One of the most important considerations in the performance of an analyzer is the relationship between input pulse amplitude and the channel number into which pulses

Fig. 16 - Integral Linearity

straight line plot of channel position vs input pulse amplitude. The following test is based on this definition.

In this test the exact position of the leading edge of a particular channel is located by adjusting the pulser so that pulses are being recorded equally in two adjacent channels. For example, in measuring the leading edge of channel 250, the pulser would be adjusted until pulses were being recorded equally in channels 249 and 250. In this manner, one can safely assume the pulse is exactly on the lower edge of channel 250. If the pulses were being recorded only in analyzer channel 250, the positional accuracy on a pulse-height scale would be limited to ± 0.5 channel. Using the criterion described above it is possible to locate the position of the pulse train to better than ± 0.1 channel. The reasonableness of this assumption can be substantiated by examining the channel profile in Fig. 15 and noting the sharpness of channel edges.

In this manner, the pulse-height analyzer zero control and the pulser amplitude control are normally adjusted until relative pulse heights of 19.50 and 199.50 are recorded on the lower edges of channels 20 and 200, respectively. (The reasons for using the values 19.5 and 199.5 are explained in detail in the calibration section.) These two points are used to establish a straight line for reference. The pulser output amplitude corresponding to the lower edges of various channels (e.g., channels 250, 200, 150, 100, 50, 10, and all channels below channel 10) are then measured and recorded. The positions of all channels below channel 10 are measured because large deviations from linearity may be exhibited in this region by some analyzers. The measured pulse height for a given channel position is then subtracted from what the expected pulse height would be, assuming a linear relationship between pulse height and channel number. The difference in these two pulse heights represents the deviation from linearity (amplifier and ADC) for that channel. In Fig. 17 the deviations (given in percentage of one channel width) are plotted against channel number for a typical system.

A quick check of integral linearity can be made by making a series of measurements for various values of pulse height and noting (with the aid of a channel profile) where (within a channel) a particular value of pulse height is being stored. Fig. 18 is a photograph of the log scope display of an analyzer showing channel positions for relative pulse heights of 199.5, 149.5, 99.5, 49.5, 39.5, 19.5, and 9.5. In this check the zero control on the analyzer and the

Fig. 17 - Plot of Integral Linearity for Laboratory Analyzer

Fig. 18 - Photograph of Analyzer Scope Display Showing Results of Linearity Check with Precision Pulser

system gain were adjusted to place pulse amplitude corresponding to potentiometer settings of 19.5 and 199.5 on the lower edge of channels 20 and 200, respectively. Using this method a complete integral linearity check can be made in a few minutes with a precision of ± 0.1 channel.

C. Differential Linearity Check

Differential linearity is a term used to describe uniformity in channel width over the entire analyzer range. Thus, a differential linearity of 1% means that the width of no channel departs by more than 1% from the average width for all channels. In Fig. 19, the channel width of channel X_1 would be $V_2 - V_1$ expressed in volts. If the channel width is plotted on the voltage axis, as in Fig. 20, the graph will now show channel width variations. W_2 represents the average channel width and W_3 and W_1 represent the maximum positive and negative deviations from the average. Maximum deviation from the average is usually used in specifications.

Generally, a sliding pulse generator is used to check differential linearity. The output of this type generator is a series of pulses whose amplitude increase linearly with time. As the pulses gradually increase in height, they are recorded in successively higher channels. The average number of

Fig. 19 - Channel Width Diagram

Fig. 20 - Differential Linearity

that is, the count rate is so high that circuit capacitance does not have time to discharge completely, and succeeding pulses appear to the analyzer to have a pulse height larger than their actual height. The effect of this distortion can be seen in Fig. 21. Every pulse occurring under these conditions has an increment of pulse height added to it. The same effect would be produced by any D.C. bias shift in the analyzer.

In addition to this effect, the gain of the amplifier and the ADC might shift with input count rate. It is important to understand the difference between gain shifts and shifts due to bias shift. In Fig. 22, V_1 represents the pulse height resulting from photomultiplier amplification of a particular light output from the crystal. V_1' represents the pulse height resulting from amplification of the very same crystal light output, but under the conditions of high count rate. The final effect is

pulses recorded in each channel is then a measure of channel width. Special care must be taken to insure that the sliding pulser sweep circuit is linear. A detailed discussion of sliding pulsers and their use is given on page 81 of Nuclear Pulse Spectrometry by R. L. Chase.⁽⁵⁾ Most modern transistor analyzers exhibit differential linearity better than $\pm 2\%$ for all channels above the first five channels.

