Calibration and Automation of a Dual-Energy Gamma System for Applications in Soil Science

CALIBRATION AND AUTOMATION OF A DUAL-ENERGY GAMMA

SYSTEM FOR APPLICATIONS IN SOIL SCIENCE

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the views of the United States Environmental Protection Agency
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ABSTRACT

Dual-energy gamma ray attenuation methods have been traditionally used in soil science to determine water content and bulk density values. Recently, interest in those techniques revived with two new applications: (1) the simultaneous determination of the volumetric non-aquous phase liquid content and water content values, and (2) the simultaneous determination of volumetric water content and salt concentration values. Based on Beer's law, the attenuation equations for all three applications were derived.

The dual-energy gamma system of the soil physics laboratory at Auburn University has been recently adapted to improve the calibration process and the data acquisition. The calibration process consists of the determination of: (1) the ^{241}Am and ^{137}Cs spectra, (2) the dead times of the single channel analyzers, (3) the Compton scattering in the ^{241}Am window, (4) the attenuation coefficients of the liquids and soils, (5) the path lengths through the porous medium, and (6) the incident count rates. The programs used in the calibration process are written in ASYST, a language especially designed for data acquisition and analysis.

A probable error analysis, based on the error propagation formula, is presented for the three applications. This analysis gives an indication of the attainable precision and is a tool to determine the optimum path length through a porous medium.

INTRODUCTION

Gamma ray attenuation methods were initially used in soil science to determine water content or bulk density values. The monoenergetic or single gamma ray attenuation method was used by Van Bavel et al. (29) to determine attenuation coefficients of soils and subsequently their dry bulk density values. Assuming a constant dry bulk density, several researchers (4, 12, 3, 23, 6) were able to determine water content values. The assumption of a constant dry bulk density implied that the monoenergetic gamma ray technique to determine volumetric water contents could only be used for non-swelling soils. Most investigators used the isotope ^{137}Cs, which emits gamma radiation photons at 662 KeV. King (15) reported promising results measuring soil water content values with the ^{241}Am isotope, which emits gamma radiation primarily at 60 KeV.

Soane (24) and Gardner and Calissendorff (8) were the first to use a dual-energy gamma radiation system to measure dry bulk density and volumetric water content simultaneously. They used ^{137}Cs and ^{241}Am as the gamma radiation sources. Theoretically, any two gamma sources with different gamma energies, such that their mass attenuation coefficients are sufficiently different, can be used to do this. Gardner and Calissendorff (8) and Corey et al. (2) showed that important factors such as half-life of the isotopes, cost, shielding, and self-absorption, make ^{137}Cs and ^{241}Am the most logical

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choices for dual-energy gamma measurements.

Soane *(24)* placed his samples between a ^{137}Cs source and the detector and then between an [241]Am source and the detector. He did not combine the sources in a single collimator, because the higher energy ^{137}Cs gamma photons, through interaction with matter, can produce lower energy photons (Compton scattering) which may interfere with the [241]Am gamma rays. The derivation of the equations used to calculate the dry bulk density and the volumetric water content is based on the simultaneous determination of ^{137}Cs and [241]Am count rates. The use of these equations, when using Soane's experimental setup, can only be justified if the soil-water system is changing slowly. Stroosnijder and de Swart *(27)* used two perpendicular beams with two separate detectors to avoid difficulties with [241]Am interference. This configuration restricts the geometry of soil-water systems that can be studied. Corey et al. *(2)* and Mansell et al. *(21)* used a common collimator for the two sources and a single detector. Corey et al. *(2)* used multichannel analyzers to correct for the Compton scattering. At least four measurements with different multichannel analyzer settings were necessary to correct for the Compton interference. This made his technique less suitable for rapidly changing soil water contents. Nofziger and Swartzendruber *(22)* expressed the correction due to Compton scattering as a function of the ^{137}Cs count rate. With the [241]Am removed and only the ^{137}Cs source remaining, they found,

by varying the attenuation, that a third degree polynomial expressed the Compton scattering the best. This correction method was later improved by Stillwater and Klute *(26)*.

Recently, the use of dual-energy gamma radiation techniques revived with two new applications. Ferrand et al. *(5)* and Lenhard et al. *(18)* experimented with the nondestructive simultaneous determination of the volumetric nonaqueous phase liquid (NAPL) and the volumetric water content, while Grismer et al. *(11)* determined the volumetric water content and the salt concentration in soils with low water contents. In all these applications it was assumed that the dry bulk density did not change with time. Ferrand et al. *(5)* reported good results with halogenated hydrocarbons such as trichloroethylene (TCE), tetrachloride and chloroform. The relatively heavy Cl atoms caused the attenuation coefficients of the halogenated hydrocarbons to differ substantially from that of water. Grismer et al. *(11)* experienced a linearly increasing attenuation coefficient with salt concentration. The best results were obtained with sodium iodide (NaI), lead nitrate $(Pb(NO_3)_2)$, and strontium chloride $(SrCl_2)$. The heavy ions in these salts (I^-, Pb^{2+}, Sr^{2+}) influenced the attenuation coefficient.

In the next section of this departmental series, a brief overview is given of the theory of gamma attenuation. The equations are derived for the simultaneous determination of

1. volumetric water content and dry bulk density,

    2. volumetric nonaqueous phase liquid content and

       volumetric water content, and

    3. salt concentration and volumetric water content.

Subsequently, the instrumentation of the dual-energy gamma radiation system of the soil physics laboratory at Auburn University is discussed, followed by a description of the calibration process. Finally, an error analysis for each of the three applications is given. In Appendix A, a brief overview of the computer language ASYST, used to automate the calibration and data acquisition, is presented, followed by listings of the programs used in the calibration process in Appendix B.

THEORY OF GAMMA RADIATION ATTENUATION

Gamma rays are electromagnetic photons which travel with the speed of light and are uncharged and unaffected by electrical or magnetic fields. When parent radionuclides decay, gamma radiation is emitted in their transition to lower lying levels. In most cases, the gamma radiation follows α or β decay. The two sources used in the soil physics laboratory at Auburn University are ^{137}Cs and ^{241}Am. The ^{137}Cs source emits gamma radiation primarily at 662 KeV following β decay, while the ^{241}Am gamma rays, emitted after α decay, have an energy of 60 KeV (17).

The three most important interactions of attenuation processes of gamma rays with matter are photoelectric

absorption, Compton scattering and pair production *(16)*. In the photoelectric absorption process, the gamma ray collides with an atom. The energy of the photon disappears completely while a photoelectron is produced along with one or more x-ray photons. For gamma rays with relatively low energy, this mode of interaction is the most important. The photoelectric absorption depends strongly on the atomic number Z of the absorbing material. The higher the Z-value, the higher the probability of interaction. In the process of Compton scattering, an incoming photon with a certain energy collides with an electron and is deflected. The deflected gamma ray has an energy that is lower than the energy of the incoming photon. Part of the energy of the incoming photon is transferred to the electron, known as the recoil electron. The third process of interaction is pair production. For this process of combining an electron and a positron, a minimum energy of 1020 KeV is required, which is impossible when using ^{137}Cs and ^{241}Am as gamma sources. The total attenuation of ^{137}Cs and ^{241}Am is, therefore, the sum of the attenuation due to Compton scattering and photoelectric absorption. Below 200 KeV the photoelectric absorption is the predominant effect, while higher energy gamma rays are more affected by Compton scattering.

The attenuation of gamma rays can be described by Beers' law:

$$I-I_o\exp\left(\sum_{i-1}^{n} \mu_i \rho_i x_i\right)$$ (1)

where I_o is the incident count rate (counts per second (cps)), I is the emergent count rate (cps), μ_i is the mass attenuation coefficient of component i ($L^2 M^{-1}$) , x_i is the path length of the gamma beam through i (L), and ρ_i is the density of i (ML^{-3}). This equation forms the starting point for the derivation of the equations for the simultaneous determination of two components with a dual-energy gamma radiation system.

Simultaneous Determination of Dry Bulk Density
and Volumetric Water Content

The attenuation of gamma radiation through a soil with dry bulk density ρ (ML^{-3}) and volumetric water content θ_w can be written as

$$I - I_o(-\mu_s \rho_s x - \mu_w \rho_w \theta_w x - \mu_g \rho_g \theta_g x)$$ (2)

where I_o is the count rate through the empty column (cps), ρ_i is the density of phase i (ML^{-3}), μ_i is the mass attenuation coefficient of phase i ($L^2 M^{-1}$), and θ_g is volumetric gas phase content. The subscripts s, w, and g denote soil, water, and gas phase, respectively. During the calibration process, the attenuation coefficient and density of a liquid are not

determined separately. Instead, a value U (L^{-1}) representing the product of the mass attenuation coefficient and the density of the liquid, $\mu_w \rho_s$, is obtained. Replacing the product $\mu_w \rho_w$ by the volumetric attenuation coefficient, U_w, and ignoring the contribution of the gas phase to the attenuation of the photons, eq. (2) becomes

$$I = I_o \exp(-\mu_s \rho_s x - U_w \theta_w x) \tag{3}$$

Introducing the subscripts c and a for the ^{137}Cs and ^{241}Am gamma radiation sources, respectively, gives

$$I_a = I_{oa} \exp(-\mu_{sa} \rho_s x - U_{wa} \theta_w x) \tag{4}$$

$$I_c = I_{oc} \exp(-\mu_{sc} \rho_s x - U_{wc} \theta_w x) \tag{5}$$

Eq. (4) and (5) can be solved for ρ_s and θ_w to yield

$$\rho_s = \frac{U_{wc} \ln\left(\dfrac{I_{oa}}{I_a}\right) - U_{wa} \ln\left(\dfrac{I_{oc}}{I_c}\right)}{x(\mu_{sa} U_{wc} - \mu_{sc} U_{wa})} \tag{6}$$

$$\theta_w = \frac{\mu_{sa} \ln\left(\dfrac{I_{oc}}{I_c}\right) - \mu_{sc} \ln\left(\dfrac{I_{oa}}{I_a}\right)}{x(\mu_{sa} U_{wc} - \mu_{sc} U_{wa})} \tag{7}$$

Simultaneous Determination of Volumetric NAPL Content

and Volumetric Water Content

The gamma ray attenuation through a porous medium with water (w), NAPL (n), and gas (g) can be written as

$$I = I_o' \exp(-\mu_s \rho_s x - \mu_w \rho_w \theta_w x - \mu_n \rho_n \theta_n x - \mu_g \rho_g \theta_g x) \tag{8}$$

where I_o' is the count rate through the empty column (cps). The NAPL has attenuation coefficient μ_n ($L^2 M^{-1}$), density ρ_n (ML^{-3}) and volumetric NAPL content θ_n. Assuming the contribution of the gas phase to be negligible and replacing $\mu_w \rho_w$ and $\mu_n \rho_n$ by U_w and U_n, respectively, eq. (8) can be written as

$$I = I_o' \exp(-\mu_s \rho_s x - U_w \theta_w x - U_n \theta_n x) \tag{9}$$

When the bulk density of the porous medium is constant in time, eq. (9) becomes

$$I = I_o \exp(-U_w \theta_w x - U_n \theta_n x) \tag{10}$$

where $I_o = I_o' \exp(-\mu_s \rho_s x)$. For a dual-energy gamma radiation system, with ^{137}Cs (subscript c) and ^{241}Am (subscript a) as the sources, the two attenuation equations are

$$I_a = I_{oa} \exp(-U_{wa} \theta_w x - U_{na} \theta_n x) \tag{11}$$

$$I_c = I_{oc} \exp(-U_{wc} \theta_w x - U_{nc} \theta_n x) \tag{12}$$

Solving eq. (11) and (12) for θ_w and θ_n yields

$$\theta_w = \frac{U_{na}\ln\left(\frac{I_{oc}}{I_c}\right) - U_{nc}\ln\left(\frac{I_{oa}}{I_a}\right)}{x(U_{wc}U_{na} - U_{wa}U_{nc})} \tag{13}$$

$$\theta_n = \frac{U_{wc}\ln\left(\frac{I_{oa}}{I_a}\right) - U_{wa}\ln\left(\frac{I_{oc}}{I_c}\right)}{x(U_{wc}U_{na} - U_{wa}U_{nc})} \tag{14}$$

Simultaneous Determination of the Volumetric Water Content and the Salt Concentration.

The attenuation of gamma radiation through a porous medium with a salt solution (subscript L) can be written as

$$I = I_o'\exp(-\mu_s\rho_s x - \mu_L\rho_L\theta_L x - \mu_g\rho_g\theta_g x) \tag{15}$$

Assuming the gas attenuation to be negligible and the dry bulk density to be constant in time, eq. (15) becomes

$$I = I_o\exp(-\mu_L\rho_L\theta_L x) \tag{16}$$

where $I_o = I_o'\exp(-\mu_s\rho_s x)$. Replacing $\mu_L\rho_L$ by U_L gives

$$I = I_o\exp(-U_L\theta_L x) \tag{17}$$

The attenuation equations for the sources ^{241}Am and ^{137}Cs are, respectively,

$$I_a = I_{oa}\exp(-U_{La}\theta_L x) \tag{18}$$

$$I_c - I_{oc}\exp(-U_{Lc}\theta_L x) \tag{19}$$

When the salt solution consists of a single salt dissolved in water, its volumetric attenuation coefficient can be written as

$$U_{La} - \mu_{wa}C_w + \mu_{ra}C_r \tag{20}$$

$$U_{Lc} - \mu_{wc}C_w + \mu_{rc}C_r \tag{21}$$

where C_w and C_r are the water and salt concentrations (ML^{-3}), respectively, and μ_{ra} and μ_{rc} are the mass attenuation coefficients of the pure salt. At relatively low salt concentrations, it can be assumed that $\theta_L = \theta_w$ and and that the product $\mu_{wj}C_w$ is a constant. U_{Lj} is then a linear function of the salt concentration only. Replacing C_r by C, $\mu_{wa}C_w$ by a (L^{-1}), $\mu_{wc}C_w$ by r (L^{-1}), μ_{ra} by b (L^2M^{-1}) and μ_{rc} by s (L^2M^{-1}), eq. (20) and (21) become, respectively,

$$U_{La} - a + bC \tag{22}$$

$$U_{Lc} - r + sC \tag{23}$$

Grismer et al. (11) experimentally·determined linear relations between the volumetric attenuation coefficients and the salt molality of various salts. Assuming $\theta_L = \theta_w$, and substituting eq. (22) in (18) and (23) in (19) yields

$$I_a - I_{oa}\exp(-[a + bC]\theta_w x) \tag{24}$$

$$I_c - I_{oc}\exp(-[r + sC]\theta_w x) \tag{25}$$

Solving eq. (24) and (25) for C and θ_w results in

$$C = \frac{a\ln\left(\dfrac{I_{oc}}{I_c}\right) - r\ln\left(\dfrac{I_{oa}}{I_a}\right)}{s\ln\left(\dfrac{I_{oa}}{I_a}\right) - b\ln\left(\dfrac{I_{oc}}{I_c}\right)} \tag{26}$$

$$\theta_w = \frac{s\ln\left(\dfrac{I_{oa}}{I_a}\right) - b\ln\left(\dfrac{I_{oc}}{I_c}\right)}{x(as - br)} \tag{27}$$

GAMMA SYSTEM INSTRUMENTATION

The dual-energy gamma system of the soil physics laboratory has recently been adapted to improve the calibration process and the data acquisition and, therefore, differs from the system previously described by Hopmans and Dane *(13, 14)*. The instrumentation of the dual-energy gamma system is presented in a block diagram in figure 1.

The two sources, a 200 mCi ^{137}Cs- and a 200 mCi ^{241}Am-source, are mounted coaxially in the center of a 0.17-m-long and 0.14-m-diameter lead shield. The Cs-source is located in the center, while the Am-source is placed at the front end of the lead shield and is contained in a brass holder, 10 mm thick and 40 mm in diameter. A thallium-activated sodium iodide (NaI(Tl)) scintillation crystal with a photomultiplier tube form the gamma ray detector (Harshaw Chemical, Solon, Ohio). The detector is enclosed in another cylindrical lead shield with a length of 0.11 m and a diameter of 0.14 m. Collimation is provided by 6.35-mm cylindrical holes in the
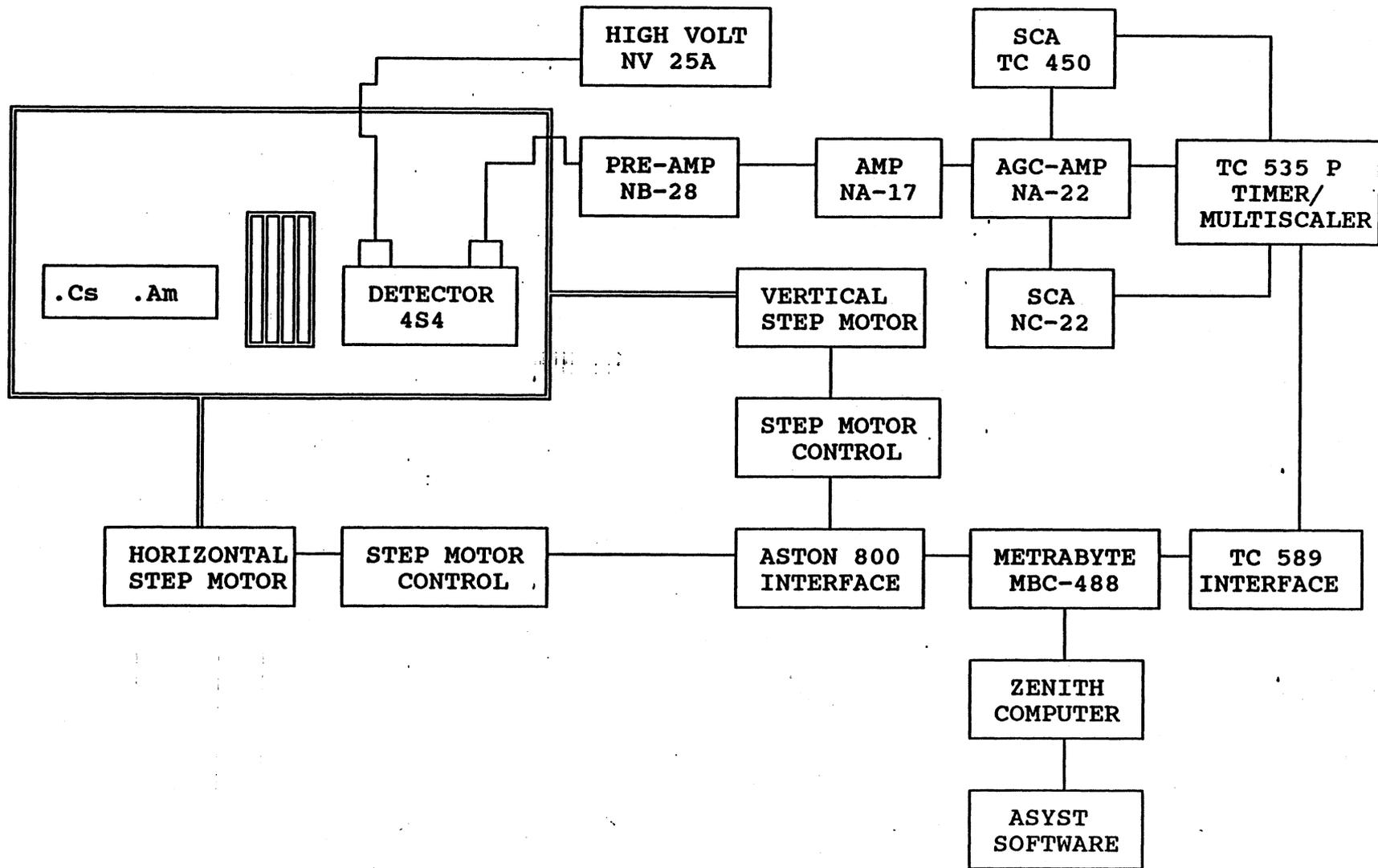
FIG. 1. Function diagram of gamma system components.

lead shields. Thallium-activated sodium iodide is widely used in the scintillation spectroscopy of gamma rays because of the high Z-value of iodide and the high density of the NaI-crystal. The interaction of gamma radiation and matter is a strong function of the Z-value and density of the material. The principle of this detection method is to create visible light pulses upon interaction of the incident gamma photons and the NaI(Tl)-crystal, followed by a conversion of the light pulses into measurable electrical pulses. The thallium is added to the NaI-crystal to increase the visible photon emission. In a pure NaI-crystal, electrons have only two discrete bands of energy available, the lower valence band and the higher conduction band. The intermediate band of energies, called the forbidden band, has never been shown to contain electrons. A gamma photon can excite an electron from the valence band to the conduction band. After this, the electron has a tendency to return to the valence band, but this process is not very effective and the photon emitted when returning to the valence band has an energy that is too high to lie in the visible range. The impurity thallium, however, creates energy sites in the forbidden gap preferred by the excited electrons. When these electrons drop back to the valence band, the likelihood of visible photons being emitted has strongly increased. The half-life or decay constant of the excited state of thallium electrons is .23 μs, which is much shorter than that of the pure NaI excited state.

