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Gamma-Ray Measurements with the Segmented Gamma Scan

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GAMMA-RAY MEASUREMENTS WITH THE SEGMENTED GAMMA SCAN

by

E. R. Martin, D. F. Jones, and J. L. Parker

ABSTRACT

A revised and updated operation and maintenance manual for the segmented gamma-scan instrument is presented, which describes routine assay techniques as well as the theory of operation in sufficient depth that an experienced assayist can make nonroutine assays on a wide variety of materials and samples. In addition, complete electronic and electrical schematics of the Los Alamos Scientific Laboratory (LASL)-designed portions of the system are presented, along with sufficient system and circuit description to facilitate maintenance and troubleshooting. Complete software system descriptions are included, although detailed listings would have to be obtained from LASL in order to make machine-language code changes.

I. INTRODUCTION

Among the techniques for nondestructively determining quantities of nuclear materials, passive gamma-ray measurements provide one of the best quantitative methods available for those isotopes that decay with a unique

gamma-ray signature. The literature is replete with extensive discussions of nuclear gamma-ray emission,¹⁻⁴ and only items relevant to the application of the segmented gamma-scan instrument will be considered here. It is assumed that the reader is at least somewhat familiar with the operation of high-resolution gamma-ray detectors of the Ge(Li) and intrinsic germanium variety, with gamma-ray spectroscopy in general, and with the interactions of gamma rays in matter. The references cited give a broad background into these subjects.

The segmented gamma scan (SGS) is both a procedure and an instrument. It is a procedure for measuring fissile or fertile nuclear materials in matrices of low-Z material that quantitatively corrects for gamma-ray attenuation on a segment-by-segment basis. The procedure can be performed with a variety of equipment configurations, and is rather complex and tedious. The SGS is an instrument in that these complex procedures have been incorporated into a plant-tested automated instrument that is simple to operate. Except for some introductory remarks, this report will be concerned with the instrument, describing its operation in detail, the computational algorithms, the software that implements these algorithms and controls the scan operation, the hardware configuration, and its application to various sample sizes and isotopes.

Usually the most difficult problem in the passive gamma-ray assay of bulk samples is to correct for the gamma-ray attenuation within the sample itself. If one can do this, one has only to measure the number of gamma rays from the sample with the unique energy of the isotope being assayed and correct that measured number for attenuation, thus obtaining a number that is directly proportional to the quantity of material in the sample.

Unfortunately, gamma-ray attenuation is not only a function of energy but also the matrix material parameters such as density, atomic weights, etc. If the matrix material is unknown or nonuniform, it cannot readily be calculated. The segmented gamma scan uses a separate external transmission source, emitting gamma radiation close to the gamma-ray energy of the isotope being measured, to determine how much attenuation is suffered by the gamma rays from the sample. In this way, a correction factor can be determined, by which the actual gamma-ray intensity is multiplied to deduce how many gamma rays would have been measured in the absence of attenuating material.

Inhomogeneities of the sample under measurement further complicate the measurement. If the matrix material varies in the sample container, the measurement of transmission at one point may not yield the transmission at the location of the material emitting the gamma rays. When the sample is divided into collimator-defined horizontal segments, each of which is separately measured for its own attenuation, and the count rate from each individual segment corrected for the respective attenuation, the sum of segment-by-segment results will yield a better measurement of the total sample than a simple attenuation average over the whole sample. This vertical segmentation of the sample accommodates variations in matrix material and yields good results for a large variety of samples that otherwise are not easily measured. The fundamental assumptions on material homogeneity must be thoroughly understood and will be treated in the next section. The cited references all discuss in a general way the effects of geometry, attenuation, inhomogeneities, and other problems; a useful compendium of these topics is found in Reilly and Parker.⁴

II. THEORY OF OPERATION

A. General

The general technique of making a gamma-ray assay consists of counting the number of gamma rays detected in a full-energy peak unique to the isotope being measured, multiplying this quantity by a correction factor based on gamma-ray attenuation and rate considerations, and dividing the product by the calibration factor, or response of the system, to obtain as a result the grams of material assayed. Thus, the equation under consideration is:

$$\text{Isotope Mass} = \frac{C \cdot CF}{k}, \quad (1)$$

where C represents the number of counts in the gamma-ray full-energy peak, CF the relevant correction factor, and k the calibration constant relating corrected counts to mass of nuclear material.

All gamma-ray spectra have backgrounds (counts under the peak but not part of it) associated with any given peak due to events that come from Compton scattering of higher-energy gamma rays, electronic pileup, and other spurious sources. Various methods have been used to subtract these backgrounds from the gross peak count, the best of which involve elaborate peak fitting routines suitable only for computer analysis. For the well-resolved peaks used in the present assays, much simpler methods are available. The method employed in the present instrument, which gives a very adequate background subtraction, is a straight-line method based on a background region on each side of the peak being measured. The regions of interest are set on both

sides of the peak being measured as indicated in Fig. 1, and a background subtraction is made, based on a straight-line background between the average values of the two regions. Using the nomenclature of Fig. 1, the background-subtracted peak count and associated statistical error estimate are:

$$\text{Counts (peak)} = \Sigma B - \frac{\Delta B}{2} \left(\frac{\Sigma A}{\Delta A} + \frac{\Sigma C}{\Delta C} \right) \quad (2)$$

and

$$\sigma^2(\text{counts}) = \Sigma B + \left(\frac{\Delta B}{2 \cdot \Delta A} \right)^2 \Sigma A + \left(\frac{\Delta B}{2 \cdot \Delta C} \right)^2 \Sigma C. \quad (3)$$

The appropriate widths and positions of the regions of interest will be discussed in Section IV.

Fig. 1. Full energy peak indicating typical regions of interest for background subtraction. ΣA , ΣB , ΣC are the integrated counts in the respective regions. $\Delta A = A_2 - A_1 + 1$, $\Delta B = B_2 - B_1 + 1$, and $\Delta C = C_2 - C_1 + 1$ are the widths of the regions of interest.

B. Segmentation

As mentioned previously, the sample is assayed as a vertical sequence of collimator-defined horizontal segments, approximately 1.25 cm in height for small samples and 5 cm in height for drums, in order to minimize the effect of vertical inhomogeneities. The segment height is a compromise between increasing segment resolution and vanishing count rate, and is primarily determined by the dimensions of the collimator in front of the detector. Experience has shown that for samples up to about twenty liters in size, approximately one centimeter is a good segment height. For the larger drums, reasonable throughput and geometrical constraints make five centimeters the smallest segment height for normal use. It should be realized that the segments overlap somewhat, especially in the assay of drums with the larger collimator height. In the LASL segmented gamma-scan instrument, the small sample collimator is 1.3 cm high (by 10.2 cm long) while the large drum collimator is 5.1 cm high (by 17.8 cm long).

The segmentation procedure provides two benefits, the first being, as explained, an effective way of dealing with vertical nonuniformity in the assay samples, and the second being the freedom to use a single-assay geometry for all sample depths greater than a required minimum. These advantages are, however, obtained at the price of some loss of sensitivity; hence, the segmented gamma scan should usually not be used on samples containing $< 1\text{g}$ of ^{239}Pu or ^{235}U . Furthermore, for the most accurate results from segmented gamma-scan assays, the assay sample should be as close as possible to the segment-defining collimator, and the depth of material in the sample should be ≥ 6 times the "thickness" of the segment. Keeping the sample as close as possible to the collimator maximizes the spatial resolution of the segments so that the measured transmission is more

clearly representative of the sample volume from which gamma rays reach the detector. Requiring the sample depth to be ≥ 6 times the segment thickness minimizes the end effect which is the second price paid for the advantages of segmentation. This end effect arises because, in general, the sample transmission measured as the top or bottom of the sample material moves across the collimator is somewhat too high, a consequence of the fact that only part of the gamma-ray beam from the transmission source is intercepted by the sample material during those intervals. An erroneously high transmission implies a too small correction factor so that the corrected count from such a segment is somewhat low. If the two criteria given above are met, the total end effect error should not ever exceed a few percent, with the greatest error occurring on samples of very low transmission.

C. Rotation

Rotating the sample is an effective way to reduce the effect of radial inhomogeneities and maintain the highest possible count rate. High count rate requires the detector to be as close as possible to the sample, whereas a large sample-diameter-to-detector-distance ratio introduces substantial count rate dependence upon radial inhomogeneities in the sample. From Fig. 2, the ratio of average count rate of a source rotating at a radius (a) to that of a source located at the center is given by

$$\frac{CR(a)}{CR(o)} = \frac{1}{1 - \left(\frac{a}{R}\right)^2}, \text{ where } R \text{ is the distance from center of}$$

detector.

The effect of rotation of the sample on count rate variation is shown in Table I for several values of a/R.

Fig. 2. Assay geometry, illustrating effect of sample rotation.

Table I
EFFECT OF ROTATION OF THE SAMPLE

<u>a/R</u>	<u>CR(a)/CR(0)</u> <u>Rotating</u>	<u>CR(R-a)/CR(R)</u> <u>Nonrotating</u>
1/2	1.33	4.0
1/3	1.125	2.25
1/4	1.067	1.78
1/5	1.042	1.56

Although the above expression and the results shown in Table I ignore the problem of self-attenuation, sample rotation clearly helps minimize the effects of radial inhomogeneity. For this reason, the sample is rotated in the

segmented gamma scan. In the LASL instrument the sample is rotated through two complete revolutions per segment.

D. Basic Assumptions

At this point, it is worth emphasizing the basic assumptions made on the sample in order to make reasonable assays with the segmented gamma scan. The fundamental assumption is that the mixture of material to be assayed and matrix (everything other than the assay material) is reasonably uniform and the particles of assay material are small enough to ignore self-attenuation within the individual gamma-ray emitting particles. In effect this assumption states that the sample attenuation (or at least that of a single segment) is characterized by a single linear attenuation coefficient. If this is not so, the correction factor computed from the measured transmission will not be accurate; unfortunately, the error will almost always be in the direction of a low assay. If, for example, the material emitting the gamma rays consists of bits of uranium metal imbedded in a low-density material, the transmission measurement of this sample would be some average of uranium metal and the low-density material; probably much closer to the attenuation of the light material since it would dominate the area of the sample seen by the transmission source, whereas the nuclear material gamma rays in this case would be attenuated mainly in the uranium metal from which they arise. The correction factor applied would then be low, yielding an assay value below the actual value (this effect can result in assays as much as a factor of two too low).

The assumption on sample uniformity imposes constraints on the general character of the sample. It requires that the material containing the nuclear isotope being assayed not be in lumps. Fuel pellets in a container of low-density waste does not, for example, meet the requirement of uniformity and will most certainly result in a low assay. On

the other hand, pure powders (PuO_2 , UO_2 , U_3O_8 , etc.) do satisfy the assumption, as does most incinerator ash and well-mixed powder scrap. Solutions, of course, by definition satisfy the assumption on uniformity.

E. Calibration Standards

The fundamental assumption of segmented gamma scanning, applies as well to the calibration standards employed. Since there are minor geometric effects in the system setup, it is desirable to use a calibration standard as similar as possible geometrically to the assay samples, although a reasonable degree of compensation is usually possible if exact geometric similarity is not possible. The calibration standard is used to determine the response of the system in terms of corrected counts per gram of material being measured. Since the calibration curve is reasonably linear for a properly adjusted instrument, a single calibration standard can suffice, although it is desirable to have two or more standards spanning the expected range of transmission. A useful check of system performance not employing a standard at all is to measure empty air, which will give a zero result for a well-adjusted system. The calibration constant is not strictly constant for all conditions, but its variation with different size samples, provided the detector-sample geometry is unchanged, is not as important as the variation with measured transmission. For best accuracy, the calibration standards should also be as similar as possible to the measured samples in attenuation, since this is the overriding variable in determining the calibration constant.

F. Rate Corrections

We now consider the problem of corrections for the rate-related losses to the counts in the transmission and assay peaks (i.e., the full-energy peaks from the external

transmission source and the chosen gamma ray from the isotope being measured). During the time a datum is being processed by the ADC and computer system, the system is dead to further detector outputs that may occur. This system deadtime increases as the rates increase, resulting in a varying fraction of full-energy events being accepted and stored by the system. In other words, since the real measurement time for each segment is fixed, the actual time the system is available to accept data is less than the real time, requiring a correction to the observed count rate. In addition to this deadtime correction, there is yet another rate-dependent effect that must be considered. If two input pulses to the amplifier are sufficiently close together so that the amplifier pulse width is longer than the pulse separation, the output pulse resulting from these two inputs will be a single pulse whose amplitude is greater than either of the input pulses, the actual output amplitude depending on the pulse separation. What has changed in this case is that both real input pulses are lost to the measurement, and an incorrectly large pulse has been measured instead. Generally, this larger pulse will be outside the data windows for the peaks being measured, so that effectively the system deadtime has been increased. This so-called pileup effect is clearly rate dependent, since the probability of two inputs occurring sufficiently close together increases with rate.

Deadtime and pileup corrections can generally be made in any one of three ways. There are electronic modules that search for pileup pulses and automatically extend the counting time to compensate for this as well as ordinary deadtime, but these are complex in operating theory, and it is not at all clear that any of them currently make precisely the right correction. In addition, they add substantially to the system complexity and thus to potential unreliability.

A second method of rate correction is to use an external electronic pulser signal injected into the preamplifier. Since the pulser emits pulses at precisely known intervals, the number of pulses generated is a known quantity, against which the measured pulser peak can be compared to determine the amount of loss due to pileup and/or system deadtime. This method has the advantage of being able to place the pulser peak anywhere in the spectrum desired, since the pulser output height is variable. However, against these advantages must be weighed the fact that a pulser is a piece of electronic equipment, subject to instabilities due to temperature variations and component aging and therefore is subject to unreliability and variability, both in pulse amplitude and rate.

Experience at LASL indicates that usually the best method of making rate corrections is by using an appropriate external gamma-ray source to provide a livetime/pileup correction peak somewhat below the energy of the transmission and assay peaks. Since this livetime/pileup correction peak comes from a separate gamma source, it competes for system resources in exactly the same way as the peaks of interest, entering the system right at the detector, thus allowing a combined correction for deadtime and pileup for the whole system. Furthermore, the rate of emission from a gamma source is not affected by temperature, pressure, or other experimental conditions. Sometimes a portion of the assay spectrum is used where no conveniently obtainable source has an appropriate gamma ray, and hence a pulser must be used, but whenever the separate source method is possible, it is superior. All of the common assays with the SGS permit rate-related loss corrections to be made conveniently by use of a separate gamma source. While this complicates the analysis by adding another peak to be analyzed, the system computer is readily able to handle the

overhead. In using a separate livetime/pileup source, the normalization rate from the correction source is measured prior to making assay measurements, with no sample in the system. Then, during actual measurements, the rate from the correction source is again measured, and the ratio of the two values is precisely the correction factor that must be applied to all other peaks to correct for deadtime and pileup. This procedure assumes that all spectral peaks suffer the same fractional loss from pileup and deadtime, which assumption is true in theory and justified by experience. It should be said that the method of using an external gamma-ray source does not result in an absolute correction, but rather a normalization in which all results are corrected to the same fraction of rate-related losses as experienced in the normalization measurement.

G. Calculation of Corrected Counts

In the actual calculation of corrected counts, defined as the actual counts multiplied by a correction factor, the correction factor depends upon both attenuation and rate corrections. In fact, the total correction factor is defined as the product of three independent or nearly independent correction factors: one for the normalization of the rate-related losses to the counts in the full-energy peak of the gamma ray upon which the assay is based (CF_{rl}), one to correct the attenuation in the sample container (CF_{con}), and one for the correction of the self-attenuation in the sample itself (CF_{att}). Symbolically, the total correction factor is given by

$$CF_{tot} = CF_{rl} \cdot CF_{con} \cdot CF_{att} \cdot \quad (4)$$

Consider the three correction factors separately: The form used for normalization of rate-related losses is given by

$$CF_{rl} = L_o/L, \quad (5)$$

where L_o is the full-energy peak count of the correction peak in the normalization (or reference run), and L is the corresponding count in any other run. Again, it should be mentioned and emphasized that this factor does not give an absolute correction but rather a normalization to the same fraction of rate-related losses as experienced in the normalization run.

The attenuation factor, CF_{att} , is clearly geometry dependent. If we consider the case, for example, of slab geometry; i.e., measuring the gamma-ray attenuation through a finite slab of material, and define the transmission as the ratio of gamma-ray intensity on the egress side of the slab to the input intensity, then the correction factor can be written in terms of the transmission, TR , for the case where the slab dimensions are all very small compared to the distance to the detector in the following way:

$$CF = \frac{-\ln(TR)}{1 - TR} \quad . \quad (\text{slab geometry})$$

In this particularly simple geometry the expression is exact and is almost the only case for which an exact expression in terms of elementary functions can be found. For the case that is usually of most interest, namely that of cylindrically shaped samples, there does exist an exact but cumbersome expression in terms of modified Bessel functions and modified Struve functions for the far-field

case (defined as that situation where the dimensions of the sample are small compared to the distance to the detector). A first-order approximation to that exact formulation yields

$$CF \approx \frac{-(\pi/4) \ln(TR)}{1 - TR^{\pi/4}} .$$

It is immediately noted that the form just given is identical to that for the slab geometry except that the transmission is raised to the $\pi/4$ power. Because the $\pi/4$ power arose from the approximation of a far field expression, and to determine whether it would yield appropriate values in a near field, collimated situation, a study was made of the general form

$$CF_{att} \approx \frac{-A \ln(TR)}{1 - TR^A} \quad (6)$$

in order to find what value of A would give the most nearly correct values over a wide range of transmissions, sample diameters, and sample-detector distances. Figure 3 shows the variation from the exact far-field values as a function of A and TR. Within the normal range of transmission values, A = 0.82 yields accuracies within one or two percent. In the segmented gamma scan codes, CF_{att} is given by Eq. (6) with A = 0.82.

