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LOW BACKGROUND Ge(Li) DETECTOR GAMMA-RAY SPECTROSCOPY SYSTEM WITH SAMPLE CHANGER

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OCTOBER 1978

MASTER

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ABSTRACT

A gamma-ray spectroscopy system used for analysis of volume soil and vegetation samples is described. It can accept samples of up to 2 kg weight and a 970 cm^3 volume. Its primary use is in the determination of U, Th, ^{137}Cs, ^{40}K, and ^{60}Co in samples obtained during ground truth AMS surveys throughout the country. The system was calibrated using standards from the DOE New Brunswick Laboratory and from the National Bureau of Standards. Detectabilities (at 3σ) in a 1500-g sample are: 0.28 ppm Th, 0.10 ppm U, 10 pCi ^{40}K, 1.0 pCi ^{137}Cs, and 1.0 pCi of ^{60}Co.

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CONTENTS

ILLUSTRATIONS

TABLES

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1. INTRODUCTION

A low background gamma-ray spectroscopy system is currently available for the analysis of soil and vegetation samples. Its primary use is for analyzing samples obtained during the AMS (Aerial Measurement System) surveys throughout the country. Two lithium-drifted germanium (GeLi) detectors are multiplexed together, which approximately doubles the efficiency available with either separately. The detector output is analyzed by a 4096-channel pulse height analyzer (PHA), and the data are stored on magnetic tape. Samples are changed automatically. The system is designed to handle samples 10.7 cm high and 12 cm in diameter, which amounts to approximately 1500 g soil of density 1.55.

Volume source standards, containing known quantities of Th ore and U ore analyzed by DOE's New Brunswick Laboratory, were used to provide calibrations from 200 keV to 3 MeV. These standards are of approximately the same density and volume as an average sample, so that calibrations performed with them take into account self absorption and effects due to the larger source area. (The variance of these effects with sample density has been tested and is negligible to within a couple of hundred grams.)

Detailed background data were taken and are periodically revised. This allows corrections to the raw data to take into account the inherent radioactivity of the counter and sample containers.

Samples are packed in standardized polypropylene containers that can be sealed airtight. A sample handling procedure is documented. Sample preparation is carried out in a clean laboratory reserved for this purpose.

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2. SYSTEM DESCRIPTION

The Ge(Li) detectors are side-looking devices, ≃40 mm long and ≃45 mm in diameter, with a 0.5-mm thick entrance window of aluminum. Their operating specifications are tabulated below:

	Ge(Li) #1	Ge(Li) #2
Point source efficiency relative to a 3 × 3 NaI (Tl) detector, 25 cm source-to-detector distance, at 1.33 MeV	16%	13.8%
Peak-to-Compton ratio	48/1	36/1
Resolution at 1.33 MeV	1.86 keV	1.95 keV

Both detectors use FET preamplifiers and ORTEC Model 472 A linear signal amplifiers. Ge(Li) #1 is powered by an Ortec 456 high-voltage (HV) supply, and Ge(Li) #2 by a Canberra 3005 HV power supply. The signal amplifier outputs are summed with an ORTEC 475 multiplexer.

A Canberra 8180 pulse height analyzer (PHA) is used to analyze the detector output. It has 4096 channels available for storage and a count capacity of 10^6 counts/channel. The ADC operates at 50 MHz. The analyzer is set for an electronic gain of approximately 0.75 keV/channel, and the system 0 is set on channel zero. These adjustments are maintained as necessary to produce a consistent data set from month to month. The usual procedure is routine counting of a 500-ppm Th standard followed by computer processing of the data. Inspection and plotting of the deviations of the individual peak energies from their correct values (see, for example, ANCR-100-2) reveals trends to the data and allows proper corrections to be made. Experience to date has permitted us to maintain correct energy calibrations within ±1 keV with little difficulty.

Data are written on magnetic tape using a Canberra model 8513 A magnetic tape controller, and a Pertec tape drive.

The actual knob settings of the various pieces of equipment used are given in Table 1.

The sample changer (Fig. 1) is a converted food processing conveyor that operates via a 1-hp motor with a simple limit switch controlling the sample motion. The conveyor belt can store up to 96 samples (see Conveyor Layout drawing, Appendix A).

The sample to be counted is moved from the primary conveyor into position in the detector area by a secondary chain conveyor. It is positioned midway

Table 1. Detector calibration knob settings

Ge(Li) #1 Linear Amplifier, Ortec 472 A	
Course gain:	200
Fine gain:	1295
BLR rate:	Medium
BLR threshold:	Variable
Shaping:	2.0 μsec, unipolar
Polarity:	Inverted
Ge(Li) #2 Linear Amplifier, Ortec 472 A	
Course gain:	200
Fine gain:	1262
BLR rate:	Medium
BLR threshold:	Variable
Shaping:	2.0 μsec, unipolar
Polarity:	Inverted
Matching Multiplexer, Canberra 475	
A gain:	500
ADC Canberra 8180	
Conversion gain:	4096
Fine zero:	490.0
DC coupled input	
Ge(Li) #1 High Voltage Supply, Ortec 459	
Positive polarity:	4800 V
Ge(Li) #2 High Voltage Supply, Canberra 3005	
Positive polarity:	4800 V

between the two detectors and is rotated at approximately 3 rpm continually during the counting cycle. This is done in order to help maintain a consistent sample detector geometry; by turning at a constant rate, any effects due to lateral density variations in the sample are eliminated.

The counting chamber itself is shielded; lead bricks were used for the walls and top surface, and the floor is of 3-inch-thick cast lead. The sample rests on an epoxy-filled depression in order to minimize gamma-ray scattering and x-ray production. The closest sample-to-lead distance is 3 inches. The detector sample geometry is illustrated in Figs. 2 and 3. Various limit switches and a simple digital control circuit provide interface capability with the PHA (see Appendix B drawing).