A photomultiplier (PM) is necessary to convert the very weak light output of a scintillation pulse into a corresponding electrical signal. The two major elements of a PM are the photocathode and the electron multiplier. The photocathode converts the incident light photons into low-energy photoelectrons. The electron multiplier collects the photoelectrons by focusing electrodes and multiplies them by a factor 10^5 - 10^8 by means of a system of dynodes. This process, known as charge amplification, is usually enough to create a charge signal to be collected at the anode of the electron multiplier.

A stable voltage source NV 25A (Harshaw) is required for an efficient charge amplification in the PM. The first dynode of the electron multiplier has to be positive with respect to the photocathode to attract the electrons, and every succeeding dynode must have a higher voltage than the previous dynode. The charges Q, by the detector, are so small that they have to be amplified. The amplification is performed by a preamplifier, NB-28 (Harshaw), and an amplifier, NA-17 (Harshaw). The preamplifier is located as close as possible to the detector to keep the noise, occurring in interconnecting cables, as low as possible. The gain of the amplifier is adjustable through a combination of a course and fine gain control.

Once amplified, the electrical pulses are linearly transmitted through an automatic gain control (AGC) unit, NA-

22 (Harshaw) to two single channel analyzers (SCA), the NC-22 (Harshaw) and the TC 450 (Tennelec, Oak Ridge, Tennessee). The AGC-unit is provided with a 'limit' display, which will turn on when the product of input amplitude and the gain set on the NA-17 exceeds the maximum amplitude detectable. The NA-22 also has a built in SCA. A SCA converts the shaped linear pulses into logic, countable, pulses by using its integral or differential discriminator. The integral discriminator produces a logic output pulse if the linear input pulse exceeds a set discrimination level. No output appears when the linear input pulse amplitude is below the discrimination level. A differential discriminator produces a logic output if the linear input pulse amplitude lies between the lower level discriminator (LLD) and the upper level discriminator (ULD). The range between the LLD and ULD is known as the SCA "window." In the calibration process, discussed in the next section, the settings of the TC 450, NC-22 and NA-22 are determined.

The accumulation of the counts over a fixed time period is recorded by the TC 535P timer/multiscaler (Tennelec). The timer/multiscaler consists of four counters, three of them are used to count the logic output pulses of the SCA's and the NA-22 and the fourth is used to display the elapsed time of a measurement. The timer/multiscaler is connected with a MBC IEEE-488 data acquisition board (MetraByte Corporation, Taunton, Massachusetts) via a TC 489 buffered interface

(Tennelec). The computer needs the data acquisition board to exchange General Purpose Interface Bus (GPIB) commands with GPIB devices such as the TC 489 buffered interface. The computer can instruct the timer/multiscaler to start and stop counting via the TC 489 buffered interface. Data can be stored temporarily in the buffer of the TC 489. The software package ASYST (ASYST Software Technologies Inc., Rochester, New Jersey) is especially designed to communicate with GPIB devices via data acquisition boards. GPIB interfacing is discussed in more detail in Appendix A.

The interconnected sources and detector are moved simultaneously, either horizontally or vertically, by stepper motors. Measurements can be taken in a 2-dimensional area of 2.10 x 1.05 m. The SP155A horizontal and vertical stepper motor control units (Superior Electric, Bristol, Connecticut) can be activated manually or by computer software. When the movement of the sources and detector is computer controlled, the Aston 800 actuator (Aston Company, Atlanta, Georgia) serves as an intermediate GPIB device, interfacing the stepper motor control units and the data acquisition board in the computer.

THE CALIBRATION PROCESS

Determination of ^{137}Cs and ^{241}Am Spectra

The amplified output pulses have a broad energy spectrum. To discriminate these pulses, the energy spectra of both

sources have to be known. First, the ^{137}Cs spectrum is determined using the pulse height analyzer part of the NA-22 ·and calibration program 1, spectrum.txt (APPENDIX B). Depending on the high voltage supply of the NV 25A and the coarse gain setting of the amplifier NA-17, the ratio of the NA-22 base line voltage to the energy of the processed pulses is a certain constant. Knowing that ^{137}Cs emits gamma radiation primarily of .66 MeV and that the E range of the NA-22 is 0-10 V, it is convenient to manipulate the high voltage setting and the coarse gain in such a way that the NA-22 base line voltage to ^{137}Cs gamma radiation energy (in MeV) ratio is 10:1. With the NA-22 in differential mode and an E setting of 6.5 V and ΔE of 0.2 V, a high voltage of 706.0 V and a coarse gain of 80 result in the highest count rate and the desired voltage to energy ratio. The high voltage should not be disturbed, because the photon detection relies on a stable voltage.

To obtain the ^{137}Cs spectrum, the toggle switch of the NA-22 should be in the disabled mode. The initial setting of E is 3.9 V and ΔE is 0.2 V. The output mode should be differential so that the LLD of the window is 3.9 V and the ULD is 4.1 V. For subsequent measurements, E is usually increased by 0.1 V. A ^{137}Cs spectrum obtained with calibration program 1, spectrum.txt, is presented in figure 2.
Based on this graph, the LLD, corresponding to E, is 5.5 V and the ULD, corresponding to E + ΔE, is 7.5 V. This results in
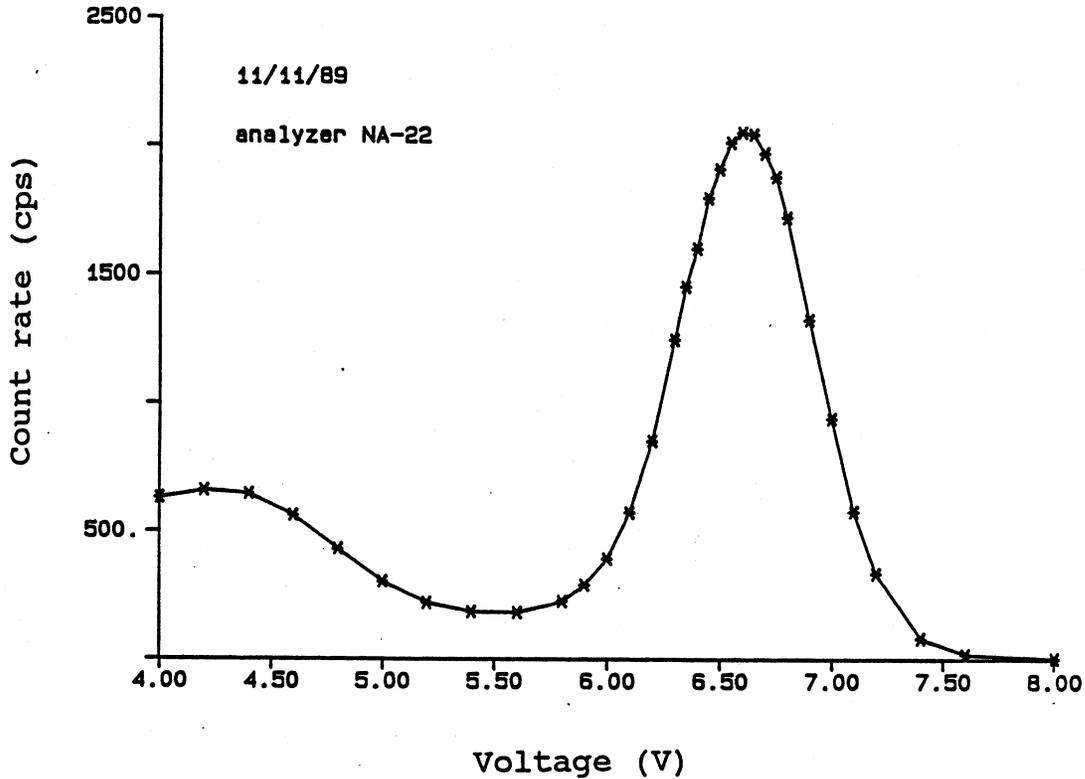
FIG. 2. Energy spectrum of ^{137}Cs.

E and ΔE settings of 5.5 and 2.0 V, respectively. After the ^{137}Cs spectrum is determined, the toggle switch of the NA-22 is set to track to prevent a shift of the Cs-window. Since the ^{241}Am count rates are obtained using both the TC 450 and the NC-22 SCA, two ^{241}Am energy spectra have to be determined. An initial E of 0.05 V is recommended while 0.1 V is a convenient window width (ΔE). For each subsequent measurement, E has to be increased by 0.03 or 0.04 V.

Operation of the TC 450 is more complicated than the NC-22, which is basically the same as the analyzer part of

the NA-22. During the determination of the TC 450 ^{241}Am spectrum, it is convenient to use the differential mode which corresponds with the 'window/asym' setting on the TC 450. The upper knob then represents 10*ΔE, while E can be manipulated with the lower knob. Once the LLD and the ULD of the spectrum are obtained, the operation is switched to the 'norm' mode, where the lower knob represents the LLD and the upper knob represents the ULD of the spectrum. The ^{241}Am spectra determined with calibration program 1 are shown in figure 3. For the NC-22, an E setting of 0.42 V and a ΔE of 0.42 V were obtained, while the TC 450 has a LLD of 0.47 and an ULD of 0.93 V. The ^{241}Am spectra contain counts due to Compton scattering of ^{137}Cs photons; a method to correct for this interference will be discussed in a later section.

Dead Time Corrections

The dead time or resolving time of a counting system is defined as the minimum amount of time which must separate two events so that they are recorded as two separate pulses (16). When an event occurs in the detector, the system needs a certain amount of time, τ (sec/count), to process the incoming gamma photon. All events occurring during a dead time τ after a recorded event will be lost. In our system, a lost event does not further extend the dead time by another period τ. The system is said to have a nonparalysable response as opposed to a system with a paralysable response
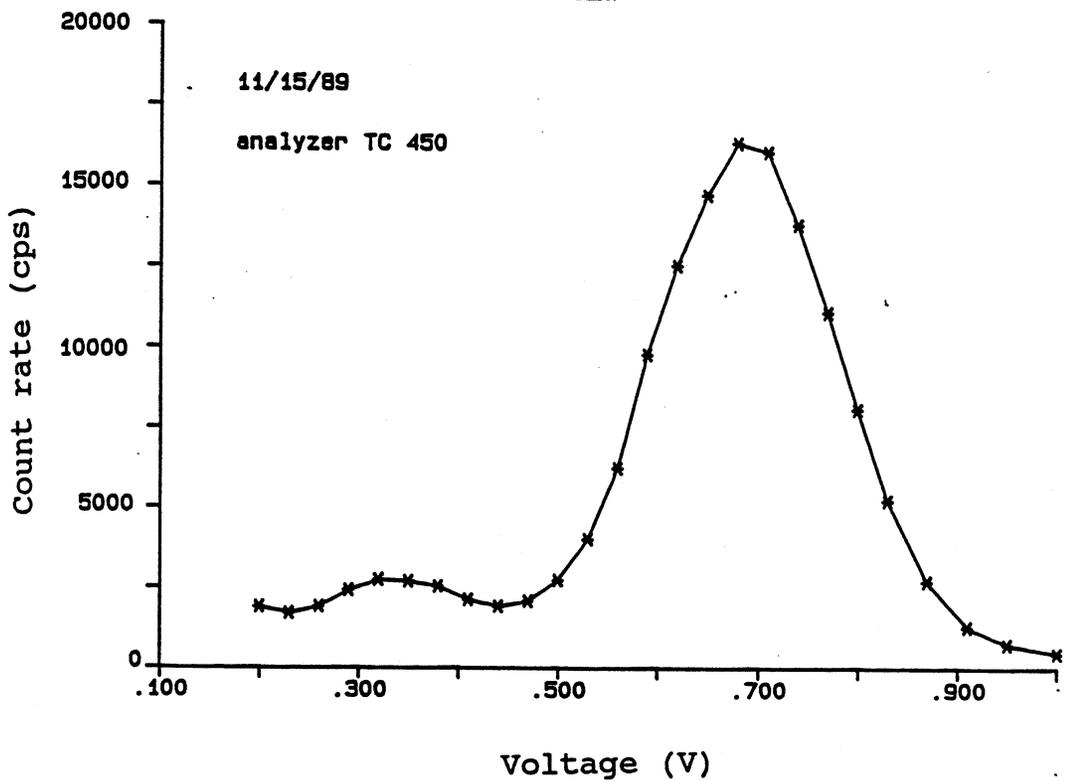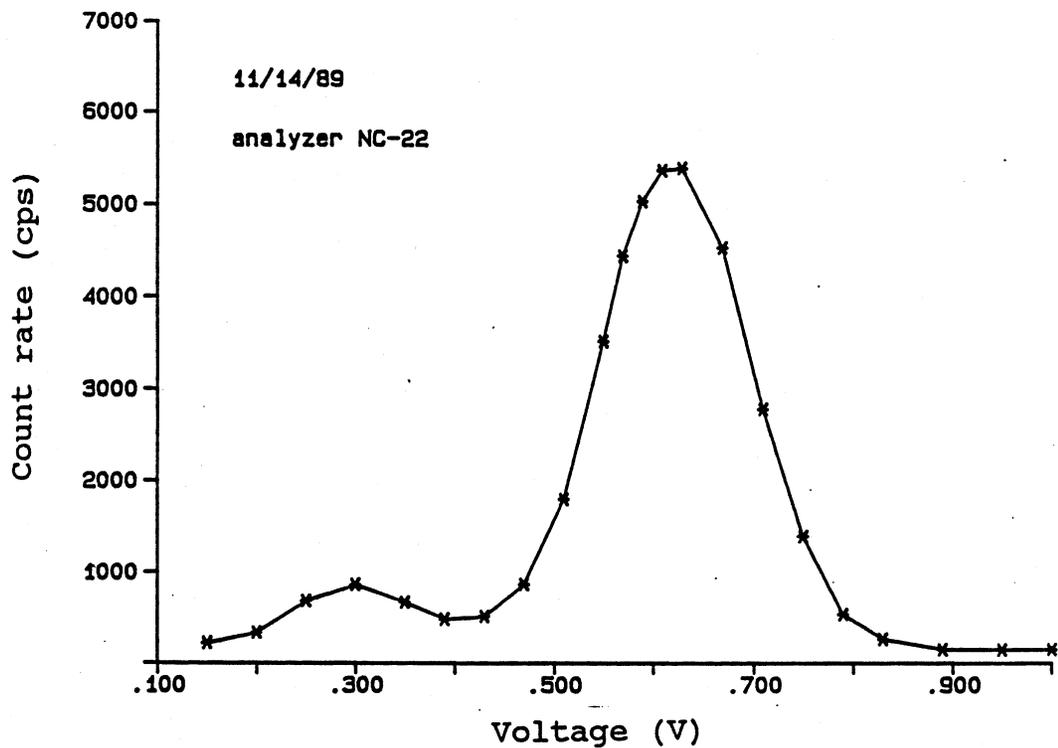
FIG. 3. The ^{241}Am spectra

where any lost event during the dead time period extends this period. When I_m is the measured count rate (counts per second, cps), the product $I_m \tau$ is the fraction per second the system is dead. The true count rate I can then be calculated with

$$I = I_m(1 - I_m\tau) \tag{28}$$

In most counting systems, SCA's are responsible for the dead time, since these are the only components with discrete processing periods. Most often, the SCA dead time is unknown or an approximate value is provided by the manufacturer. For correction purposes accurate dead time values are needed. Before Fritton *(6)* described a method to determine dead times, most researchers did not correct their measured count rates for system dead time. Only Gurr *(12)* mentioned the use of a measured dead time of 9 μsec for his system, but he did not outline his dead time determination procedure. Fritton varied the path length through the materials water, soil, lead, and Plexiglas and corrected the measured count rates according to eq. (28) for dead times varying from 0.1 to 7.0 μsec. He assumed that the linearized equation describing the attenuation process of a single material was

$$\ln(I) = -\mu\rho x + \ln(I_o) \tag{29}$$

where I and I_o are the corrected count rates through a

material with thickness x and 0, respectively. After plotting ln(I) versus x for the different dead times and calculating the slopes with linear regression, the best value of the resolving time minimizes the weighted variance (w.v.). The expression of this weighted variance is

$$\text{w.v.} = \sum_{i=1}^{n} \Delta y^2 / I_i \qquad (30)$$

where n is the number of points used for the line and Δy are the deviations from the calculated regression line. For all the materials used in his study, Fritton found a dead time of 5.0 μsec. He concluded that, when a correction for dead time is made, the mass absorption coefficients are much closer to the theoretical values. Nofziger and Swartzendruber (22) used the same method, except they minimized the weighted sum of variances in I compared to the weighted sum of variances in ln(I) used by Fritton.

In another effort to determine dead time, Stroosnijder and de Swart (27) measured count rates with and without an absorber for three different distances between source and detector. The ratios between the corrected (eq. 28) count rates with and without the absorber were calculated and plotted against dead time. The three ratio-dead time curves intersected in one point where the three ratios and the dead time are the same. This dead time was then assumed the system

dead time. Hopmans and Dane *(13, 14)* modified this method by using 3 different absorber thicknesses instead of three source-detector distances.

A more precise, direct way to determine the dead time of a SCA was presented by Stillwater and Klute *(26)*. They used a square wave generator to simulate input pulses to the SCA and a dual channel oscilloscope to view input and output pulses. At low square wave frequencies, the ratio of input to output pulses is 1:1, which means that all the input pulses are processed, and at high frequencies this ratio is 2:1, which means that only 50% of the incoming pulses are processed. When starting at a low frequency and increasing this frequency slowly, it should be possible to find the transition point or a narrow transition band where the input to output ratio changes from 1:1 to 2:1. The reciprocal of the transition frequency is then the dead time of the SCA. This method was used to determine the dead time of our SCA's and the SCA part of the NA-22. The results are shown in table 1.

Table 1. Dead Times
(μsec) of SCA's and NA-22

Device	Dead Time
TC 450	0.60
NC-22	1.67
NA-22	1.25

Hopmans and Dane *(13, 14)* reported indirectly determined dead

times of 2.5 μsec for both the NA-22 and NC-22.

Stillwater and Klute *(26)* discussed the validity of eq. (28), which has been used by most researchers to correct for dead time. They argued that, when a SCA is operated in the integral mode, all pulses exceeding the LLD are processed and counted, while a SCA in differential mode also processes all pulses exceeding the LLD, but only counts those pulses between the preset LLD and ULD. The fraction of a second the SCA is dead is therefore determined by the count rate of the processed pulses (I_p) and not by the count rate of the measured pulses (I_m). To obtain the dead time corrected count rate, I, the measured count rate has to be divided by the fraction of a second, $1-I_p\tau$, the system is not dead, i.e.,

$$I = I_m/(1-I_p\tau) \tag{31}$$

The ^{137}Cs radiation count rates measured in differential and integral mode with the NA-22 are practically equal, because only a few incoming photons have energies greater than the ULD set. This means that eq. (28) can still be used for ^{137}Cs radiation count rates. For ^{241}Am, however, the integral count rate, which equals I_p, is usually much larger than the measured rate in differential mode, I_m, and eq. (31) must be used to correct for dead time. Replacing I_m by the differential ^{241}Am count rate I_{ad} and I_p by the integral count rate I_{ai}, eq. (31) becomes

$$I_a = I_{ad}/(1-I_{ai}\tau_a) \tag{32}$$

where I_a and τ_a are the dead time corrected count rate and dead time of the [241]Am SCA, respectively.