Finally, consider the last factor, CF_{con} . In actual practice, most samples are contained in a container that causes some attenuation itself, for which Eq. (6) is not a proper correction factor form. Since the container transmission is a constant, it can be separated from the transmission of the contents of the container and included as a constant factor in the expression for the total correction.

Fig. 3. Variations of the approximate correction factor values from the exact far-field values as a function of transmission TR and the parameter A.

It is easily measured in practice by simply assaying an empty container and reading off the transmission values from the printout. If it is assumed that all gamma rays from the sample pass through the minimum container thickness, the correction factor due to container transmission is:

$$CF_{con} = \frac{1}{\sqrt{TR_{con}}} \quad (7)$$

where TR_{con} is the container transmission.

Then the final equation for the corrected counts in the i^{th} segment can be written as follows:

$$CC(i) = C(i) \cdot CF_{tot}(i) = C(i) \cdot CF_{rel}(i) \cdot CF_{att}(i) \cdot CF_{con}(i), \quad (8)$$

where $C(i)$ is the full-energy peak count from the assay gamma ray and the various correction factors are as defined above in Eqs. (4), (5), (6), and (7). Transmission of the sample is given by

$$TR = \frac{T}{T_o} \cdot \frac{L_o}{L} \cdot \frac{1}{TR_{con}} = \frac{T}{T_o} \cdot CF_{rl} \cdot CF_{con}^2, \quad (9)$$

where T and L are the full-energy peak counts from the transmission and correction gamma-ray spectral peaks, respectively, and the subscript "o" refers to values from the no-sample (or background) measurement.

The sum of the corrected counts for all segments is related to the quantity of material being assayed and is written as

$$CC_{total} = \sum_{i=1}^N CC(i), \quad (10)$$

which corresponds to $C \cdot CF$ in Eq. (1).

H. General Isotopic Measurements

For the general problem of measuring specific isotopic contents in nuclear materials, the energy to be measured must be determined, and suitable transmission and correction sources chosen. Some of the more common combinations of sources for given isotopes are given in Table II.

With the exception of the ^{235}U assay, or in the attempt to measure simultaneously more than one isotope of plutonium, all of these assays are three-peak measurements. Note that the transmission and rate correction gamma-ray energies are chosen lower in energy than the assay energy, when possible, in order to reduce the backgrounds that would result from Compton scattering of any additional higher energy gamma rays. Also, at all energies, but most

TABLE II

COMMON COMBINATIONS OF SOURCES FOR GIVEN ISOTOPES

<u>Isotope</u> <u>(Gamma Energy)</u>	<u>Transmission</u> <u>(Source Energy)</u>	<u>Rate Corrections</u> <u>(Source Energy)</u>
Pu-238 (766.4 keV)	Cs-137 (661.6 keV)	Ba-133 (356.3 keV)
Pu-239 (413.7 keV)	Se-75 (400.1 keV)	Ba-133 (356.3 keV)
U-235 (185.7 keV)	Yb-169 (177.2, 198.0 keV)	Co-57 (122.0 keV)
U-238 (1001.1 keV)	Mn-54 (834.8 keV)	Cs-137 (661.6 keV)
Np-237 (311.9 keV)	Hg-203 (279.2 keV)	U-235 (185.7 keV)

particularly at lower energies where the mass attenuation curves have steep slopes, the transmission peak energy should be as close as possible to the assay energy in order to reduce the energy-dependent effects of attenuation. Transmission peak attenuations that differ from the assay peak attenuation can be mathematically accommodated, as will be discussed later, but this requires additional knowledge about the matrix material that is not required when the transmission peak accurately reflects the attenuation experienced by the actual assay peak.

I. ²³⁵U - A Four-Peak Assay

Because of its rather low assay energy (185.7 keV), ²³⁵U requires special consideration in the measurement of its transmission. Fortunately, the ¹⁶⁹Yb decay produces two gamma rays that bracket the uranium assay energy, at 177.2 keV and 198.0 keV. In this energy region, the mass

attenuation coefficient is rapidly changing with energy, so that it is quite critical to determine the attenuation exactly at 185.7 keV to avoid undue error. The procedure here is to take peak information from both ^{169}Yb peaks and make a linear interpolation between them to obtain the transmission at 185.7 keV. This adds yet another gamma peak to the assay information and considerably complicates both the assay calculation and the error calculation. For this case, the transmission to be used in Eq. (9) becomes with good accuracy:

$$TR = 0.6 \cdot TR_{\ell} + 0.4 \cdot TR_h, \quad (11)$$

where TR_{ℓ} and TR_h are the measured transmissions at the low and high transmission energies, namely, 177.2 keV and 198.0 keV.

As a practical matter, ^{169}Yb has the short half-life of only 32 days, which means that this source must be replaced frequently in order to provide sufficient counts for an accurate transmission measurement through denser materials. The ^{57}Co source used with uranium measurements has a half-life of 271 days, much better than the ^{169}Yb , but still requiring replacement (or at least position adjustment) about once a year.

Another method of determining the transmission at 185.7 keV exactly is to use ^{235}U itself as the transmission source, making a two-pass assay, once with the transmission source shuttered and once with it open, then making a subtraction to determine the contribution due to ^{235}U in the sample and that due to ^{235}U in the transmission source. This technique does, in fact, work well for some samples of low uranium concentration, but the problem is that the self-attenuation of uranium is so great that it is always

difficult and often impossible to obtain a source of sufficient intensity. The best method for segmented gamma-scan applications is the use of ^{169}Yb with its two transmission peaks, the short half-life notwithstanding.

J. Simultaneous ^{239}Pu , ^{241}Pu Assay

For most plutonium measurements, the percentage of ^{241}Pu is down several orders of magnitude from that of ^{239}Pu . However, since the intensity of the 208-keV gamma ray from the ^{237}U daughter of ^{241}Pu is several orders of magnitude greater than the 414-keV gamma ray from ^{239}Pu , the simultaneous measurement of these two isotopes is frequently feasible. The primary problem is finding a transmission gamma ray with which to determine the 208-keV attenuation. Another transmission source could be used, but aside from the physical difficulties of collimating two sources properly, the additional background from yet another source is undesirable. The alternative is to use another of the existing ^{75}Se source gamma rays. Selenium-75 has an intense gamma ray at 265 keV, which can be used to determine the transmission at 208 keV by making an adjustment to Eq. (6) that takes into consideration the variation of mass attenuation coefficients between the assay and transmission peaks. This requires some knowledge of the matrix materials, but for low-Z materials (up to about $Z = 25$ or so), the ratio of these mass attenuation coefficients can be taken to be about 1.2. The error incurred here will be discussed later in the section on mu-ratio considerations. In the case of ^{239}Pu , ^{241}Pu simultaneous measurements, five peak counts must be obtained for each segment; the usual three peaks plus an additional assay peak and transmission peak. In effect, two three-peak measurements are performed using the five-peak areas.

K. Two-Pass Assays

Up to now, we have been discussing assays in which both the transmission and assay peaks (and, of course, the correction peak) are measured on the same pass through the sample. In fact, the transmission gamma ray was specifically chosen at a lower energy than the assay gamma ray in order to minimize Compton interference with the latter. There are, nevertheless, cases where backgrounds from the transmission source interfere with the assay peak and where it becomes desirable to minimize this effect. In the case of uranium, for example, some interference at 185.7 keV is inevitable from the ^{169}Yb gamma rays of 198.0 and 177.2 keV.

One solution to this problem is to assay the sample in two passes, once with the source open to measure the transmission, and again with the source shuttered to measure the assay peak. This procedure improves the precision and often the accuracy of the measurement, but it becomes particularly relevant in the case of uranium or small amounts of plutonium. It also increases the assay time by a factor of two, so careful consideration must be given in each case to determine whether two passes will result in significant improvement of the measurement result. The calculation is considerably more complex in the case of two pass assays, since the livetime-pileup correction peak must be measured for both cases. Also, if two-pass assays are to be made, the background (straight through) run must be a two-pass run as well, because typically the background run is done once per day and serves for all subsequent assay, one-pass or two-pass. Here, one rate correction would be applied to the transmission peak, and another to the assay peak. The rate-loss correction factor for the assay peak, CF_{rl} , should always be referenced to the second background pass (transmission source shut off) because of its lower fraction of

loss and because the correction peak value will change more slowly with time (see Section II-N for a full explanation of this effect). It is also clear that rate losses in the transmission peak should be referenced to the first-pass (shutter open) of the background run.

In order to eliminate unnecessary use of the two-pass option and yet preserve its better precision and accuracy when necessary, it is convenient to invoke a computer check automatically on the data as they are received to decide after the first pass has been completed whether another pass is necessary or not. It is a simple matter to take full data on the first pass, and have the computer check the assay peak to background ratio, and determine whether another pass would be useful. In this way, the operator is relieved from the task of making an arbitrary decision on the matter, and maximum throughput consistent with best statistical accuracy is maintained. In the LASL segmented gamma-scan system, if the sum over all segments examined of the variances of the assay peak areas is greater than twice the sum of the assay peak areas, a second pass is required. This criterion is plausible when one remembers that the variance of the peak area of a no-background peak is the peak area itself.

Four types of assay procedures have now been discussed:

- (a) three-peak, one-pass assays,
- (b) four-peak, one-pass assays,
- (c) three-peak, two-pass assays, and
- (d) four-peak, two-pass assays.

For the sake of clarity, all the expressions relating to each type of assay are collected and presented below. The subscript 1 refers to passes with the transmission source open and the subscript 2 refers to passes with the

transmission source shuttered, for either background runs or assay runs. Also, as before, the subscript o refers to background run values while the subscripts l and h refer to the low and high energy transmission peaks respectively in four peak (two transmission peaks) assays.

The general form for the corrected count from a segment is given by (dropping the segment subscript)

$$CC = C \cdot CF_{rl} \cdot CF_{att} \cdot CF_{con}$$

where the forms for CF_{att} and CF_{con} are as always

$$CF_{att} = \frac{-A \ln(TR)}{1 - TR^A}$$

and

$$CF_{con} = \frac{1}{\sqrt{TR_{con}}}$$

For one-pass assays the forms for C, CF_{rl} and TR are:

$$\begin{aligned} C &= C_1 \\ CF_{rl} &= L_{o2}/L_1 \\ TR &= \frac{T_1}{T_{o1}} \cdot \frac{L_{o1}}{L_1} \cdot CF_{con}^2 \quad (\text{For three-peak assays}) \end{aligned}$$

$$TR = (0.6)TR_l + (0.4)TR_h \quad (\text{For four peak assays})$$

with

$$TR_{\ell} = \left(\frac{T_1}{T_o} \right)_{\ell} \cdot \frac{L_{o1}}{L_1} \cdot CF_{con}^2$$

and

$$TR_h = \left(\frac{T_1}{T_{o1}} \right)_h \cdot \frac{L_{o1}}{L_1} \cdot CF_{con}^2 \quad .$$

For two-pass assays the forms for C, $CF_{r\ell}$ and TR are:

$$C = C_2$$

$$CF_{r\ell} = \frac{L_{o2}}{L_2}$$

$$TR = \frac{T_1}{T_o} \cdot \frac{L_{o1}}{L_1} \cdot CF_{con}^2 \quad (\text{For three-peak assays})$$

$$TR = (0.6)TR_{\ell} + (0.4)TR_h \quad (\text{For four-peak assays})$$

with

$$TR_{\ell} = \left(\frac{T_1}{T_{o1}} \right)_{\ell} \cdot \frac{L_{o1}}{L_1} \cdot CF_{con}^2$$

$$TR_h = \left(\frac{T_1}{T_{o1}} \right)_h \cdot \frac{L_{o1}}{L_1} \cdot CF_{con}^2 \quad .$$

L. Error Calculations

Next of concern is the estimation of the random errors associated with the segmented gamma-scan technique. Systematic errors are not readily amenable to calculation, and can be partially discovered and evaluated only by use of information not usually obtainable by the computer during an assay run.

There are two general sources of error in the final assay values; the statistical error in the corrected counts,

and the error in the calibration constant that relates corrected counts to mass of material. The former is of primary concern at assay time, since the computer has the data available to evaluate statistical random errors in the corrected counts, which are based solely on the accumulated counts in several gamma-ray spectra peaks.

Thus, for the following discussion, the propagation of error includes only that from Poisson counting statistics; no contributions from electronic instabilities or from calibration uncertainty are considered.

With each gamma-ray peak bracketed by counting windows as indicated in Fig. 1, Eqs. (2) and (3) indicate the calculations of background-subtracted peak counts and the associated statistical error. Note that if the background were much less than the peak, the error estimate of the peak counts (Eq. (3)) reduces to the familiar square root of the peak number. Unfortunately, in actual practice, backgrounds can be quite large, and the final two terms in Eq. (3) cannot be neglected in making error estimates for each peak used in the assay calculation.

The estimates of precision are derived from the expressions for the corrected count per segment by use of the formula for the variance of a function of n independent variables; that is,

$$\sigma^2 [V(x_1, x_2, \dots, x_n)] = \left(\frac{\partial V}{\partial x_1} \right)^2 \sigma^2 (x_1) + \left(\frac{\partial V}{\partial x_2} \right)^2 \sigma^2 (x_2) + \dots + \left(\frac{\partial V}{\partial x_n} \right)^2 \sigma^2 (x_n).$$

The expressions for the corrected counts are written in terms of the measured independent quantities, namely the full-energy peak areas of the assay, transmission and correction peaks that have been denoted C , T , and L , respectively with appropriate subscripts. The values of the

correction and transmission peaks from the background run (both passes) are assumed to have no random error because they enter into a long series of assay measurements as constants. They are measured typically only once per day and then to high precision by averaging over a large number of segment values. Thus, even on a long-term basis there is very little random variation associated with the values from the background and it is reasonable to assume none. The correction factor for the container, $CF = \sqrt{1/TR_{con}}$, is also assumed to have no random error. As discussed above there are four types of assay runs with slightly different expressions for the corrected count and each consequently has a somewhat different expression for the estimated precision. The complexity of the expressions varies because the number of independent variables with respect to which derivatives must be taken ranges from three (three-peak and one-pass assays) to five (four-peak and two-pass assays). The three-peak two-pass assays and the four-peak one-pass assays have four independent variables. The expressions will not be derived here but the results will be given, expressed not in terms of the actual independent variables but simplified by expressing them in terms of the corrected counts, the correction factors, the transmissions and the relative standard deviations of the independent variables. The complexity, even so, of the resulting expressions emphasizes the necessity for automatic computational capability when dealing with any but the simplest of gamma-ray assay procedures. After the estimates of the precision for the corrected count of each segment have been computed, the square root of the sum of the squares of the segment estimates yields the precision estimate for the total corrected count.

The expressions for the precision estimate for the four types of assay are given below. For simplicity the segment

subscript has been omitted as it applies to all quantities except A, the constant in the expression for CF_{att} , and CF_{con} , the container correction factor that is assumed constant. Note again that the relative standard deviation has been used where by definition $\sigma_r(V) = \sigma(V)/V$ with the standard deviations being estimated by Eq. (3). It must be remembered that the actual forms of CC, CF_{rl} , and TR vary with the type of assay. Finally, the appearance of the final expressions may be simplified by making a substitution for a complex factor appearing in all four of them.

By letting

$$K = \frac{A}{CF_{att}} \cdot \frac{(1 - TR^A \cdot CF_{att})}{1 - TR^A}$$

the following expressions are obtained.

For the three-peak, one-pass assay

$$\sigma^2(CC) = CC^2 \cdot \left[\sigma_r^2(C_1) + K^2 \cdot \sigma_r^2(T_1) + (1-K)^2 \cdot \sigma_r^2(L_1) \right] .$$

For the three-peak, two-pass assay

$$\sigma^2(CC) = CC^2 \cdot \left\{ \sigma_r^2(C_2) + \sigma_r^2(L_2) + K^2 \left[\sigma_r^2(T_1) + \sigma_r^2(L_1) \right] \right\} .$$

For the four-peak, one-pass assay

$$\sigma^2(CC) = CC^2 \cdot \left\{ \sigma_r^2(C_1) + K^2 \cdot \left[\left(\frac{TR_l}{TR} \right)^2 \cdot \sigma_r^2(T_{1l}) + \left(\frac{TR_h}{TR} \right)^2 \cdot \sigma_r^2(T_{1h}) \right] + (1-K)^2 \cdot \sigma_r^2(L_1) \right\} .$$

For the four-peak, two-pass assay

$$\sigma^2(CC) = CC^2 \cdot \left\{ \sigma_r^2(C_2) + \sigma_r^2(L_2) + K^2 \cdot \left[\left(\frac{TR_\ell}{TR} \right) \cdot \sigma_r^2(T_{1\ell}) + \left(\frac{TR_h}{TR} \right)^2 \cdot \sigma_r^2(T_{1h}) + \sigma_r^2(L_1) \right] \right\}.$$

The quantity K is always less than 1.0 and in the range $0.1 \leq TR \leq 0.7$, $0.29 \leq K \leq 0.39$.

M. Varying the Mu Ratio

All equations derived up to this point have assumed that the transmission gamma-ray and assay gamma-ray energies are sufficiently close together that their mass attenuation coefficients are essentially the same. However, this is not always the case, particularly in the case of ^{241}Pu assay, where the 208-keV assay energy is corrected for transmission as measured by the 265-keV ^{75}Se gamma ray. In the cases where the transmission energy differs significantly from the assay energy, Eq. (6) is no longer a correct expression for the correction factor, and since the correction factor is multiplied by the actual counts to yield corrected counts, errors in the correction factor are reflected directly into assay errors.

Figure 4 shows a plot of the correction factor vs mu ratio for several values of transmission, where the mu ratio is the ratio of μ_a , the mass attenuation coefficient at the assay energy and μ_t , the mass attenuation coefficient at the transmission energy. Note that at very high transmissions (low attenuation), the effect of the mu-ratio variation is negligible. However, at high attenuation, using an incorrect mu ratio can result in large errors in the correction factor, and hence, in the assay results.

Fig. 4. Plot of the correction factor vs the μ ratio for several values of transmission.