D. Test for Count-Rate Shift

1. Description of Zero Shift and Gain Shift: Any shift in the analyzer zero due to changing experimental conditions is highly undesirable. Count-rate shift is usually caused by pulse pile-up;

Fig. 21 - Count-Rate Shift

5. R. L. Chase, Nuclear Pulse Spectrometry, McGraw-Hill (1961).

Fig. 22 - Photomultiplier Gain Shift

to move the pulse to a higher position on the characteristic curve, but not to cause any effective change in the zero intercept of the characteristic curve.

Analysis of observed shift with changes in count-rate can be accomplished most easily for the case where photomultiplier gain shift is known to be the only contributing factor. The location of a single photopeak of known energy will establish the gain scale. To correct a spectrum with both photomultiplier gain shift and zero bias shift would require two photopeaks of known energy. Zero or bias shifts resulting from change in count-rate can be avoided by the use of a double-differentiating amplifier. The negative portion of

the amplifier's bipolar output discharges circuit capacitance immediately after charging by the positive portion. There is then no residual charge to distort the height of following pulses. Tests with this type amplifier have indicated no observable bias shift ($> 0.05\%$) for rates up to 40,000 input pulses per second.

2. Count-rate Shift Test: The count-rate shift test for an analyzer system should isolate effects of gain or zero bias shift in the electronic system from the gain shift due to the photomultiplier tube. Preferably it should also differentiate between gain change in the ADC and zero bias shift with rate.

The usual method involves the measurement of pulser output and a radioactive source simultaneously. A stable relay pulser is connected to the pre-amplifier input in parallel with the scintillation detector. With no source on the detector, the pulser is adjusted until equal numbers of pulses are being recorded in two adjacent channels. The channel position should be chosen so that it is well above the channel range required for the radioactive source to be measured. Next, the source is placed on the detector and the resultant spectrum of pulser and source placed together is obtained (typically, a 30,000 cps Cs^{137} source is used for this purpose). Any zero-bias or conversion-gain shift in the analyzer will be indicated by comparison of the position of the pulser in the two measurements. The sensitivity of this measurement is related to the sharpness of the channel edges. Reference to the channel profile concept will give an estimate of the minimum amount of count-rate shift detectable. With no difficulty a shift of less than 0.1 channel may be readily detected.

Fig. 23 illustrates the results of this test for a laboratory spectrometer. The bottom portion of the figure shows the pulser output

Fig. 23 - Scope Display of Count-Rate Shift Test

with no source on the detector. The pulser output has been adjusted to store equal numbers of pulses in two adjacent channels. The top portion of the figure shows the spectrum resulting from the simultaneous measurement of pulser and radioactive source. It will be noted that no observable shift occurred in the position of the pulser. This indicates that no measurable rate-shift occurred in either conversion gain or zero bias. If a shift is observed then measurements must be made for two different amplitudes from the pulser to differentiate between gain and zero bias shift.

E. Test for Live-Timer Accuracy

1. Description of Live Timer:

The deadtime of an analyzer is that time during which the analyzer is occupied with the processing of pulses and therefore not able to accept input pulses. Deadtime corrections for counting losses in time-conversion type ADC's are

difficult and tedious to calculate. During the analog-to-digital conversion process, a conversion oscillator is permitted to send pulses to the channel address register for a time proportional to the height of the pulse being processed. Therefore, analyzer deadtime varies with the height of the pulse. In general, the deadtime, t_d , associated with the processing of a pulse which is stored in channel N is

$$t_d = T_s + NP$$

where T_s is the fixed time required for storage in the core memory and P is the period of the clock oscillator. T_s is approximately 20-30 microseconds for most analyzers and P is usually about 0.5 microsecond. T_s includes the time required for conversion of signals and storage of the final address in the memory.

In order to provide a method for making deadtime correction, most modern analyzers have incorporated live timers. The live timer requires the analyzer to operate for an additional calendar time equal to the total deadtime during a measurement such that the total analyzer live time will be equal to the specified measurement time. "Live time" for this purpose is taken to mean that time during which the analyzer is in readiness to accept signal pulses. In general, pulses from a live time oscillator are controlled by the linear gate in the analog-to-digital

converter. At those times when the ADC is not busy with the processing of a signal pulse, the linear gate permits live timer oscillator pulses to be gated into a live time register. At the moment the number of pulses recorded by the register reach a preset count, analysis is automatically terminated. If precise quantitative measurements are required it is necessary that the live time circuitry be accurate over a wide range of input count rate.