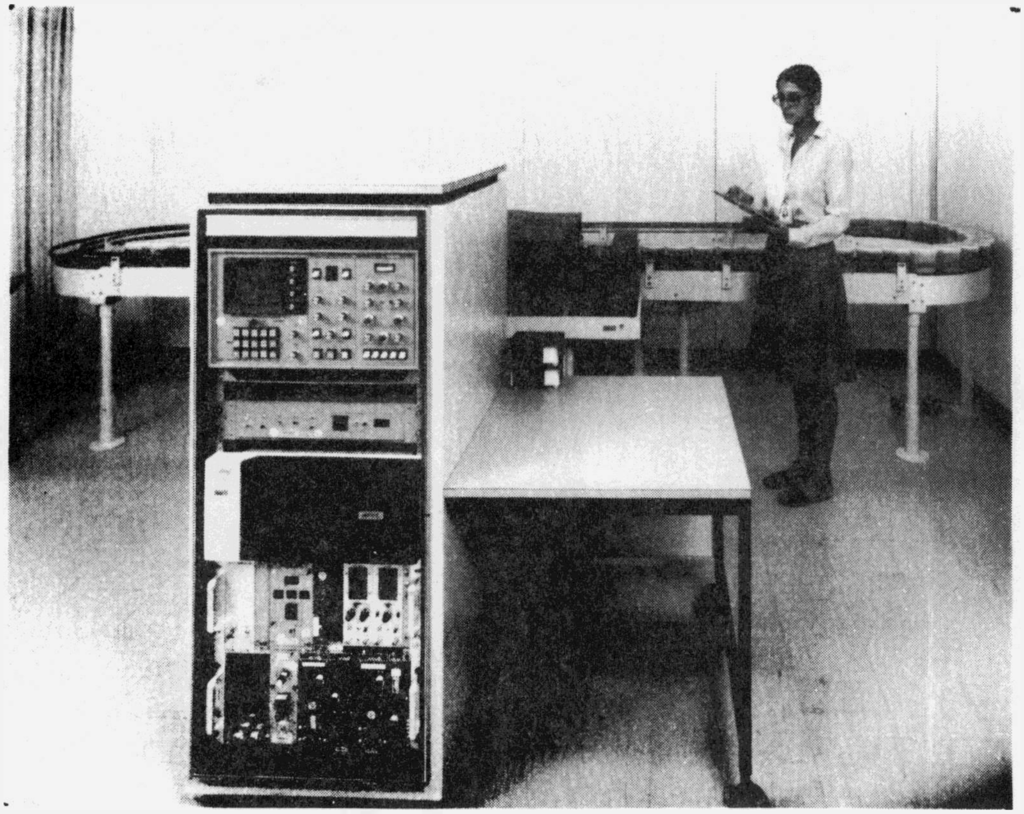

Fig. 1. Sample changer and counting electronics

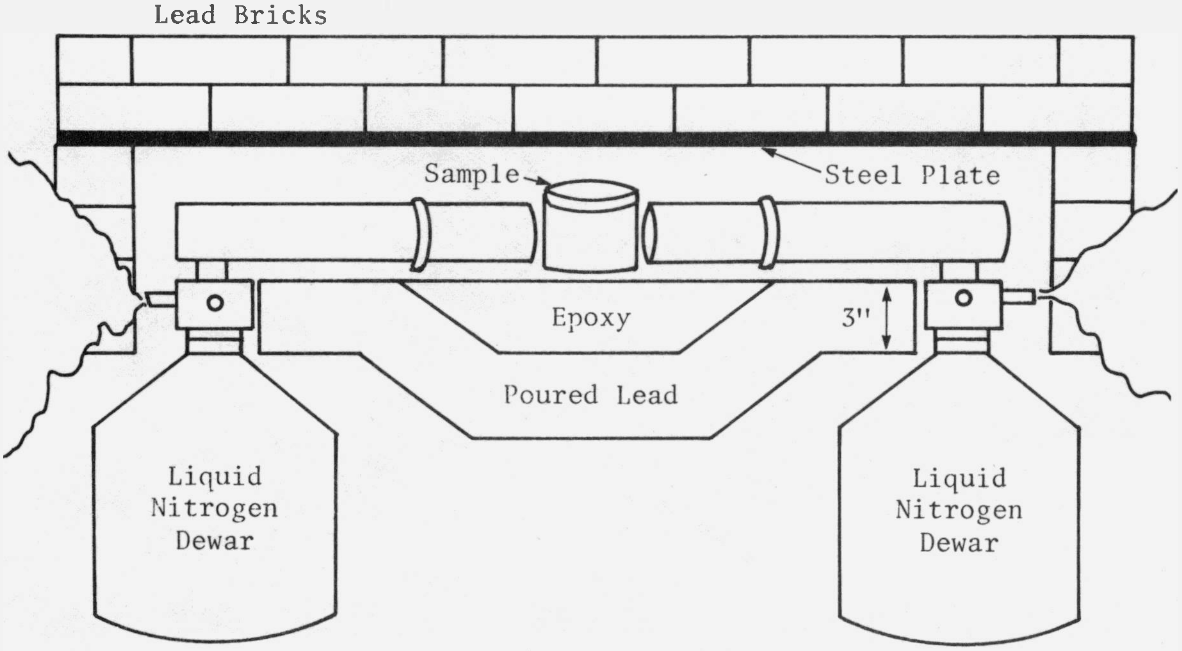

Fig. 2. Cross-section of detector shield

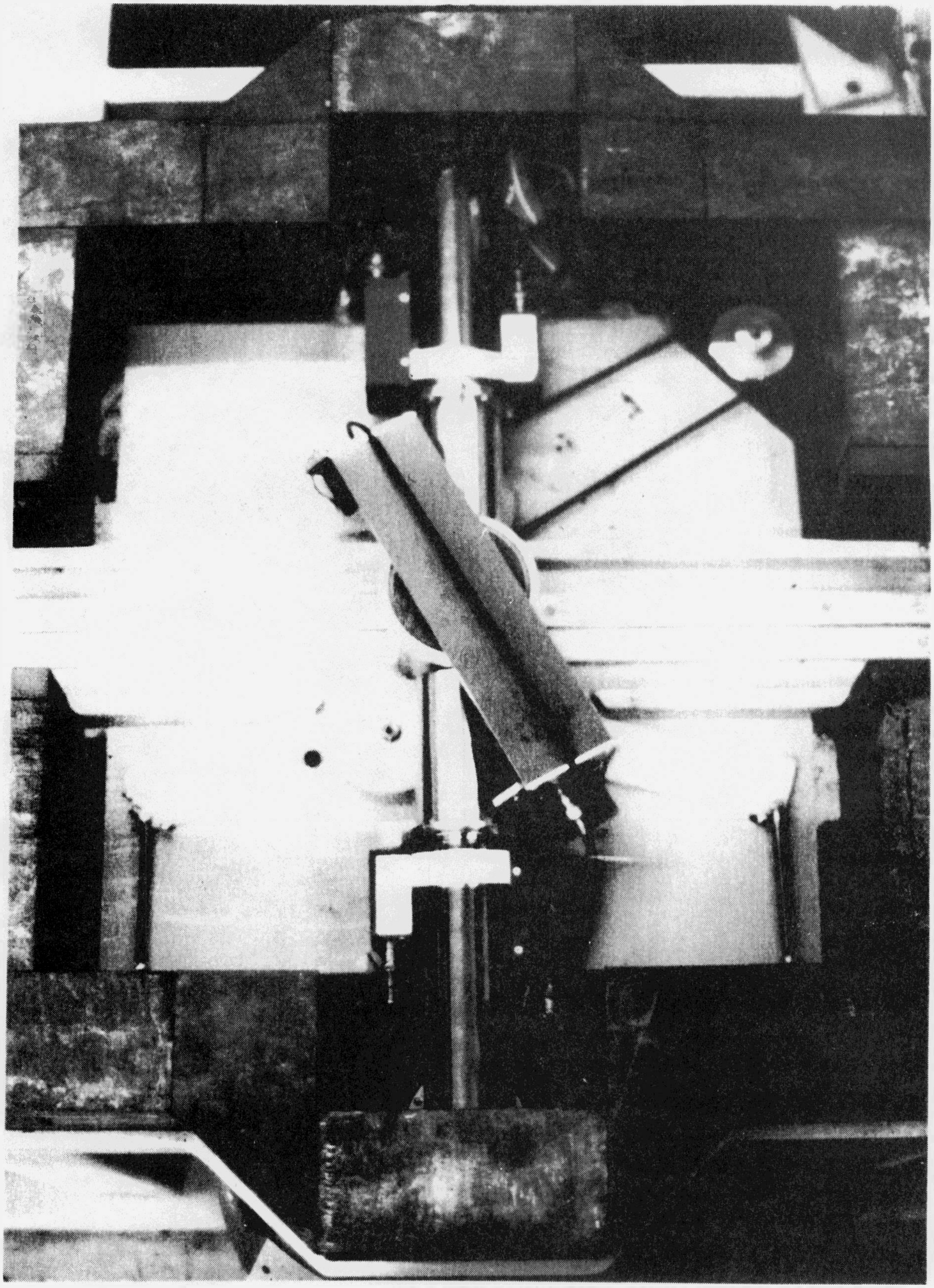

Fig. 3. Top view of completed sample changer

3. DETECTOR COOLING SYSTEM

The Ge(Li) detectors must be maintained at -196°C to keep the lithium from drifting. Allowing the detectors to warm up for any length of time would make them inoperable. Liquid nitrogen (LN) cooling is used to keep them at the proper operating temperature. The LN dewars are monitored using two ORTEC Model 729 A LN level monitors (thermistor devices), which are connected to an alarm system that sounds if the level falls below 40%. Along with this system, two force transducer weighing devices are in position under the dewars. These are connected to 0-100% LED readouts, for continuous dewar weight monitoring.

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4. SAMPLE CONTAINER

The polypropylene sample containers (Fig. 4) are approximately 10.7 cm high and 12 cm in diameter. They have a twist-on cap, also of polypropylene. The can volume is 970 cm^3, and the container plus top weighs approximately 114 g. A 1500-g sample of density 1.55 g/cm^3 would just fill the container.

In order to control contamination problems, all samples are packed in these containers for counting.

Fig. 4. Polypropylene sample containers

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5. SAMPLE PREPARATION SCHEME

The following steps have been adopted as a sample preparation scheme. The samples are usually received as loose material in plastic bags, and are marked with the site name and a coded location at the site. The samples are prepared and canned at the earliest possible time after receipt.

1. Log sample by number and date received in log book.
2. Weigh sample as received, log weight and date weighed.
3. Dry sample >10 hours (or overnight) at 40°C and log dry weight. (In this process they are spread out over a 3-inch by 6-inch area to help speed up the process.) Calculate percent of moisture by weight.