Equation (6) is corrected for the μ -ratio variation by changing the geometric factor, $\underline{A}$, to an $\underline{AK}$, where K is now the μ ratio as just defined. This same substitution must be made in all subsequent equations, including error calculations, wherever the geometric factor $\underline{A}$ appears. Note that if the μ ratio is different than unity, assumptions have been made implicitly concerning the nature of the matrix

material in the sample being measured. It is always best to use the transmission and assay energies sufficiently close together to make the difference in attenuation negligible. However, in the case of ^{241}Pu and other special cases where the energies are quite different, the system can include a μ ratio different than unity.

N. Time Dependence of Calibration Constant

Let us remind ourselves that the correction for the rate-related losses (deadtime and pileup) made by the use of the livetime-pileup correction peak in the reference spectrum is actually a normalization rather than an absolute correction. The correction factor LT_0/LT does not in fact make a full correction for all rate-related losses but rather normalizes all results to the fraction of losses in the reference spectrum. Thus, if 90% of full-energy events are stored in the full-energy peaks of the reference spectrum, the corrected count finally computed will only be 90% of what it would have been if complete correction had been made for the rate-related losses. As the sources involved in the reference run decay, the gross rate of detector interactions decreases and the fraction of full-energy events stored in the full-energy spectral peaks will slowly increase. One result of this situation is that the system calibration constant will slowly increase with time. This slow increase in calibration constant is of no particular disadvantage, for daily calibration checks must be made in any proper use of the segmented gamma-scan assay system. However, it is operationally desirable to have the calibration constant remain as nearly constant as possible. This can be accomplished by using a reference run which does not involve the shorter half-lived transmission sources (^{169}Yb - 32 days and ^{75}Se - 120 days) but only the longer-lived reference sources (^{57}Co - 271 days and ^{133}Ba - 11 years).

A two-pass background run is thus required for all assays (one pass with both reference source and transmission source and one pass with only the reference source), but that is necessary at any rate if the two-pass assay option is to be permitted at all. The important point of this discussion is that a slow change in the calibration constant may be expected but does not matter. The advantage in using the gamma-ray source method for rate-related loss correction (better referred to as normalization) more than outweighs the slight inconvenience of a calibration constant, which changes slowly with rate correction source decay.

O. Detector Resolution

Another important parameter in monitoring system performance is the detector resolution. The analysis system computes this parameter automatically, checking the resolution every time a background run is taken. In the present system, the program assumes that a three-peak or five-peak assay utilizes the 356-keV ^{133}Ba gamma line as the rate correction peak, determines the full-width-at-half-maximum in channel numbers, divides the center peak value by 356 keV to determine the system calibration in terms of channels per keV, and prints out the system resolution as a regular part of the background run printout. In the case of uranium, the program assumes the 122-keV energy peak from ^{57}Co as the rate correction peak. In this way, a running check on system resolution is maintained, with hard copy data to guarantee that the detector system was functioning properly at the time of each background run.

It should be added and emphasized that a detector of good resolution is highly desirable for it will yield better precision and accuracy than a detector of relatively poor resolution. Without going into a lengthy discussion of detector performance and specifications, experience

indicates that a detector capable of ≤ 2.0 -keV resolution at 1332 keV and ≤ 1.00 keV at 122 keV is satisfactory for measurements done with the segmented gamma scan. With fairly short amplifier time constants (1.5 μ s to 2.0 μ s) and gross count rates of approximately 20000 s^{-1} , the system resolution at the correction peak energies should preferably be ≤ 1.1 keV at 122 keV (^{235}U assays) and ≤ 1.3 keV at 356 keV (^{239}Pu and/or ^{241}Pu assays).

P. Extensive Peak Fitting

As a final comment on the general theory of system operation, it is appropriate to remark that with a computer as an integral part of the system, the potential exists to do extensive peak fitting on the spectra as they are received in each assay. This permits, for example, extraction of isotopic information from data where peaks overlap. It should be remarked, however, that the codes required to accomplish extensive spectral fitting are quite complex and would require considerably more memory than the 2^{14} (16384) words used in the LASL segmented gamma-scan system.

III. SYSTEM SOFTWARE

A. General

Software for computer-controlled instruments such as the segmented gamma scanner can be written, in general, in any one of three broad categories of programming languages, assembly (machine) language, compiler language, or interpreter language. Assembly language permits maximum optimization of system resources, speed, and memory size. Compiler language permits somewhat more flexible programming without serious time loss in most calculational tasks, but must be compiled before the program can be loaded into the system and run. Interpreter languages permit maximum ease in programming, but are the most memory inefficient (since the interpreter

must be resident while the program is executing) and tend to run the slowest. One can argue persuasively for any of the three methods of programming, but in the safeguards field one overriding consideration is gradually emerging that will likely eliminate the interpreter mode from consideration. A program written in interpreter language is easy to change on-line to give whatever result the operator desires without detection, since it has available at run time all the system resources necessary to make program changes. This threat to the system software security will probably result in a mandate that software be handled in either compiler language or assembler language, both of which require separate programs to generate the object code for actual running, so that it often requires more system resources to make the compilation or assembly than are actually available at the instrument itself. Such codes are almost impossible to change on-line, and are thus much more secure.

The sections of code that actually interact with peripheral equipment (stepping motors, ADC interfaces, scopes, teleprinters, etc.) are almost always written in assembly language, but may be written as compiler-callable subroutines. In the long run, the most likely mode for producing instrument codes for safeguards equipment will probably consist of I/O drivers written in assembler language, embedded as callable subroutines in compiler-language programs.

The present instrument uses codes written in Data General^R-compatible assembly language, which permits maximum software flexibility, maximum hardware-software optimization, minimum core size (which substantially increases system reliability), and fast computer operation. The present codes fit into 8K words of 16-bit core memory, but a 16K board is used to permit possible system expansion or linking to a central accounting computer if desired. The

code is broken into four relocatable routines that generally handle interrupt, display, calculational, and floating point operations, respectively. In this system, all calculations are performed with floating point numbers and software sub-routines that generally require a few milliseconds for a floating point operation. The display routines generate plots on a point-by-point basis, with the computer generating a digital number for each x,y point to be displayed, and the storage scope used to hold the information. Each DAC used for the display has 10-bit resolution, so that 1024 points can be displayed on each axis of the scope.

B. Detailed Flow Charts

The software system is split into several relocatable sections as mentioned above, which we will now discuss as flow charts of the program flow. The state of the computer is characterized by its interrupt situation; i.e., which external (or internal) devices can interrupt it at any given time. Table III indicates the five conditions permitted in the segmented gamma-scan software. Basically, Condition 1 is the idle state where no operation is underway, and the computer is ready to accept interrupts from the switch panel, by which all operations are controlled. As soon as one of the front-panel switches gives an interrupt, the machine enters one of the other conditions, depending upon which instruction is given. Condition 2 is a run condition, in which the only interrupts permitted are from the ADC or scan table, or the system stop switch. Condition 3 is a cursor display condition, where the display is being used interactively to enter windows or locate spectral peaks with the intensified cursor. Condition 4 is a general busy situation, where only a system stop will be permitted, as for example, when a display is being updated, or extensive calculations are being made. Condition 5 is a special

TABLE III

COMPUTER INTERRUPT CONDITIONS

<u>Condition</u>	<u>Interrupts Enabled</u>	<u>Mask</u>
1	RANGE SWITCH, ALL "READY" SWITCHES Enter Constants a Start Background Start Assaya Start Setupa Start Cursor Start Analyze Start Integrate DYMAL Transfer	10767 ₈
2	ADC, "SYSTEM STOP"	5777 ₈
3	RANGE SWITCH, "SYSTEM STOP", "START WINDOW", "STOP WINDOW"	13777 ₈
4	"SYSTEM STOP"	15777 ₈
5	RANGE SWITCH, "SYSTEM STOP"	11777 ₈

^aThere is a hardware mask that permits "start assay", and "start background" only when the "computer-local" switch is in the "computer" position, in which case "start setup" is locked out; conversely, in the "local" position, "start setup" is permissive and "start assay" and "start background" are locked out.

NOTE: Table end-of-assay and end-of-segment interrupts are always enabled.

situation of Condition 4, where, however, a change of the range switch is permitted to update the display.

Figure 5 shows the flow chart of the start of the program. From the Condition 1 idle loop, the interrupt is identified and appropriate action taken. The small circles with letters indicate another entry point to a subsequent

Fig. 5. Flow chart for first portion of the SGS analysis program.

flow chart. "DYMAC XFER" refers to an option in the system, not generally used except at LASL, for transferring data in serial form to a central accounting facility directly from the segmented gamma-scan computer with operator intervention.

Figures 6-16 indicate detailed operation of the program with its various branches and options, and they are self-explanatory. Detailed operation of the actual system controls will be given in the next section.

C. Interrupts, Storage, and Pointers

The inhibit masks that control the various machine conditions as described above are controlled by software bits on the data lines. These are established by an MSKO command, as follows in Table IV:

TABLE IV

MASK BIT ASSIGNMENT AND COMPUTER RECOGNITION CODES
FOR EXTERNAL DEVICES

<u>Device</u>	<u>Mask Bit</u>	<u>Device Code</u>
ADC	3	44 ₈
Range Switch	4	42 ₈
Window Switches	5	42 ₈
"Ready" Condition	6	42 ₈
Storage Scope	-	34 ₈
Scan Table	-	74 ₈

Fig. 6. Partial flow chart for the SGS analysis program.

Fig. 7. Partial flow chart for the SGS analysis program.

Fig. 8. Partial flow chart for the SGS analysis program.

Fig. 9. Partial flow chart for the SGS analysis program.

Fig. 11. Partial flow chart for the SGS analysis program.

* The algorithm used in the calculations varies, depending on whether the assay is one or two pass, and whether it is a three-peak (Pu-239 or Pu-238), a four-peak (U-235, or a five-peak (Pu-239 and Pu-241) assay.

Fig. 12. Partial flow chart for the SGS analysis program.

Fig. 13. Partial flow chart for the SGS analysis program.

Fig. 14. Partial flow chart for the SGS analysis program.

Fig. 15. Partial flow chart for the SGS analysis program.

Fig. 16. Partial flow chart for the SGS analysis program.

Once an interrupt is given, it is recognized by the computer via a polling procedure to identify the unit with its busy signal set. If it is the switch panel giving the interrupt (device code 42_g), the actual switch is recognized by checking the data bits set from the panel register, fetched via a DIA with device code 42_g, and checked against the following convention:

TABLE V
BIT ASSIGNMENTS FOR FUNCTION SWITCHES

<u>Function</u>	<u>Bit Number</u>
System Stop	15
Range Switch	14
Start Window	13
Stop Window	12
Enter Constants	11
Start Assay	10
Start Background	9
Start Setup	8
Start Integrate	7
Start Analyze	6
Start Cursor	5

Bits 4 through 1 give the setting of the range switch coded in Binary Coded Decimal (BCD) with bit 4 as the Least Significant Digit (LSD); bit 0 gives the setting of the printout mode switch (if the bit is set, the switch is set to "long" printout).

The scan table interrupts with busy set on device code 74₈ if the interrupt corresponds to the end of a segment, or with done set if it corresponds to the end of the assay (all segments complete).

In addition to storing the various constants that enter into the equations detailed earlier in this manual, certain large blocks of storage are allocated within the computer memory for specific data. These, together with the various software pointers, are indicated in Fig. 17. The notation here is the same as in the previous equations. Table VI gives the absolute addresses for some of the pointers and flags used in the software codes.

D. Plotting Routines

For purposes of writing on the scope, both x and y information must be given to the interface DACs, as well as an intensify pulse to store the information. All information is stored as dots on the oscilloscope. The maximum resolution of this device is 1024 dots in either coordinate; hence, 10-bit DACs are used, and 10 data bits must be given for each coordinate. This information is passed to the interface by giving a DOA instruction for the x-coordinates, and a DOB for the y, together with 10 bits of information passed on data lines 15 through 6 (15 is the LSB) together with device code 34₈. The intensify pulse is given by the "start" pulse appended to any instruction with device code 34₈. The IOPLS pulse and DC 34 will place the storage scope in the "nonstore" condition, from which it is returned to the store mode by giving an erase command, CLR with code 34₈, or an IORST.

HRZLN is a subroutine that writes a horizontal line on the scope. This subroutine expects the x and y coordinates of the starting point to be passed in accumulators 0 to 1, with the line length in dots in accumulator 2.

TABLE VI
SOFTWARE POINTERS AND BUFFER ADDRESSES FOR
VARIOUS FLAGS AND STORAGE LOCATIONS

<u>Mnemonic</u>	<u>Absolute Address (Octal)</u>	<u>Purpose</u>
DATAD	121	Starting address of spectrum storage
BUFAD	116	Starting address of current plot
FLAG	161	Equals 0 if 2K points in plot Equals 1 if 256 points in plot
WNFLG	75	Equals -1 if previous entry was "stop" Equals 0 if previous entry was "start"
FF	140	Current value of counts/g
FFS	142	Current value of counts/g for ^{241}Pu
AK	154	Value of geometric factor multiplied by mu ratio value
AKS	216	Same as AK, except applied to ^{241}Pu
SRCAN	152	Square root of can transmission
RNFLG	104	Equals 0 if assay run Equals 1 if background run
SEGCT	105	Number of segments in current assay
SEGDT	124	Starting address of segment data storage

TABLE VI (cont)

<u>Mnemonic</u>	<u>Absolute Address (Octal)</u>	<u>Purpose</u>
SEGLK	125	Address of current segment storage
PO	244	Equals 0 if short printout Equals 1 if long printout
WINLM	122	Starting address of window limit storage
WNSTR	123	Floating pointer for window limits
BUMP	11732	Number of windows set in
AFLG	10451	Equals 0 if end of assay interrupt Equals -1 if end of segment interrupt
MTPL	165	Equals 0 if single run Equals 1 if multiple run
PASSF	50	Zero if first pass; one if second pass
F241	212	Zero if not ^{241}Pu , one if ^{241}Pu
URAN	136	One if uranium assay; zero if not
GRATF	166	Zero if window entry; one if integrate

FIND is a subroutine that interrogates the range switch and sets up the proper pointers to output the desired section of the spectrum from the data buffer. It also sets cell FLAG to zero if the entire 2K spectrum is to be plotted, or to -1 if 256 points are to be plotted. It then sets the appropriate starting address of the section to be plotted in BUFAD.

PLOT is a subroutine that interrogates FLAG and BUFAD and makes the appropriate display. It starts the display by

Fig. 17. Storage map for SGS analysis program.

making ordinate fiducials at the decade points of the graph. For a 256-point display each datum is plotted with four horizontal spaces between it and its neighbor. The full 2K spectrum demands that every two points be averaged and plotted as a single point. In either case, all points are plotted on a logarithmic scale; hence, the vertical scale runs from unity to 100K in decades.

E. Teleprinter Subroutines

Subroutines have been provided for printing on the terminal as well as for fetching characters from the keyboard. PUTC is a subroutine that requires either a starting address or an ASCII character in accumulator zero. If an ASCII character is passed, it will simply output the character and return. If an address is passed, it will output the entire message pointed to by the address, until a null word is detected. In either case, a carriage return (ASCII code 15₈) causes a line feed to be echoed as well. Hence, this subroutine can be used to output whole messages or single characters.

GETC is a subroutine that simply fetches a character from the keyboard and echoes it back to the printer as well as returning it to the program right-justified in accumulator zero. The floating point interpreter uses both of these subroutines in its operation. SBND C is a subroutine to output the contents of a memory in decimal to the teletype with leading zeroes suppressed. DBIN is a subroutine that converts an ASCII character string from the teletype to internal binary numbers.

F. Handling the Window Limits

Window limits are set only when the cursor is on. This condition is handled by a subroutine called CURSE, which calls in FIND and PLOT to first output the desired data

display, and then continually reads the thumbwheel switches related to the cursor position and displays an intensified dot accordingly. These thumbwheel switches are read by a DIB command with device code 42_g. The data thus obtained are in the form of a four-digit BCD number, which the program then translates to binary and fetches the data from the cell thus addressed and displays it. This subroutine also allows for interrupts that will set window limits. Hence, the subroutine must be re-entrant.

WNFLG is a page-zero pointer that signals which window limit has just been entered, zero if "start" and -1 if "stop." STRWN is the subroutine that handles actual sorting of these limits as they are entered. At the termination of entering window limits, when SYSTEM STOP is pressed, subroutine DIFF determines the widths on regions of interest, signals the operator if any of these are negative, and stores the differences for future program use. Subroutine LIMS prints out in decimal the limits just entered for operator information.

G. Handling Data Runs

Upon receiving any interrupt that signals the start of a data run (setup, assay, or background), the interrupt program sets RNFLG accordingly and jumps to the appropriate subroutine.

SETUP handles setup runs by simply storing the data as received, and displaying every twentieth event in the non-store mode, so that the operator has an idea of where most data are being stored in the spectrum.

As regards data storage, both background and assay runs are identical. Subroutine PNT stores the data as they are received from the ADC. At the termination of each segment, data are sorted, the spectrum displayed, calculational values stored, and the buffer cleared for the next segment.

At the end of the run, a determination is made of whether a background or an assay run is involved. In the case of background runs, subroutine STHRU receives control and calculates the transmission and livetime peaks, printing out these values, two of each (for the transmission-open and shuttered cases), and storing the numbers for future use. The detector and system resolution at the rate-correction peak energy is also calculated and printed out at this time. In the case of an assay run, the analysis mode is automatically entered and the calculated data printed out.

Subroutine INIT is used to clear the relevant data storage and prepare the system for the beginning of a run or for the start of the next segment.

SEGCT is a page-zero cell used for counting the number of segments in the particular run. This number is used later for printout as well as for short form calculation.

H. Analysis Codes

At the termination of an assay run, or when the START ANALYZE interrupt is recognized, a determination is made whether short or long printout is desired by reading the toggle switch, and cell PO is set accordingly. Henceforth, all further analysis proceeds with the output determined by the setting of this flag. For a short printout, each segment is calculated and saved, but not printed out. For a long printout, the data are printed on the teleprinter. The calculation is made according to the equations previously described. Subroutine ANALYZ is used to perform this function, which draws heavily on the floating point interpreter for its calculations. If the long printout has been requested, the code gives the operator the choice of which segments to include in the final calculation and error analysis. In the case of a short printout, all segments involved in the run under analysis are included in the

calculation and error computation. In either case, STRT and ENDY contain the addresses of the starting and ending storage for the segments to be included.