Stillwater and Klute (26) proposed the use of a SCA which is able to supply both the integral and differential counts simultaneously to two different scalers. With our system, we use a different setup to obtain the same result. Since none of our SCA's is able to produce both I_{ai} and I_{ad}, we have to use two SCA's supplying I_{ai} and I_{ad}. Since the TC 450 SCA has the smallest τ_a, it was chosen to provide I_{ad} and τ_a. To use eq. (32), however, the I_{ai} produced by the TC 450 has to be known also. An indirect way to obtain this I_{ai} is to determine the relation between the I_{ai} of the NC-22 and the TC 450 during calibration of the system. This relation can then be used to transform a measured integral count rate supplied by the NC-22 into a calculated I_{ai} of the TC 450. Calibration program 2, rel.txt (APPENDIX B), is used to determine this relation, which appears to be highly linear (fig. 4.). The data points shown in figure 4 are obtained by moving the sources and detector with respect to a teflon prism and taking subsequent measurements.

Correction for Compton Scattered [137]Cs Photons in the [241]Am Window.

Due to Compton scattering, ^{137}Cs photons release part of
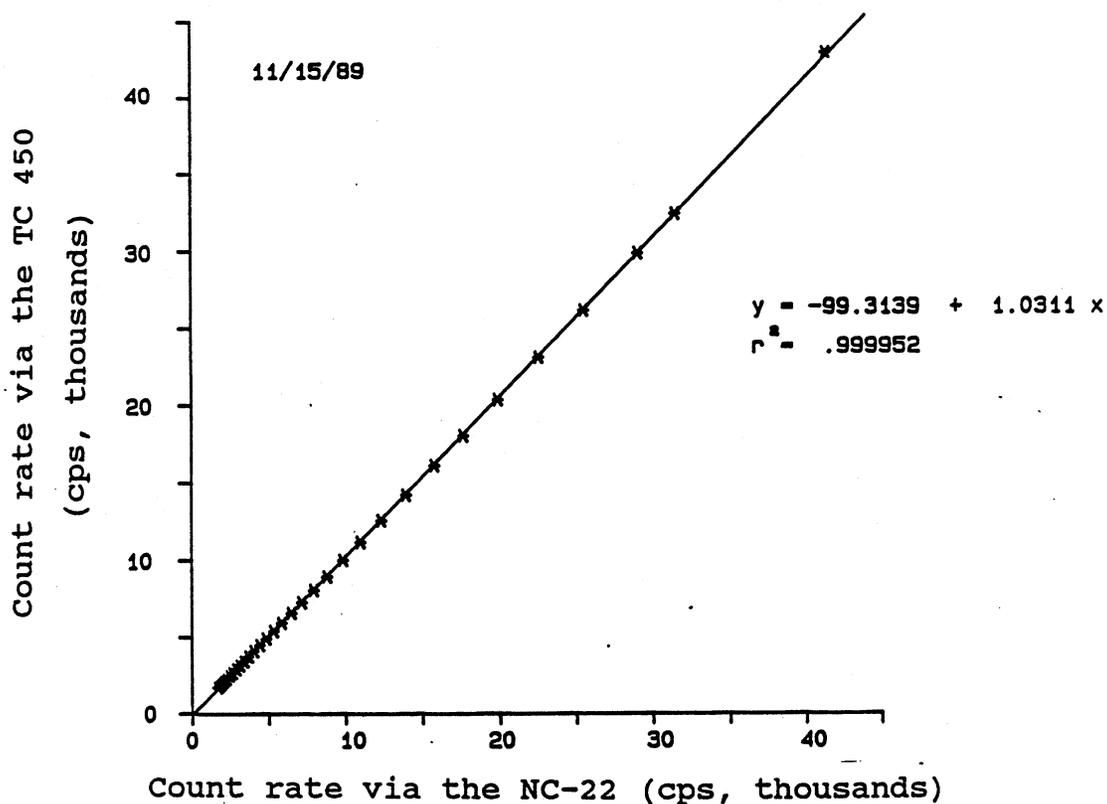
FIG. 4. Relation between the integral ^{241}Am count rates of the NC-22 and the TC-450 single channel analyzers.

their energy. When one detector is used to simultaneously determine ^{241}Am and ^{137}Cs photons, part of the Compton scattered ^{137}Cs photons cause interference in the ^{241}Am window set on the TC 450 SCA. The production of these lower energy ^{137}Cs photons originates in the NaI(Tl) crystal and not in the material placed between the sources and detector (22). Compton scattering will cause the photon to deflect from its original path while giving up some of its energy. These characteristics of Compton scattering imply that the

probability for the attenuation material to reduce the energy of a ^{137}Cs photon by 90%, without changing its path, is very small. According to Nofziger and Schwartzendruber (22), a ^{137}Cs photon needs four collisions at an angle of 180° to have its energy reduced from 662 KeV to 60 KeV and to remain in the collimated radiation beam. The results of experiments they performed with different materials (glass, granular quartz, water, brass, Salkum soil, Ruskell soil) showed the material independence of the low ^{137}Cs energy photon count rate in the ^{241}Am window. Loch and Kay (19) also reported this independence of the Compton scattering on the attenuation materials Plexiglas, brass, aluminum, wood, lead, and water.

The Compton interference of the low energy ^{137}Cs photon count rate in the ^{241}Am window ($I_{c,low}$) as a function of the high energy ^{137}Cs count rate (I_c) is described by either a cubic polynomial (22, 13, 19),

$$I_{c,low} = a + bI_c + cI_c^2 + dI_c^3 \tag{33}$$

or by a linear polynomial (30, 28, 26),

$$I_{c,low} = a + bI_c \tag{34}$$

Goit et al. (10) did not provide an equation for the nonlinear relation they observed. All the relations described by cubic polynomials show a slight curvature at higher count rates and the coefficients c and d are very small. For example, Hopmans

and Dane *(13)* reported a value of $-2.315935*10^{-5}$ sec/count for c and $5.5831407*10^{-9}$ sec^2/count^2 for d. Swartzendruber et al. *(28)* showed that a reduction of the high energy ^{137}Cs count rate range results in a linearization of the Compton scattering relation.

Theoretically, since the gamma system geometry determines the probability a photon will cause a pulse of a given energy, the ratio of the low energy ^{137}Cs photon count rate in the ^{241}Am window to the high energy ^{137}Cs photon count rate is a constant *(26)*. The relation between the two count rates should be a line passing through the origin. Stillwater and Klute *(26)* attributed the nonlinearity at high count rates found by some researchers to the lack of dead time correction of the count rates. It has been common practice to do the Compton correction before the dead time correction, because Compton-Compton-corrected count rates were needed in the indirect methods to determine the dead time. The direct dead time determination proposed by Stillwater and Klute made it possible to do the dead time correction before the Compton correction, resulting in a more accurate determination of the true ^{241}Am count rate. In order to obtain the true ^{241}Am count rate ($I_{a,true}$), the dead time corrected low energy ^{137}Cs photon count rate in the ^{241}Am window ($I_{c,low}$) has to be subtracted from the total dead time corrected ^{241}Am count rate ($I_{a,total}$):

$$I_{a,true} = I_{a,total} - I_{c,low} \qquad\qquad (35)$$

With calibration program 3, compton.txt (APPENDIX B), the relation between the dead time corrected high energy ^{137}Cs photon count rate and the dead time corrected low energy ^{137}Cs photon count rate in the ^{241}Am window is determined. Two brass plates were placed in front the detector to block the emitted ^{241}Am photons and all the photons detected in the ^{241}Am window were then assumed to be Compton scattered ^{137}Cs photons. A teflon prism placed between the sources and detector provided variable radiation attenuation. The Compton relation obtained is shown in figure 5. A linear polynomial provides the best fit for the data points. Hopmans and Dane *(13)* reported a cubic Compton relation for approximately the same high energy ^{137}Cs photon count rate, using uncorrected count rates. Apparently, the curvilinear character of the Compton relation disappears when a dead time correction precedes the Compton correction in the calibration procedure.

Determination of Attenuation Coefficients

Volumetric Attenuation Coefficients of Liquids

The volumetric attenuation coefficient of a liquid, U_{ij}, where i refers to the liquid and j to the gamma source, consists of the product of the mass attenuation coefficient, μ_{ij}, and the density of the liquid, ρ_i. To obtain U_{ij} a Plexiglas cell with four parallel compartments is placed
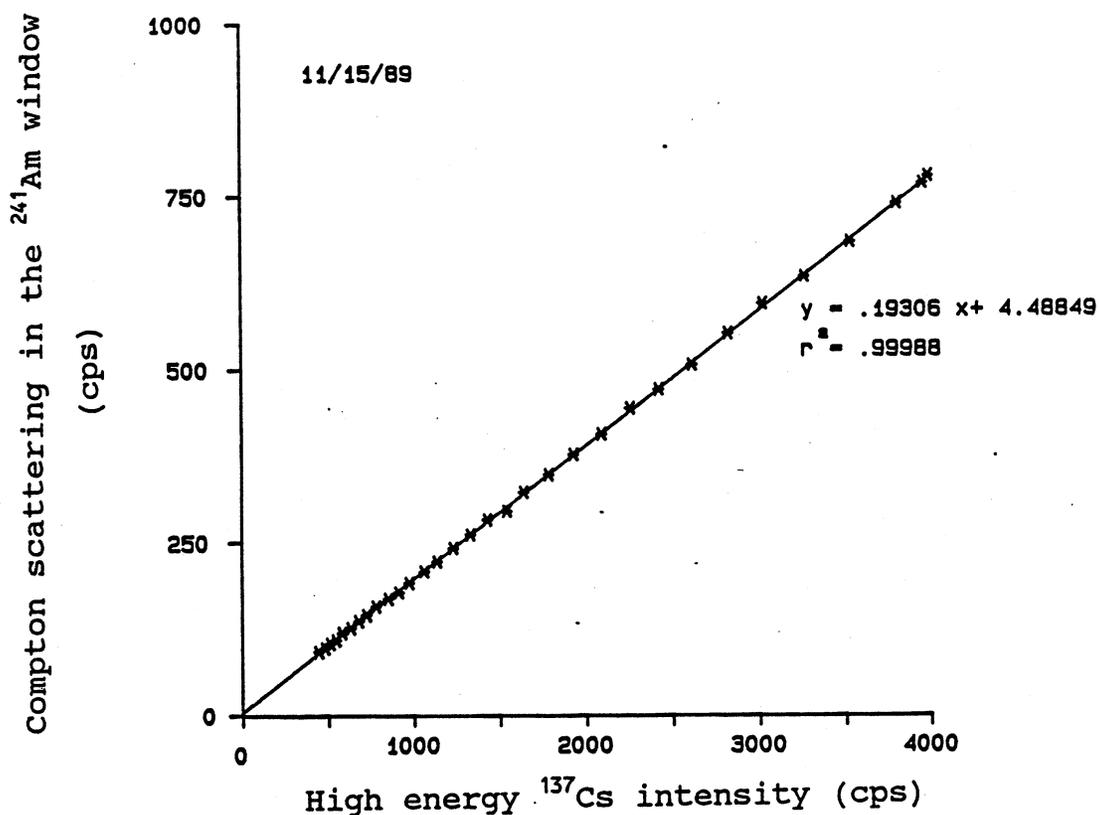
FIG. 5. Compton scattering in the [241]Am window versus the high energy ^{137}Cs intensity. All count rates are dead time corrected.

between the sources and detector such that the gamma beam is perpendicular to the compartmental walls and the radiation traverses through all the compartments. The path lengths through the compartments are determined with a caliper. First, count readings are obtained at five different locations on the empty cell, and subsequently on the cell with 1-4 compartments filled with the liquid of interest. This procedure results in a total of 25 count rates for each of the two gamma sources. Since the liquid is the only material

causing attenuation, the linearized attenuation equation for
the compartmental cell, with n filled compartments, can be
written as

$$\ln(I_{nj}) - \ln(I_{oj}) - U_{ij}y_n \tag{36}$$

where I_{oj} is the count rate (cps) through the empty cell, I_{nj}
is the count rate (cps) through the cell with n filled
compartments, and y_n is the path length through n filled
compartments, i.e.

$$y_n - \sum_{k=0}^{n} y_k \qquad n - 0,1,2,3,4 \tag{37}$$

where k refers to each individual compartment.   A linear
regression of the 25 y_n-$\ln(I_{nj})$ data pairs yields the slope of
eq. (36).   The absolute value of this slope equals the U_{ij} of
the liquid.   Calibration program 4, atten.txt (APPENDIX B),
guides the user through the process of data acquisition and
the linear regression.   The program produces a plot with the
[241]Am and ^{137}Cs regression lines.   Examples of such plots are
presented in figure 6.

For the simultaneous determination of salt concentration
and volumetric water content, the linear relations between
liquid salt concentration, C, and its volumetric liquid
attenuation coefficient, U_{Lj}, have to be determined.   With
calibration program 4, the U_{Lj}-values of a series of salt
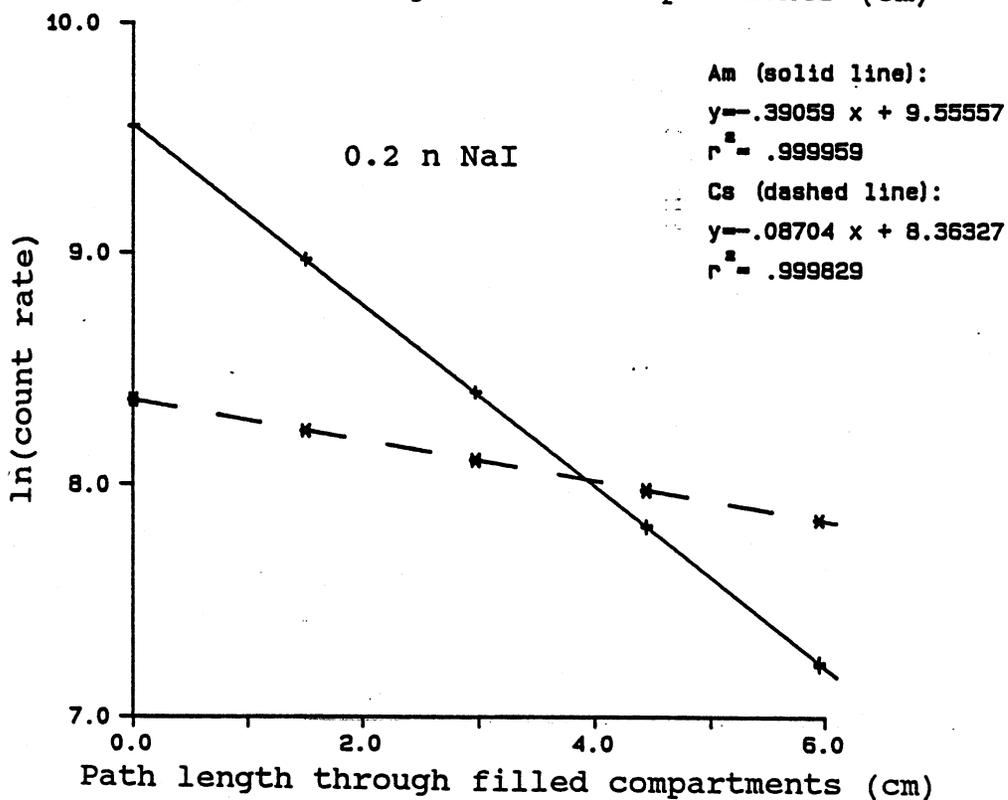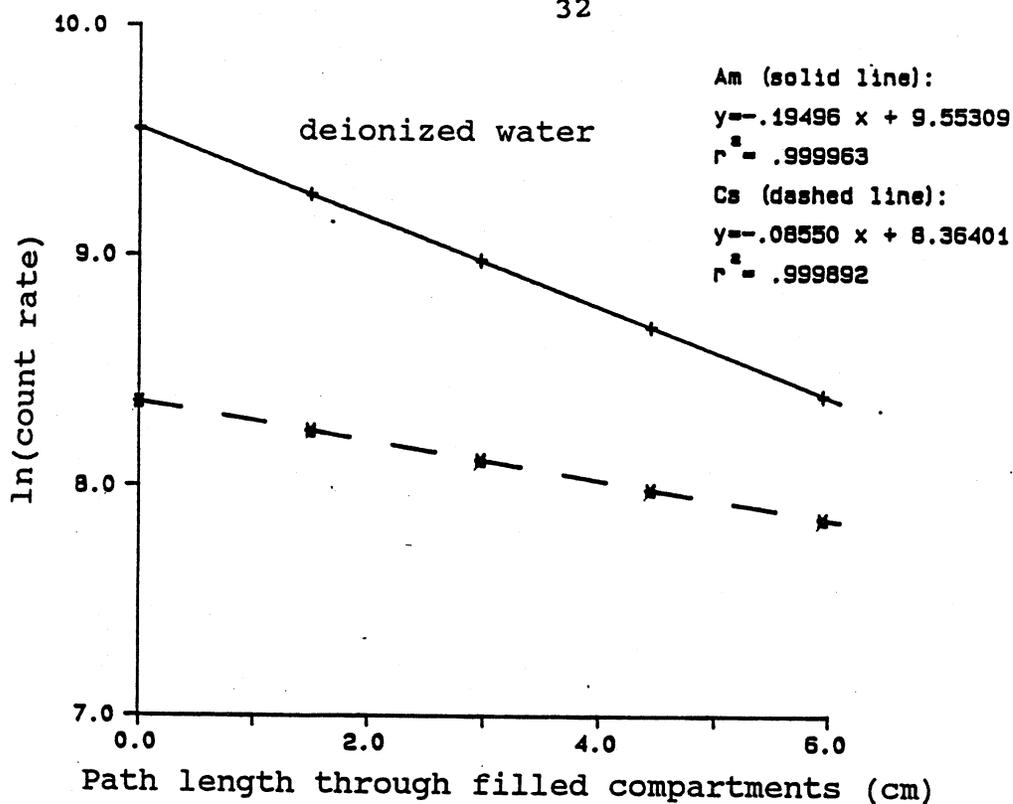
FIG. 6. Relation between path length through a solution and
the natural log of the corrected count rates for deionized
water and a 0.2 n NaI solution. The absolute value of the
slope is the volumetric liquid attenuation coefficient.

solutions over the concentration range of interest can be
obtained. Linear regressions of U_{Lc} and U_{La} versus C result in
the coefficients a and b of eq. (22) and r and s of eq. (23),
respectively. Figure 7 shows $C-U_{Lj}$ relations of the salt NaI
and their calculated regression coefficients. The high
correlation coefficients of both lines show that the
assumption of linearity is acceptable.