4. Mix up sample, break larger lumps, and render into a uniform mixture.
5. Place at least 1200 g soil in polyethylene sample container. Fill to upper ridge, shaking and tamping to result in a uniform density from can to can.
6. Seal container using teflon tape around edge under cap to insure an airtight seal. Label side with a felt marker including serial number and date sealed. Cover numbers with Scotch tape to prevent smearing.
7. Seal up an empty container along with the actual samples.
8. Weigh plastic container, record weight, and calculate actual density of material packed and record in book.

Sample data page headings are as follows:

Sample I.D.	Date Rec'd	Wt. as Rec'd Grams Date	Dry Wt. Grams	Percent Moisture	Wt. in Can, Grams	Density

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6. DETECTOR SYSTEM CALIBRATIONS

The analyzer zero and linearity have been carefully investigated using NBS sources. The energy versus channnel data were fit to a least squares line, allowing the zero to be found to within 0.1 channel of true zero. The gain adjustment is set to yield around 0.75 keV/channel. The exact value can be checked from the slope of the energy versus channel data fit line.

After the zero and gain are properly adjusted, a background run (with an empty sample can in place) and the necessary standard runs are made. The data are analyzed by program SAMPO to yield area counts for each major gamma-ray peak. The background area counts are subtracted and the net counts per second in the peak used to determine an efficiency at that energy. Corrections were made for the Ottawa Sand contribution to the background by an iterative technique (see Appendix C).

For volume sample analysis two general types of efficiency data are calculated. The first relates ppm in a known standard directly to detector counts per second at a particular peak energy in the standard spectrum. A counter factor is determined from this having the units of (ppm × gm)/(counts/sec). This is used to calculate ppm from the area counts of the sample under investigation.