Subroutine PKCOR is used to perform the background subtraction of the peak being analyzed. This is a linear subtraction based on the two windows bracketing the peak itself, and has been described previously. All calculations in the analysis codes are based on double-precision floating point numbers exclusively.

I. Floating Point Calculations

Calculations are made with floating point numbers via an interpreter to which program control is transferred for calculational purposes, rather than having special subroutines for each floating point function. In this way, programming for floating point calculations is simply an extension of machine language arithmetic instructions, and the interpreter is transparent to the programmer.

Floating point numbers are internally stored in two consecutive 16-bit words. Of these 32 bits, one is used for the sign of the number, seven are used for the characteristic, and 24 for the mantissa; hence, the approximate range of numbers that the interpreter can handle is from 2.4×10^{-78} to 7.2×10^{75} . The maximum error of a normalized mantissa is less than 6×10^{-8} .

The detailed algorithms will not be given here, but are standard in the industry, requiring milliseconds for their completion in this machine. In all calculations performed in the present codes, the maximum relative error is approximately 10^{-7} , which is much less than would be noticed for any of the numbers produced in these routines.

IV. SYSTEM HARDWARE

The text of this section describes the SGS system before the addition of the large scan table that has been added to some system configurations. A brief description of the large scan table is given in Appendix B along with schematics of the additional electronics required and the necessary wiring list changes. The addition of the second scan table also required some modification to the already existing interface electronics, and the schematics given in this section include those changes.

A. Overall Operation

The special electronic interfaces consist of two chassis, the motor control box and the main control box. These will be described in that order.

Figures 18 and 19 show the block diagrams of the motor control box. The function of this unit is to control the two stepping motors of the scan table after receiving commands from the front panel (manual operation) or communicating with the computer through the main interface box. This latter unit will be described later.

As the block diagram shows, the heart of the motor control unit consists of two oscillators which drive commercial bipolar chopper motor drivers through a gating system that switches between the two oscillators. One is a high-frequency crystal oscillator with divider network, which is used to get a stable speed for table motion during actual data taking. The other is a ramp oscillator used to move the table rapidly from one limit to the other when data are not being taken.

Also shown in Fig. 18 are four "slots" (limit switches) that are mounted on the scan table itself to detect the two

Fig. 18. Block diagram, motor control box, general section.

Fig. 19. Block diagram, motor control box, computer section.

extremes of travel up and down. The two middle slots initiate control action to change direction or ramp down and stop. The two outside slots are emergency stops. If the table ever reaches either of these positions, something has failed and both oscillators are immediately gated off.

Figure 18 also shows circuitry to clean up switch bounce and drive an indicator light associated with the "up-down" switch. Following this is circuitry designed to make sure the ramp oscillator has time to ramp down before the computer or the front panel switch can change directions or stop. The remaining portion of this diagram is a counter chain that watches the vertical motor's encoder and determines the end of a segment and the end of an assay (last segment).

Referring now to Fig. 19 the four control flipflops are along the left half, and the computer I/O lines continue to the right. All four control flipflops can be accessed by the computer, and the lower three (start, up, fast) also by hardware controls. The three lower flipflops serve the functions implied by their names. The "start" flipflop instructs the table to start or stop, the "up" determines the direction, and the "fast" dictates the speed. The "internal busy" flipflop gates the oscillator off to keep the table stopped until the computer resets it.

Moving to the computer I/O side of Fig. 19 we find three more flipflops whose outputs are gated onto computer sense lines. At the end of a segment the "interrupt" and "busy" flipflops are set, and at the end of an assay (last segment) the "interrupt" and "done" flipflops reset. Only the computer can reset these flipflops.

Notice also on this diagram there are two busy flipflops. The only difference between these two is the line used to reset them. This enables the computer to reset its own busy line and talk to the scope while leaving the internal busy (table movement) set.

Directly below the computer flipflops are gates that gate status information into the computer upon command. This status information includes "load position", "local-computer", "top slot", "fast flipflop", "start flipflop", and "up flipflop".

The block diagram of the main control box is shown in Figs.20 and 21. The former contains the front panel switch control interface. Starting with the thumbwheel switches, their outputs go directly into a tri-state bus through tri-state gates on command from the computer.

The 10 pushbutton switches first go to the mask gates, which in turn are gated by the three mask flipflops set by the computer and the local-computer switch on the motor control box. If the mask is permissive for the switch activated, it sets into the latch its own unique bit and also sets the computer interrupt and busy flipflops. The output of the latches connects to the output tri-state bus on command from the computer.

The range switch also goes through a mask gate to set the computer interrupt and busy flipflops, as well as to the tri-state bus, through gates, on command from the computer. The mode switch, like the thumbwheels, is gated directly on the tri-state bus by the computer.

Moving to Fig. 21, we have on the left side the ADC control interface and on the right side the scope control interface. Starting with the ADC interface, we receive data lines (A0-A10) from the ADC and go into a set of latches. Since the ADC will store an event until reset, the ADC itself is one buffer and the interface latch is a second data buffer, making this a double-buffered system and increasing its instantaneous data rate capability.

The busy flipflop keeps track of the latch and doesn't allow the ADC to write into it until the computer retrieves its data. The busy and interrupt flipflops tell the computer

the latch has data to be read. The mask flipflop enables the computer to stop interrupts from the ADC if it is busy with something else.

The scope control interface on the right half of Fig. 21 is the only interface that cannot interrupt the computer. Its only line to the computer is the busy line, which it uses to indicate to the computer when it has reached a new location and is ready to intensify. The computer loads a 10-bit word into the x-latch and the y-latch to define a dot location and then gives an intensify pulse after waiting for the busy line to go down. Other computer pulses as shown can erase or put the scope into a nonstore mode for a setup run, as described in detail in the software section.

B. Detailed Circuit Description

This section will discuss the interface, board by board, in enough detail to facilitate repair or alignment. Reference should be made to the individual board schematics as indicated. Note that on these schematics some numbers and letters have circles or squares around them. The numbers circumscribed by squares are card edge pins, and the ones with circles around them indicate IC numbers. These two interface chassis with boards installed are shown in Figs. 22 and 23.

1. Motor Control Box

Board 1 of the motor control box (Fig. 24) is a general purpose differential receiver card containing DM8820 differential line receiver ICs. The board is used to receive control lines from the main interface box. The 0.02- μ F capacitors allow an internal resistor to terminate the twisted-pair line in 120 ohms for ac signals, but they do not draw excessive current for dc signals. The 160-ohm resistors are pullup resistors for the DM8820's open collector outputs. Pin J goes to the local-computer switch and gates these receivers off when in the local mode.

Fig. 20. Block diagram, computer interface to main control panel.

Fig. 21. Block diagram, computer interface to ADC and storage scope.

Fig. 22. Main control box, showing card locations.

Fig. 23. Motor control box, showing card locations.

DM 8820

Fig. 24. Board #1, motor control box.

Board 2 of the motor control box (Fig. 25) is a general purpose differential line driver board using DM8830 differential line driver ICs. Pin #3 goes to the local-computer switch to prevent hanging on the computer interrupt, busy, or done lines while in local. Pin Z brings in a signal initiated by the computer which gates the status signals into the main interface box.

Board 3 of the motor control box (Fig. 26) has three main functions: limit switch receivers, oscillator control gating, and indicator light control. Starting with the limit switch section, the limit switches are MCA-8 slotted pairs consisting of a gallium-arsenide infrared-light-emitting diode and a silicon photodarlington looking through an air gap. These have a very good light/dark ratio and are not bothered by ambient light sources, since they operate in the infrared region. These are hooked up in a fail-safe configuration such that an opening in the cable or a power failure will cause the motors to stop. A minor disadvantage is their high saturation voltage (0.8 V), which was overcome by going into an LM339 connected as a Schmitt trigger with a high threshold (2.5 V) and a large hysteresis (1 V). The resistor chain between 5 V and ground on the positive inputs of the LM339 provide a reference voltage (3 V) and the 3K resistor from this positive input to the output provides positive feedback and, hence, the large hysteresis. Note that the top and bottom switches are ORed together, and either one will gate off both oscillators via the gates in the upper right-hand corner of this figure. This gating of the oscillators is straightforward, except for the R and S lines leaving the board. These points go to a pulse synchronizer that does the actual gating of the crystal oscillator.

Pin W is the actual output to the up-down motor driver. The circuitry in the bottom righthand corner of the schematic controls the red-green LED. The LED has only two

DM 8830

Fig. 25. Board #2, motor control box.

leads, which necessitates considerable circuitry for proper operation.

Board 4 of the motor control box (Fig. 27) contains the three scan table control flipflops. Starting with the "start" flipflop, IC-7 output #6 and IC-6 output #6, there are several points worthy of special note. First, the B-SLOT resets the flipflop through an edge detector, IC-1 output #10 and IC-6 output #3, to allow it to be started in an up direction while on the bottom limit. On the falling edge of B-SLOT pin #2 of IC 6 goes up and stays up. Pin #1 on IC 6 was up and stays up until the 0.01- μ F capacitor discharges through the 390-ohm resistor. While these two inputs are up, the output goes down and stays down until the 0.01- μ F capacitor is discharged, at which time the output goes back up. This makes the output width the same as the R-C time constant, regardless of how long B-SLOT stays set.

Another point of interest involving the "start" flipflop is the stop command coming in through IC-8 output #8. The purpose of this is to allow the computer to stop the motors after the table has been started in the up direction, but it is still on the bottom limit.

Moving down to the "up" flipflop, IC-6 output #11 and IC-7 output #12, there is a slow-down R-C network on the set, IC-6 pin #12. The purpose of this time constant is to guarantee that the "start" flipflop gets reset to stop before the "direction" flipflop changes to "up". This prevents the table from backing off the bottom limit.

For all three flipflops, IC-8 output #11 prevents a computer reset (which would set the three flipflops to move the table down to the load point at the bottom limit at high speed) if the table is already on a bottom limit. Without this guard successive computer resets would drive the table beyond the bottom limit because the start flipflop is coupled to the bottom limit through the edge trigger, which would recognize the bottom limit after the first contact.

Fig. 27. Board #4, motor control box.

Notice also that the two lines on this board using slowdown circuits, IC-6 pin #1 and IC-6 pin #12, are received by a 74132 Schmitt trigger to prevent oscillation on the slow rise and fall.

Board 5 of the motor control box (Fig. 28) houses the two oscillators and the pulse synchronizers that gate the crystal oscillator output. This is the only board in the system built on a ground-plane board.

Starting with the crystal oscillator along the top half of the figure, there is a crystal oscillator packaged in a 14-pin DIP IC package. It has a 16.384-MHz TTL-compatible output, which goes into a divide-by-five and a divide-by-two counter embodied in the 74196. The next IC, a COSMOS CD4020 divides by 2^{13} to achieve 200 Hz, and by 2^{14} for the 100-Hz output. Only COSMOS permits such divisions in a single package. However, COSMOS suffers two main disadvantages: low-speed and low-drive capability. The low speed dictates the previous IC, 74196, be hooked up in a divide-by-five and then -by-two rather than the reverse, so its output is a square wave of proper speed. The low drive makes the two transistor drivers necessary. The 74120 IC is a pulse synchronizer that permits gating the pulse trains while making sure the first and last pulses are full width. This is necessary because the motor drivers and motors are so much slower than the counters which track the stepping. Without this precaution, the first and last steps of a segment might be counted by the scalars but not by the motors.

Moving to the high-speed ramp oscillator at the bottom of Fig. 28, note that the oscillator itself is built around the NE555 timer IC. The 0.22- μ F capacitor charges through the 510-ohm and 15-k Ω resistors and discharges through the 510-ohm and the 1N4154 diode into pin #7. The 1N4154 diode supplies a silicon forward junction voltage drop to insure self-starting of the oscillator when power is

Fig. 28. Board #5, motor control box.

turned on. The 0.01-μF capacitor provides noise decoupling on the internal control voltage, and the 1-kΩ resistor in pin #3 provides a pull-up on the output. The two transistors are connected as a differential current pair that opens (high speed) or closes, placing a resistor in parallel with the 15-kΩ charging resistor. The speed input on pin #15 uses a standard TTL output to charge and discharge the 180-μF capacitor through the first 10-kΩ resistor. This R-C time constant determines the ramp duration. The ramp duration, high speed, and low speed can be changed within limits by changing the values of the 180-μF capacitor through the first 10-kΩ

resistor. This R-C time constant determines the ramp duration. The ramp duration, high speed, and low speed can be changed within limits by changing the values of the 180- μ F capacitor, the 680-ohm resistor, or the 15-k Ω resistor, respectively.

The 74107 IC following the oscillator is a dual flipflop that squares up the output and divides the frequency to 100-1000 Hz or 200-2000 Hz. At present we are using the 100-1000-Hz output.

Board 11 of the motor control box (Fig. 29) provides two basic functions. The circuitry at the lower half of the figure watches the scan height thumbwheel switches and changes a 00 to a 01 so that even if the operator mistakenly sets the switches to 00, he will still get a two-segment assay (1.0 in.). Without this precaution the interface would give a constant interrupt to the computer with the switches set at 00. This system hangup is prevented by the circuitry described, which thus effectively makes zero a forbidden setting for assay length.

The upper portion of Fig. 29 requires a short preface. The position of the motors is indicated by an optical encoder mounted on the nameplate end of the up-down motor. Each time the motor takes a step, depending on load, the encoder may see bounces up to one step off in either direction until the motor settles down. The IC4 is the last stage of an up-down counter that counts the pulses from this encoder. The associated circuitry and the gate to the right of this counter gate off its output when the encoder could be bouncing and thus cause a premature end-of-segment command. The IC-7 output #13 provides a delay triggered by the table coming off the top limit or by the computer starting a new segment. The IC-3 output #1 and IC-7 output #5 monitor the CW line from the encoder and initiate a delay on the first CW pulse. The feedback from IC-7 pin #5 to IC-3 pin #3 prevents

Fig. 29. Board #11, motor control box.

updating on subsequent CW pulses until the end of the delay. This gates the end signal off until the last half of a motor step, when bouncing should have died out.

Board 12 of the motor control box (Fig. 30) contains the computer interrupt, busy, and done flipflops as well as scaler reset gating, the internal busy flipflop, and the motor encoder receiver.

Starting with the scaler reset circuitry, IC-3 output #2 and IC-2 output #8, we see that a computer general reset, IORST, into IC-2 pin #9 will reset the scaler that counts steps to determine the end of a segment. The pulse signaling the end of a segment will also loop back and reset the scalars, IC-2 pin #10. In addition, the scalars are held in a reset mode, preventing counting if the table is on the top limit, IC-2 pin #12, and until the table is going down slowly, IC-3 pin #1.

Moving to the flipflop section, we see that at the end of a segment the internal busy, IC-5 outputs #4 and #10, the computer interrupt, IC-7 output #11 and IC-2 output #6, and in turn, the computer interrupt, IC-6 output #5, flipflops are set. Only signals from the computer can reset these flipflops. The two busy flipflops are needed so that the computer can reset its own busy line, thus removing the interrupt in order to communicate with other system elements while leaving the table busy flipflop set.

At the end of the last segment the two busy flipflops and the interrupt flipflop are set, but nanoseconds later the done flipflop, IC-6 output #8, is set, resetting the two busy flipflops.

The circuitry at the bottom of the schematic is the optical encoder receiver. Output from the encoder is in the form of two pulse trains, "gate" and "count". The receiver consists of a positive edge detector, IC-4 output #6, a negative edge detector, IC-4 output #11, and gates controlled

Fig. 30. Board #12, motor control box.

by the gate signal to pass "up" and "down" pulses. A positive transition on the count line while the gate line is up indicates a CW motion of the motor. Conversely, a negative transition on the count line while the gate line is up indicates CCW movement of the motor. These edge detectors are the same as described on board 4 of the motor control box; the R-C slow-down circuits are received by 74132 Schmitt triggers to prevent oscillation.

Board 13 of the motor control box (Fig. 31) houses the bulk of the two counter chains for determining the end of a segment and the end of the last segment. ICs 1,2, and 5 are the first three stages of a four-stage up-down counter that counts 1000 steps of the vertical movement motor which signals the end of a segment. This signal comes back into the board from the fourth counter section on pin #9 and into IC-6 pin #12 where it is divided by two by a flipflop. This division is necessary because the scan height switches used for comparison give the height in inches, and a single segment in 1/2-in.

From this point the signal goes to a counter made up of IC 4, IC-7 output #6, and IC-6 output #5. The output of this counter is compared with the scan height switch by a comparator made up of IC 3, IC-7 output #3, IC-7 output #11, and IC-8 output #12. When the two are equal this comparator sends out an end signal, indicating the end of the last segment, and then resets itself. The 0.01- μ F capacitors on the switch lines are used to minimize the effects of noise on the lines.

Board 14 of the motor control box (Fig. 32) contains circuitry to clean up switch bounce on the up-down switch, give the fast oscillator time to ramp down before changing direction or stopping, and gating which determines speed and direction of table motion.

Fig. 32. Board #14, motor control box.

Beginning with the switch bounce problem, we see the "up" side and the "down" side of the switch coming into IC 5 as well as the OR gates, IC 2. On the first contact of the switch, IC 5, a univibrator, starts its output. The UV time constant is long enough that it holds IC-2 pin #5 or #9 until the switch stops bouncing and pin #3 or #10 can take over.

Notice that the outputs of the direction and speed flipflops also come into this section. The "up" and "down" fast signals come into IC-2 pins #4 and #11, respectively, and are treated just like the switch. The "down slow" goes past the ramp circuits straight to the "go" output. The "fast" and switch signals are first gated by the limit

switches and then go into univibrators, IC 7, and gating that drives the "go", "speed", and "direction" outputs. These univibrators are connected as trailing edge detectors that act to prevent a change of direction or a stop until they have timed out. This time constant can be changed by adjusting the associated 50-k Ω potentiometer. The time constant is set up to match the charging and discharging time of the 180- μ F ramp capacitor on board 5, motor control box. The speed output goes out to charge or discharge this capacitor. The direction output goes straight out to the motor driver.