Since some NAPL's dissolve Plexiglas, the compartmental
cell cannot be used to determine their U_{ij}. An example of such
a NAPL is trichloroethylene (TCE), a solvent frequently used
in immiscible flow studies. To overcome this problem, an
alternative compartemental cell was created for these liquids
by glueing four glass French square bottles in series to a
wooden base. This setup allows the use of basically the same
method to determine volumetric attenuation coefficients
described previously for liquids with the Plexiglas
compartmental cell. While running program 4, the user is
prompted to choose either the Plexiglas or glass compartmental
cell. The path length through each of the four French square
bottles is determined with a method outlined in the next
section of this chapter. The [241]Am and ^{137}Cs regression lines
for TCE, determined with the glass compartmental cell, are
shown in figure 8.
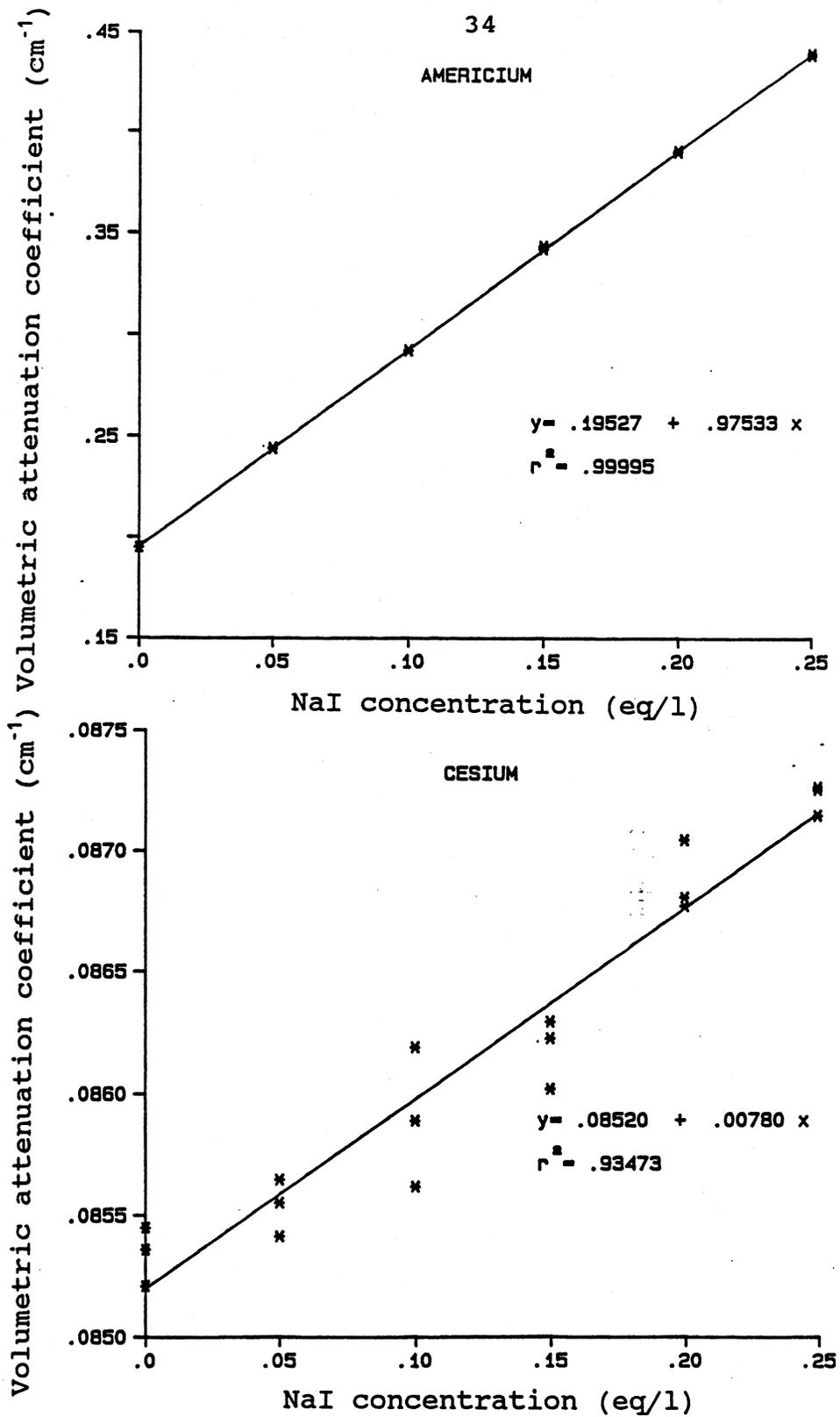
FIG. 7. Experimentally determined relations between the NaI concentration of a solution and the volumetric attenuation coefficient for ^{241}Am and ^{137}Cs. Each data point is obtained with calibration program 4.
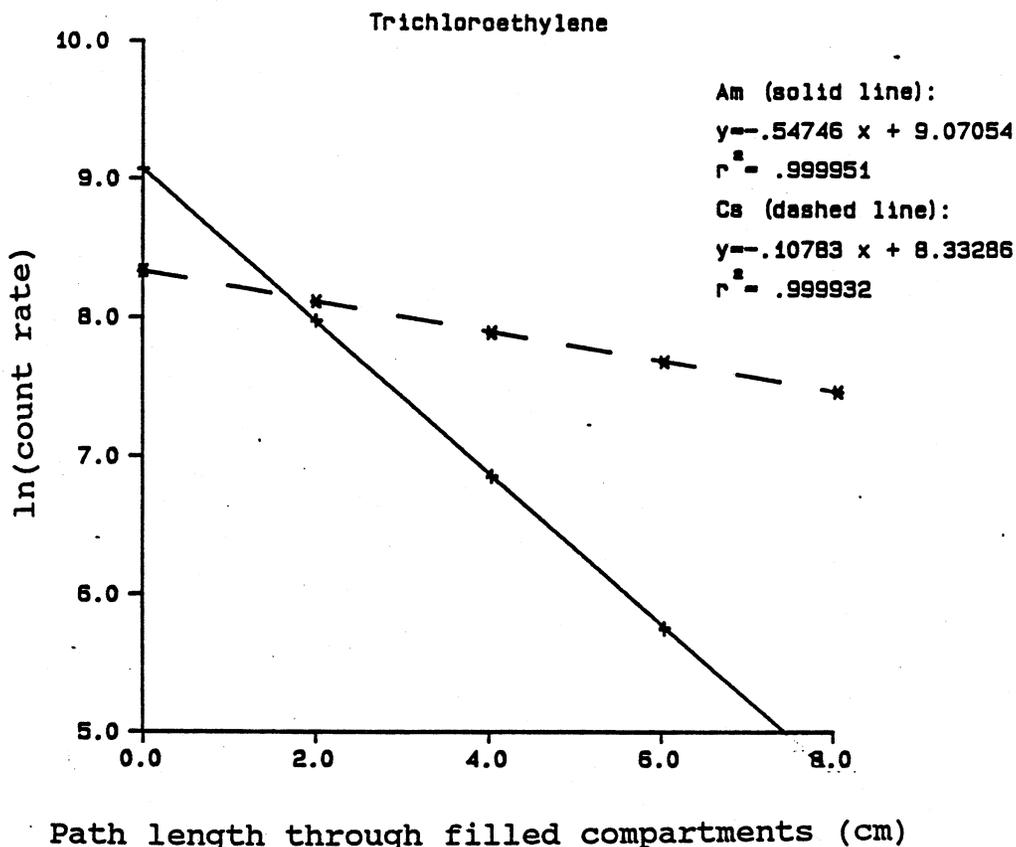
FIG. 8. Relation between path length through TCE and the natural log of the corrected count rates. The absolute value of the slope is the TCE volumetric attenuation coefficient.

Mass Attenuation Coefficients of Soils.

The Plexiglas compartmental cell is employed to determine mass attenuation coefficients of soils, μ_{sj} (L^2M^{-1}). When (air dry) soil is used to fill the compartments, it is likely to have different bulk density values, ρ_k, and different volumetric water content values, θ_k, for the compartments k, k=1,..,4. With the soil and water as the

attenuating materials, the linearized attenuation equation for the compartmental cell with only compartment 1 filled can be written as

$$\ln(I_j) + U_{wj}\theta_1 y_1 - \ln(I_{oj}) - \mu_{sj}\rho_1 y_1 \tag{38}$$

In generalized form, with n compartments filled, eq. (38) becomes

$$\ln(I_j) + U_{wj}\sum_{k=0}^{n}\theta_k y_k - \ln(I_{oj}) - \mu_{sj}\sum_{k=0}^{n}\rho_k y_k \tag{39}$$

The count rates I_j and I_{oj} are determined with calibration program 5a, sat5a.txt (APPENDIX B). First, count rate readings are obtained at five different locations, with all four compartments filled with soil. Then, starting with compartment 4, the compartments are subsequently emptied in moisture cans and count rates are obtained at exactly the same locations. The bulk density and volumetric water content values of each compartment are determined gravimetrically. When, finally, $\sum_{k=0}^{n}\rho_k y_k$ is plotted against the left hand side of eq. (39), the absolute value of the slope of the regression line is the mass attenuation coefficient of the soil. The linear regression and the calculation of the mass attenuation coefficients are performed by calibration program 5b,

sat5b.txt (APPENDIX B).

Path Length Determination

At each position of a column or two-dimensional flow container where measurements will be taken, the path length through the porous medium needs to be determined. To accomplish this, count measurements have to be obtained at each location when the column or container is empty, resulting in I_{oj}, and when the column or container is filled with deionized water, resulting in I_j. Solving the linearized attenuation equation, with deionized water as the only attenuating material, for path length x_j, gives:

$$x_j = \ln(I_{oj}/I_j)/U_{wj} \tag{40}$$

With calibration program 6, x.txt (APPENDIX B), the path lengths x_j at each position of interest are determined. It has been our experience that the x_a and x_c-values at the same position vary by a maximum of 0.85%. Normally, the average path length, $(x_a+x_c)/2$, is accepted as the true path length through the porous medium at a certain position. Program 6 creates a data file where the count rates I_{oj} and path lengths x_j are stored in separate subfiles. This information can be read from the data file in future applications.

Determination of the Incident Count Rates I_{oj}

Besides the values of the attenuation coefficients and the path lengths, the parameters I_{oj} are needed to allow application of eq. (6) and (7), eq. (13) and (14), or eq. (26) and (27).

For the simultaneous determination of the dry bulk density and volumetric liquid content, the incident count rates I_{oj} represent count rates through an empty column or a 2-dimensional container. Due to variation in the wall thickness, the I_{oj} values are generally not constant in position and have to be determined at each location where future measurements will be taken. It is not necessary, however, to include a separate calibration step to obtain these data since values of I_{oj} at each location were already obtained during the determination of the path lengths with program 6. The I_{oa} and I_{oc} data were stored in the first and second subfile, respectively, of the data file created with program 6.

For the simultaneous determination of the volumetric water content and the volumetric NAPL content or the volumetric liquid content and the salt concentration, the incident count rates I_{oj} are the count rates through a column or 2-dimensional container filled with an oven-dry, non expanding soil, and can be expressed as

$$I_{oj} = I_{oj}'\exp(-\mu_s \rho_s x) \qquad (41)$$

where I_{oj}' is the count rate through the empty column or container. To obtain the I_{oj} values directly at each position of interest, count measurements can be taken with oven dry soil. Assuming the dry bulk density remains constant in time, the determined I_{oj} data can be used in the appropriate equations. Normally, however, as a result of wetting and drying, some consolidation and therefore changes in dry bulk density may occur and the initially determined I_{oj} values will not represent the actual situation accurately. In our calibration process, a method is used to determine I_{oj} that takes into account the possibility of soil consolidation. First, the column or container containing the oven-dry soil, is saturated, followed by a bulk density determination using eq. (6). The column or container is then drained and again saturated, followed by another bulk density determination. This drainage-wetting cycle is repeated until the dry bulk density remains constant. Once the dry bulk density is known, the I_{oj} values can be calculated using eq. (41), since all the other variables, appearing on the right hand side of this equation, were previously obtained.

Calibration program 7a, bulk.txt (APPENDIX B), guides the user through this part of the calibration process. After measurements are taken at each location, a printout with the bulk density and volumetric water content values is produced. The user decides to quit the program when the values remain constant, taking into account a small variation, due to the

random nature of the gamma radiation, of approximately 0.01 g/cm^3. With calibration program 7b, bulkin.txt (APPENDIX B), the bulk density values that will be used to calculate I_{oj} at each position are entered in the data file created with program 6, containing the I_{oj}' and path length values.

Once the I_{oj} values are determined, the calibration process has been completed.

ERROR ANALYSIS

A probable error analysis for quantities determined utilizing the dual gamma method gives an indication of the achievable precision and is a tool to determine the optimum path length through a porous medium. According to Bevington (1), the expected variance of any quantity y, which is calculated based on n independent observations x_i, can be expressed with the error propagation formula:

$$\sigma_y^2 = \sum_{i=1}^{n} \left(\frac{\partial y}{\partial x_i}\right)^2 \sigma_{x_i}^2 \tag{42}$$

To evaluate the variance of y, the variance of each set of independent observations x_i and the functional relationship between y and x_i must be known.

Error Analysis for the Simultaneous Determination of the Dry Soil Bulk Density, ρ_s, and the Volumetric Water Content, θ_w

Eq. (6) and (7) show that ρ_s and θ_w are both functions of the variables I_a, I_{oa}, I_c, I_{oc}, x, μ_{sa}, μ_{sc}, U_{wa}, and U_{wc}. Replacing x_i in eq. (42) by these variables results in

$$\sigma_y^2 = \left(\frac{\partial y}{\partial I_a}\right)^2 \sigma_{I_a}^2 + \left(\frac{\partial y}{\partial I_{oa}}\right)^2 \sigma_{I_{oa}}^2 + \left(\frac{\partial y}{\partial I_c}\right)^2 \sigma_{I_c}^2 + \left(\frac{\partial y}{\partial I_{oc}}\right)^2 \sigma_{I_{oc}}^2 + \left(\frac{\partial y}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial y}{\partial U_{wa}}\right)^2 \sigma_{U_{wa}}^2 + \left(\frac{\partial y}{\partial U_{wc}}\right)^2 \sigma_{U_{wc}}^2 + \left(\frac{\partial y}{\partial \mu_{sa}}\right)^2 \sigma_{\mu_{sa}}^2 + \left(\frac{\partial y}{\partial \mu_{sc}}\right)^2 \sigma_{\mu_{sc}}^2 \tag{43}$$

where y denotes ρ_s or θ_w.

Expressions for the partial derivatives appearing in eq. (43) are obtained using eq. (6) and (7) for ρ_s and θ_w, respectively, and are listed in table 2.

Gardner et al. *(9)* stated that the variance of a quantity y, determined with the dual gamma method, is the sum of the variance due to the randomness in the radioactive emission, $\sigma_{y(re)}^2$, and the variance due to the measurement or calibration error, $\sigma_{y(ca)}^2$. The expressions for $\sigma_{y(re)}^2$ and $\sigma_{y(ca)}^2$ are, respectively,

$$\sigma_{y(re)}^2 = \left(\frac{\partial y}{\partial I_a}\right)^2 \sigma_{I_a}^2 + \left(\frac{\partial y}{\partial I_{oa}}\right)^2 \sigma_{I_{oa}}^2 + \left(\frac{\partial y}{\partial I_c}\right)^2 \sigma_{I_c}^2 + \left(\frac{\partial y}{\partial I_{oc}}\right)^2 \sigma_{I_{oc}}^2 \tag{44}$$

$$\sigma^2_{y(ca)} = \left(\frac{\partial y}{\partial x}\right)^2 \sigma^2_x + \left(\frac{\partial y}{\partial U_{wa}}\right)^2 \sigma^2_{U_{wa}} + \left(\frac{\partial y}{\partial U_{wc}}\right)^2 \sigma^2_{U_{wc}} + \tag{45}$$

$$\left(\frac{\partial y}{\partial \mu_{sa}}\right)^2 \sigma^2_{\mu_{sa}} + \left(\frac{\partial y}{\partial \mu_{sc}}\right)^2 \sigma^2_{\mu_{sc}}$$

Table 2. Expressions for Partial Derivatives $\partial\theta_w/\partial x_i$ and $\partial\rho_s/\partial x_i$.

x_i	$\partial\theta_w/\partial x_i$	$\partial\rho_s/\partial x_i$
I_a	μ_{sc}/xkI_a	$-U_{wc}/xkI_a$
I_{oa}	$-\mu_{sc}/xkI_{oa}$	U_{wc}/xkI_{oa}
I_c	$-\mu_{sa}/xkI_c$	U_{wa}/xkI_c
I_{oc}	μ_{sa}/xkI_{oc}	$-U_{wa}/xkI_{oc}$
x	$-\theta_w/x$	$-\rho_s/x$
U_{wa}	$\mu_{sc}\theta_w/k$	$-U_{wc}\theta_w/k$
U_{wc}	$-\mu_{sa}\theta_w/k$	$U_{wa}\theta_w/k$
μ_{sa}	$\mu_{sc}\rho_s/k$	$U_{wc}\rho_s/k$
μ_{sc}	$-\mu_{sa}\rho_s/k$	$-U_{wa}\rho_s/k$

$$k = U_{wc}\mu_{sa} - U_{wa}\mu_{sc}$$

Several investigators (9, 5, 11) showed that the variance due to random emission is the dominant error source in dual gamma measurements.

The ^{241}Am and ^{137}Cs gamma emissions follow a Poisson

distribution for which the best estimate of the variance from the true mean for a single count measurement, N, is the count measurement itself *(16)*. The best estimate of the standard deviation is $\sqrt{N}$. A common error is the association of the standard deviation with the square root of any quantity which is not a directly measured number of counts. The standard deviation of the count rate I is not equal to $\sqrt{I}$ since I is not measured directly but obtained by dividing N by the counting time t. Using the error propagation formula, the variance of a dead time corrected count rate I can be written as

$$\sigma_I^2 = \left(\frac{\partial I}{\partial N}\right)^2 \sigma_N^2 \qquad (46)$$

Replacing σ_N^2 by It and the partial derivative by 1/t, eq. (46) becomes

$$\sigma_I^2 = I/t \qquad (47)$$

The counting time, t_o, used to determine the initial count rates I_{oa} and I_{oc} is not necessarily the same as t_m, the counting time used to determine I_a and I_c. Eq. (47) can be used to evaluate the variances of the ^{137}Cs count rates:

$$\sigma_{I_c}^2 = I_c/t_m \qquad (48)$$

$$\sigma^2_{I_{oc}} = I_{oc}/t_o \tag{49}$$

Eq. (47), however, is not directly applicable to the ^{241}Am count rates, because these count rates are corrected for Compton scattering *(26)*. The corrected count rate I_a can be written as

$$I_a = I_{at} - (pI_c + q) \tag{50}$$

where I_{at} is the uncorrected count rate and the term in parentheses is the correction due to the Compton scattering in the ^{241}Am window. The constants p and q of the linear Compton relation are determined in the calibration process with program 3, compton.txt. Using the error propagation formula, the variance of I_a can be expressed as

$$\sigma^2_{I_a} = \left(\frac{\partial I_a}{\partial I_{at}}\right)^2 \sigma^2_{I_{at}} + \left(\frac{\partial I_a}{\partial I_c}\right)^2 \sigma^2_{I_c} \tag{51}$$

Expressions for the partial derivatives in eq. (51) are obtained using eq. (50), resulting in $(\partial I_a/\partial I_{at}) = 1$ and $(\partial I_a/\partial I_c) = -p$. With $\sigma^2_{I_{at}} = I_{at}/t_m$ and $\sigma^2_{I_c} = I_c/t_m$, eq. (50) can be rewritten to yield

$$\sigma^2_{I_a} = (I_{at} + p^2 I_c)/t_m \tag{52}$$

Replacing I_{at} by $I_a + (pI_c + q)$ gives

$$\sigma^2_{I_a} = (I_a + (p^2 + p)I_c + q)/t_m \qquad (53)$$

For $\sigma^2_{I_{oa}}$ a similar expression can be derived.