The second type of efficiency relates gamma-rays per second at a given energy to net cps. This is the usual efficiency curve versus energy found in the literature. However, the present data take into account the extended volume source configuration we have (see Table 2). The various standards contributed many gammas of different energy, so the efficiency data for a volume source extend from ≃200 keV

Table 2. Efficiency versus energy for standard 1600-g sample

Source	Energy (keV)	Efficiency (count/gamma)
Th	209.40	1.185 (-2)
Th	238.63	1.074 (-2)
Th	277.36	9.586 (-3)
U	295.22	9.145 (-3)
Th	300.11	9.032 (-3)
Th	338.40	8.250 (-3)
U	351.99	8.008 (-3)
Th	463.00	6.512 (-3)
U	609.37	5.292 (-3)
U	768.40	4.443 (-3)
Th	911.10	3.907 (-3)
U	934.00	3.834 (-3)
U	1120.40	3.342 (-3)
U	1509.30	2.669 (-3)
U	1764.60	2.372 (-3)
U	2204.30	2.006 (-3)
U	2448.00	1.853 (-3)
Th	2614.47	1.721 (-3)

(-3)

to $\simeq$3 MeV. Only those peaks able to be fit by SAMPO with less than a 3% fitting error were used to determine this curve. The data were fit to a least squares power curve that allowed interpolation to any energy within the limits of the calibration. These fitted data are then used by SAMPO to calculate intensity counts at a given energy from the area counts in the peak. It is this efficiency which is used in the calculation of pCi/g of ^{137}Cs and ^{40}K. A graph of the efficiency versus energy data is shown in Fig. 5. The low energy efficiency data (E $<\sim$0.6 MeV) are affected by self absorption. Corrections for this effect are being generated.

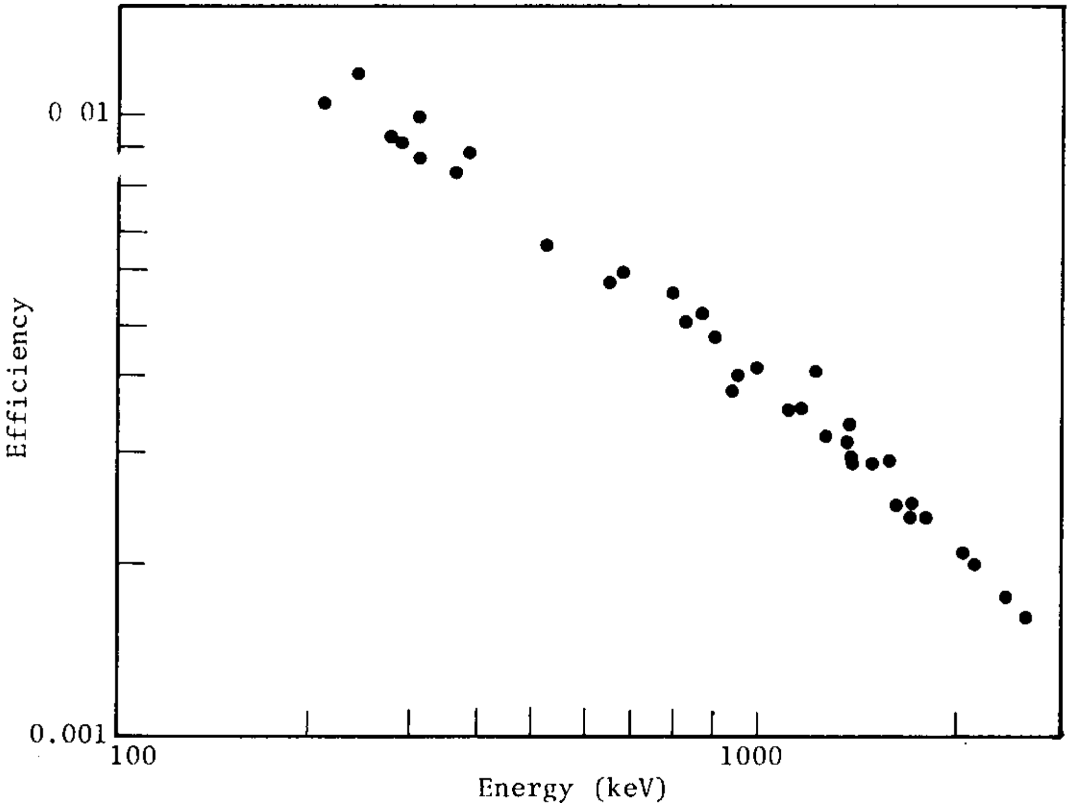

Fig. 5. Sample changer efficiency versus energy

7. DETECTABILITY

There are many definitions of detectability, and we will use the simplest one here: if at a given energy the net counts exceed 3 times the standard deviation of the background, then a positive indication of the presence of that energy gamma-ray has been obtained. Restated briefly, we shall use a 3σ detectability. To this end a 50,000-sec background count was run, and the peaks of interest were fit by program SAMPO. The standard deviation of the background area counts was found, and this value transformed into ppm assuming a 1500-g sample weight and a 30,000-sec counting time. The ppm obtained from the three major lines of U and Th, respectively, were averaged, and this value is reported here. A detectability for ^{137}Cs and ^{40}K was found in roughly the same manner, but using the intensity counts calculated by SAMPO to yield pCi. The detectability is reported in absolute pCi independent of sample weight.

Isotope	Detectability for a 1500-g sample, in ppm for a 30,000-sec Count
^{238}U	0.10 + 0.03
^{228}Th	0.28 + 0.07

	Detectability in pCi for a 30,000-sec Count
^{137}Cs	1 pCi
^{40}K	10 pCi
^{60}Co	1 pCi

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8. SAMPLE COUNTING AND DATA REDUCTION TECHNIQUES

The samples are allowed to age a minimum of 15 days after canning to let the U series approach secular equilibrium. (If the container wasn't airtight the ^{222}Rn from the ^{238}U decay series would be vented to the atmosphere and lost from the sample.) The samples are normally counted for 30,000 seconds (8.3 hours), but this time may be increased if a sample has very low activity in any of the isotopes of interest. Usually, it is desirable to count a sample for a long enough time to obtain <5% error in the results.

The data, stored on magnetic tape, are used as input to the computer code SAMPO, written by Dr. Routti at LBL, which is available to us on our time share terminal. The code determines exact channel locations, peak areas, peak energies, and intensities of gamma-ray-produced peaks in multichannel PHA data. Various statistical quantities relating to the quality of fit attainable from the data are also calculated.

The peak areas are determined by a least squares technique using internally generated analytical functions to represent peak shapes. These functions are developed by the code from a reference spectrum. The same calibration run may be used to assign energy per channel data and efficiency numbers. These can be fit with linear, log, or polynomial functions.

The reference spectrum should contain a number of intense well-isolated lines. These are used as internal calibrations and result in a code-generated table of shape parameters. This table contains the gaussian width and the upper and lower exponentials for each peak and correlates shape parameter versus channel number. In analysis of unknown spectra the code interpolates the shape parameters versus channel number to find a suitable analytic function for the peak in question. This function is then fit to the peak via a least squares technique. The continuum under the peak can be either a straight line or a second order function, depending on the peak width.