2. Main Control Box

Board A-1 of the main Control box (Fig. 33) receives the data lines from the ADC. The resistor chain terminates the twisted-pair cable in 132 ohms to prevent reflections and present a low impedance to noise while still being driven by a standard TTL output. The 7414 is a Schmitt trigger that provides still greater noise immunity.

Board A-2 of the main control box (Fig. 34) receives and drives bidirectional lines from the computer. Notice that as on board A-1 this cable is made up of twisted pair and is terminated by a resistor chain feeding into a Schmitt trigger. The difference is that these are bidirectional lines and are terminated at both ends of the line. This dictates higher resistor values if it is to be driven by a TTL output. Also, we see the addition of the 7406 open-collector output drivers for sending signals to the computer.

Board A-3 of the main control box (Fig. 34) is for receiving and driving bidirectional lines from the computer. It is identical to board A-2 main control box except for the addition of one inverter, IC-3 output #10.

Board A-4 of the main control box (Fig. 35) receives control lines from the computer. It terminates twisted-pair cable with a resistor chain (see board A-1) and is received by 7414 Schmitt triggers.

Fig. 33. Board A-1, main control box.

Fig. 34. Boards A-2 and A-3, main control box.

Fig. 35. Boards A-4 and A-5, main control box.

Board A-5 of the main control box receives control lines from the computer. It is identical to board A-4.

Board A-6 of the main control box (Fig. 36) is another general purpose board used to receive signal lines from the motor control box. The ICs are DM8820 differential line receivers, which terminate the twisted-pair cable with an internal resistor through the external $0.01\text{-}\mu\text{F}$ capacitor. This ac coupling allows good termination but prevents dc power drain. The transistor amplifier watches the + 5-V power supply in the motor control box and gates off the receivers when the power is off. This prevents hanging on the computer lines if power is not on.

Board A-7 of the main control box (Fig. 37) is a general purpose differential line driver board used to drive the control lines to the motor control box. It uses DM8830 differential line driver ICs. Pin 2 is a gate not used on this board. It is hooked to +5 V to hold the drivers on at all times.

Board A-8 of the main control box (Fig. 38) is a general purpose 16-bit latch board with tri-state outputs. ICs 1, 2, and 3 are used for latching the data lines from the ADC, and IC 4 is used for holding data lines 0-3 of the tri-state bus down when not in use. Notice that IC-4 pin #15 is tied to +5 V. This holds it in a constant reset mode. In ICs 1, 2, and 3 information is latched on the rising edge of the clock pulse, which comes in on pin #21 and is transmitted to the tri-state bus when the output control line, pin #3, is interrogated.

Board A-9 of the main control box (Fig. 39) contains the ADC control logic. It receives from the ADC the "store" command on pin #22 and sends out to the ADC the "clear" signal on pin #9. Notice once again that these are twisted-pair lines in a cable and that the receiving is done through a resistor chain into a Schmitt trigger. On the first "store"

Fig. 36. Board A-6, main control box.

Fig. 37. Board A-7, main control box.

Fig. 38. Boards A-8 and B-12, main control box.

Fig. 39. Board A-9, main control box.

command the ADC gate signal goes out to latch the data into the interface latches as well as a "clear" signal to start the ADC again. Notice that the "clear" pulse is generated by a univibrator, IC-2 output #8 and IC-4 output #3, which widens the pulse as required by the ADC circuitry. This pulse also sets the busy flipflop, IC-6 outputs #6 and #8, which in turn sets the computer interrupt flipflop, IC-1 outputs #5 and #6, if the mask flipflop, IC-1 output #8, has not been set by the computer.

Notice that until the computer resets the busy flip-flop, the "store" signal from the ADC is gated off, and the ADC must hold new data while the computer retrieves the first data from the interface latches, thus providing double buffering on input data.

Board A-10 of the main control box (Fig. 40) is another general purpose board containing 74125 tri-state driver ICs. In this case the board serves to gate the motor status bits onto the tri-state bus to the computer. Since there are only six bits of information, the remaining inputs are grounded. A signal on pin #22 opens the gates to the bus.

Board A-14 of the main control box (Fig. 41) drives the switch-enable LEDs, detects a change in the range switch, and decodes the device codes from the computer. The cathodes of the enable LEDs hook to the 120-ohm current limiting resistors, and the anodes connect to +5 V.

The range switch code lines are watched by the OR circuits IC-8 output #6 and IC-6 output #10. When any line changes, a univibrator is triggered, IC-7 output #13. The time constant of this univibrator is long enough that switch bounce dies out before the end of this output pulse. At the falling edge of the output, the second univibrator, IC-7 output #5, is triggered. The output of this second univibrator is long enough to be TTL compatible.

74125

Fig. 40. Board A-10, main control box.

The bottom of Fig. 41 shows the device code decoder. The computer furnishes a six-line code to indicate which device is to be interrogated or controlled. This circuit changes these codes, used in this interface, into a one-line command.

Board B-1 of the main control box houses a commercial 15-V power supply. Caution: 115-V ac comes in on pins #19, #20, #21, and #22. Pins #3 and #4 are the -15-V output, pins #5 and #6 are the output common, and pins #7 and #8 are the +15-V output. This power supply furnishes power to the digital-to-analog converters that drive the x- and y-deflection inputs on the oscilloscope.

Board B-4 of the main control box (Fig. 42) contains the oscilloscope x- and y-digital-to-analog converters. These are in a 16-pin DIP package and have 10-bit resolution. The output of these converters is a current signal that connects to a variable resistor network to ground to produce a voltage signal. To boost this voltage and lower the impedance to the requirements of the oscilloscope, the signal is amplified by an LM301 operational amplifier with a fixed gain of about 1.3. The 33-pF capacitor sets its frequency response down to a stable point. The 1-k Ω potentiometer permits adjustment of the output voltage between narrow limits to match the oscilloscope gain requirements.

Board B-6 of the main control box (Fig. 43) is a general purpose latch board used in this case to store the oscilloscope x-input -bit address. The unused sections are left unconnected. The output control pin Z is tied to ground to enable the tri-state output at all times. The clock signal is a computer control pulse which gates in a new address on the rising edge of the pulse.

Fig. 42. Board B-4, main control box.

Fig. 43. Boards B-6 and B-7, main control box.

Board B-7 of the main control box (Fig. 43) is a general purpose latch board used here for storage of the ten-bit address of the y-input scope deflection. It is the same board and is used in the same way as board B-6.

Board B-8 of the main control box (Fig. 44) contains the oscilloscope interface, line drivers for the computer interrupt and busy lines, and gating involved in tying down unused lines on the tri-state bus.

The main portion of the scope interface transforms combinations of computer pulses into signals that drive the oscilloscope. The only part requiring detailed discussion is the busy section. This section must present a busy signal to the computer after it gives a new x- and/or y- position until the scope has had time to respond. The Tektronix 613 oscilloscope watches for a change in its coordinate inputs and furnishes a 613 busy signal, but it will not see a small change of only one or two bits in the 10-bit digital-to-analog converter. For this reason, IC-8 output #6 is a uni-vibrator designed to trigger on an x- or y-latch signal. The time constant here is long enough to insure that the scope is ready or has given out its own busy signal. These two busy signals are ORed together before being sent to the computer.

A few SGS units have a Tektronix 603 display unit rather than a Tektronix 613 display. The interfaces differ somewhat. The schematic for Board B-8 for units with the Tektronix 603 is given as Fig. B-7 of Appendix B.

The interrupt and busy signals from all parts of the interface come into the appropriate section of IC 3, where they are ORed together, after which they go through open collector twisted-pair line drivers, IC-7 outputs #2 and #12, to the computer.

The section in the upper right-hand corner of the above schematic gates on or off pull-down gates on the

Fig. 44. Board B-8, main control box.

tri-state bus as needed. Without such pull downs the TTL inputs will float up and be subject to noise. This could drag down the computer data lines and prevent proper operation of the computer program.

Board B-9 of the main control box (Fig. 45) handles several portions of the front panel-switch interface. It contains the computer busy and interrupt flipflops related to the switches, IC-6 outputs #11 and #8, and IC-7 output #8, respectively. It also contains the three mask flipflops, IC-3 outputs #5 and #6, IC-7 output #6, and IC-3 output #9, which are set up by the computer program to control access to the computer interrupt line by the switches.

IC-6 output #3 is set up as a leading edge detector designed to clean up the ORed switch output before storing the switch identity in the switch latches.

The remaining section at the bottom of Fig. 45 codes the range switch in a four-bit BCD format.

Board B-10 of the main control box (Fig. 46) is a general purpose tri-state buffer board divided for this application into two sections. The upper five bits gate the four-bit range switch position, and the one-bit print mode switch position onto the tri-state bus on request of the computer. The lower portion of the board is used for pull-down of bits 5-15 on the tri-state bus when they are not in use. This prevents the interface from dragging down the computer lines when not being interrogated.

Board B-11 of the main control box (Fig. 47) contains the logic that masks and ORs the signals from the interrupting front panel switches. The inverted signals from the board go to latches that set a particular bit on the computer data lines corresponding to the activated pushbutton. The gating signals come from the three mask flipflops and the local-computer switch to enable only relevant switches at any given time. After filtering through the mask gates the

Fig. 45. Board B-9, main control box.

74125

Fig. 46. Board B-10, main control box.

Fig. 47. Board B-11, main control box.

signals are ORed and go out to set the latches and computer interrupt. The three "run enable" LED drivers, IC-4 outputs #3 and #8, are also on this board. The 120-ohm resistors hook to the cathode of the LEDs, and the anode is connected to the +5-V bus.

Board B-12 of the main control box (Fig. 38) is a general purpose tri-state latch board. IC's 1, 2, and 3 gate the identities of the interrupting front panel switches onto the tri-state bus upon request from the computer. IC 4 is used to pull down bit 4 on the tri-state bus when not in use.

Board B-13 of the main control box (Fig. 48) contains receiver debouncer circuits for the I/O pushbutton switches on the front panel. These are built around the MCS-2 photo-SCR opto-isolator driving into a 7414 Schmitt trigger. When the switch is closed, 5 V is applied across the 100-ohm current limiting resistor and the LED. This triggers the SCR that discharges the $0.001\text{-}\mu\text{F}$ capacitor into the 510-ohm resistor. This creates a voltage drop across the 510-ohm resistor which triggers the 7414. This R-C time constant creates a $1\text{-}\mu\text{s}$ output pulse. Switch bounce is eliminated since the SCR, once triggered, will not turn off until it has discharged the $0.001\text{-}\mu\text{F}$ capacitor. After discharging the capacitor, the $10\text{-M}\Omega$ resistor cannot furnish sufficient holding current, and the SCR turns off. The capacitor then charges through the $10\text{-M}\Omega$ resistor, and the circuit is armed again. This last charging time constant is long enough that accidental double triggering of the switch will result in only one output pulse.

Board B-14 of the main control box (Fig. 49) is a general purpose tri-state driver board used here to gate the cursor position thumbwheel switches onto the tri-state bus upon request from the computer. The $0.01\text{-}\mu\text{F}$ capacitors suppress noise on the switch lines.

Figure 50 indicates the method of connecting and switching the 115-V ac line.

MCS-2

Fig. 48. Board B-13, main control box.

74125

Fig. 49. Board B-14, main control box.

TABLE VII

MOTOR CONTROL BOX WIRING LIST

<u>Connections</u>		<u>Function</u>	<u>Connections</u>		<u>Function</u>
J-1-1*	A-3-19	TOP F SLOT	J-6-34*	A-1-10	DATA-
J-1-6*	A-3-2	GND	J-6-14*	A-1-M	ROENB+
J-1-2*	A-3-Y	TOP F SLOT SUPPLY	J-6-33*	A-1-11	ROENB-
J-1-7*	A-3-2	GND	J-6-13*	A-1-P	STRT+
J-1-3*	A-3-13	TOP SLOT	J-6-32*	A-1-13	STRT-
J-1-8*	A-3-B	GND	J-6-12*	A-1-R	CLR+
J-1-4*	A-3-21	TOP SLOT SUPPLY	J-6-31*	A-1-14	CLR-
J-1-9*	A-3-B	GND	J-6-9*	A-2-F	SELB+
J-2-1*	A-3-16	BOTTOM SLOT	J-6-28*	A-2-6	SELB-
J-2-6*	A-2-B	GND	J-6-8*	A-2-E	INTR+
J-2-2*	A-3-2	BOTTOM SLOT SUPPLY	J-6-27*	A-2-5	INTR-
J-2-7*	A-2-B	GND	J-6-7*	A-2-K	SELD+
J-2-3*	A-3-X	BOTTOM F SLOT	J-6-26*	A-2-9	SELD-
J-2-8*	A-2-2	GND	J-6-6*	A-2-8	DATA 15+
J-2-4*	A-3-22	BOTTOM F SLOT SUPPLY	J-6-25*	A-2-J	DATA 15-
J-2-9	A-2-2	GND	J-6-5*	A-2-N	DATA 14+
J-3-A*	A-12-19	COUNT	J-6-24*	A-2-12	DATA 14-
J-3-B*	A-12-2	GND	J-6-4*	A-2-11	DATA 13+
J-3-H	A-1-A	+5V	J-6-23*	A-2-M	DATA 13-
J-3-E*	A-12-18	GATE	J-6-3*	A-2-15	DATA 12+
J-3-D	A-12-2	GND	J-6-22*	A-2-S	DATA 12-
J-4-A*	A-3-W	U-D PULSE	J-6-2*	A-2-14	DATA 11+
J-4-B*	A-3-B	GND	J-6-21*	A-2-R	DATA 11-
J-4-E*	A-14-21	DIRECTION	J-6-1*	A-2-18	DATA 10+
J-4-D*	A-14-2	GND	J-6-20*	A-2-V	DATA 10-
J-4-H	A-1-B	GND	A-3-11	A-5-5	S
J-5-A*	A-5-8	ROT PULSE	A-3-17	A-5-6	R
J-5-B*	A-5-2	GND	A-3-12	A-12-17	BUSY
J-5-H	A-1-2	GND	A-3-5	A-4-S	FAST
J-5-E*	A-1-1	+5 (ROT DIRECTION)	A-3-8	A-5-14	FAST OSC
J-5-D*	A-1-2	GND	A-3-18	A-5-10	U-D SYNC OUT

* twisted pair

TABLE VII (cont)

<u>Connections</u>		<u>Function</u>	<u>Connection</u>		<u>Function</u>
J-6-19	A-1-2	GND	A-3-7	A-14-22	GO
J-6-18*	A-1-C	DC74+	A-3-14	A-4-V	<u>T-SLOT</u>
J-6-37*	A-1-3	DC74-	A-4-V	A-12-15	<u>T-SLOT</u>
J-6-17*	A-1-F	IOPLS+	A-12-15	A-14-6	<u>T-SLOT</u>
J-6-36*	A-1-6	IOPLS-	A-3-15	A-4-E	<u>B-SLOT</u>
J-6-16*	A-1-H	IORST+	A-4-E	A-14-13	<u>B-SLOT</u>
J-6-35	A-1-7	IORST-	A-3-S	A-2-10	T-SLOT
J-6-15*	A-1-L	DATIA+	A-3-V	A-2-7	LOAD
A-4-C	A-1-N	STRT	A-3-10	LED	LED
A-4-D	A-1-4	DC74	A-14-4	SWITCH	L-C SWITCH
A-4-W	A-13-22	ENG (SEG)	A-14-4	A-3-6	L-C SWITCH
A-13-22	A-12-11	ENG (SEG)	A-3-6	A-1-J	L-C SWITCH
A-4-F	A-1-8	IORST	A-14-9	SWITCH	DOWN SWITCH
A-4-F	A-12-13	IORST	A-14-8	SWITCH	UP SWITCH
A-12-13	A-13-21	IORST	A-11-3	SWITCH	1 LSB
A-4-D	A-4-N	DC74	A-13-15	SWITCH	2 HEIGHT SWITCH
A-4-N	A-12-5	DC74	A-13-16	SWITCH	4
A-4-P	A-1-S	CLR	A-13-12	SWITCH	8 MSB
A-4-R	A-2-13	START	A-14-8	A-3-3	UP SWITCH
A-4-J	A-14-3	"UP"	A-14-9	A-3-4	DOWN SWITCH
A-4-K	A-2-W	UPF.F.	A-2-3	A-3-6	L-C SWITCH
A-4-X	A-14-7	DN FAST	A-1-1	J-6-11	+5 ON
A-4-U	A-14-5	DN SLOW	A-2-P	A-2-3	L-C SWITCH
A-4-T	A-2-T	FAST	J-6-10	A-1-T	DATOA+
A-4-Y	A-3-7	GO	J-6-29	A-1-16	DATOA-
A-5-15	A-14-14	SPEED	A-1-15	A-12-D	DATOA
A-12-16	A-14-10	SCALER ENABLE	A-12-22	A-13-10	RUN
A-12-14	A-13-9	END	A-13-11	A-11-21	CARRY
A-12-7	A-2-H	SELB	A-13-M	A-11-20	BORROW
A-12-6	A-1-5	IOPLS	A-12-14	A-11-9	END
A-12-4	A-1-9	DATIA	A-11-10	A-13-14	LSB HEIGHT

*twisted pair

TABLE VII (cont)

<u>Connections</u>		<u>Function</u>	<u>Connections</u>		<u>Function</u>
A-12-12	A-13-5	RESET SCALER	A-13-15	A-11-D	HEIGHT
A-12-9	A-1-12	RQENB	A-13-16	A-11-5	HEIGHT
A-12-10	A-2-4	INTR	A-13-12	A-11-C	HEIGHT
A-12-8	A-2-L	SELD	A-13-13	A-11-4	MSB HEIGHT
A-12-3	A-2-Z	DRIVER GATE	A-11-22	A-13-5	RESET SCALER
A-12-21	A-13-3	CCW	A-11-14	A-13-4	CW
A-12-20	A-13-4	CW	A-11-16	A-12-17	BUSY
A-3-20	LED	LOAD LED	A-11-15	A-3-S	T-SLOT
A-3-9	LED	LED	A-4-11	A-13-20	INIT