At this point, expressions for the partial derivatives and the variances of the count rates appearing in eq. (44) are known, so that the $\sigma^2_{y(re)}$ can be written as a function of the counting times t_m, and t_o, the attenuation coefficients μ_{sa}, μ_{sc}, U_{wa}, and U_{wc}, the path length x, and the count rates I_a, I_{oa}, I_c, and I_{oc}. When I_a is replaced with eq. (4) and I_c with eq. (5), this results in the following relations for $\sigma^2_{\theta_w(re)}$ and $\sigma^2_{\rho_s(re)}$, respectively:

$$
\sigma^2_{\theta_w(re)} = \frac{1}{t_m}\left[\left(\frac{\mu_{sc}}{xk}\right)^2\left(\frac{\exp(x\mu_{sa}\rho_s + xU_{wa}\theta_w)}{I_{oa}} + \right.\right. \qquad (54)
$$
$$
\left.\frac{(p^2 + p)I_{oc}\exp(-x\mu_{sc}\rho_s - xU_{wc}\theta_w) + q}{I^2_{oa}\exp(-2x\mu_{sa}\rho_s - 2xU_{wa}\theta_w)}\right) +
$$
$$
\left.\left(\frac{\mu_{sa}}{xk}\right)^2\frac{\exp(x\mu_{sc}\rho_s + xU_{wc}\theta_w)}{I_{oc}}\right] +
$$
$$
\frac{1}{t_o}\left[\left(\frac{\mu_{sc}}{xk}\right)^2\left(\frac{I_{oa} + (p^2 + p)I_{oc} + q}{I^2_{oa}}\right) + \left(\frac{\mu_{sa}}{xk}\right)^2\left(\frac{1}{I_{oc}}\right)\right]
$$

$$\sigma^2_{\rho_s(re)} = \frac{1}{t_m}\left[\left(\frac{U_{wc}}{xk}\right)^2\left(\frac{\exp(x\mu_{sa}\rho_s + xU_{wa}\theta_w)}{I_{oa}} + \frac{(p^2 + p)I_{oc}\exp(-x\mu_{sc}\rho_s - xU_{wc}\theta_w) + q}{I^2_{oa}\exp(-2x\mu_{sa}\rho_s - 2xU_{wa}\theta_w)}\right) + \left(\frac{U_{wa}}{xk}\right)^2\frac{\exp(x\mu_{sc}\rho_s + xU_{wc}\theta_w)}{I_{oc}}\right] + \frac{1}{t_o}\left[\left(\frac{U_{wc}}{xk}\right)^2\left(\frac{I_{oa} + (p^2 + p)I_{oc} + q}{I^2_{oa}}\right) + \left(\frac{U_{wa}}{xk}\right)^2\left(\frac{1}{I_{oc}}\right)\right]$$

(55)

These formulas should be used to determine the optimum path length through a porous medium for a certain experiment. The values of the attenuation coefficients and the coefficients of the Compton relation (p, q) are determined in the calibration process and are assumed to be constant. Once a decision is made on the wall material and its thickness S, values for the incident count rates I_{oa} and I_{oc} can be obtained by observing the count rates through the material with a thickness of 2S. With known values for μ_{sa}, μ_{sc}, U_{wa}, U_{wc}, I_{oa}, and I_{oc}, the variance of θ_w and ρ_s and functions of ρ_s, θ_w, t_m, t_o, and x only. For a fixed set of quantities ρ_s, θ_w, t_m, and t_o, the variances or standard deviations as a function of path length can be calculated and plotted. Examples of such plots are presented in figure 9 for four different sets of ρ_s, θ_w, and t_m values. The counting time t_o, used during calibration, should be maximized. Most often, the limiting factor is the overflow of the scaler that is used to determine the integral [241]Am count rates. We used t_o=200 sec. for all applications.
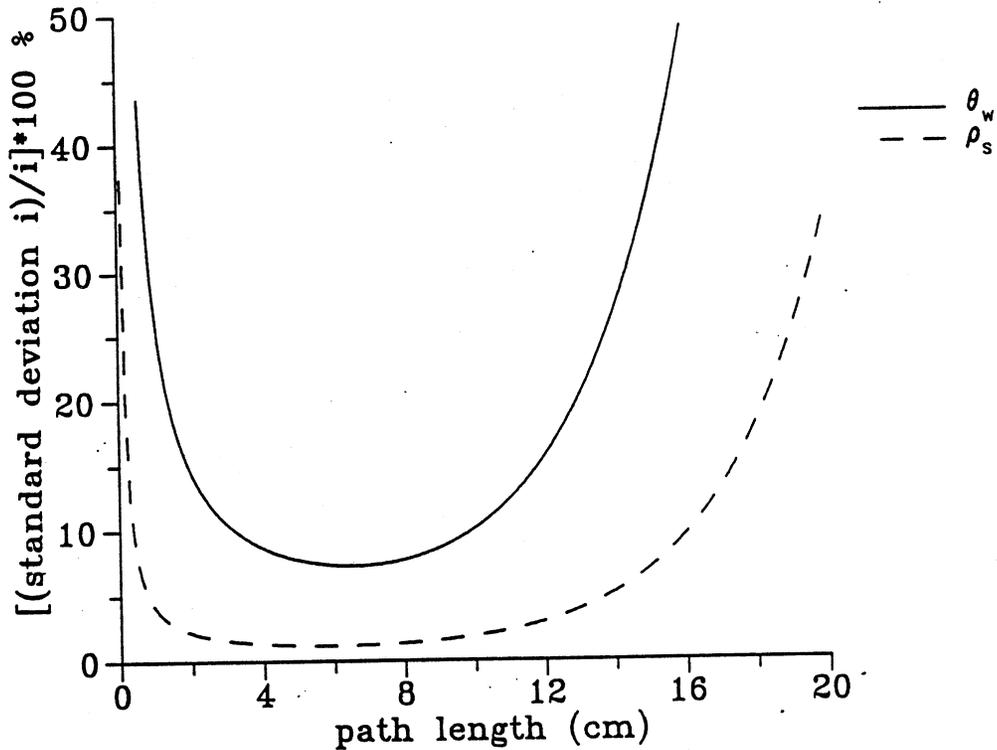
FIG. 9A. Relative standard deviation in ρ_s and θ_w versus path length x for ρ_s=1.6 g/cm^3, θ_w=0.3 and t$_m$=60 sec.
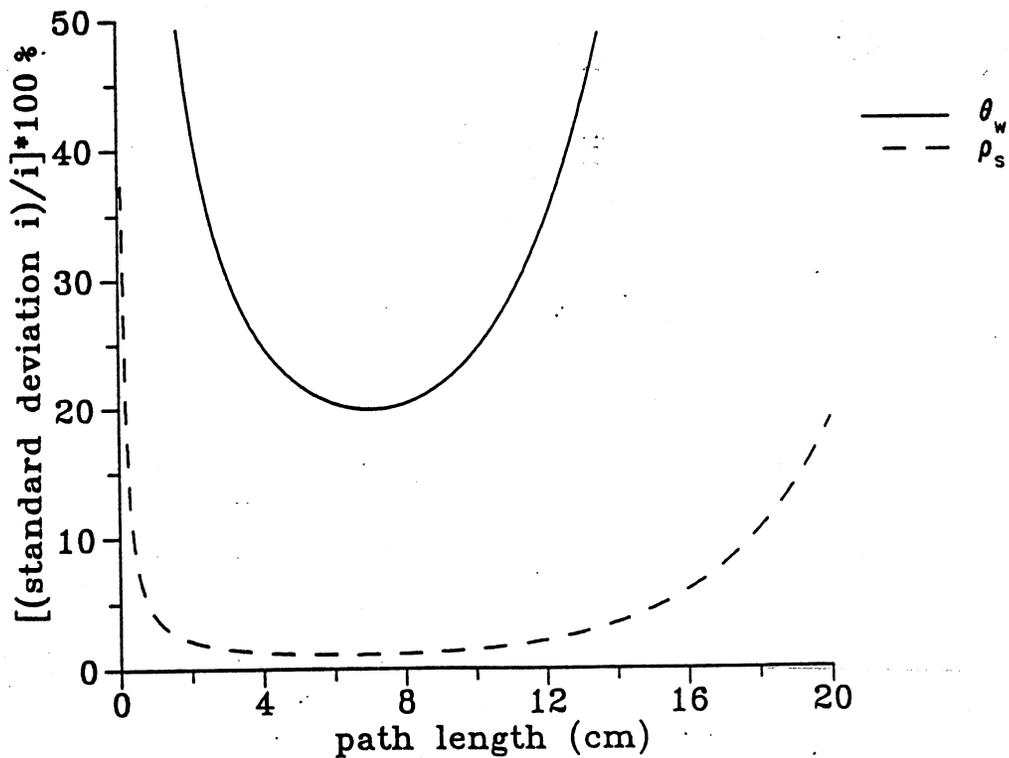
FIG. 9B. Relative standard deviation in ρ_s and θ_w versus path length x for ρ_s=1.6 g/cm^3, θ_w=0.1 and t$_m$=60 sec.
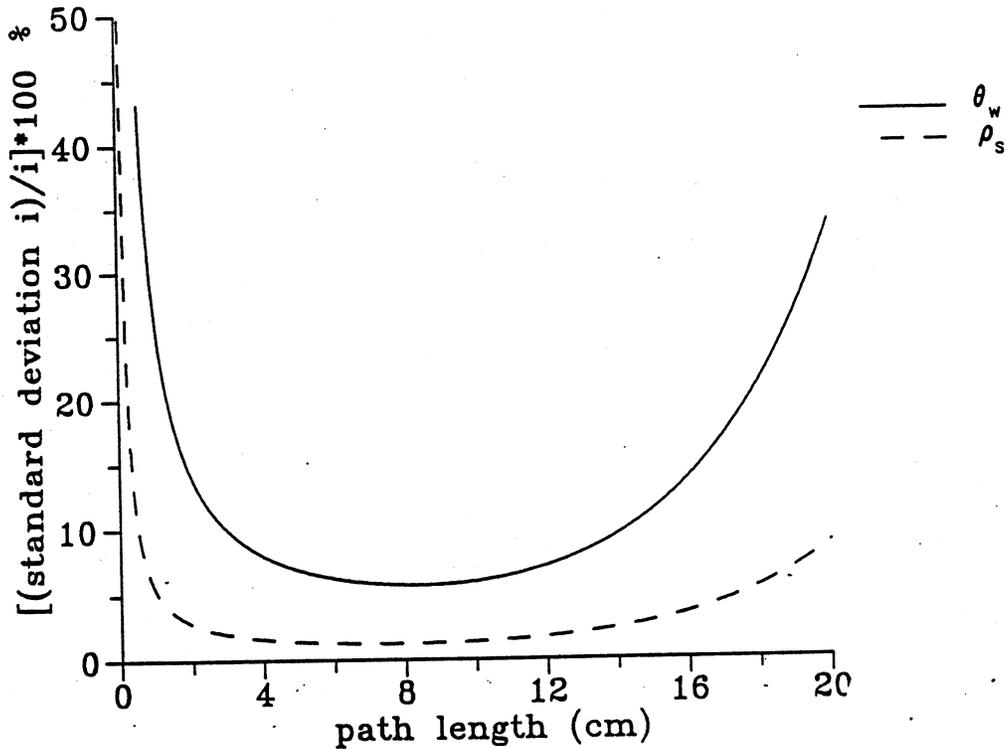
FIG. 9C. Relative standard deviation in ρ_s and θ_w versus path length x for ρ_s=1.2 g/cm^3, θ_w=0.3 and t_m=60 sec.
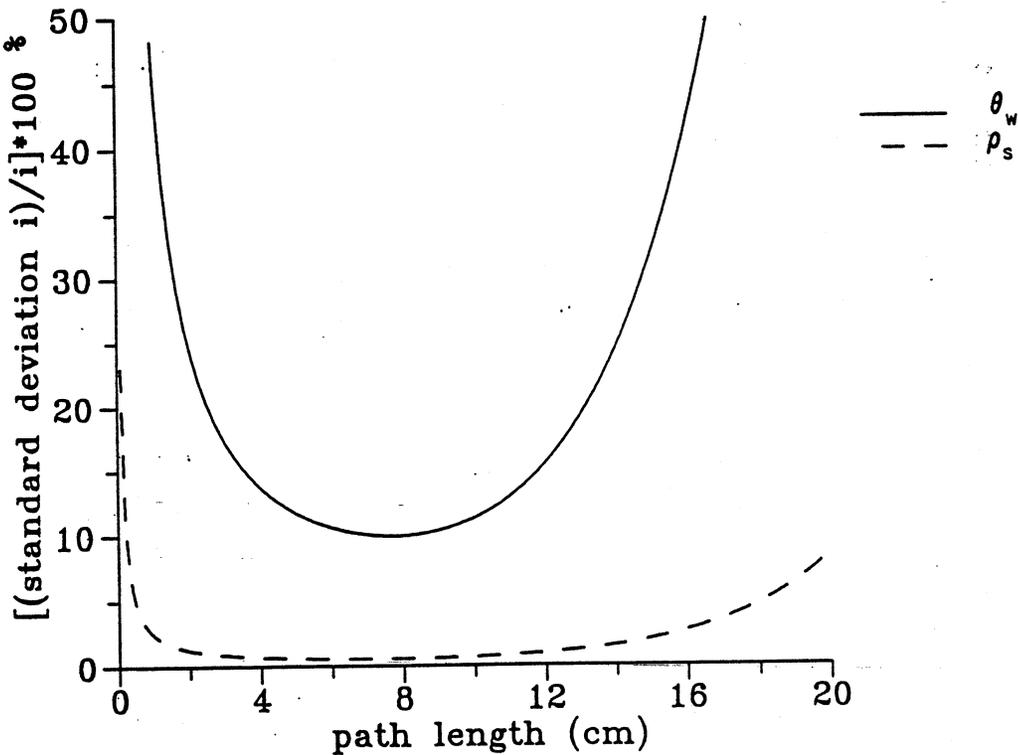
FIG. 9D. Relative standard deviation in ρ_s and θ_w versus path length x for ρ_s=1.6 g/cm^3, θ_w=0.1 and t_m=300 sec.

The attenuation coefficients used have the following values: μ_{sa}=0.2526 cm^2/g, μ_{sc}=0.0817 cm^2/g (Flint Shot 2.8 sand), U_{wa}=0.1950 cm^{-1}, U_{wc}=0.0854 cm^{-1} (deionized water). For the incident count rates, values of I_{oa}=17000 cps and I_{oc}=8100 cps were used (based on measurements), which correspond with 0.25" Plexiglas walls. The errors in ρ_s are less sensitive than the errors in θ_w, while the accuracy in both ρ_s and θ_w improves when their magnitudes increase. The optimum range for dual gamma measurements appears to be 6-10 cm for θ_w, and 4-12 cm for ρ_s. The probable error can be minimized by using large counting times. However, for some experiments this may conflict with rapidly changing water content values.

The variance in ρ_s and θ_w due to calibration errors, as described with eq. (45), depends strongly on the methods used to determine the attenuation coefficients and the path length. Our attenuation coefficients are absolute values of slopes determined with linear regression. According to Steel and Torrie (25), for n data pairs (X_i, Y_i), an unbiased estimate of the true variance of the slope is given by

$$\sigma^2_{slope} = \frac{\sum_{i-1}^{n} (Y_i - \overline{Y})^2 - \dfrac{\left[\sum_{i-1}^{n} (X_i - \overline{X})(Y_i - \overline{Y})\right]^2}{\sum_{i-1}^{n} (X_i - \overline{X})^2}}{(n-2)\sum_{i-1}^{n} (X_i - \overline{X})^2} \tag{56}$$

The order of magnitude of the variances of the attenuation coefficients, calculated using eq. (56), varies between 10^{-7} and 10^{-9}, indicating an insignificant contribution to the total variance.

Based on the calibration method to determine the path length x, the variance in the path length x is estimated to be 0.02 cm. The contribution of the estimated variance of the path length x to the total variance in ρ_s and θ_w is calculated by evaluating the first term of eq. (45), which can be rewritten as $0.02y^2/x^2$, where x is the path length in cm. The relative standard deviation due to the variance in path length x is then $14.1/x\%$, for both ρ_s and θ_w, independent of their values and the counting time. For ρ_s determinations, this additional error has the same order of magnitude as the error due to random emissions. For the more important θ_w determinations, however, this error is in most cases considerably smaller than the error due to random emissions and it does not affect the optimum path length range observed.

Error Analysis for the Simultaneous Determination of the Volumetric Water Content, θ_w, and the Volumetric NAPL Content, θ_n.

Eq. (13) and eq. (14) show that θ_w and θ_n are both functions of the variables I_a, I_{oa}, I_c, I_{oc}, U_{na}, U_{nc}, U_{wa}, U_{wc}, and x. The error propagation formula, eq. (42), can be used

to express the variance of θ_w and θ_n,

$$\sigma_y^2 = \left(\frac{\partial y}{\partial I_a}\right)^2 \sigma_{I_a}^2 + \left(\frac{\partial y}{\partial I_{oa}}\right)^2 \sigma_{I_{oa}}^2 + \left(\frac{\partial y}{\partial I_c}\right)^2 \sigma_{I_c}^2 + \qquad (57)$$

$$\left(\frac{\partial y}{\partial I_{oc}}\right)^2 \sigma_{I_{oc}}^2 + \left(\frac{\partial y}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial y}{\partial U_{wa}}\right)^2 \sigma_{U_{wa}}^2 +$$

$$\left(\frac{\partial y}{\partial U_{wc}}\right)^2 \sigma_{U_{wc}}^2 + \left(\frac{\partial y}{\partial U_{na}}\right)^2 \sigma_{U_{na}}^2 + \left(\frac{\partial y}{\partial U_{nc}}\right)^2 \sigma_{U_{nc}}^2$$

where y denotes θ_w or θ_n. The partial derivatives in eq. (57) are evaluated using eq. (13) and (14) for θ_w and θ_n, respectively, and are listed in table 3.

Table 3. Expressions for Partial Derivatives $\partial\theta_n/\partial x_i$ and $\partial\theta_w/\partial x_i$.

x_i	$\partial\theta_n/\partial x_i$	$\partial\theta_w/\partial x_i$
I_a	$-U_{wc}/xKI_a$	U_{nc}/xKI_a
I_{oa}	U_{wc}/xKI_{oa}	$-U_{nc}/xKI_{oa}$
I_c	U_{wa}/xKI_c	$-U_{na}/xKI_c$
I_{oc}	$-U_{wa}/xKI_{oc}$	U_{na}/xKI_{oc}
x	$-\theta_n/x$	$-\theta_w/x$
U_{wa}	$-U_{wc}\theta_w/K$	$U_{nc}\theta_w/K$
U_{wc}	$U_{wa}\theta_w/K$	$-U_{na}\theta_w/K$
U_{na}	$-U_{wc}\theta_n/K$	$U_{nc}\theta_n/K$
U_{nc}	$U_{wa}\theta_n/K$	$-U_{na}\theta_n/K$

$$K = U_{wc}U_{na} - U_{wa}U_{nc}$$

The total variance σ^2_y is the sum of the variance due to random emission, $\sigma^2_{y(re)}$, consisting of the first four terms of eq. (57), and the variance due to the calibration error, $\sigma^2_{y(ca)}$, consisting of the last five terms of this equation. By replacing the partial derivatives by the appropriate expressions in table 3 and the count rates by their expressions obtained in the previous section, $\sigma^2_{y(re)}$ can be written as a function of the counting times, the path length, the attenuation coefficients of the two liquids, and the count rates. When I_a is substituted with eq. (11) and I_c with eq. (12), this relation becomes, for the variance of θ_w and θ_n, respectively,

$$
\sigma^2_{\theta_w(re)} = \frac{1}{t_m}\left[\left(\frac{U_{nc}}{xK}\right)^2\left(\frac{\exp(xU_{wa}\theta_w + xU_{na}\theta_n)}{I_{oa}} + \right.\right. \tag{58}
$$
$$
\left.\frac{(p^2 + p)\,I_{oc}\exp(-xU_{wc}\theta_w - xU_{nc}\theta_n) + q}{I^2_{oa}\exp(-2xU_{wa}\theta_w - 2xU_{na}\theta_n)}\right) +
$$
$$
\left.\left(\frac{U_{na}}{xK}\right)^2\frac{\exp(xU_{wc}\theta_w + xU_{nc}\theta_n)}{I_{oc}}\right] +
$$
$$
\frac{1}{t_o}\left[\left(\frac{U_{nc}}{xK}\right)^2\left(\frac{I_{oa} + (p^2 + p)\,I_{oc} + q}{I^2_{oa}}\right) + \left(\frac{U_{na}}{xK}\right)^2\left(\frac{1}{I_{oc}}\right)\right]
$$

$$
\sigma^2_{\theta_n(re)} = \frac{1}{t_m}\left[\left(\frac{U_{wc}}{xK}\right)^2\left(\frac{\exp(xU_{wa}\theta_w + xU_{na}\theta_n)}{I_{oa}} + \right.\right. \tag{59}
$$
$$
\left.\frac{(p^2 + p)\,I_{oc}\exp(-xU_{wc}\theta_w - xU_{nc}\theta_n) + q}{I^2_{oa}\exp(-2xU_{wa}\theta_w - 2xU_{na}\theta_n)}\right) +
$$
$$
\left.\left(\frac{U_{wa}}{xK}\right)^2\frac{\exp(xU_{wc}\theta_w + xU_{nc}\theta_n)}{I_{oc}}\right] +
$$
$$
\frac{1}{t_o}\left[\left(\frac{U_{wc}}{xK}\right)^2\left(\frac{I_{oa} + (p^2 + p)\,I_{oc} + q}{I^2_{oa}}\right) + \left(\frac{U_{wa}}{xK}\right)^2\left(\frac{1}{I_{oc}}\right)\right]
$$

With these formulas, the optimum range of the thickness of the porous medium for a certain experiment can be determined. The values of the volumetric attenuation coefficients of water and the NAPL are determined in the calibration process. Recalling that the initial count rates I_{oj} are calculated from $I_{oj} = I_{oj}'\exp(-\mu_s\rho_s x)$, assumed or known values for I_{oj}' and ρ_s reduce the variables that determine $\sigma^2_{y(re)}$ to the counting times t_m, t_o, the path length x, θ_w and θ_n. For a fixed set of values for t_m, θ_w and θ_n, $\sigma^2_{y(re)}$ can be calculated and plotted as a function of the path length. Four examples are presented in figure 11 for a column with 0.25" Plexiglas walls. Based on measurements, it was assumed that I_{oa}'=17000 cps, I_{oc}'=8100 cps, and t_o=200 sec. Trichloroethylene, with U_{na}=0.54746 cm^{-1} and U_{nc}=0.10783 cm^{-1}, is used as the NAPL, while the dry bulk density of the soil is assumed to be 1.6 g/cm^3. It appears that the optimum ranges for both liquids are approximately between 4 and 8 cm.