The code automatically searches for peaks by a second-difference technique with gaussian weighting determined from the shape table. Once a peak is identified and passes significance and shape tests, its area centroid in channel number and centroid in energy are determined. The efficiency data are then used to calculate gamma intensities. A typical output of these results produced by SAMPO is shown below:

```
 RUN NUMBER AND INDICATIVE DATA
XTLR 2-E DUAL DET SYS MAY 78 CALIB. TAPE 207        1416.2   20000.780233               10         -0        4000
COMMENTS = XTLR 2-E DUAL DET SYS MAY 78 CALIB. TAPE 207        1416.2   20000. S TAG 10 4000                         DATE =   11 OCT 78

ENERGIES RECOMPUTED USING OPTION  2

INTENSITIES RECOMPUTED USING OPTION  4

TABLE OF RESULTS

NUMBER  CHANNEL   CHANNEL   ENERGY   ENERGY   AREA      PC-AREA  INTENSITY   INTENSITY   RELATIVE    REL.INT.       INTENSITY
                  ERROR     IN KEV   ERROR    COUNTS    ERROR                ERROR PC    INTENSITY   ERROR PC       PER TIME


    1    255.393    .171    185.720      .137 3.197E+02   10.62 2.4643E+04      11.04    5.062E+00     12.416 1.2322E+00
    2    326.368    .019    238.630      .052 9.040E+02    9.18 8.4184E+04       9.66    1.729E+01     11.211 4.2092E+00
    3    369.154    .513    270.802      .389 6.709E+01   43.36 6.8730E+03      43.47    1.412E+00     43.839 3.4365E-01
    4    401.629    .132    295.220      .110 3.413E+02    8.68 3.7317E+04       9.18    7.665E+00     10.803 1.8659E+00
    5    460.000    .009    338.617      .050 1.745E+02    8.84 2.1167E+04       9.34    4.348E+00     10.936 1.0584E+00
    6    477.988    .097    351.990      .088 6.919E+02    5.56 8.6404E+04       6.31    1.775E+01      8.501 4.3202E+00
    7    690.808    .194    510.689      .153 4.171E+02    9.08 6.8973E+04       9.56    1.417E+01     11.126 3.4487E+00
    8    787.967    .013    583.140      .051 3.267E+02    8.38 5.9712E+04       8.90    1.226E+01     10.565 2.9856E+00
    9    822.629    .010    609.370      .051 5.505E+02    4.83 1.0402E+05       5.68    2.137E+01      8.044 5.2011E+00
   10    892.872    .005    661.747      .050 2.421E+03    4.84 4.8686E+05       5.69    1.000E+02      8.049 2.4343E+01
   11    934.302    .040    692.639      .058 3.405E+01   23.84 7.0874E+03      24.03    1.456E+00     24.692 3.5437E-01
   12    981.056    .251    727.502      .194 8.291E+01   11.72 1.7906E+04      12.10    3.678E+00     13.369 8.9532E-01
   13    993.466    .392    736.755      .296 2.801E+01   29.18 6.1079E+03      29.33    1.255E+00     29.880 3.0539E-01
   14   1035.803    .034    768.324      .056 5.113E+01   16.16 1.1508E+04      16.43    2.364E+00     17.391 5.7538E-01
   15   1106.554    .297    821.080      .227 3.097E+01   23.21 7.3276E+03      23.40    1.505E+00     24.086 3.6638E-01
   16   1125.929    .306    835.527      .234 3.005E+01   27.23 7.2061E+03      27.40    1.480E+00     27.983 3.6030E-01
   17   1141.857    .128    847.403      .108 4.357E+01   19.77 1.0558E+04      20.00    2.169E+00     20.790 5.2791E-01
   18   1159.861    .307    860.828      .234 5.963E+01   21.06 1.4622E+04      21.87    3.003E+00     22.597 7.3111E-01
   19   1227.281    .178    911.100      .142 1.677E+02    8.03 4.2915E+04       8.57    8.815E+00     10.288 2.1458E+00
   20   1259.176    .023    934.941      .053 3.600E+01   19.03 9.3968E+03      19.27    1.930E+00     20.090 4.6984E-01
   21   1304.565    .186    968.868      .147 1.176E+02   10.01 3.1525E+04      11.02    6.475E+00     12.405 1.5763E+00
   22   1338.836    .043    994.484      .059 2.345E+01   37.15 6.4134E+03      37.27    1.317E+00     37.706 3.2067E-01
   23   1507.292    .126   1120.400      .107 1.595E+02    7.67 4.7711E+04       8.24    9.800E+00     10.010 2.3855E+00
   24   1664.998    .187   1238.028      .148 5.845E+01   11.73 1.8855E+04      12.11    3.873E+00     13.383 9.4275E-01
   25   1767.881    .596   1314.766      .447 1.947E+01   41.16 6.5745E+03      41.27    1.350E+00     41.661 3.2873E-01
   26   1791.623    .057   1332.475      .066 3.726E+01   15.86 1.2707E+04      16.14    2.610E+00     17.116 6.3535E-01
   27   1852.179    .578   1377.642      .434 4.232E+01   23.20 1.4798E+04      23.39    3.040E+00     24.077 7.3991E-01
   28   1883.959    .425   1401.346      .321 1.631E+01   40.28 5.7790E+03      40.39    1.187E+00     40.788 2.8895E-01
   29   1908.485    .256   1419.639      .197 2.484E+01   17.77 8.8859E+03      18.02    1.825E+00     18.899 4.4429E-01
   30   1963.536    .089   1460.700      .083 3.319E+02    4.84 1.2131E+05       5.70    2.492E+01      8.054 6.0657E+00
   31   2141.026    .318   1593.235      .243 3.502E+01   18.21 1.3669E+04      18.46    2.808E+00     19.315 6.8344E-01
   32   2314.026    .066   1722.418      .070 2.167E+01   28.01 8.9680E+03      28.17    1.842E+00     28.735 4.4840E-01
   33   2370.516    .015   1764.600      .051 1.328E+02    8.35 5.6001E+04       8.87    1.150E+01     10.538 2.8001E+00
   34   2824.718    .290   2103.873      .222 4.101E+01   13.92 1.9739E+04      14.24    4.054E+00     15.334 9.8696E-01
   35   2958.283    .378   2203.641      .287 2.832E+01   22.94 1.4119E+04      23.14    2.900E+00     23.826 7.0595E-01
   36   3508.321    .118   2614.500      .101 1.993E+02    5.04 1.1304E+05       5.87    2.322E+01      8.174 5.6518E+00
   37   3779.014   1.023   2816.698      .765 3.332E+00   70.81 1.9991E+03      70.87    4.106E-01     71.100 9.9953E-02
   38   3879.027    .275   2891.405      .211 1.544E+01   13.22 9.4483E+03      13.56    1.941E+00     14.703 4.7242E-01

COUNTING TIME =  2.0000E+04
```