2. Live Timer Test: The live timer test is based on the following reasoning: If the live timer works accurately for a particular setting, the analyzer will be "alive"--that is, in readiness to accept signal pulses--for the same accumulated time regardless of count rate. Therefore, if a weak source and a hot source were counted simultaneously, the total counts of the weak source recorded should be the same as if the weak source were being counted by itself. A hot low-energy source and a weak high-energy source are used for the live timer test. Typical sources used are Hg^{203} (15,000 cps) and Zn^{65} (200 cps).

First, the hot source and weak source are counted simultaneously. Next, the weak source is counted alone. The counts in the photopeak of the weak source are totaled for both runs. A comparison of the totals indicates the accuracy of the live timer. A pulser can be used in the place of the weak source and, thereby, eliminate the uncertainty due to the error in integration of the weak source photopeak. However, consideration should be given to the possibility of errors due to momentary lock-in of the pulser with the analyzer live timer. In both cases random coincidence summing must be considered in the analysis of data. Live timers of transistorized analyzers evaluated by our laboratory have shown inaccuracies ranging from 12% down to less than 0.5% for input rates up to 30,000 pulses/sec.

Fig. 24 illustrates the live timer test using a hot low-energy source and a weak high-energy source. When the high-energy source is replaced with a pulse generator the results would be very similar in appearance to those obtained from the zero bias shift check (Fig. 23).

IV. Calibration and Routine Checking of Analyzers

A. Pulse-Height Scale Considerations

If precision energy measurements are to be made and reproducible operating conditions maintained, a well defined pulse-height scale

Fig. 24 - Scope Display of Live
Timer Test Using Radioactive Source
Method

must be established. Since the ADC in a modern analyzer is very nearly linear we should consider the advantage of various methods for the adjustment of the zero control on the analyzer. For reasons to be described, the zero is normally set at -0.5 channel.

Since a channel represents a band of pulses from V to $V + \Delta V$, the total number of pulses in a given channel i will be

$$N_i = \int_V^{V + \Delta V} n(V) dV$$

where V is the amplitude corresponding to the lower edge of the channel and ΔV is the channel width. If the channels are non-overlapping the average amplitude for a continuous function $n(V)$ will be approximately equal to the point at the center of the channel. This means that an observed channel count rate is considered as a measure of the count rate for pulses corresponding in amplitude to the center of the channel. If the first data channel is called channel 1, it will contain a range of pulse amplitudes from 0.5 to 1.5. Pulses with amplitude less than 0.5 will not be recorded. On this scale, zero pulse amplitude corresponds to -0.5 channel and channel 50 covers a range from 49.5 to 50.5 on an amplitude scale. The use of this scale makes the relative amplitude of two pulses independent of the zero reference. This scale is illustrated in Fig. 25. If the system is linear, there will be a one-to-one correspondence between channel number and pulse amplitude.

Fig. 25 - Pulse-Height Scale Histogram

B. Method of Initial Zero Alignment

The method of zero alignment is achieved in the following manner: the voltage adjustment on the pulser is adjusted to obtain equal numbers of pulses in channels 199 and 200. This corresponds to the upper edge of channel 199. This adjustment is made with the decade potentiometer control on the pulser set at 199.5. The potentiometer control is then adjusted to 19.5. The zero control on the analyzer is then adjusted to obtain equal numbers of pulses in channels 19 and 20. This procedure is repeated until the slope and intercept of the pulse-height scale are determined. If the analyzer circuitry were absolutely linear the zero intercept would then be -0.5 channel. The upper edge of channel 19 was chosen because serious non-linearity exists in the bottom 10 channels of many analyzers. The linearity check described above can be used to evaluate the actual channel position to be expected for pulses of small amplitude.

C. Routine Calibration Check

Analyzer-system performance and gain-scale calibration are usually checked daily in the following manner: standard radioactive sources of 28-yr Bi^{207} are used for this purpose. This nuclide emits photons of 0.075, 0.569, and 1.064 MeV. A gamma-ray spectrum of Bi^{207} is shown in Fig. 26. The combination of long half-life and peaks widely spaced in energy provides a convenient means for checking live-timer accuracy, zero position and energy-scale calibration. Once the zero position of the analyzer has been established using the techniques previously described, the energy scale is established with Cs^{137} . For the standard 10 keV/channel scale the gain of the system is adjusted so that the Cs photopeak falls in channel 66.162. Although computer data processing techniques will not be discussed in this report, least-squares peak fitting procedures can be applied to determine the position of a photopeak to an accuracy of several hundredths of a channel. Once this gain scale has been established, the Bi^{207} standard is measured on the analyzer in a carefully established standard geometry, for a given live time period. The results of this measurement are then recorded on perforated tape for future reference. To check the performance of the analyzer (i.e., live timer, zero position, and energy scale) the standard source is remeasured under the same conditions and compared with the previously recorded standard tape. This comparison will reveal any deviation in the location and height of the various features of the spectrum. Deviation in peak positions indicate a change in either the zero level, the gain scale or the linearity of the analyzer. Deviation in the amplitude of the two spectra would indicate a change in live timer performance. This method can provide a very quick and accurate means of checking analyzer performance. The zero position can be checked with an accuracy of ± 0.01 channel with little difficulty.