TABLE VIII

MAIN CONTROL BOX WIRING LIST

<u>Connections</u>		<u>Function</u>	<u>Connections</u>		<u>Function</u>
B-1-3*	B-4-5	-15V	B-6-8	B-7-8	BIT 12
B-1-5*	B-4-R	GND	B-6-9	B-7-9	BIT 11
B-1-6*	B-4-E	GND	B-6-10	B-7-10	BIT 10
B-1-8*	B-4-F	+15V	B-6-11	B-7-11	BIT 9
B-4-2	B-6-2	GND	B-6-12	B-7-12	BIT 8
B-4-3	B-6-E	X BIT 15	B-6-13	B-7-13	BIT 7
B-4-4	B-6-F	X BIT 14	B-6-14	B-7-14	BIT 6
B-4-5	B-6-H	X BIT 13	B-6-Z	B-6-B	ENABLE
B-4-6	B-6-J	X BIT 12	B-7-Z	B-7-B	ENABLE
B-4-7	B-6-K	X BIT 11	B-6-Y	B-8-E	X LATCH
B-4-8	B-6-L	X BIT 10	B-7-Y	B-8-H	Y LATCH
B-4-9	B-6-M	X BIT 9	B-8-F	A-4-10	DATOA
B-4-10	B-6-N	X BIT 8	B-8-J	A-4-9	DATOB

*twisted pair

TABLE VIII (cont)

<u>Connections</u>		<u>Function</u>	<u>Connections</u>		<u>Function</u>
B-4-11	B-6-P	X BIT 7	B-8-3	A-14-7	DC34
B-4-12	B-6-R	X BIT 6	B-8-5	A-5-9	IOPLS
B-4-13	B-7-E	Y BIT 15	B-8-7	A-4-3	CLR
B-4-14	B-7-F	Y BIT 14	B-8-11	A-5-19	STRT
B-4-15	B-7-H	Y BIT 13	A-1-D	A-8-5	AO
B-4-16	B-7-J	Y BIT 12	A-1-5	A-8-6	A1
B-4-17	B-7-K	Y BIT 11	A-1-C	A-8-7	A2
B-4-18	B-7-L	Y BIT 10	A-1-4	A-8-8	A3
B-4-19	B-7-M	Y BIT 9	A-1-3	A-8-9	A4
B-4-20	B-7-N	Y BIT 8	A-1-22	A-8-10	A5
B-4-21	B-7-P	Y BIT 7	A-1-Z	A-8-11	A6
B-4-22	B-7-R	Y BIT 6	A-1-21	A-8-12	A7
B-6-5	A-2-C	BIT 15	A-1-X	A-8-13	A8
B-6-6	A-2-D	BIT 14	A-1-Y	A-8-14	A9
B-6-7	A-2-E	BIT 13	A-1-20	A-8-15	A10
B-6-8	A-2-H	BIT 12	A-8-16	A-8-2	GND
B-6-9	A-2-F	BIT 11	B-8-18	B-9-W	SWITCH READ
B-6-10	A-2-V	BIT 10	B-8-19	B-9-19	T.W. READ
B-6-11	A-2-W	BIT 9	B-8-22	A-9-10	ADC READ
B-6-12	A-2-X	BIT 8	B-8-20	A-8-Z	DATA 0-3 FREE
B-6-13	A-2-Y	BIT 7	A-8-3	A-9-10	ADC READ
B-6-14	A-2-Z	BIT 6	A-8-Y	A-9-7	ADC GATE
B-6-5	B-7-5	BIT 15	B-8-6	B-8-S	SELB
B-6-6	B-7-6	BIT 14	A-8-E	A-2-3	DATA 15
B-6-7	B-7-7	BIT 13	A-8-F	A-2-4	DATA 14
A-8-J	A-2-7	DATA 12	A-12-14	B-11-7	ANALYZE
A-8-K	A-2-6	DATA 11	B-13-W	B-11-J	CURSOR
A-8-L	A-2-19	DATA 10	B-12-15	B-11-8	CURSOR
A-8-M	A-2-18	DATA 9	A-14-U	B-12-6	RANGE CHANGE
A-8-N	A-2-20	DATA 8	B-12-6	B-11-5	RANGE CHANGE
A-8-P	A-2-21	DATA 7	B-12-Y	B-9-C	SWITCH LATCH
A-8-R	A-2-22	DATA 6	B-9-3	B-11-P	SWITCH OR
A-8-S	A-3-3	DATA 5	B-12-3	B-9-W	SWITCH READ
A-8-T	A-3-4	DATA 4	B-12-E	A-8-E	DATA 15
			A-8-H	A-2-5	DATA 13

TABLE VIII (cont)

<u>Connections</u>		<u>Function</u>	<u>Connections</u>		<u>Function</u>
A-8-U	A-3-5	DATA 3	B-12-F	A-8-F	DATA 14
A-8-V	A-3-7	DATA 2	B-12-H	A-8-H	DATA 13
A-8-W	A-3-6	DATA 1	B-12-J	A-8-J	DATA 12
A-8-X	A-3-19	DATA 0	B-12-K	A-8-K	DATA 11
A-9-13	A-4-J	DATIA	B-12-L	A-8-L	DATA 10
A-9-14	A-14-J	DC 44	B-12-M	A-8-M	DATA 9
A-9-8	B-8-V	SELB	B-12-N	A-8-N	DATA 8
A-9-3	A-5-V	RQENB	B-12-P	A-8-P	DATA 7
A-9-4	B-8-P	INTR	B-12-R	A-8-R	DATA 6
A-9-15	A-4-3	CLR	B-12-S	A-8-S	DATA 5
A-9-21	A-5-L	IORST	B-11-N	B-9-X	SWITCH OR
B-8-21	B-10-22	DATA 5-15 FREE	B-11-14	B-9-T	MASK
B-10-4	B-12-22	DATA 4 FREE	B-11-13	B-9-14	MASK
B-13-10	B-11-U	STOP	B-11-12	B-9-15	MASK
B-12-5	B-11-17	STOP	B-9-Y	A-4-8	DATIB
B-13-9	B-11-V	WINDOW START	B-9-20	A-14-H	DC 42
B-12-7	B-11-18	WINDOW START	B-9-21	A-4-J	DATIA
B-13-K	B-11-T	WINDOW STOP	B-9-18	A-5-V	RQENB
B-12-8	B-11-16	WINDOW STOP	B-9-17	A-5-L	IORST
B-13-M	B-11-5	ENTER	B-9-Z	B-8-7	CLR
B-12-9	B-11-15	ENTER	B-9-S	B-7-14	DATA 6
B-13-11	B-11-K	ASSAY START	B-9-16	A-5-U	MSKO
B-12-10	B-11-9	ASSAY START	B-9-U	A-3-C	DATA 5
B-13-12	B-11-L	BKGD START	B-13-S*	SWITCH	ANALYZE
B-12-11	B-11-10	BKGD START	B-13-15*	SWITCH	RTRN
B-13-18	B-11-M	SETUP	B-13-T*	SWITCH	CURSOR
B-12-12	B-11-11	SETUP	B-13-16*	SWITCH	RTRN
B-13-17	B-11-F	ECHO	A-14-11	LED	READY
B-12-13	B-11-6	ECHO	A-14-15	LED	CURSOR ON
B-13-U	B-11-H	ANALYZE			
A-14-S	LED	CURSON ON	J-2-32*	A-7-M	STRT-

*twisted pair

TABLE VIII (cont)

<u>Connections</u>		<u>Function</u>	<u>Connections</u>		<u>Function</u>
A-14-M	LED	READY	J-2-12*	A-7-15	CLR+
A-14-12	LED	READY	J-2-31*	A-7-S	CLR-
A-14-P	LED	READY	A-6-12	B-11-R	LOC-COMP
A-14-13	LED	READY	B-9-19	B-14-22	T.W. READ
B-11-22	LED	READY-LOCAL	B-9-W	B-10-3	SWITCH READ
B-11-W	LED	READY-COMP	B-9-22	B-8-U	SELB
B-11-X	LED	READY-COMP	B-9-V	B-8-N	INTR
B-8-L	A-10-22	MOTOR READ	B-9-15	A-14-16	MASK
B-8-12	A-14-9	DC 74	B-9-14	A-14-17	MASK
B-8-13	B-9-21	DATIA	B-9-T	A-14-T	MASK
A-10-4	A-8-E	DATA 15	B-9-5	B-10-J	RANGE "1"
A-10-5	A-8-F	DATA 14	B-9-D	B-10-H	RANGE "2"
A-10-6	A-8-H	DATA 13	B-9-4	B-10-F	RANGE "4"
A-10-7	A-8-J	DATA 12	B-9-9	B-10-E	RANGE "8"
A-10-8	A-8-K	DATA 11	B-10-8	A-3-4	DATA 4
A-10-9	A-8-L	DATA 10	B-10-7	A-3-5	DATA 3
A-10-10	A-8-M	DATA 9	B-10-6	A-3-7	DATA 2
A-10-11	A-8-N	DATA 8	B-10-5	A-3-6	DATA 1
A-10-12	A-8-P	DATA 7	D-10-4	A-3-19	DATA 0
A-10-13	A-8-R	DATA 6	B-14-4	B-12-E	DATA 15
A-10-14	A-8-S	DATA 5	B-14-5	B-12-F	DATA 14
A-10-15	A-8-T	DATA 4	B-14-6	B-12-H	DATA 13
A-10-16	A-8-U	DATA 3	B-14-7	B-12-J	DATA 12
A-10-17	A-8-V	DATA 2	B-14-8	B-12-K	DATA 11
A-10-18	A-8-W	DATA 1	B-14-9	B-12-L	DATA 10
A-10-19	A-8-X	DATA 0	B-14-10	B-12-M	DATA 9
J-2-19	A-1-B	GND	B-14-11	B-12-N	DATA 8
J-2-18*	A-7-6	DC 74+	B-14-12	B-12-P	DATA 7
J-2-37*	A-7-F	DC 74-	B-14-13	B-12-R	DATA 6
J-2-17*	A-7-5	IOPLS+	B-14-14	B-12-S	DATA 5
J-2-36*	A-7-E	IOPLS-	B-14-15	B-10-8	DATA 4
J-2-16*	A-7-9	IORST+	B-14-16	B-10-7	DATA 3

*twisted pair

TABLE VIII (cont)

<u>Connections</u>	<u>Function</u>	<u>Connections</u>	<u>Function</u>
J-2-35* A-7-K	IORST-	B-14-17 B-10-6	DATA 2
J-2-15* A-7-8	DATIA+	B-14-18 B-10-5	DATA 1
J-2-34* A-7-J	DATIA-	B-14-19 B-10-4	DATA 0
J-2-14* A-7-12	RQENB+	A-14-4 A-5-8	DS5
J-2-33* A-7-N	RQENB-	A-14-C A-5-J	DS4
J-2-13* A-7-11	STRT+	A-14-3 A-5-3	DS3
A-14-E A-4-W	DS2	A-7-4 A-5-9	IOPLS
A-14-D A-4-18	DS1	A-7-L A-5-L	IORST
A-14-5 A-4-19	DS0	A-7-7 A-9-13	DATIA
B-8-10* J-1-4	Z	A-7-P A-9-3	RQENB
B-8-2* J-1-5	GND	A-7-10 A-5-19	STRT
B-8-8* J-1-18	<u>ERASE</u>	A-7-T A-9-15	CLR
B-8-2* J-1-17	GND	A-6-4 B-8-T	SELB
B-8-9* J-1-6	<u>NONSTORE</u>	A-6-5 B-8-M	INTR
B-8-C J-1-13	GND	A-6-8 A-3-22	SELD
B-8-4 J-1-7	<u>BUSY</u>	A-7-Z A-7-A	+5V
B-8-D* J-1-9	GND	A-9-6 A-5-U	MASKO
A-1-7* J-3-1	A0	A-9-D A-3-E	DATA 3 (RCV)
A-1-H* J-3-20	GND	A-14-X B-9-5	RANGE "1"
J-2-9* A-6-C	SELB+	A-14-21 B-9-D	RANGE "2"
J-2-28* A-6-3	SELB-	A-14-22 B-9-4	RANGE "4"
J-2-8* A-6-F	INTR+	A-14-Z B-9-9	RANGE "8"
J-2-27* A-6-6	INTR-	A-14-Y SWITCH	RANGE 0
J-2-7 A-6-H	SELD+	B-9-13 B-11-4	RANGE MASK
J-2-26* A-6-7	SELD-	B-9-12 A-3-D	DATA 4 (RCV)
J-2-6* A-6-L	DATA 15+	B-9-F SWITCH	RANGE 1
J-2-25* A-6-10	DATA 15-	B-9-H SWITCH	RANGE 2
J-2-5* A-6-M	DATA 14+	B-9-7 SWITCH	RANGE 3
J-2-24* A-6-11	DATA 14-	B-9-J SWITCH	RANGE 4
J-2-4* A-6-P	DATA 13+	B-9-K SWITCH	RANGE 5
J-2-23* A-6-13	DATA 13-	B-9-8 SWITCH	RANGE 6
J-2-3* A-6-R	DATA 12+	A-1-8* J32	A1

*twisted pair

TABLE VIII (cont)

<u>Connections</u>	<u>Function</u>	<u>Connections</u>	<u>Function</u>
J-2-22* A-6-14	DATA 12-	A-1-J* J-3-21	GND
J-2-2* A-6-T	DATA 11+	A-1-9* J-3-3	A2
J-2-21* A-6-16	Data 11-	A-1-K* J-3-22	GND
J-2-1* A-6-U	DATA 10+	A-1-10* J-3-4	A3
J-2-20* A-6-17	DATA 10-	A-1-L* J-3-23	GND
A-10-D A-6-9	DATA 15	A-1-11* J-3-5	A4
A-10-E A-6-12	DATA 14	A-1-M* J-3-24	GND
A-10-F A-6-N	DATA 13	A-1-13* J-3-6	A5
A-10-H A-6-S	DATA 12	A-1-P* J-3-25	GND
A-10-J A-6-15	DATA 11	A-1-14* J-3-7	A6
A-10-K A-6-V	DATA 10	A-1-R* J-3-26	GND
A-7-H A-14-9	DC74	A-1-15* J-3-8	A7
A-1-16* J-3-9	A8	A-2-10* J-4-16	DATA 13
A-1-T* J-3-28	GND	A-2-L* J-4-1	GND
A-1-17* J-3-10	A9	A-2-11* J-4-17	DATA 14
A-1-U* J-3-29	GND	A-2-M* J-4-1	GND
A-1-18* J-3-11	A10	A-2-12* J-4-18	DATA 15
A-1-V* J-3-30	GND	A-2-N* J-4-1	GND
A-9-22* J-3-12	STORE	A-4-5* J-4-19	DATIA
A-9-2* J-3-31	GND	A-4-E* J-4-1	GND
A-9-9* J-3-13	CLEAR	A-4-6* J-4-20	DATIB
A-9-2* J-3-32	GND	A-4-F* J-4-1	GND
A-4-4* J-4-2	CLR	A-4-7* J-4-21	DATIC
A-4-D* J-4-1	GND	A-4-H* J-4-1	GND
A-3-16* J-4-3	DATA 0	A-4-11* J-4-22	DATOA
A-3-T* J-4-1	GND	A-4-M* J-4-1	GND
A-3-9* J-4-4	DATA 1	A-4-12* J-4-23	DATOB
A-3-K* J-4-1	GND	A-4-N* J-4-1	GND
A-3-8* J-4-5	DATA 2	A-4-13* J-4-24	DATOC
A-3-J* J-4-1	GND	A-4-P* J-4-1	GND
A-3-10* J-4-6	DATA 3	A-4-14* J-4-25	DCHA
A-3-L* J-4-1	GND	A-4-R* J-4-1	GND
		A-1-S* J-3-27	GND

* twisted pair

TABLE VIII (cont)

<u>Connections</u>	<u>Function</u>	<u>Connections</u>	<u>Function</u>
A-3-11* J-4-7	DATA 4	A-4-15* J-4-26	DCHI
A-3-M* J-4-1	GND	A-4-S* J-4-1	GND
A-3-12* J-4-8	DATA 5	A-3-17* J-4-27	DCHM 0
A-3-N* J-4-1	GND	A-3-U* J-4-1	GND
A-2-13* J-4-9	DATA 6	A-3-15* J-4-28	DCHM 1
A-2-P* J-4-1	GND	A-3-S* J-4-1	GND
A-2-14* J-4-10	DATA 7	A-5-21* J-4-29	DCHO
A-2-R* J-4-1	GND	A-5-Y* J-4-1	GND
A-2-15* J-4-11	DATA 8	A-4-16* J-4-30	DCHP
A-2-S* J-4-1	GND	A-4-T* J-4-1	GND
A-2-17* J-4-12	DATA 9	A-3-14* J-4-31	DCHR
A-2-U* J-4-1	GND	A-3-R* J-4-1	GND
A-2-16* J-4-13	DATA 10	A-4-20* J-4-32	DS0
A-2-T* J-4-1	GND	A-4-X* J-4-1	GND
A-2-9* J-4-14	DATA 11	A-4-21* J-4-33	DS1
A-2-K* J-4-1	GND	A-4-Y* J-4-1	GND
A-2-8* J-4-15	DATA 12	A-4-22* J-4-34	DS2
A-2-J* J-4-1	GND	A-4-Z* J-4-1	GND
A-5-D* J-4-1	GND	B-10-12 B-12-N	DATA 8
A-5-5* J-4-36	DS4	B-10-13 B-12-M	DATA 9
A-5-E* J-4-1	GND	B-10-14 B-12-L	DATA 10
A-5-6* J-4-37	DS5	B-10-15 B-12-K	DATA 11
A-5-F* J-4-1	GND	B-10-16 B-12-J	DATA 12
A-5-7* J-4-38	INTA	B-10-17 B-12-H	DATA 13
A-5-H* J-4-1	GND	B-10-18 B-12-F	DATA 14
A-5-11* J-4-39	INTP	B-10-19 B-12-E	DATA 15
A-5-M* J-4-1	GND	B-13-C* SWITCH	STOP
B-8-14 J-4-40	INTR	B-13-3* SWITCH	RTRN
B-8-C* J-4-1	GND	B-13-D* SWITCH	WINDOW START
A-5-12 J-4-41	IOPLS	B-13-4* SWITCH	RTRN
A-5-N* J-4-1	GND	B-13-E* SWITCH	WINDOW STOP
A-5-13* J-4-42	IORST	B-13-5* SWITCH	RTRN
		A-5-4 J-4-35	DS3