For volume source analysis an addendum to the SAMPO program has been written which calculates net ppm or pCi/g for the isotopes of interest from the SAMPO fitted data. Three peaks in the U spectrum and three in the Th spectrum are reduced to yield ppm (609.37, 1120.40, 1764.60 keV for U; and 583.14, 911.10, 2614.47 keV for Th). An average that is weighted by the fitting errors of the individual peaks is found. This is the value reported for the isotope. In addition the 1.00 MeV ^{234}Pa line of U is analyzed to determine whether the U contained in the sample is an equilibrium or not. (This line is not averaged with the other three U lines, because its low yield doesn't allow for as good a data fit.)

The equation for the calculation of ppm U or Th for each energy is:

$$\text{Net ppm} = \frac{\left(\begin{matrix}\text{SAMPO Generated} & & \text{Background} \\ \text{Area Counts/sec} & - & \text{Area Counts/sec}\end{matrix}\right)}{(\text{Sample Weight})} \times \text{Counter Factor}^*$$

The Background Area Counts/sec are calculated from a 50,000-sec run with an empty can in the detector. The error term associated with this reflects the SAMPO-generated error due to the quality of the peak fit (PC area error on data printout), the ppm versus cps error, the background error, and the estimated sample weighing error. The calculation for error is as follows:

$$\begin{aligned}\text{ppm Error} = \Bigg\{ & \begin{pmatrix}\text{Gross}\\ \text{ppm}\end{pmatrix}^2 \left[\begin{pmatrix}\text{Estimated}\\ \text{Fractional}\\ \text{Sample}\\ \text{Weighing}\\ \text{Error}\end{pmatrix}^2 + \begin{pmatrix}\text{Fractional}\\ \text{SAMPO}\\ \text{Generated}\\ \text{Area Error}\end{pmatrix}^2 + \begin{pmatrix}\text{Fractional}\\ \text{Counter}\\ \text{Factor}\\ \text{Error}\end{pmatrix}^2\right] \\ & + \left(\frac{\begin{matrix}\text{Background Area}\\ \text{Counts/sec}\end{matrix}}{\text{Weight Sample}}\right)^2 \Bigg[\begin{pmatrix}\text{Fractional}\\ \text{Background}\\ \text{Area Counts}\\ \text{Error}\end{pmatrix}^2 + \begin{pmatrix}\text{Fractional}\\ \text{Counter Factor}\\ \text{Error}\end{pmatrix}^2 \\ & + \begin{pmatrix}\text{Estimated}\\ \text{Fractional}\\ \text{Weighing}\\ \text{Error}\end{pmatrix}^2\Bigg]\Bigg\}^{1/2}\end{aligned}$$

Gross ppm is the ppm calculated for the line without subtracting a background. The fractional background error is the error found by SAMPO in fitting the background spectrum data. The ppm versus CPS error is that associated with the Counter Factor calculation.

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*See Section 6 for a discussion of the Counter Factor.

Cesium and potassium net pCi/g are calculated as follows:

$$\text{net pCi/g} = \frac{\left(\begin{matrix}\text{Sample Intensity}\\ \text{Counts}\end{matrix}\right) - \left(\begin{matrix}\text{Background Intensity}\\ \text{Counts}\end{matrix}\right)}{(\text{Counting Time}) \qquad\qquad (\text{Sample Weight})}\left(\frac{1}{0.037}\times\frac{1}{\text{Yield}}\right)$$

where 1/0.037 is a constant to convert disintegrations/second to pCi, and intensity is peak area/efficiency as determined by SAMPO. The error term reflects the SAMPO-generated intensity error, background error, and estimated errors due to weighing and assignment of yield. The equation for the error calculation is as follows:

$$\text{Error pCi/g} = \left\{\left(\begin{matrix}\text{Gross}\\ \text{pCi/g}\end{matrix}\right)^2\left[\left(\begin{matrix}\text{Fractional}\\ \text{Intensity}\\ \text{Counts Error}\end{matrix}\right)^2 + \left(\frac{1}{\begin{matrix}\text{Fractional}\\ \text{Yield Error}\end{matrix}}\right)^2 + \left(\begin{matrix}\text{Estimated}\\ \text{Fractional}\\ \text{Weighing}\\ \text{Error}\end{matrix}\right)^2\right] + \left(\begin{matrix}\text{Gross}\\ \text{Background}\\ \text{pCi/g}\end{matrix}\right)^2\left[\left(\begin{matrix}\text{Background}\\ \text{Intensity}\\ \text{Counts Error}\end{matrix}\right)^2 + \left(\frac{1}{\begin{matrix}\text{Fractional}\\ \text{Yield Error}\end{matrix}}\right)^2 + \left(\begin{matrix}\text{Estimated}\\ \text{Fractional}\\ \text{Weighing}\\ \text{Error}\end{matrix}\right)^2\right]\right\}^{1/2}$$

$$\text{where gross pCi/g} = \left(\frac{\text{Intensity Counts/sec}}{\text{Sample Weight}}\right)\left(\frac{1}{0.037}\times\frac{1}{\text{Yield}}\right)$$

$$\text{Gross Background pCi/g} = \left(\frac{\text{Background Intensity Counts/sec}}{\text{Sample Weight}}\right)\left(\frac{1}{0.037}\times\frac{1}{\text{Yield}}\right)$$

and the fractional yield error is obtained from the literature. The U and Th yield data used to determine the efficiency versus energy curve were obtained from Smith and Wollenberg. The ^{137}Cs and ^{40}K yield data are from Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine, September 1975.

```
                                                    INTENSITY OR       INTENSITY PC OR   NET PPM/G
        ISOTOPE           ENERGY OF PEAK     PEAK AREA COUNTS     AREA PC ERROR    OR PCI/G          + OR -

TIME =   20000.78      WEIGHT =  1416.2

TH 232                       583.140          3.267E+02              8.38               .147          .17

UR 238   FROM BI 214         609.370          5.505E+02              4.83               .436          .04

CS 137                       661.747          4.868E+05              5.69               .547          .03

TH 232                       911.100          1.677E+02              8.03               .372          .12

UR 238   FROM BI 214        1120.400          1.595E+02              7.67               .695          .08

CO 60                       1332.475          1.271E+04             16.14               .006          .00

K 40                        1460.700          1.213E+05              5.70               .040          .07

UR 238   FROM BI 214        1764.600          1.328E+02              8.35               .543          .09

TH 232                      2614.500          1.993E+02              5.04               .416          .17

UR 238   FROM BI 214 (AVE)                                                              .495          .03

TH 232   (AVERAGE)                                                                      .326          .09

RA 226   (AVERAGE)                                                                      .165          .01

CO 60   (AVERAGE)                                                                      .006          .00
```