Since the variances of the volumetric attenuation coefficients are very small and range from 10^{-8} to 10^{-9}, the path length term is the only significant term of $\sigma^2_{y(ca)}$. For both θ_w and θ_n, the relative standard deviation, assuming a path length variance of 0.02 cm, is 14.14/x%. This additional error is too small to change the optimum ranges observed.
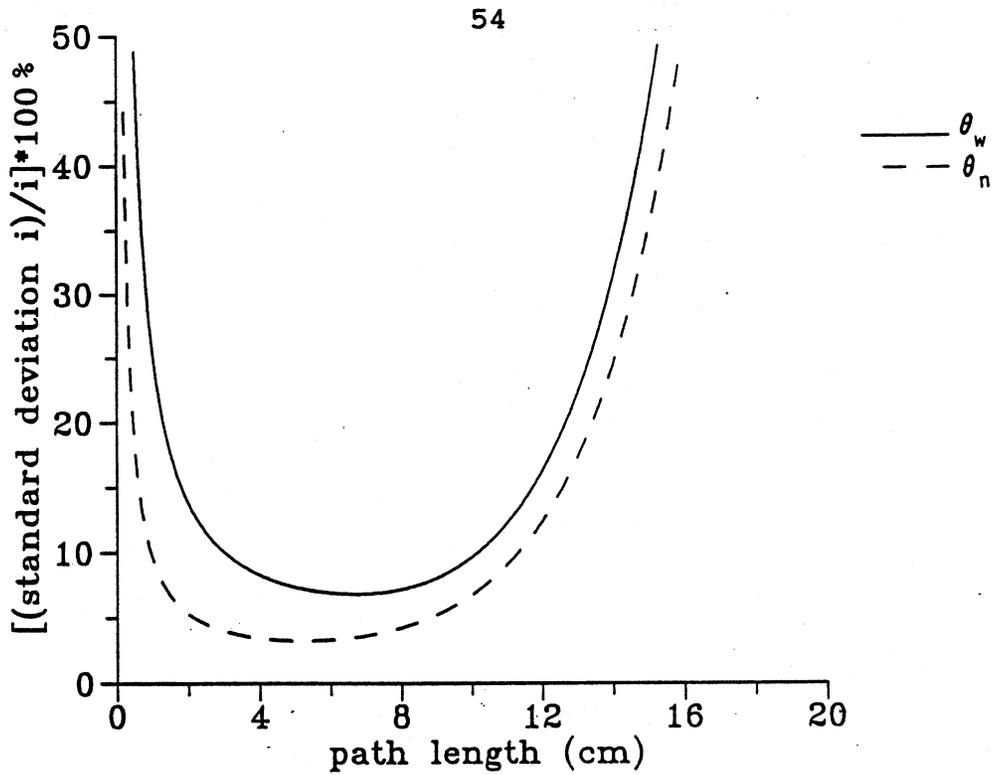
FIG. 10A. Relative standard deviation in θ_w and θ_n versus path length x for θ_w=0.15, θ_n=0.15 and t_m=60 sec.
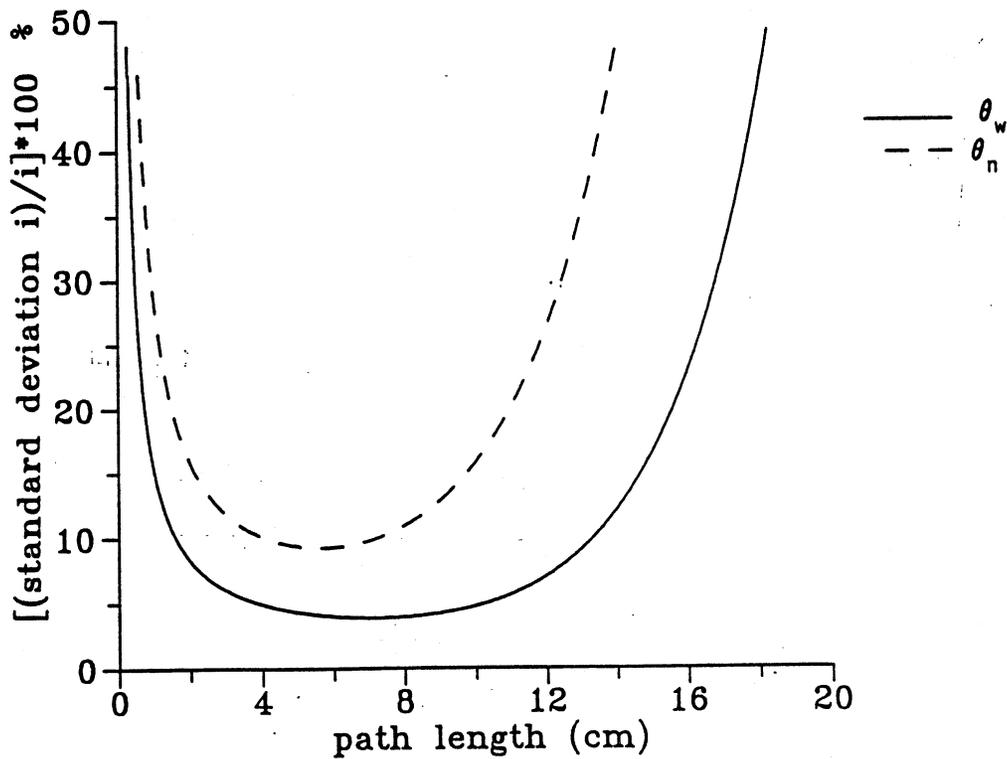
FIG. 10B. Relative standard deviation in θ_w and θ_n versus path length x for θ_w=0.25, θ_n=0.05 and t_m=60 sec.
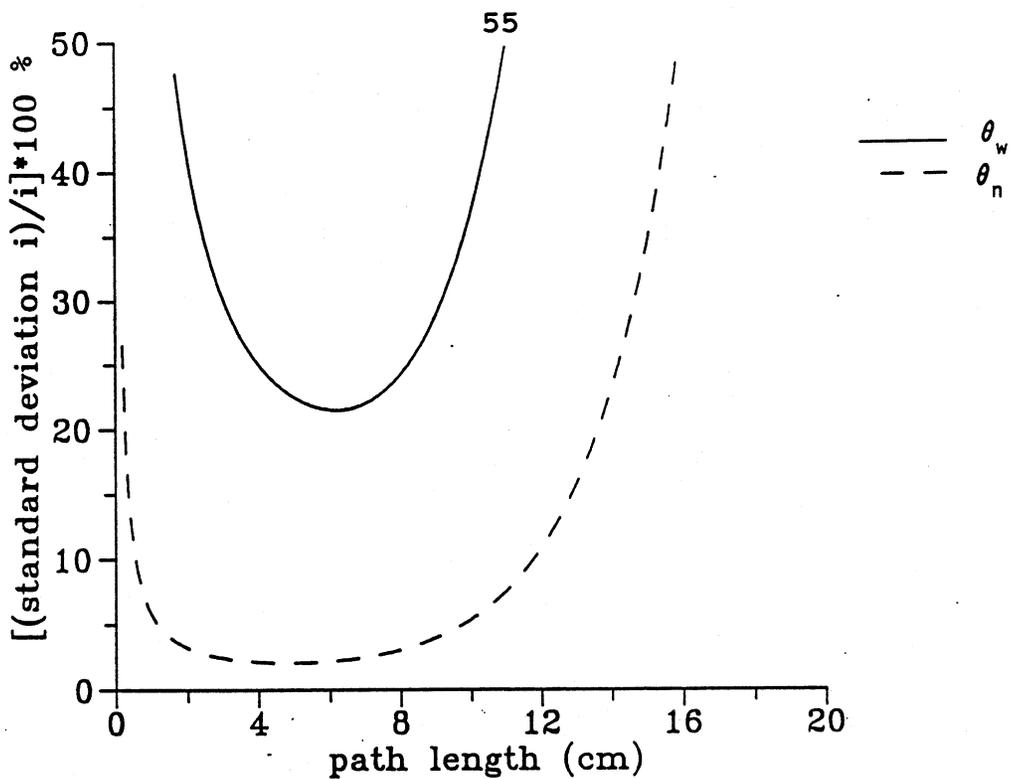
FIG. 10C. Relative standard deviation in θ_w and θ_n versus path length x for θ_w=0.05, θ_n=0.25 and t_m=60 sec.
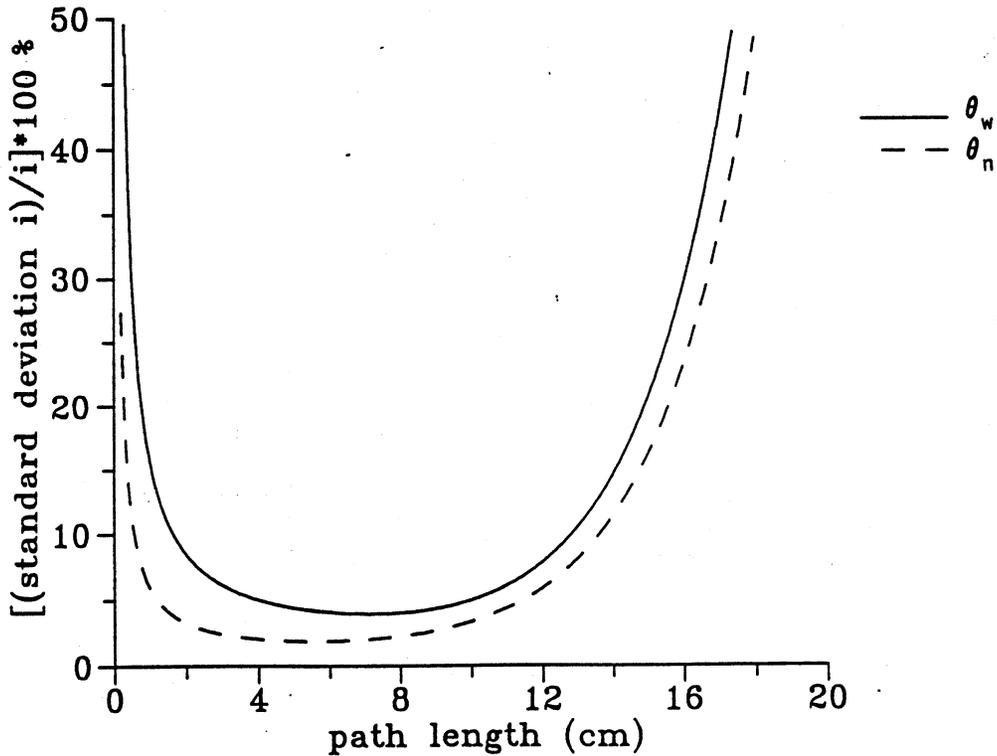
FIG. 10D. Relative standard deviation in θ_w and θ_n versus path length x for θ_w=0.15, θ_n=0.15 and t_m=300 sec.

Error Analysis for the Simultaneous Determination of the
Volumetric Liquid Content, θ_w, and the Salt Concentration, C.

According to eq. (26) and (27), both θ_w and C are
functions of I_a, I_{oa}, I_c, I_{oc}, a, b, r, s, and x. Using the
error propagation formula, the variance of θ_w and C can be
expressed as

$$\sigma_y^2 = \left(\frac{\partial y}{\partial I_a}\right)^2 \sigma_{I_a}^2 + \left(\frac{\partial y}{\partial I_{oa}}\right)^2 \sigma_{I_{oa}}^2 + \left(\frac{\partial y}{\partial I_c}\right)^2 \sigma_{I_c}^2 + \tag{60}$$
$$\left(\frac{\partial y}{\partial I_{oc}}\right)^2 \sigma_{I_{oc}}^2 + \left(\frac{\partial y}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial y}{\partial a}\right)^2 \sigma_a^2 +$$
$$\left(\frac{\partial y}{\partial b}\right)^2 \sigma_b^2 + \left(\frac{\partial y}{\partial r}\right)^2 \sigma_r^2 + \left(\frac{\partial y}{\partial s}\right)^2 \sigma_s^2$$

where y denotes θ_w or C.

The partial derivatives in eq. (60) are evaluated using
eq. (26) and eq. (27) for C and θ_L, respectively, and are
listed in table 4.

The first four terms of eq. (60) make up the variance due
to random emission, $\sigma_{y(re)}^2$, while the remainder is the variance
due to the calibration error. Replacing the partial
derivatives by their expressions in table 4, and the variances
of the count rates by their expressions derived previously,
$\sigma_{y(re)}^2$ can be written as a function of the counting time, the
path length, the count rates, and the coefficients of the
linear relations between salt concentration and the volumetric
attenuation coefficient. When I_a is replaced by eq. (24) and
I_c by eq. (25), this relation becomes, for θ_w and C,

Table 4. Expressions for Partial Derivatives $\partial\theta_w/\partial x_i$ and $\partial C/\partial x_i$; $n = x\theta_w(s[a + bC] - b[r + sC])$.

x_i	$\partial\theta_w/\partial x_i$	$\partial C/\partial x_i$
I_a	$-s/\{x(as - br)I_a$	$(r + sC)/I_a n$
I_{oa}	$s/\{x(as - br)I_{oa}$	$-(r + sC)/I_{oa} n$
I_c	$b/\{x(as - br)I_c$	$-(a + bC)/I_c n$
I_{oc}	$-b/\{x(as - br)I_{oc}$	$(a + bC)/I_{oc} n$
x	$-\theta_w/x$	0
a	$x\theta_w U_{Lc}$	$U_{Lc}(sU_{La} - bU_{Lc})$
b	$-x\theta_w U_{La}$	$CU_{Lc}(sU_{La} - bU_{Lc})$
r	$\theta_w(r - U_{Lc})(as - br)$	$-U_{La}(sU_{La} - bU_{Lc})$
s	$\theta_w(a + U_{La})(as - br)$	$-CU_{La}(sU_{La} - bU_{Lc})$

respectively,

$$\sigma^2_{\theta_w(re)} = \frac{1}{t_m}\left[\left(\frac{s}{x(as - br)}\right)^2\left(\frac{\exp(x\theta_w(a + bC))}{I_{oa}} + \frac{(p^2 + p)I_{oc}\exp(-x\theta_w(r + sC)) + q}{I_{oa}^2\exp(-2x\theta_w(a + bC))}\right) + \left(\frac{b}{x(as - br)}\right)^2\frac{\exp(x\theta_w(r + sC))}{I_{oc}}\right] + \frac{1}{t_o}\left[\left(\frac{s}{x(as - br)}\right)^2\left(\frac{I_{oa} + (p^2 + p)I_{oc} + q}{I_{oa}^2}\right) + \left(\frac{b}{x(as - br)}\right)^2\left(\frac{1}{I_{oc}}\right)\right] \qquad (61)$$

$$\sigma^2_{C(re)} = \frac{1}{t_m}\left[\left(\frac{r + sC}{n}\right)^2\left(\frac{\exp(x\theta_w(a + bC))}{I_{oa}} + \frac{(p^2 + p)I_{oc}\exp(-x\theta_w(r + sC)) + q}{I^2_{oa}\exp(-2x\theta_w(a + bC))}\right) + \left(\frac{a + bC}{n}\right)^2\frac{\exp(x\theta_w(r + sC))}{I_{oc}}\right] + \frac{1}{t_o}\left[\left(\frac{r + sC}{n}\right)^2\left(\frac{I_{oa} + (p^2 + p)I_{oc} + q}{I^2_{oa}}\right) + \left(\frac{a + bC}{n}\right)^2\left(\frac{1}{I_{oc}}\right)\right] \tag{62}$$

These formulas are the basic tools to calculate the optimum thickness of the porous medium for a certain experiment. Following the same reasoning as in the previous section, it can be shown that $\sigma^2_{y(re)}$ is a function of x, t_m, t_o, θ_L and C only, when the count rates I_{oj}' and the dry bulk density are known. For each fixed set of t_m, θ_w, and C values, the relation between the variance (or standard deviation) and the path length x can be calculated as will be demonstrated by four examples, with NaI as the attenuating salt. It was assumed that t_o=200 sec, I_{oa}'=17000 cps, I_{oc}'=8000 cps and ρ_s=1.6 g/cm^3. The coefficients a, b, r, and s for the NaI concentration-volumetric attenuation coefficient relations have values of 0.19527 cm^{-1}, 0.97533 cm^2/eq, 0.08520 cm^{-1}, and 0.00780 cm^2/eq, respectively (see figure 7).

Figure 11 shows that the optimum path length range for C is 5-9 cm and that the error in θ_w is rather insensitive to variations in x over a range from 4 to 20 cm.