* twisted pair

TABLE VIII (cont)

<u>Connections</u>	<u>Function</u>	<u>Connections</u>	<u>Function</u>
A-5-P* J-4-1	GND	B-13-F* SWITCH	ENTER
A-5-14* J-4-43	MSKO	B-13-6* SWITCH	RTRN
A-5-R* J-4-1	GND	B-13-H* SWITCH	ASSAY START
A-5-15* J-4-44	OVFLO	B-13-7* SWITCH	RTRN
A-5-S* J-4-1	GND	B-13-J* SWITCH	BKGD START
A-5-16* J-4-45	ROENB	B-13-8* SWITCH	RTRN
A-5-T* J-4-1	GND	B-13-P* SWITCH	SETUP
B-8-15* J-4-46	SELB	B-13-13* SWITCH	RTRN
B-8-D* J-4-1	GND	B-13-R* SWITCH	ECHO
A-3-13* J-4-47	SELD	B-13-14* SWITCH	RTRN
A-3-P* J-4-1	GND	B-9-6 SWITCH	RANGE 7
A-5-20* J-4-48	STRT	B-9-E SWITCH	RANGE 8
A-5-X* J-4-1	GND	B-14-D SWITCH	T.W. 1 (LSB)
B-4-N** J-1-15	Y+	B-14-E SWITCH	T.W.2
B-4-M* J-1-16	Y-	B-14-F SWITCH	T.W.4
R-6-2** J-1-3	Y SHIELD	B-14-H SWITCH	T.W.8
B-4-C** J-1-1	X+	B-14-J SWITCH	T.W.1
B-4-B** J-1-2	X-	B-14-K SWITCH	T.W.2
B-7-2** J-1-14	X SHIELD	B-14-L SWITCH	T.W.4
B-12-U B-10-8	DATA 4	B-14-M SWITCH	T.W.8
B-10-9 B-12-S	DATA 5	B-14-N SWITCH	T.W.1
B-10-10 B-12-R	DATA 6	B-14-P SWITCH	T.W.2
B-10-11 B-12-P	DATA 7	B-14-R SWITCH	T.W.4
B-14-U SWITCH	T.W.2	J-2-10* A-7-14	DATOA+
B-14-V SWITCH	T.W.4	J-2-29* A-7-R	DATOA-
B-14-W SWITCH	T.W.8 (MSB)	A-7-13 A-4-10	DATOA
B-10-D SWITCH	PRINT MODE	J-4-49 SWITCH	POWER ON
A-6-J J-2-11	+50N	J-4-1 SWITCH	GND
		B-14-S SWITCH	T.W.8
		B-14-T SWITCH	T.W.1

*twisted pair

**shielded twisted pair

Fig. 50. Alternating-current wiring.

C. Wiring Lists

The wiring connections for the board-to-board hookup of the motor control and main control boxes are given in Tables VII and VIII, respectively. Each line of the tables calls out the two ends of a single wire and names its function. Each wire end is designated first by a letter, either J indicating a connector on the back panel, or A or B designating the card cage. Next the socket or connector number is given, 1-14, and finally the pin number or letter on the connector; for example, B-12-Z calls out card cage B, connector 12, pin Z.

V. SYSTEM OPERATION

A. Physical Setup

After the basic units of the system have been unpacked, they should be physically configured as shown in Figs. 51 and

Fig. 51. SGS system showing large scan table.

Fig. 52. SGS system showing small scan table.

52. This arrangement permits the interconnecting cables to reach each unit. The electronic units should be mounted in the large rack in the order shown in the figures, with the display at the top, since this arrangement not only matches the interconnecting cables, but has been found to be operationally convenient. The physical placement of the small racks containing the motor drivers is not important provided that the cables will reach the scan tables, since in normal operation these units will not be used by the operator, except to turn on ac power to them. Figure 53 shows the cable arrangement between the various units of the system as viewed from the rear of the main electronics rack. The cables are not shown for the second set of detector, scan table, and motor drivers, but the arrangements are identical with the first set.

Figure 54 shows the cables and controls on the front of the electronics rack. The unipolar output of each amplifier goes to the appropriate input of a linear switch, and the output of the linear switch goes to the input of the analog to digital converter and to the oscilloscope used to monitor detector performance. The bipolar output of either amplifier may be taken to the input of the ratemeter to provide a quantitative check on gross count rates.

The ac line connections to the system components are shown in Fig. 55. All system units operate on 110-120 -V ac power at either 50 or 60 Hz. The terminal will require slight modification to change from one frequency to the other. For use in areas using 220-V ac power, a transformer is provided to bring the voltage down to the required level.

B. Operation of Power Switches

Provided that the units have been connected to ac power as shown in Fig. 56, operation is ready to commence. The operator should first make certain that the HV power supplies

Fig. 53. SGS System interconnecting cables.

Fig. 54. Closeup view of electronics rack.

Fig. 55. ac power connections.

Fig. 56. Close up of small scan table with shielding and collimator.

in the NIM bin are turned down to zero-volts output and the NIM bin switch is turned on. The key at the left-hand side of the computer controls ac power to this unit. It can also control power to all other electronics units as follows: When the power switch on the main interface panel is turned to the COMPUTER position, then ac power will be on this and all other units only if the computer key switch is turned on. In other words, with the interface power switch in this position, the computer key controls all ac power to the system. This will be the situation for normal operation. In case power must be placed on the other electronic units with the computer turned off, the power switch on the main interface panel must be placed in the ON position. This will permit power to all electronic units independent of the computer switch. The individual power switches on the other units operate as normal ac line switches when the general interface power switch is in the ON position, or when it is in the COMPUTER position, with the computer key switch turned on.

C. Program Loading

After the system is initially set up and cables connected, the first step toward operation is to load the program into the computer. This is done by transferring the system code from the tape cassettes to the computer via the GE Terminet 30 terminal. First, load the cassette containing the binary loader program into the tape transport mechanism on top of the terminal (either side will do) and make sure the terminal is in transparency mode. Next, set the computer console switches at 10_8 and press the RESET and PROGRAM LOAD switches on the computer console. Finally, press the READ switch on the cassette drive mechanism of the GE Terminet 30 causing the binary loader program to be read into the computer, which will take about a minute. The computer will halt when reading is complete, and the cassette can then be rewound and removed from the terminal. Next, the actual SGS codes are read into the computer by starting the computer at 37777_8 (rather than 10_8) and reading the SGS code cassette in the same fashion as for the binary loader cassette, (save that the processor START switch is pressed instead of PROGRAM LOAD), which will take about 8 min. The starting address for the SGS code is 440_8 ; hence, after loading the codes, this address is set into the computer console switches. The terminal is removed from the transparency mode, the RESET and START switches on the computer console are then pressed and the computer is up and running. The manufacturer's manuals for the GE Terminet 30 and its associated cassette mechanism should be consulted to become familiar with their operation.

D. Geometry

Referring now to Figs. 51 and 52, which show the scan tables, both large and small, it is imperative that the detector cryostat end cap be properly aligned with the transmission source and collimator. Various adjustments are available on the source holder, which permit exact alignment of these two elements. The detector is placed on its holder so that the end cap face is parallel with the front of the table and facing the source holder. The height and angular position of the source holder is adjusted so that the center of the source collimator views the exact center of the detector, and the line between them passes through the center of rotation of the turntable.

E. Collimation and Shielding

It is usual practice to place a thin disk of medium-Z gamma-ray absorber (cadmium is often used) over the front of the detector end cap in order to reduce preferentially the intensity of the lower energy x-rays and gamma rays that otherwise increase the gross counting rates and degrade the system performance without contributing to the information obtained. Provided that the disk is no thicker than about 1 mm, there are no serious attenuation problems at the energies of interest, even when uranium is being assayed.

The detector collimator for the small scan table, as shown in Fig. 57, consists of several lead bricks assembled around the front of the detector, with one specially machined brick that forms a 1.3-cm-high by 10.2-cm-deep slit in front of the detector. It is this collimator that determines the segment size on the sample assay. The collimator must be carefully assembled so that it is centered on the detector axis and is in close alignment with the transmission source holder and collimator.

Fig. 57. Close up of control panels.

More lead bricks are used to provide detector shielding from various background sources by building up the shield around all sides and the rear of the detector as shown in the figure. The detector collimator for the large scan table (when provided) is 5.1 cm high by 17.8 cm deep.

F. Matching Detector and Amplifier

At this point, the HV and signal cables should be checked to make sure they are properly connected. The preamp (located on the detector) receives its power from a connector on the back of the amplifier in the electronics rack, and its cable should also be checked. Make sure the amplifier in the NIM bin has power, so that the preamp is powered. Make sure the polarity of the HV power supply is correct before power is applied. Run up the high voltage slowly (no more than 200 V/s) to the prescribed voltage written on the detector (usually around 3 kV). At this point, the detector should be functional and signals should be seen at the output of the amplifier. It is virtually imperative that an oscilloscope

be used to adjust the system at this point, and the amplifier output should be monitored for the next few steps.

Place a source near the detector end cap (the rate correction source will do nicely at this point) and adjust the amplifier gain until the main peak from this source has an amplitude of a few volts. The pole-zero control on the amplifier must now be adjusted. The purpose of this adjustment is to match the preamplifier and amplifier time constants. The gain adjustment on the oscilloscope should be increased until the over- or undershoot on the signal at the baseline is clearly visible. It is also worthwhile to decrease sweep speed so that several pulses are seen on a trace in order to see more clearly the baseline return of the signal. If the baseline restorer has an On-Off switch turn it off during the pole-zero adjustment. While adjusting the pole-zero control (a small screwdriver is required for this adjustment), the effect of this adjustment should be seen clearly on the overshoot and undershoot of the signal at the baseline. Adjust the pole zero until the over- and undershoot is a minimum. This is a very important adjustment, and it is worthwhile to experiment until a satisfactory minimum has been achieved. The effect of poor pole-zero adjustment will be broadening of the peaks and a marked deterioration in system resolution. With the pole-zero control properly adjusted, make sure, if necessary, that the baseline restorer is turned on. The choice of amplifier time constants also influences the system resolution. A choice between 1.5 μs and 3.0 μs will probably be optimal, depending on whether or not high count rates ($>2 \times 10^4 \text{s}^{-1}$) are expected. The manufacturer's manuals should be checked to make sure the amplifier operation is clearly understood.

G. Rate Considerations

It is now appropriate to mount the transmission source in its holder and the rate correction source on the end cap of the detector. In order to have the best possible statistical precision, high rates are desired for the two sources, but high rates mean high system overhead and high pileup. Consequently, a balance must be achieved between the best possible statistics and proper system performance. After some experience, a visual check of the oscilloscope pulses at the output of the amplifier and with the sources in place gives a rough indication of whether the system is being overloaded. The rate from the livetime-pileup source is most easily adjusted simply by sliding the source back and forth along the end cap of the detector until the desired rate is achieved. Alternatively, it is also convenient to place a thin (less than 2 mm) lead shield between the source and the detector to cut down on lower energy gamma rays. After the system is set up, the sources should be adjusted to give about ten thousand counts per segment (10 s) for each peak. The positions of the sources may have to be adjusted to achieve these rates during set-up, after which background runs are taken. Remember that a new background run must be made after any change in source position or filtering.

H. Gain

The SGS system is set up to acquire and display 2048 (2^{11}) channels of information corresponding to the full 10-V input range of the analog-to-digital converter. It is reasonable to try to keep the spectral region of interest for a given assay in the upper half of the available spectrum storage. The easiest way to establish rough-gain settings is to adjust the coarse-gain and fine-gain controls on the amplifier until the highest energy peak of interest (use the standard sample if necessary) has an amplitude of seven to

eight volts at the output of the amplifier. Since the display is available on the scope in eight 256-channel segments, it may be convenient later on to adjust slightly the gain to get as many as possible of the relevant peaks located on a single display segment. For the moment, with the gain set as described, the system operation can be considered more generally.

I. General Operation

Referring to Fig. 57, consider the general operation of the front control panel. The panel immediately below the display provides power on-off, scan height setting, and manual control for table motion. The local position is used to make setup runs. In normal operation, the local position is seldom used. We shall describe its operation in more detail shortly. The scan height thumbwheel switches determine the number of segments to be used in a given assay. The maximum setting here is 19, corresponding to 38 segments, and the minimum setting is 1, corresponding to two segments. The scan height is in units of inches (with apologies to all metric system users) for the small table, and in units of 4-in. (more apologies) for the barrel handler. The switch to the right selects the table to be used for the assay. Changing this switch after an assay has begun will not affect operation until the next assay starts.

The Light Emitting Diode (LED) under the UP-DOWN toggle switch indicates when the table is in the load position (at the top). The LED above the switch glows red when the table is at a limit (top or bottom) and the operator attempts to move further in the same direction; it glows green when the table is being moved manually.

On the main control panel, immediately below the manual operation panel, are ten pushbutton switches to initiate various functions and two rotary switches to select display

ranges and long or short print-outs. The thumbwheel switches are used to select the cursor (intensified dot) position on the display when the system is in the cursor or integrate mode. From left to right, the functions are as follows. The ENTER CONSTANTS function is used to set in the calibration factor and container transmission, and in the case of ^{241}Pu assay, the mu ratio. We shall say more about this later. The next three pushbuttons, START BKGD, START ASSAY, and START SET UP all initiate data acquisition. The first two require that the table be under computer control, but the set-up button is operable only when the local-computer switch is in the local position. The STOP WINDOW and START WINDOW pushbuttons relate to the cursor mode, either for setting regions of interest or for the integrate function. In either case they establish a region of interest based upon the setting of the cursor position thumbwheel switches at the time they are activated. The START CURSOR pushbutton activates the window-setting functions and causes the intensified cursor to be displayed on the storage screen along with the spectral display. In this mode, the cursor position thumbwheel switches are active and control the cursor position. The START ANALYZE function initiates the analysis of the segment-by-segment data in exactly the same way that this function is performed automatically at the end of the normal assay. The reason for the pushbutton is to permit additional copies of the analysis, if desired, or to reanalyze different portions of the segment-by-segment data if desired. The START INTEGRATE function activates the cursor exactly as with the window-setting function, but in this case, the cursor is used in conjunction with the START WINDOW and STOP WINDOW pushbuttons to define regions of the spectrum whose integrated counts are printed out on the printer after each pair of entries on the window. In this mode, regions to be integrated can be entered from either direction, left to right or

right to left. The SYSTEM STOP is an overriding system function that will interrupt whatever other function is in progress and return the system to the idle condition. It can be used as a panic stop for interrupting an assay or background run, or an analysis printout, or it can be used to return the system to an idle mode from the integrate function or the cursor (window-setting) condition.

The SCOPE RANGE switch selects the spectrum segment for display in eight 256-channel portions of the full 2048 channel spectrum; in other words, it selects the horizontal segment of the spectrum to be displayed. The horizontal segment can be changed during display periods without changing in any way the data actually stored for calculation. It is to be remembered that the vertical display is always logarithmic and not subject to change by the operator. The PRINT MODE switch selects either a long or short printout. Only in the long printout mode, where all segment data are printed, can the operator select which of the segments are to be used in the calculation. In the short printout mode, all segments are used.

J. Stabilization

As mentioned in previous sections of this manual, stabilization of the system gain is essential for long-term gain stability. This is accomplished by proper operation of the ADC stabilizer to the immediate right of the ADC in the NIM bin, just below the computer. Once the gain has been properly set on the amplifier as described above, a setup run of several minutes should be taken with the livetime source in place. At the conclusion of this run, press START CURSOR and adjust the thumbwheel switches to reveal the center channel number on the livetime peak. This digital value is then set into the stabilizer switches. The stabilizer control switch

should now be turned to the on position and another setup run taken while the stabilizer meter and light are observed to insure that the unit is tracking on the peak. Minor adjustments can now be made in the amplifier fine-gain control until the stabilizer correction meter is exactly centered with the unit on, and the system is now stabilized. Details of the stabilizer operation may be found in the manufacturers manual.

K. Setting Regions of Interest for Assay

A sample of the material to be assayed is placed on the turntable and the table manually adjusted such that the collimator is viewing the material. The livetime and transmission sources must be in place. Another several-minute setup run is now taken for the purpose of storing in the computer the regions-of-interest (ROI) that will be used for the actual assays. At the conclusion of the setup run, press START CURSOR and prepare to actually enter the limits of the ROI. Three ROI are entered for each peak to be used in the assay, with two limits for each ROI. Thus, for uranium with four peaks in the assay, twelve ROI with twenty-four limits will be entered. Single-isotope plutonium assays require three peaks, which corresponds to nine ROI or eighteen limits. If ^{241}Pu is assayed simultaneously with ^{239}Pu , five peaks are involved, with fifteen ROI, or thirty limits. In any case, the ROI limits must be entered from left to right on the display for each peak the left background region first, then the main peak region, and finally the right background region. Each ROI is entered by alternately pressing the START WINDOW and STOP WINDOW pushbuttons with the thumb-wheel switches set at the desired location.