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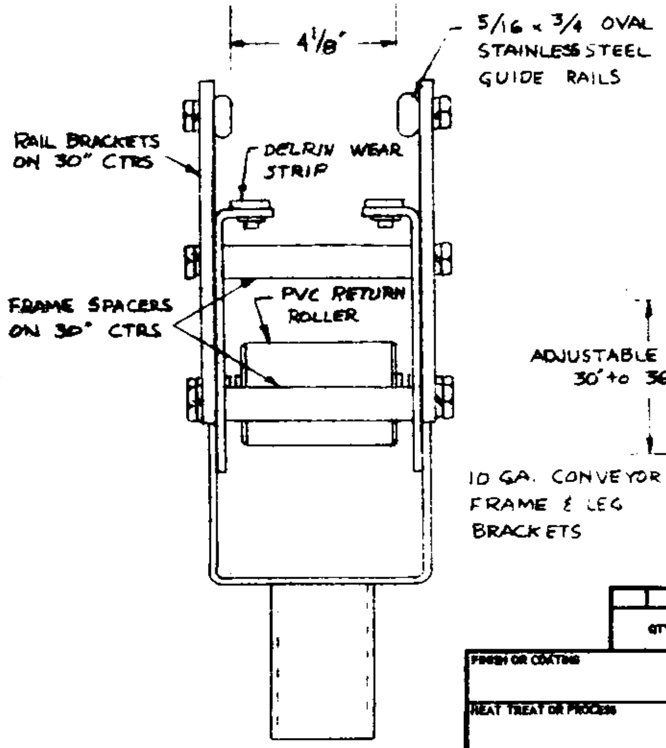
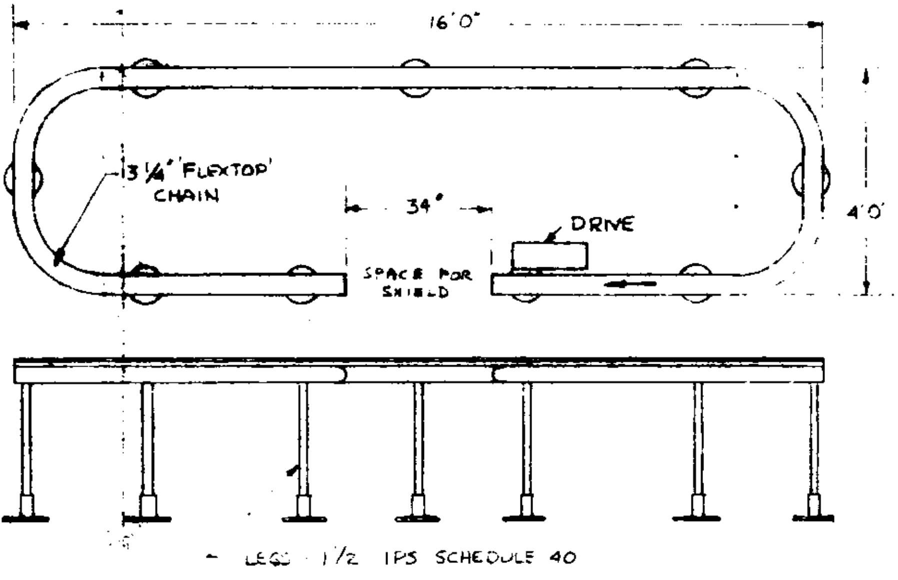
APPENDIX A: CONVEYOR LAYOUT DRAWING

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED





			-1	PART NO OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	CODE IDENT	REF DESIG	ZONE	FIND NO.
QTY REQD				PARTS LIST							

FINISH OR COATING

HEAT TREAT OR PROCESS

APPLY PART NO. IN LOCATION SHOWN

NEXT ASSY	USED ON	QTY REQD
APPLICATION		

UNLESS OTHERWISE SPECIFIED
1. DIMENSIONS ARE IN INCHES
2. BREAK ALL SHARP EDGES .005 - .015
3. REMOVE BURRS & SHARP EDGES
4. SURFACE ROUGHNESS ✓ MAX
5. DIMENSIONS APPLY AFTER FINISHING
6. DO NOT SCALE THIS DRAWING