When NaI is used, it can be shown that the contribution

When NaI is used, it can be shown that the contribution to the total variance of the a, b, r and s terms in eq. (60) is negligible. Since b and s are the slopes of the salt concentration-volumetric attenuation coefficient relations of ^{241}Am and ^{137}Cs, respectively, their variances can be calculated with eq. (49), resulting in $\sigma^2_b = 3.0*10^{-6}$ and $\sigma^2_s = 4.8*10^{-7}$, for the lines shown in figure 7. The variances of the intercepts with the attenuation axes of the plots, a and r, are calculated using Steel and Torrie *(25)*:

$$\sigma^2_i = \left(\frac{1}{n} + \frac{\overline{X}^2}{\sum_{i-1}^{n} (X_i - \overline{X})^2} \right) \left(\frac{\sum_{i-1}^{n} (Y_i - \overline{Y})^2 - \frac{\left[\sum_{i-1}^{n} (X_i - \overline{X})(Y_i - \overline{Y}) \right]^2}{\sum_{i-1}^{n} (X_i - \overline{X})^2}}{(n-2)} \right) \quad (63)$$

This results in $\sigma^2_a = 6.8*10^{-7}$ and $\sigma^2_r = 1.1*10^{-7}$. All the coefficient variances are very small compared to the variances in the count rates and can, therefore, be ignored. Another probable error analysis for the simultaneous determination of salt concentrations and volumetric liquid contents was done by Grismer et al. *(11)*. They based their analysis on the assumption that $\sigma^2_N = 2\sqrt{N}$, where N is the observed count (Grismer et al. used the symbol I for both the count rates and observed counts, which is especially confusing in the probable error analysis and should be avoided. For clarity, we use N for observed counts and I for count rates). Generally, the
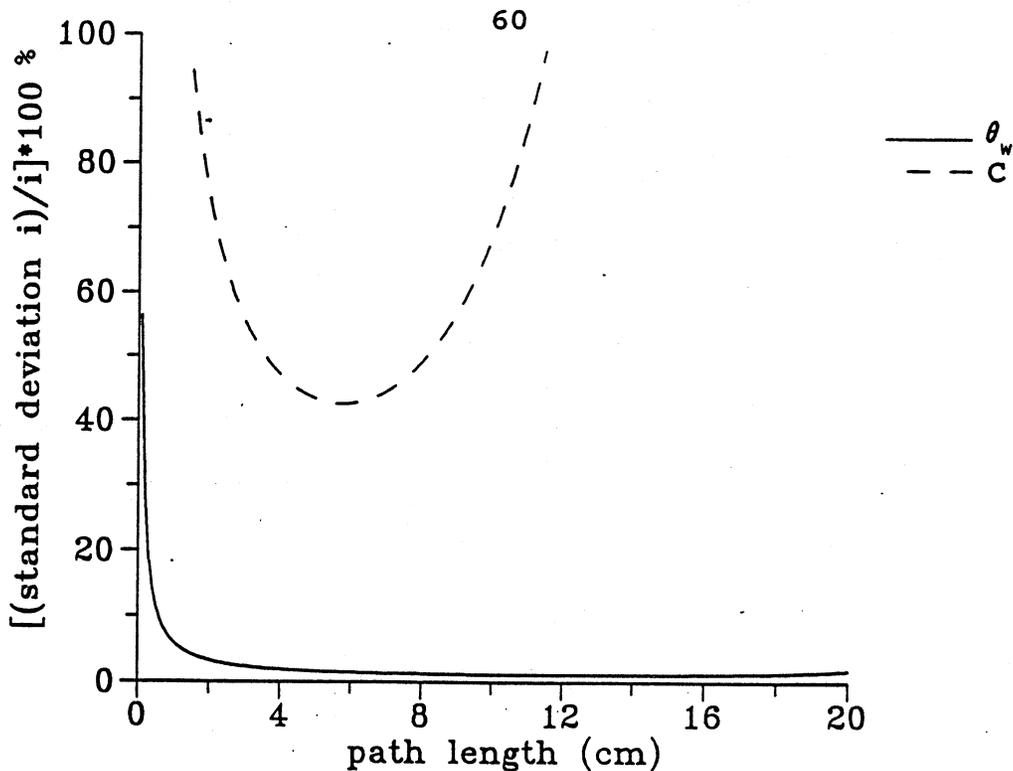
FIG. 11A. Relative standard deviation in θ_w and C versus path length x for θ_w=0.35, C=0.01 meq/ml, and t_m=60 sec.
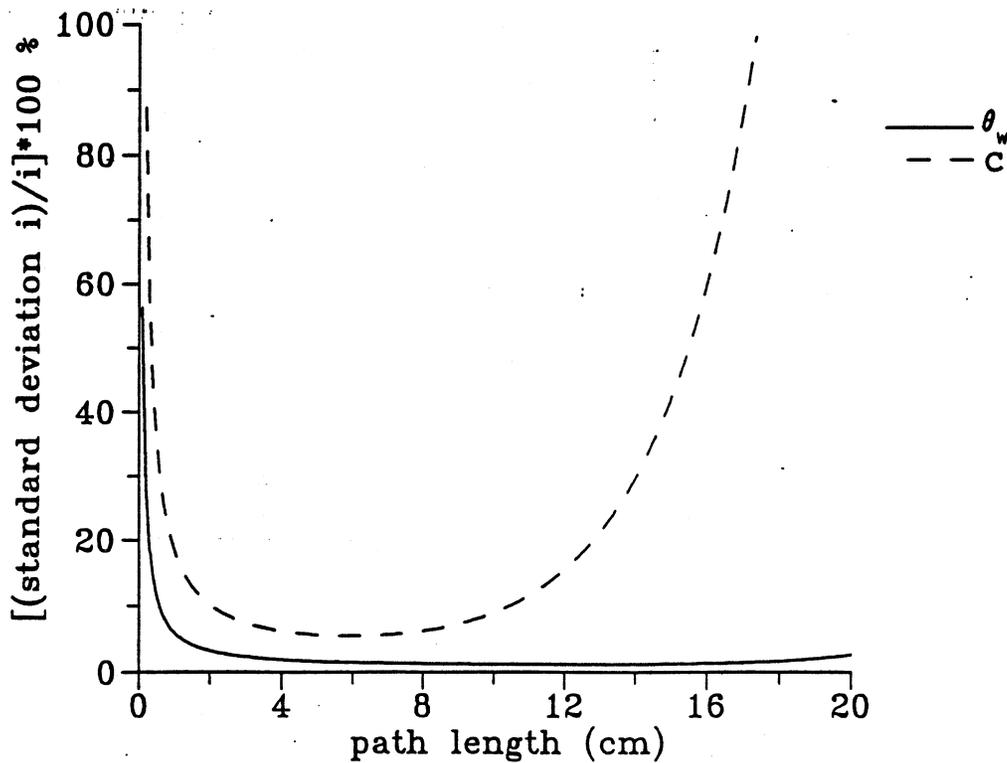
FIG. 11B. Relative standard deviation in θ_w and C versus path length x for θ_w=0.35, C=0.1 meq/ml, and t_m=60 sec.
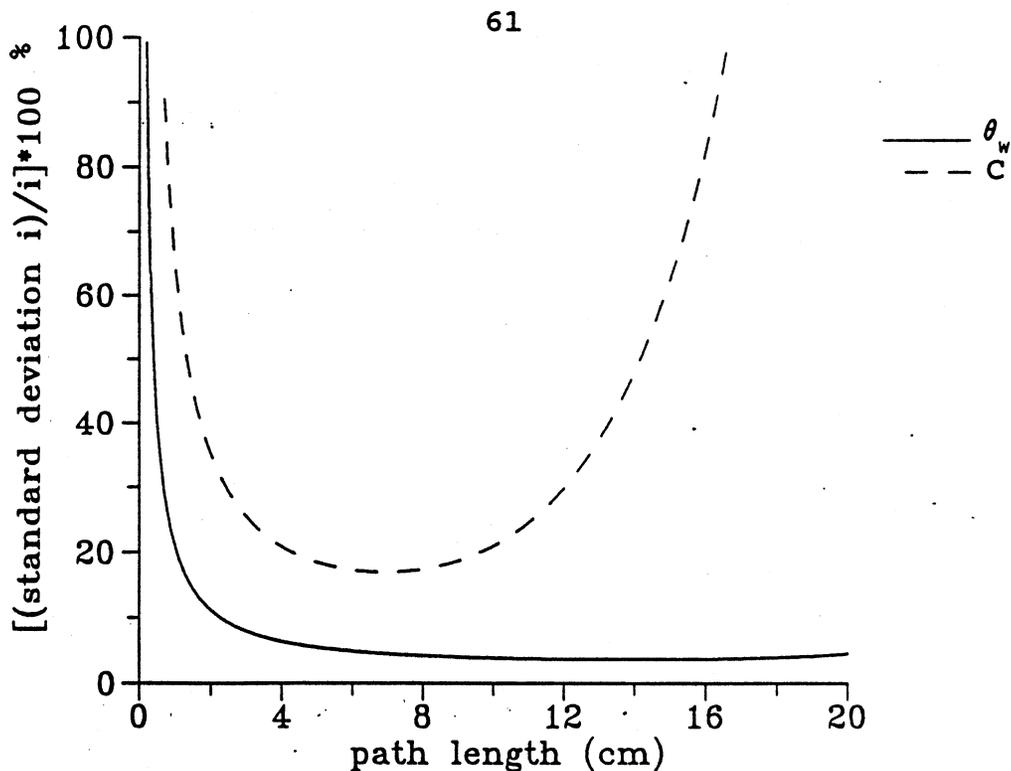
FIG. 11C. Relative standard deviation in θ_w and C versus path length x for θ_w=0.1, C=0.1 meq/ml, and t_m=60 sec.
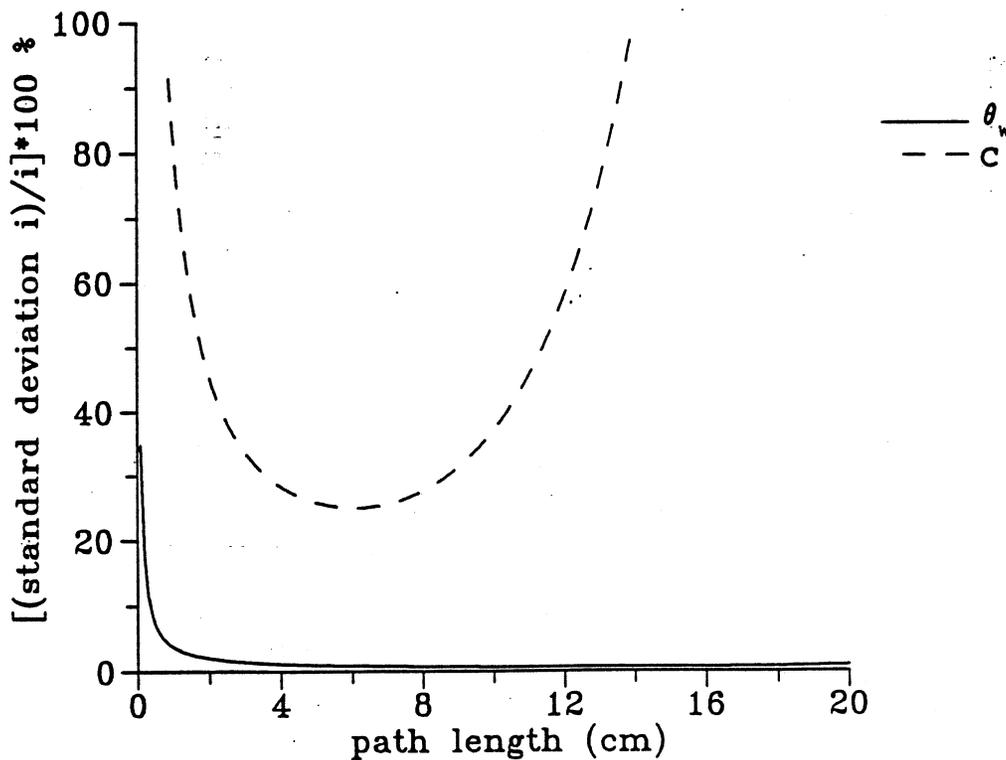
FIG. 11D. Relative standard deviation in θ_w and C versus path length x for θ_w=0.35, C=0.01 meq/ml and t_m=300 sec.

assumption that $\sigma^2_N = \sqrt{N}$ is used since radio-active decay processes can be approximated by a Poisson distribution *(9, 5)*. Grismer et al. *(11)* referenced Knoll *(16)* to back up their assumption. Knoll, however, clearly states that for radioactive decay processes, the variance of an observed count is the count itself. The errors due to random emission in the paper by Grismer et al. (the first terms of their eqs. (11) and (12), p. 166), should therefore be divided by a factor 4. Furthermore, the form in which their eqs. (11) and (12) are written allows easy calculation of the probable error of actual measurements only, whereas our eqs. (61) and (62) can also be used to predict probable errors for all theoretical combinations of the dependent variables.

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APPENDIX A

ASYST Software

1. Introduction

The software package ASYST 3.0 is an important tool in the automation of the dual-energy gamma radiation system. ASYST is especially designed for data acquisition, analysis and graphics. The package contains a pre-written acquisition driver for the Metrabyte MBC-488 interface board. This driver makes it possible to communicate directly to General Purpose Interface Bus (GPIB) devices. The GPIB devices in our dual-energy gamma radiation system are:

- The Aston 800 interface (controls the stepper motors)

- The Tennelec TC 589 buffered interface (controls the timer/multiscaler)

- The Hewlett Packard HP 3497A data acquisition control unit (interfaces pressure transducers and thermocouples).

ASYST can perform analysis functions varying from curve fitting to matrix algebra. The results can be plotted with the graphics part of the package. This part of the software is not as developed as the GPIB interfacing and the analysis parts.

2. The programming language Asyst

ASYST is a programming language, allowing the entry of simple commands or complete programs. The language and its

commands, called words, are extensively described in the ASYST manuals. In this section, a brief overview of the language is presented.

Numbers are manipulated in a special area, called the number stack, which holds numbers for later operation. The word *stack.display* shows the contents of the stack on the screen. The last entered element is at the top of the stack. After entering 25 and 1.6, the word *stack.display* gives as a result 1.6 25. To erase the contents of the stack, *stack.clear* has to be entered. There are many words available to manipulate the number stack contents, e.g. the word *swap* will cause the two numbers on top of the stack to switch places.

ASYST uses the Postfix Notation. Two numbers are required on the stack before a function can be performed, e.g., an addition. As in other high level languages, integer, real, and complex numbers are supported, all with single or double precision. In addition to numbers, ASYST supports named variables (scalars) and arrays. Like numbers, a scalar and an array element can be either a single or double precision integer, real or complex number. For example, to create an integer with the name alpha, one has to enter *integer scalar alpha*. To assign the value 5 to this variable, *5 alpha :=* must be entered. The same words that manipulate numbers and scalars can be used to manipulate arrays and their elements. Arithmetic operations can be applied to arrays regardless of the size of the array or the dimension. The maximum array

size is 64 K.

A very important feature of ASYST is its ability to create personal commands. These commands are called colon definitions. An example of such a colon definition is

: a

10 ramp sqrt ;

This colon definition is named *a* and it leaves the square root of a 10-element ramped (each element contains its index number) array on top of the number stack. Every colon definition starts with a colon and ends with a semicolon. The words inside a colon definition are not executed when created. Only when the name is entered (in this case *a*) are the individual words that make up the colon definition executed. All personal words inside a colon definition have to be defined previously. Colon definitions form the basis of ASYST programming and groups of newly created words can be included in subsequent new definitions.

ASYST also supports strings which are stored temporarily on the symbol stack. An example of a string in ASYST is " *this is a string*" . All strings have a space after the first ". The space is called a delimiter between the " and the actual string while the second " denotes the end of the string. String variables can be defined and text can be assigned to them. Strings are used extensively in the communication with GPIB devices.

Execution of some ASYST words (e.g., comparisons) results

in a TRUE/FALSE value. These values are also placed on the symbol stack. Besides the common mathematical operations (+,-,*,:,**,exp, etc.), ASYST allows the use of trigonometric, hyperbolic, and special functions. For data analysis purposes, ASYST has words to carry out statistical functions. For our applications, the words related to the analysis of variance (ANOVA) are very useful. To create programs, ASYST has a simple word processor. An array editor can be used to view the array, change values, and perform calculations with elements.

As for any other higher level computer language, the use of conditional statements such as *if...then* and *if...else...then* is relatively straightforward. The conditional statements are frequently used in the calibration programs listed in Appendix B. Although the statements resemble the Fortran and Pascal statements, they work completely different. For example, *if...else...then* checks the top of the symbol stack for a TRUE or a FALSE condition. If this condition is TRUE, the series of words between *if* and *else* are executed, if the condition is FALSE, the words between *else* and *then* are executed. The TRUE/FALSE condition on top of the symbol stack is removed by the *if* word. Quite often a conditional statement is executed after a comparison. Comparisons leave a TRUE or FALSE on top of the symbol stack. The simplest comparison operator is the word =, which compares the two top numbers on the number stack and determines whether or not the two numbers are equal. If

they are equal, a logical TRUE is placed on the symbol stack, if not, a logical FALSE.

To repeat a series of statements several times, loops can be used. Frequently the statements that have to be repeated are placed between the words *do* and *loop*. Other useful loops are *begin...until* and *begin...while...until*.

3. Asyst overlays and configuration

ASYST's possibilities are extensive. Most applications use only a few of them simultaneously. To avoid the occupation of computer memory by unused parts of ASYST, it is possible to select the capabilities you want to have permanently resident. ASYST can be configured into a custom version that meets the requirements of a specific application and the hardware being used. Such a system is smaller than a complete system and is more memory efficient. Words (commands) are grouped according to their function. These groups of words are called overlays. An overlay is defined as a file containing pre-compiled word definitions. These word definitions are basically the same as colon definitions. Examples of system overlays are:

gpib.sov   contains all the GPIB words;

datafile.sov provides all the words to read and write numerical arrays from and to a disk.

The user can also create overlays containing his own colon definitions. These overlays are called application

overlays. The ASYST configuration menu allows the user to permanently load system and application overlays into a custom version. This menu also helps to configure the hardware, the memory, and the GPIB board. All configurations have a default setup. These defaults can be changed by following the menu commands. For example, to obtain a custom version that contains all graphics overlays available, one has to permanently load the overlays *charts* and *HP plotter driver* from the menu.

To work with the dual-energy gamma radiation system and the HP plotter, a custom version is set up with the following permanent overlays, chosen from the configuration menu: *GPIB master, type 1 nec GPIB driver, data files, HP plotter driver, statistics and special functions, polynomial operations, matrix and curve fit functions.* With these overlays permanently loaded, we are able to control the system, to acquire data, and to perform data analysis and graphics.

4. Interfacing the computer with GPIB devices

The General Purpose Interface Bus, or GPIB, was developed by Hewlett Packard to interface computers with laboratory instrumentation. The GPIB was adopted in 1975 by the Institute for Electrical and Electronic Engineers as the IEEE-488 standard. This standardization was necessary to improve interfaces with highly specialized software and hardware. Most of these interfaces were designed for only one specific

task and were very inflexible. The main advantage of the GPIB is the reduction of the hardware requirements of a computer to one interface for the entire system compared to one interface for each instrument. Furthermore, GPIB interfacing allows for board independent generalized software. ASYST is a software package that makes use of this feature. During a configuration procedure of a certain custom version in ASYST, the used board has to be specified. From then on, the software package internally takes care of the conversion of generalized commands to Metrabyte specific commands.

A primary address has to be assigned to all of the GPIB devices. This address can be set with DIP switches on the back of, or inside, each device. For example, to assign the name motor to the Aston 800 actuator with a DIP switch setting of 2, the statement *2 gpib.device motor* has to be entered.

Communication between the computer and the GPIB devices on the bus is established by specifying one device which sends information and at least one other device which receives this information. The device receiving the commands is called *listener*, while the device sending the information is called *talker*. For most applications, the computer is the controller of the system, which chooses the talker and listeners and specifies the commands to be sent. The controller can also be the talker or a listener. Frequently, the computer is the talker. To set up communication with a GPIB device, one has to enter the following commands:

send.interface.clear

remote.enable.on

With the first command the computer is made the controller and it receives automatically the name *me*. The second command allows all the GPIB devices connected to the bus to respond to commands from the controller. To make the Aston 800 actuator the listener and the computer the talker, the following commands have to be entered:

untalk unlisten

motor listener me talker

It is important to distinguish between GPIB commands and device commands. A GPIB command is a specific command from the IEEE standard list, while the device commands are strings of data defined by the manufacturer of the devices. The commands differ from device to device. Commands like *talk*, *talker, unlisten* are all GPIB commands. The string

" *sm0,ma+000000*" is a device command which will cause the Aston 800 actuator to move sources and detector vertically to its original position.

Sending a device command from the talker to the listener is not enough for a command to be executed. End Of Transmission delimiters are needed to tell the device receiving the data that there are no more data to be sent. Our three GPIB devices use End Of String (EOS) characters as End Of Transmission delimiters. Every string sent from or to the Aston 800 actuator and the HP 3497A has to end with a

carriage return-line feed as the EOS command. For example, in order to let the sources and detector move to their original position, the talk device command to be sent over is " *sm0,ma+000000*" "*cr.lf*" "*cat*. The "*cat* command catenates the two substrings. The Tennelec TC589 uses ASCII character 13 (carriage return) as an EOS character. Before a device command can be sent over to the Tennelec TC589, one has to enter:

> *gamma eos.on*

> *13 eos.character*

One very important feature of the IEEE-bus is the possibility to do service requests. A device can ask for service from the controller. With our system this feature is used to poll the Aston 800 actuator. It takes some time for the sources and detector to move from one location to the next. Since the next line in the program should only be executed after the sources and detector have arrived at the new location, the computer can poll the Aston 800 actuator for its status. The actuator returns what is called a "serial poll byte," which determines the status of the device and the condition which is responsible for this. It changes when the stepper motor has completed the movement of the sources and detector. The command sequence of a serial poll of the actuator is:

> *begin*

> *stack.clear*

```
serial.poll.enable

untalk unlisten

me listener motor talker

stack.listen

serial.poll.disable

untalk unlisten

16 =

until
```

Once the sources and detector start to move, a serial poll loop is done until the number 16 is returned. This number represents the arrival of the sources and detector at the new location. The next line in the program can then be executed.

APPENDIX B

Listing of Calibration Programs

This Appendix contains the ASYST programs for the calibration of the gamma radiation system. The format is similar for all the programs and is self explanatory.

SPECTRUM.TXT   : Determination of the energy spectra.

REL.TXT   : Determination of the relation between the integral ^{241}Am count rate via the TC 450 and the NC-22.

COMPTON.TXT   : Determination of the Compton relation.

ATTEN.TXT   : Determination of volumetric attenuation coefficients of liquids.

SAT5A.TXT   : Count rate data acquisition for mass attenuation coefficient determination of soils.

SAT5B.TXT   : Calculation of mass attenuation coefficients.

X.TXT   : Determination of path lengths.