D. Check of System Stability

As a check of analyzer stability a stable pulser may be fed into the system and allowed to accumulate data in one channel for a long

Fig. 26 - Bi²⁰⁷ Pulse-Height Spectrum

period of time. Any short-term gain drift will be indicated by drifting of the channel position. As a practical test of long-term stability of the entire spectrometer system an analyzer in our laboratory was allowed to operate for a period of several weeks with no adjustment of phototube voltage, amplifier gain, or analyzer zero position. A Bi²⁰⁷ standard was measured daily and the amount of gain and zero drift determined by least-squares peak fitting to determine the position of the 0.569- and 1.064-MeV peaks. In this measurement, zero drift would be indicated by a change in the ratio of the 0.569-MeV peak position to 1.064-MeV peak position. In a typical test over a period of 30 days the 1.064-MeV peak drifted 1.5 channels during the first few days of the test and remained within ± 0.5 channel of the same value for the remainder of the month. No zero shift (> 0.1 channel) was detected over the 30-day

period. In this case, the initial drift was thought to be due to a power interruption occurring shortly before the start of the test period.

APPENDIX I

Method for Determining Equivalent Absorption of Can and Packaging Material in a Commercial Scintillation Detector Unit

The effective absorption of gamma rays by packaging material surrounding the crystal in commercial scintillation detectors can be determined experimentally by measuring the attenuation of low-energy photons emitted from a radioactive source. If a source with known decay rate were available, a simple measurement under known geometry would suffice to determine the amount of absorber between the NaI detector and the source. Since calibrated sources are not normally available some alternative must be applied. A simple method has been used in this laboratory which makes it possible to measure the absorption of the top surface of the detector can with moderate precision. As an example, Cs^{137} sources can be used for this purpose. This nuclide decays with the emission of 0.032-MeV Ba K x-rays and 0.6616-MeV gamma rays. If we assume that the packaging material is largely aluminum, then the x-rays will be attenuated to a much larger degree than the gamma rays. In order to determine the relative intensity ratio for x-rays to gamma rays to be expected with no absorber present, the Cs^{137} spectrum was measured with a 3" x 3" NaI detector which was prepared at this laboratory. The measurement was made for a 1 mg/cm² point source at 10 cm from the front face of the crystal. Since the detector used was canned in a very thin aluminum container, (approximately 30 mg/cm²) attenuation of both x-ray and gamma ray was small and calculable. A known amount of Be absorber was used in this measurement to stop beta rays. The spectrum was then analyzed to obtain the ratio of counts in the x-ray peak to counts in the gamma-ray photopeak. The area of the x-ray peak was corrected for the contribution due to Compton distribution of the gamma ray. A correction was then applied for absorption in the beta absorber. A value of 0.216 was obtained for the ratio of x-ray to gamma-ray photopeak counts under these conditions. For comparison, similar measurements made on a typical commercial 3" x 3" detector gave a ratio of 0.169.

Using the conventional relationship for gamma-ray absorption:

$$I = I_0 e^{-\mu x}$$

we may solve for the amount of absorber used in the commercial detector package. Using the values indicated above for the no-absorber case and the ratio obtained from the commercial detector, and neglecting the absorption of the gamma ray, we obtain a value of 0.318 gm/cm² for the thickness of aluminum absorber between source and crystal. This value may be used as a first estimate to correct for absorption of the gamma ray if a more precise result is required. For the purpose of the measurements, absorption coefficients used for the absorption of the x-ray and gamma ray in aluminum were 0.773 cm²/gm and 0.0594 cm²/gm, respectively. These values represent the results of an experimental determination of gamma-ray absorption in aluminum as a function of

photon energy. It is necessary to use experimentally determined values for this purpose rather than those usually quoted to take into account the geometry used in the experiment.

Analysis of the errors to be expected in a measurement of this type indicates that it is possible to obtain a precision of better than 20% for the amount of absorber in the detector package. Using the experimental ratio for Cs^{137} , one may compare this with similar measurements for commercial detectors of the same size to determine the amount of absorber between the front face of the crystal and the source. For gamma rays above 0.1 MeV the precision obtainable is quite adequate for most experimental measurements.