TOLERANCES

DECIMALS	
.X	±.1
.XX	±.03
.XXX	±.010

ANGLES
MACHINED ±0° 30'
FORMED ±2°
CHAMFER ±5°

HOLES: SIZE RANGE / TOL

CONTRACT NO		
DRAWN	Keith L	DATE 5-4-75
CHECKED		
DESIGNER		
ENGINEER		
PROJ ENGR		
OTHER APPROVAL		

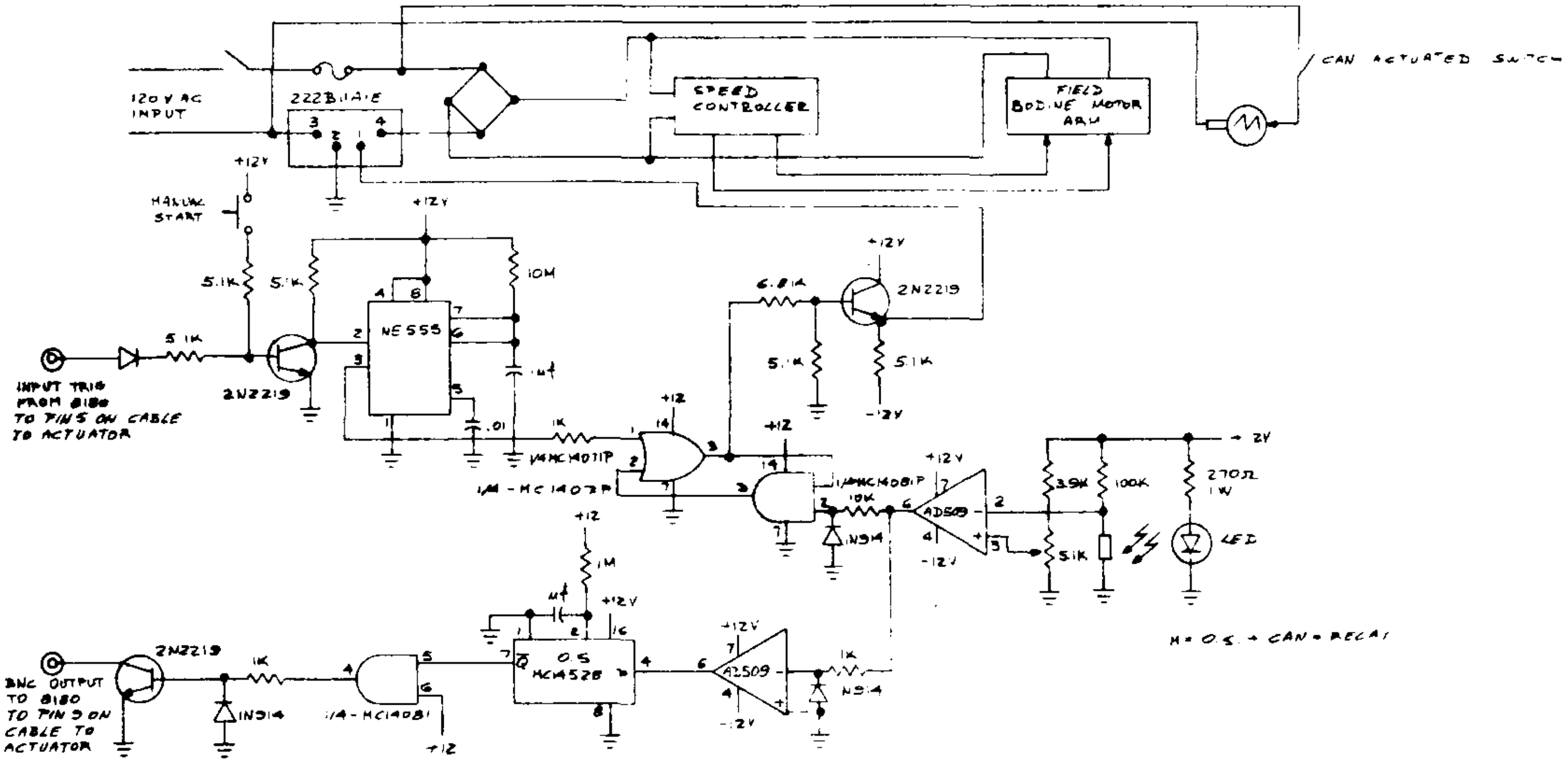
EG&G
SANTA BARBARA DIVISION
130 ROBIN HILL ROAD GOLETA, CALIFORNIA 93017

CONVEYOR LAYOUT & CROSS SECTION

SIZE	CODE OR IDENT NO	DRAWING NO
B	99626	CAS 1051

SCALE SHEET OF

APPENDIX B: DIGITAL CONTROL CIRCUIT FOR SECONDARY CONVEYOR



NIM MODULE CONNECTOR

+12	PIN 16
-12	PIN 17
GND	PIN 34

EG&G
130 ROBIN HILL ROAD, GOLETA, CALIFORNIA 93017

		DATE
DWN	E.S	10-77
CHK		
ENGR		

SAMPLE CHANGER
ELECTRICAL DIAGRAM

SIZE C
CODE OR IDENT NO 99626
DRAWING NO [illegible]
REV
USED ON
REQD
SCALE NONE
SHEET OF

APPENDIX C: DOCUMENTATION RELATING TO STANDARD MATERIALS USED

C.1 STANDARDS

The standards available for calibration purposes contain known quantities of NBS-analyzed U and Th are mixed with a low-radioactivity diluent of Ottawa sand.

C.2 500 PPM THORIUM STANDARD

This standard was made by mixing 72.33 g of the NBS Th ore sample, No. 79-A (1% Th) with 1374.3 g of Ottawa sand. 1429.0 g of the mixture was then packed in a standard sample container. The density is approximately 1.69 g/cm^3. The yield, at time of mixing (June 1976), was 2.88 (3) dis/sec.

The standard actually contains 502.3 ppm Th due to the Ottawa sand contribution.

C.3 500 PPM URANIUM STANDARD

This standard mixture was made up of 20.050 g of NBL U ore standard No. 42-1 (4.04 ±0.04% U) and 1600 g of Ottawa sand. The net standard weight in the container is 1525.0 g with a density of approximately 1.69 g/cm^3. The sample yield, in June 1976, was 9.40 (3) dis/sec.

The standard actually contains 501.0 ppm U due to the Ottawa sand contribution.

UNITED STATES ATOMIC ENERGY COMMISSION
NEW BRUNSWICK LABORATORY
CERTIFICATE OF ANALYSIS

ANALYZED SAMPLE NO. 79-A
THORIUM ORE

Thorium 1.00 Percent*

Uranium 0.04 Percent

This material was made by mixing weighed quantities of a monazite sand (Th = 8.44%) with dunite.

*Chemical analyses for thorium were performed on several bottles of the final preparation giving the result shown above with an absolute standard deviation of 0.01%.

Clement J. Rodden

Clement J. Rodden
Area Manager

New Brunswick, New Jersey
January 22, 1970

UNITED STATES ATOMIC ENERGY COMMISSION

NEW BRUNSWICK LABORATORY

PROVISIONAL CERTIFICATE OF ANALYSIS

ANALYZED SAMPLE NO. 42-1 TO 42-4

URANIUM COUNTING SAMPLES

These four samples were prepared from pitchblende diluted with dunite for use in calibrating counting equipment. Uranium and radium analyses of the pitchblende used in preparation of these materials indicate that the ratio of grams of radium per grams of uranium is 3.45×10^{-7}.

Chemical analyses of the samples show the following amounts of uranium:

% U
4.04 ± 0.04
1.99 ± 0.006
1.07 ± 0.003
0.52 ± 0.006

Precision is at 95% confidence level.

CJ Rodden

C. J. Rodden
Area Manager

New Brunswick, New Jersey
August, 1957