The system program will derive from the number of ROI actually entered the information on what material is being

assayed, but in general, the ROI must be entered in the following order. Rate correction peak, main (left) transmission peak, main assay peak, second (right) transmission peak, and finally the ^{241}Pu assay peak. For a three-peak assay, the entry would be terminated after entering three peaks as listed by pressing SYSTEM STOP. A four-peak assay would be similarly terminated after entering the second transmission peak. For a five-peak assay, the system will automatically terminate after five peaks are entered. In any case, the actual decimal values of each start and stop channel for the ROI entered will now be printed out on the terminal for a successful entry. If an illegal action has been taken, for example, an improper number of window limits were entered, or a start value is larger than stop value (thus giving a negative window width), the relevant message will be given to the operator, and the whole procedure of entering window must be reinitiated. Errors during entry of ROI limits cannot be rectified except by starting the procedure over again, except in the case of the immediate entry. If, for example, the operator has just entered an incorrect start (stop) value, he can press the start (stop) switch again with the correct value, and the incorrect value will be overwritten.

If the operator desires to see the current values for the ROI limits at any time, he can obtain a printout of these values by simply lifting data switch #8 (corresponding to 200_g) on the computer console, and pressing the INTEGRATE pushbutton. Values will be printed for the maximum number of 30 ROI. The values for ROI not being used will be meaningless and should be ignored.

It is important to note that the ROI limits must be entered before entering constants or before making a background run, since it is by this mechanism that the number of peaks to be used in the assay is determined.

The widths and positions of the main peak ROI and the background ROI need some consideration. Obviously, the main-peak ROI should include all, or at least nearly all, of the peak counts and be centered on the peak. Experience indicates that it ranges from about twice the full-width-at-half-maximum (FWHM) of the peak to about three times the FWHM. To make the main-peak ROI too wide will hurt the precision by greatly increasing the background under the peak without appreciably increasing the actual peak counts. To make the main-peak ROI too narrow may result in small systematic errors due to slightly changing resolution as a result of rate changes. Probably the best compromise for the SGS system is to make the main-peak ROI about 2.5 times the FWHM of the peak. It is difficult to estimate the FWHM from the logarithmic display but after a background run is made the system will give a value of resolution for the correction peak. The background ROI should be several channels wide (five has been the usual choice with the SGS system) but narrower background ROI must be used if an interfering peak is too close to that being used. It is sometimes necessary even to put a background ROI on the far side of an interfering peak in order to avoid a falsely high background measurement. In particular special care should be exercised in setting up the ROI around the 198.0-keV gamma ray of ^{169}Yb in a ^{235}U assay because of the weak but annoying ^{235}U gamma rays at 194.9, 198.9 and 202.1 keV. The background ROI obviously should not start on any obvious tails of the peak even if it means moving a channel or two away from the main-peak ROI. It should finally be emphasized that care in setting ROI will tend to maximize precision and to minimize some possible small systematic errors.

L. Entering Constants

At this point in the operating procedure, it is necessary to enter the constants that will be used in the equations. The main two entries here are the container transmission and the calibration constant. The former can be measured by assaying an empty container, but its value contributes only logarithmically to the error, so it is not critical. The latter has units of counts per gram and must be determined from the calibration standard (or standards) for each particular geometry used in assays. In the case of a simultaneous ^{241}Pu assay (five-peak assay), the operator will also be required to enter the mu ratio constant between the 208-keV ^{241}Pu gamma ray as described previously. Since this can vary with matrix material, the operator must enter it. In lieu of better information, the value 1.2 is suitable for use with most low-z matrix materials.

The constants can be changed at any time the system is not taking data, and the new values will be used for all subsequent assays. For each assay, the counts/gram value is printed out along with the assay data. Before a calibration run has been made, the calibration constant actual value is unknown, but the operator must still enter some nonzero value.

M. Making a Background Run

Now that the ROI and constants have been entered, the next step is to make a background run that will establish the straight-through (no sample) values used in the calculation of the various correction factors. For maximum statistical precision, the maximum number of segments should be specified for the background run (38 for the small table scanner, and 8 for the barrel handler). With all material removed from the scan table, press the START BACKGROUND button. The system will now automatically make a long two-pass background, average the data obtained, and print out the results. The

results, which are averaged over all segments taken, are printed out as two values for the deadtime-pileup correction peak and one or two values for the transmission peak. For the correction peak, the first value corresponds to the transmission source open, and the second value to the source shuttered. In the case of the transmission values, the first value is the first (main) transmission peak, and the second value, if any, is the second transmission peak. All these averaged peak areas are automatically stored in the system, the printed values being for the operators information only.

In addition to these values, the system resolution at the correction peak energy will also be printed out. This serves as a powerful system diagnostic and should be kept as part of the permanent record, since it gives a useful indication of how well the system was operating.

N. Making a Calibration Run

With the background run information in the system, the calibration constant is now determined. This, of course, requires at least one known standard. Since the calibration constant is the quotient of the corrected counts obtained from the assay and the known mass of the standard, and since this constant will be used to divide all unknown assay corrected counts, the easiest way to make this determination is simply to press the ENTER CONSTANTS pushbutton and enter as the calibration constant the mass of the fissile material in the calibration standard. In this way, the assay value obtained will be the calibration constant, the two being reciprocals of one another. The standard is then placed on the table, and START ASSAY pressed. Of course, one should select the proper scan height for the assay. Since this is a calibration run, it is worthwhile to make several runs and average the results in order to increase statistical precision. The system can do this automatically, as will be described in

the next section. After the proper value for the calibration constant has been determined, it should be entered into the system via the ENTER CONSTANTS pushbutton.

In the original setup of the SGS system for a particular kind of assay and for the thorough periodic rechecks of system operation, it is desirable to use at least two, and preferably three or four, known standards of appropriate geometry and spanning the expected transmission range. By so doing, the constancy of the calibration constant over the range of transmission can be confirmed and possible small systematic errors may be detected. Thereafter, a single standard should suffice to make regular daily calibration runs. It must be emphasized that the calibration should be checked every day the system is operated and that the calibration runs should always include the background run. These daily calibration runs are necessary both because the calibration will slowly change with time and because it is probably the best way to detect system malfunctions. In the use of the SGS system, as with any measurement system, a carefully thought-out measurement control program should be used to assure that the estimated precision and accuracy are being achieved.

O. Multiple Runs

Any assay initiated via the START ASSAY pushbutton (calibration or unknown) can be repeated automatically by the system without operator intervention and the results automatically averaged at each new iteration if desired. To initiate a multiple run, the operator has only to terminate the sample ID query with an asterisk instead of the usual carriage return. The operator will then be asked how many runs are desired, and the assay will proceed for this number of iterations. However, the run can be terminated at any time by simply pressing SYSTEM STOP. As each pass is completed, the

running average of the assay value with the associated propagated one sigma error estimate is printed.

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APPENDIX A

MAINTENANCE OF SCAN TABLE

This appendix was written for the maintenance of the small scan table. However, nearly all the material applies directly to the large scan table as well and should suffice for the maintenance of the large scan table.

Elevator Drive (refer to Figs. A-1 and A-2)

Always run the elevator plate to the lowest position (load position) and block support in a level position before loosening the adjustable idler. This prevents inadvertent dropping of the elevator.

After each forty hours of operation, check and perform the following:

- a) Check motor belt B for proper tension. Tighten the belt by loosening motor base plate screws, moving motor away from center of unit applying tension to belt, and retightening motor base plate screws.
- b) Check elevator belt D for proper tension. Tighten belt by loosening the adjustable idler E housing screws, moving idler toward center of unit, thus applying tension to belt, and retightening idler housing screws.
- c) Apply five to six drops of spindle oil to the thrust bearing at each of the three drive-screw assemblies.
- d) Using light-grade oil applied sparingly to a rag, wipe down the 2-in.-diam ball-bushing rods and lead screws.

All pulleys and couplings are pinned to associated shafts with 1/8-in.-diam roll pins.

Fig. A-1. Typical elevator drive (three per unit).

A: 2-in.-diam ball-bushing rod;

B: lead screw;

C: thrust bearing.

Fig. A-2. Scan table main base, bottom view.

- A: motor pulley (16-tooth)
- B: motor belt
- C: driver pulley (32-tooth)
- D: elevator belt
- E: adjustable idler (smooth)
- F: adjustable motor base plate

Turntable Drive (refer to Fig. A-3)

After each forty hours of operation, remove the turntable belt cover and inspect the belt for wear and proper tension. To tighten the belt, loosen the knurled brass knob associated with the adjustable idler B, move the idler in toward the belt and tighten the knurled knob. Replace the belt cover.

Stepping Motor Fluid Dampers

On each of the two stepping motors is connected a fluid damper. The purpose of these is to supply the motor with a load sufficient to dampen out as much vibration as possible. This cuts down on noise and wear of parts, but most importantly carries the motor through various speed resonances to which stepping motors are particularly prone. Without the use of such dampers these motors may stop, lose torque, change speed, or even change directions at certain stepping frequencies. When properly functioning, these dampers will effectively eliminate these problems.

The dampers are made up of an aluminum housing, which is connected rigidly to the motor on one end and to the load on the other. Inside the housing is a brass or tungsten disk rotating around a center shaft. The only friction between the outside housing and the internal disk is a film of grease. The viscosity of this grease determines the amount of damping.

The primary difficulty with the damper is the grease itself. The grease undergoes great stresses and after long running times at high temperatures may chemically break down or separate into its component elements. This materially changes the viscosity and, hence, the damping effect. If this occurs, the only remedy is to repack the damper.

Fig. A-3. Scan table elevator plate, bottom view.

- A: motor pulley (12-tooth)
- B: adjustable idler (24-tooth)
- C: turntable belt
- D: turntable pulley (60-tooth)

Repacking the damper is accomplished by removing the damper from the system and performing the following steps (note that the vertical movement motor damper is pinned at both ends with roll pins):

1. Remove the eight #4 Allen head screws holding the cover plate.
2. Take note of the two positioning pins through the cover into the main housing. The alignment of these pins is not symmetrical, so a scribe mark on the edge of the cover and main housing will facilitate alignment on reassembly.
3. Using caution not to ruin the gasket; pry the cover up, at the pin positions, until it comes off.
4. With the cover plate removed, note the two threaded holes in the brass disk. These are intended to be used for pulling the disk with 4-40 screws. By inserting screws in these holes and locking the screws in a vise, pull off the disk.
5. Clean all parts. Freon TMC solvent in an ultrasonic cleaner works very well for this cleaning.
6. Spread a slight excess of light "Celvacence" vacuum grease on the inside of the housing.
7. With the bottom Teflon washer in place, press the disk back into the housing. A vise will accomplish this easily. Leave pressure on the unit until all excess grease has been squeezed out and the disk has bottomed in the housing.
8. Install the top Teflon washer and spread a layer of grease, free from bubbles, across the top of the disk. Level this layer with a straight edge to match the rim of the housing.

9. After making sure the gasket is in good condition, realign the top plate on the housing and install the retaining screws. If a new gasket must be made, use oil-resistant paper 1/32 in. thick.

APPENDIX B

THE LARGE SCAN TABLE

The large scan table has an adjustable transmission source housing and an adjustable detector platform so that assays can be performed on package sizes up to the 55-gal (208-liter) size. The large scan table can take loads up to 1000 lb (435 kg). Additional circuitry was added to the system to allow switching between the two scan tables with a single switch. The additional circuitry and wiring list changes are given below in Figs. B-1, B-2, B-3, B-4, B-5, B-6, and in Table B-1. Finally, Fig. B-7 gives the circuit diagram of Board B-8, main control box for those SGS units employing a Tektronix 603 display scope rather than a Tektronix 613 display.

Fig. B-1. Shutter control circuitry; Board 6, motor control box.

Fig. B-2. Limit switch receivers; Board 7, motor control box.

Fig. B-3. Limit switch multiplexer; Board 8, motor control box.

Fig. B-4. Large scan table control; Board 9, motor control box.

Fig. B-5. Large scan table speed control; Board 10, motor control box.

Fig. B-6. Linear switch for detectors; separate chassis, motor control box.

Fig. B-7. Board B-8, main control box for units with Tektronix 603 displays.

TABLE B-I

WIRING LIST CHANGES

MAIN CONTROL BOX

	<u>Remove</u>			<u>Add</u>	
A-7-13	A-4-10	DATOA	A-7-13	A-148	DC75

MOTOR CONTROL

	<u>Remove</u>		<u>Add</u>	
A-3-8	A-5-14	A-10-15	A-12-12	RESET SCALER
A-4-D	A-1-4	A-12-20	A-10-20	CW
A-4-T	A-2-T	A-3-8	A-5-14	FAST OSO
A-9-3*	A-5-10	A-4-12	A-6-8	RESET
A-9-16	A-5-7	A-12-11	A-6-9	END SEG
A-9-21	A-5-7	A-4-P	A-12-E	CLEAR
A-12-20	A-13-4	A-4-D	A-6-7	DC74·75
A-12-21	A-13-3	A-4-N	A-6-6	DC74
A-3-8	A-5-13	A-1-15	A-6-5	DC75
A-3-19*	J-1-1	A-4-C	A-6-4	START
A-3-2*	J-1-6	A-6-3	SSR	SHUTTER SSR
A-3-13*	J-1-3	A-2-T	A-8-E	B DRUM
A-3-B*	J-1-8	A-9-3	A-5-7	DRUM SYNC
A-3-16*	J-2-1	A-9-10	A-5-10	CAN SYNC
A-2-B*	J-2-6	A-10-21	A-13-4	CW

*Twisted Pair

TABLE B-I (cont)

	<u>Remove</u>		<u>Add</u>	
A-3-X*	J-2-3	A-12-21	A-10-22	CCW
A-2-2*	J-2-8	A-10-Z	A-13-3	CCW
A-3-W*	J-4-A	A-10-19	A-8-7	B DRUM
A-3-B*	J-4-B	A-9-4	A-13-10	RUN
A-5-8*	J-5-A	A-9-7	A-3-E	F·C
A-5-2*	J-5-B	A-9-6	A-3-F	F·LIMIT
A-3-19	J-1-1	A-9-9	A-5-13	FAST OSC
A-3-2	J-1-6	A-9-8	A-14-22	GO
A-3-13	J-1-3	A-9-18	A-14-21	DIRECTION
A-3-B	J-1-8	A-9-14	A-8-7	B DRUM
A-3-16	J-2-1	A-3-W	A-9-17	U-D PLUSE
A-2-B	J-2-6	A-8-21	A-7-F	E TOP DRUM
A-3-X	J-2-3	A-8-Y	A-7-4	E DRUM
A-2-2	J-2-8	A-8-22	A-7-6	TOP DRUM
A-3-W	J-4-A	A-8-Z	A-7-3	DRUM
A-3-B	J-4-B	A-8-S	A-7-H	B DRUM
A-5-8	J-5-A	A-8-T	A-7-7	E B DRUM
A-5-2	J-5-B	A-8-20	A-7-10	INTERLOCK
		A-8-14	A-7-P	E TOP
		A-8-R	A-7-13	TOP
		A-8-15	A-7-T	BOT
		A-8-16	A-7-16	E-BOT
		A-8-3	A-1-15	DC75

*Twisted Pair

TABLE B-I (cont)

	<u>Add</u>				<u>Add</u>
A-8-4	A-12-6	IOPLS	J-5-B*	A-9-2	GND
A-6-14	A-8-7	B-DRUM	J-7-H	A-1-2	GND
A-8-9	A-3-19	E-T	J-7-A*	A-10-9	GATE
A-8-J	A-3-13	T	J-7-B*	A-10-2	GND
A-8-8	A-3-16	B	J-7-F*	A-10-3	COUNT
A-8-K	A-3-X	E-B	J-7-C*	A-10-2	GND
A-8-D	A-14-4	LOC COMP	J-7-E*	A-10-A	+5
A-6-16	A-8-D	LOC COMP	J-7-D*	A-10-B	GND
A-6-15	SSR	CAN SSR	J-8-H	A-1-2	GND
A-6-2	SSR	GND	J-8-B*	A-9-13	DRUM ROT
A-8-C	SWITCH	DRUM CAN	J-8-A*	A-9-2	GND
J-1-1*	A-7-14	TOP F SLOT	J-8-C*	A-9-15	DRUM UP
J-1-6*	A-7-2	GND	J-8-F*	A-9-B	GND
J-1-3*	A-7-R	TOP SLOT	J-8-D*	A-9-19	DRUM DN
J-1-8*	A-7-2	GND	J-8-E*	A-9-B	GND
J-2-1*	A-7-15	BOTTOM SLOT	J-9-1*	A-7-19	+LED
J-2-6*	A-7-B	GND	J-9-20*		-LED
J-2-3*	A-7-S	BOTTOM F SLOT	J-9-2*		+LED
J-2-8*	A-7-B	GND	J-9-21*	A-7-W	-LED
J-4-A*	A-9-20	V-D DRIVER	J-9-3*	A-7-5	E-DRUM
J-4-B*	A-9-2	GND	J-9-22*	A-6-B	GRN
J-5-A*	A-9-22	ROT DRIVER	J-9-4*	A-7-C	DRUM
			J-9-23*	A-6-Z	GND

* Twisted Pair

TABLE B-I (cont)

	<u>Add</u>			<u>Add</u>	
J-9-5*	A-7-20	+LED	J-9-30*	A-8-2	GND
J-9-24*		-LED	J-9-12*	A-7-J	E BOT
J-9-6*		+LED	J-9-31*	A-8-B	GND
J-9-25*	A-7-X	-LED	J-9-13*	A-7-22	+LED
J-9-7*	A-7-D	E TOP	J-9-32*		-LED
J-9-26*	A-8-2	GND	J-9-14*		+LED
J-9-8*	A-7-E	TOP	J-9-33*	A-7-Z	-LED
J-9-27*	A-8-2	GND	J-9-15*	A-7-9	SOURCE
J-9-9*	A-7-21	+LED	J-9-34	A-8-B	GND
J-9-28*		-LED	J-9-16*	A-7-K	DETECTOR
J-9-10*		+LED	J-9-35	A-8-B	GND
J-9-29*	A-7-Y	-LED	A-8-E*	BB	B DRUM
J-9-11*	A-7-8	BOT	A-9-B*	BB	GND

*Twisted Pair