BULK.TXT   : Determination of dry bulk density values. When the dry bulk density values are known, the incident count rates can be calculated.

```
\ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ PROGRAM SPECTRUM.TXT
\
\ Calibration program 1
\
\ This program determines the spectrum of Americium-241 or
\ Cesium-137.
\ Data pairs (E, count rate) are stored in a specified
\ datafile.
\ A plot is made of E vs. count rate.
\
\ Minimum ASYST overlay requirements on custom version:
\ gpib master,
\ type 1 nec gpib drive,
\ data files
\ HP plotter driver
\ charts
\
\ At the c:\ prompt enter c:\asyst\total in order to
\ get into a correct ASYST environment. The overlays
\ mentioned above are all part of the custom version
\ 'total'.
\ When in the correct ASYST environment (or custom version)
\ do the following:
\ 1. Load the program by entering:
\ load c:\asyst\spectrum.txt
\ 2. Enter at the subsequent OK prompt:
\ spectrum.determination
\ 3. Follow the instructions carefully.
\
\ 07/19/89
\
\ M.Oostrom
\
\ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

\ *****************************************************************
\
\ All scalars, arrays, and strings have to be declared in the
\ beginning of each program.
\
\ *****************************************************************

real scalar counting.time
\ Counting time set on the timer/multiscaler
real scalar count.time
\ Counting time transferred to buffer
real scalar rate
\ Calculated count rate
real scalar count
\ The total number of measurements done
```

```
real scalar deltaE
\ The width of the window (volts)
real dim[ 2 ] array dumx
\ A dummy array used in the graphics part
real dim[ 2 ] array dumy
\ A dummy array used in the graphics part
real dim[ 51 , 2 ] array res
\ The data are temporarely stored in this array
\ the first column contains the E values, the
\ second the count rates.
\ Position (51,1) is reserved for the number of
\ measurements done. Position (51,2) is reserved
\ for the delta E used.
real dim[ 50 ] array x
\ For programming reasons the first column of array
\ res (except for position 51) is copied into array x
real dim[ 50 ] array y
\ The second column of array res is copied into y
0. res := 0. x := 0. y :=
\ The arrays are initialized
real scalar dummy
\ While converting the string (transferred from
\ the buffer to the computer) into numbers, some
\ of the acquired numbers are useless.
\ These useless numbers are assigned to the variable
\ dummy. This saves memory space.
72 string sl
\ The string that is transferred to and from the
\ buffered interface. This string contains the infor-
\ mation obtained from the three scalers and the
\ timer of the timer/multiscaler TC 535P.
72 string namefile
\ The name of the output file.
2 gpib.device gamma
\ The buffered interface is named 'gamma'.
\ The number 2 refers to the way the dip switches
\ are set inside the bufferred interface.

\ ***************************************************************
\
\ The colon definition 's' is used after the prompt 'Press
\ any key when ready'. After pressing a key, a number value,
\ representing the key, and a T/F value are left on the
\ number and symbol stack, respectively. The words drop and
\ ?drop delete the expressions on both stacks. After this,
\ the screen is cleared  and the next prompt will appear
\ in the middle of the screen. The 'p' macro also
\ clears the screen and moves the cursor to the middle of
\ the next screen.
\
\ ***************************************************************
```

```
: s
pckey drop ?drop screen.clear 10 1 do cr loop ;

: p
screen.clear 10 1 do cr loop ;


\ ********************************************************
\
\ This macro takes care of the GPIB connections. In this
\ program, the only GPIB device is the buffered interface.
\ All commands to the buffer need a carriage return as an
\ 'end of string'. The ASCII representation of a carriage
\ return is 13.
\
\ ********************************************************

: interface
send.interface.clear
remote.enable.on
gamma eos.on
13 eos.character ;


\ ********************************************************
\
\ This colon definition lets the user set up the gamma
\ system properly in order to do the spectrum determination.
\ After this, the computer is made the controller
\ (me talker) and the buffer the listener (gamma listener).
\ A 'control R' catenated with a 'control C'
\ is sent to the buffer in order to set the scalers to 0.
\
\ ********************************************************

: pre.comments
cr
." Turn power to NH85 off." cr
." The NH85 is to the right of the buffered interface." cr
 cr ." Press any key when ready." s
." Set stop/count button of TC 535P on 'count' and" cr
." set .01 min/.1 sec button on '.1 sec'." cr cr
." Press any key when ready." s
." Preset timer." cr
." (Timer formula: timebase*n*10**m.)" cr
." Set CH A PRESET to '96'" cr cr
." Press any key when ready." s
." Disconnect all three analyzer-timer/multiscaler" cr
." connections." cr
." NA-22 from channel A, pos" cr
." TC 450 from channel B, pos" cr
." NC-22 from channel C, pos (on the back)" cr cr
." Press any key when ready." s
```

```
." The analyzer of interest should be in differential" cr
." mode. Check this." cr
." (For the TC 450 use 'window/asym'. The top knob then" cr
." represents delta E * 10. E can be manipulated" cr
." with the 'lower level' knob.)" cr cr
." Press any key when ready." s
." Connect the analyzer of interest to channel B, pos." cr
 cr ." Press any key when ready." s
." Make sure the readout mode of the buffer TC 589 is" cr
." on auto recycle and that the output format is" cr
." on normal." cr cr
." Press any key when ready." s
." Turn power of NH85 on and wait till the counting" cr
." stops." cr cr
." Press any key when counting is finished." s
interface
untalk unlisten
gamma listener me talker
18 ASCII" 3 ASCII" "CAT TALK ;


\ ***********************************************************
\
\ All data and some additional information must be stored in
\ a data file. The data file contains 7 comments and 1
\ subfile for the actual data. The exact organization of a
\ data file has to be specified after the command
\ 'file.template'. The 'file.create' word creates a file
\ according the latest 'file.template' definition.
\ The name of the data file is entered and is assigned
\ to a string named 'namefile'.
\ The user is prompted to enter the 7 comments:
\ 1. date
\ 2. source
\ 3. analyzer name
\ 4. delta E
\ 5. high voltage
\ 6. coarse gain
\ 7. fine gain.
\ The entered delta E is also converted to a number and is
\ stored in the (51,2) position of array res.
\
\ ***********************************************************

: specifications.file
file.template
7 comments
real dim[ 51 , 2 ] subfile
end
." Enter name of output file (including path)." cr
"input namefile ":=
namefile defer> file.create
```

```
namefile defer> file.open p
." Enter date (format: xx/xx/xx)." cr
"input 1 >comment  p
." Enter source (format: Am or Cs)." cr
." The TC 450 and the NC-22 are normally used for Am." cr
." The NA-22 is used for Cs."
"input 2 >comment  p
." When the chosen source is Am, the toggle switch of" cr
." the NA-22 should be set to track. When the Cs is" cr
." the source, the switch should be on disable."  cr cr
." Press any key when ready." s
." Enter name of analyzer." cr
." Format: NA-22, NC-22 or TC 450." cr
"input 3 >comment p
." Set delta E on the analyzer." cr
." For the Cs spectrum a delta E of 0.2 volts and for" cr
." the Am spectrum a delta E of 0.1 volts is" cr
." recommended." cr
." When in the 'window asym' mode on the TC 450, the" cr
." window (delta E) has a range of 0 - 1 volts." cr
." A setting of 1.00 volts on the top knob means a" cr
." delta E of 0.1 volts." cr cr
." Press any key when ready." s
." Enter delta E (format x.xx)." cr
"input "dup 4 >comment p
32 "number ?drop "drop
res [ 51 , 2 ] :=
res [ 51 , 2 ] deltaE :=
." Enter voltage on NV-25A" cr
"input 5 >comment p
." Enter coarse gain on amplifier NA-17" cr
"input 6 >comment p
." Enter fine gain on amplifier NA-17" cr
"input 7 >comment p
file.close ;


\ ***********************************************************
\
\ The counting time is entered and assigned to the scalar
\ counting.time.
\
\ ***********************************************************

: time.count
." Enter counting time in seconds. (format: 10.)" cr
." A counting time of 10 seconds is enough for a" cr
." spectrum determination." cr
#input 1000 * counting.time := p
stack.clear ;


\ ***********************************************************
```

```
\
\ The array res is copied into the subfile of the datafile.
.\ The dimensions of the array have to be the same as the
\ subfile.
\
\ *********************************************************

: create.arrays
namefile defer> file.open
1 subfile
res file>array
file.close ;


\ *********************************************************
\
\ This macro initializes the plotter.
\
\ *********************************************************

: plotter cr
." Put paper in the HP 7475." cr
." Press any key when HP is ready to plot data." s
hp7475 device.init
7.8 10.15 plotter.size
normal.coords ;


\ *********************************************************
\
\ The plot of the Cs-137 spectrum is made by colon
\ definition 'GRAPHCS'. The plot of the Am-241 spectrum,
\ obtained with the NC-22 analyzer, is prepared with the
\ macro 'GRAPHAMNC22'. The graph of the Am-241 spectrum,
\ obtained with the TC 450, is made by definition
\ 'GRAPHAMTC450'.
\
\ *********************************************************

: graphCs
4. dumx [ 1 ] :=
7.99 dumx [ 2 ] :=
.0 dumy [ 1 ] :=
2499 dumy [ 2 ] :=
horizontal grid.off 0 1 label.points label.scale.off
vertical grid.off label.scale.off
.2 .25 axis.orig
.7 .65 axis.size normal.coords
.2 .25 axis.point
1. 1. tick.just
.01 .01 tick.size
8 5 axis.divisions
```

```
count 1.1 + 1 do
res [ i , 1 ] x [ i ] :=
x [ i ] deltaE 2. / + x [ i ] :=
res [ i , 2 ] y [ i ] :=
loop
"   " symbol dumx dumy xy.auto.plot
" *" solid&symbol
x sub[ 1 , count ]
y sub[ 1 , count ]
xy.data.plot
normal.coords
.55 .14 position " Voltage (V)" centered.label
.55 .07 position " ENERGY SPECTRUM OF Cs-137" centered.label
90 label.dir normal.coords
.08 .573 position " Counts per second" centered.label
0 label.dir normal.coords
.26 .84 position 1 comment> label
.26 .78 position " analyzer " 3 comment> "cat label ;


: graphAmNC22
.1 dumx [ 1 ] :=
.99 dumx [ 2 ] :=
.0 dumy [ 1 ] :=
6999 dumy [ 2 ] :=
horizontal grid.off 0 2 label.points label.scale.off
vertical grid.off 1 1 label.points label.scale.off
.2 .25 axis.orig
.7 .65 axis.size normal.coords
.2 .25 axis.point
1. 1. tick.just
.01 .01 tick.size
9 7 axis.divisions
count 1.1 + 1 do
res [ i , 1 ] x [ i ] :=
x [ i ] deltaE 2. / + x [ i ] :=
res [ i , 2 ] y [ i ] :=
loop
"   " symbol dumx dumy xy.auto.plot
" *" solid&symbol
x sub[ 1 , count ]
y sub[ 1 , count ]
xy.data.plot
normal.coords
.55 .14 position " Voltage (V)" centered.label
.55 .07 position " ENERGY SPECTRUM OF Am-241" centered.label
90 label.dir normal.coords
.08 .573 position " Counts per second" centered.label
0 label.dir normal.coords
.26 .84 position 1 comment> label
.26 .78 position " analyzer " 3 comment> "cat label ;

: graphAmTC450
```

```
.1 dumx [ 1 ] :=
.99 dumx [ 2 ] :=
.0 dumy [ 1 ] :=
19999 dumy [ 2 ] :=
horizontal grid.off 0 2 label.points label.scale.off
vertical grid.off no.labels label.scale.off
.2 .25 axis.orig
.7 .65 axis.size normal.coords
.2 .25 axis.point
1. 1. tick.just
.01 .01 tick.size
9 7 axis.divisions
count 1.1 + 1 do
res [ i , 1 ] x [ i ] :=
x [ i ] deltaE 2. / + x [ i ] :=
res [ i , 2 ] y [ i ] :=
loop
"  " symbol dumx dumy xy.auto.plot
" *" solid&symbol
x sub[ 1 , count ]
y sub[ 1 , count ]
xy.data.plot
normal.coords
.181 .257 position " 0" label
.141 .415 position " 5000" label
.125 .572 position " 10000" label
.125 .74 position " 15000" label
.125 .9 position " 20000" label
.55 .14 position " Voltage (V)" centered.label
.55 .07 position " ENERGY SPECTRUM OF Am-241" centered.label
90 label.dir normal.coords
.08 .573 position " Counts per second" centered.label
0 label.dir normal.coords
.26 .84 position 1 comment> label
.26 .78 position " analyzer " 3 comment> "cat label ;

\ ***********************************************************
\
\ Depending on the information stored in comment 3
\ (analyzer name) of the data file, a plot is constructed.
\ The comment is compared with an analyzer name.
\ When the two are the same, a True value is left on the
\ symbol stack and the commands between the 'if' and
\ 'then' words are carried out. If the comment is
\ not the same, a False value is returned and the program
\ skips to the first word after 'then'.
\
\ ***********************************************************

: graph
create.arrays
plotter
```

84

```
namefile defer> file.open
3 comment> " nc-22" "=
if graphAmNC22 then
3 comment> " NC-22" "=
if graphAMNC22 then
3 comment> " na-22" "=
if graphCs then
3 comment> " NA-22" "=
if graphCs then
3 comment> " TC 450" "=
if graphAmTC450 then
3 comment> " tc 450" "=
if graphAmTC450 then
file.close
;


\ ************************************************************
\
\ The actual data collection is done in this colon
\ definition. The 'P' command stores the string with all
\ the information in the buffer.
\ The 'gpib.read' word reads the string into the memory of
\ the computer. The string is analyzed and the
\ useful parts are stored in the scalars
\ 'count.time' and 'count.rate'. The maximum number of
\ measurements is 50.
\ After each measurement the user can quit.
\
\ ************************************************************

: spectrum.loop
51 1 do
." Measurement  " i . cr cr
." Set E on chosen analyzer" cr cr
i 1 =
if
." When determining the spectrum with the NA-22 the" cr
." first E setting should be 3.9. For the increments" cr
." a value of 0.1 is advised." cr
." A spectrum determination with the TC 450 or the" cr
." NC-22 the first E setting should be 0.05 and the" cr
." increments 0.02." cr cr
then
." Press any key when ready." s
." Enter E (format x.xx)." cr
#input res [ i , 1 ] := ?drop  p
." Press any key when system is ready to do measurement." cr
." Wait for the next prompt." s
gamma listener me talker
27 ASCII" TALK
counting.time 1000 + msec.delay
gamma listener me talker
```

```
" P" 3 ASCII" "CAT TALK
4 1 do
gamma sl gpib.read
loop
sl
5 1 do
32 "number ?drop
loop
dummy :=
rate :=
dummy :=
count.time :=
"drop
rate count.time / 10. * res [ i , 2 ] :=
." Stored data" cr cr
." E:   " res [ i , 1 ] . cr
." Count rate (cps):   " res [ i , 2 ] . cr cr
." Enter 'q' if you want to stop taking measurements." cr
." Press enter to continue." cr
"input
" q" "= not p
if
else
i res [ 51 , 1 ] :=
i count :=
namefile defer> file.open cr cr
1 subfile
res array>file
file.close
." If you don't want to determine other energy spectra," cr
." reconnect the analyzers to the multiscalar in the" cr
." following  way:" cr
." NA-22 to channel A, pos" cr
." TC 450 to channel B, pos" cr
." NC-22 to channel C, pos (on the back)." cr cr
." Press any key when ready." s
." The disable/track switch of the NA-22 has to be set" cr
." on track." cr cr
." Press any key when ready." s
graph
." Determine lower level E (LL E) and delta E from the" cr
." plot." cr
." Set these E and delta E values on the analyzer." cr
." The mode of the TC 450 should be in 'norm'. The" cr
." 'lower level' knob corresponds with E on the other" cr
." analyzers. The 'upper level or 'window' knob should" cr
." be set to be the sum of LL E and delta E." cr cr
." Both the NC-22 and the NA-22 have to be set in" cr
." integral mode." cr cr
." Press any key when ready." pckey drop ?drop screen.clear
quit
then
```

```
    loop ;

\ **************************************************
\
\ The main program.
\ Entering 'spectrum.determination' will execute the
\ program.
\
\ **************************************************

: spectrum.determination p
pre.comments
specifications.file
time.count
spectrum.loop
;
```

```
\ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ PROGRAM REL.TXT
\
\ Calibration program 2
\
\ This program determines the linear relation between
\ integral Am-241 count rates obtained via the NC-22
\ single channel analyzer and the TC 450 single channel
\ analyzer.
\ The vertical stepper motor is used to send the gamma
\ beam through different positions of a teflon prism.
\ With each step the path length through the teflon
\ increases.
\
\ Minimum ASYST overlay requirements on custom version:
\ gpib master,
\ type 1 nec gpib drive,
\ data files
\ HP plotter driver
\ statistics and special functions
\ polynomial operations
\ matrix and curve fit functions.
\
\ At the c:\prompt enter c:\asyst\total in order to get
\ into a correct ASYST environment. All the overlays
\ mentioned above are part of the custom version 'total'.
\ Then enter load c:\asyst\rel.txt To run the
\ program enter relation.determination.
\
\ 07/26/89
\
\ M.Oostrom
\
\ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ **************************************************************
\
\ Variable declaration.
\
\ **************************************************************

dp.integer scalar counting.time
\ Counting time set on the timer/multiscaler
real scalar t
\ Counting time transferred to buffer
real scalar ratetc
\ Calculated count rate via the TC 450
real scalar ratenc
\ Calculated count rate via the NC-22
real dim[ 33 , 2 ] array res
\ The measured count rates are stored in this array.
```

```
\ The rates via the NC-22 are placed the first column;
\ the rates via the TC 450 in the second.
0. res :=
real scalar dummy
\ This dummy variable is used when converting the
\ data string coming from the buffer into numbers.
72 string s1
\ Datastring that contains count rates and measured time.
72 string namefile
\ The output file (including the path)
2 gpib.device gamma
\ The name 'gamma' is assigned to the buffered inter-
\ face.
3 gpib.device motor
\ The name 'motor' is assigned to the Aston 800 actuator.
real dim[ 33 ] array x
\ Array used in the graphics part of the program. It
\ contains the NC-22 count rates.
real dim[ 33 ] array y
\ Array used in the graphics part of the program. It
\ contains the TC 450 count rates.
real dim[ 2 ] array dumx
real dim[ 2 ] array dumy
\ The use of the arrays 'dumx' and 'dumy' will keep
\ the plot within reasonable boundaries.
real dim[ 2 ] array lin.coef
\ The coefficients of the regression line
9 gpib.device hp3497
\ The HP 3497 is named hp3497.
integer scalar number.days
\ The number of calender days the program is running.
integer scalar day
integer scalar days
\ Day of the month.
dp.integer scalar extra
integer scalar sec
integer scalar min
integer scalar hours
integer scalar month
dp.integer scalar time0
72 string s2
\ The time string 'month:day:hour:min:sec' is read from
\ the hp3497.


\ ***********************************************************
\
\ The colon definition 's' is used after the prompt 'Press
\ any key when ready'.
\ The 'p' macro clears the screen and the cursor will move
\ to the middle of the screen. Macro 's' does the same
\ thing after the user has pressed a key.
\
```

```
\ ***********************************************

: s
pckey drop ?drop screen.clear 10 1 do cr loop ;

: p
screen.clear 10 1 do cr loop ;

\ ***********************************************
\
\ The colon definition 'interface' takes care of the GPIB
\ connections.
\ In this program, the three GPIB devices are the buffered
\ interface, defined as 'gamma' ,the Aston 800, defined
\ as 'motor', and the HP3497, defined as 'hp3497'.
\ The buffered interface requires a 'carriage return'
\ (ASCII character 13) as an EOS (end of string) character.
\ The Aston 800 and the HP3497 require a "cr.lf",
\ catenated with the rest of the string that is sent over
\ as an EOS. The HP3497 accepts capitals only.
\
\ ***********************************************

: interface
bus.init
send.interface.clear
remote.enable.on
gamma eos.on
13 eos.character ;

\ ***********************************************
\
\ The Aston800 actuator is polled frequently when the
\ system moves from one location to the other. The moment
\ the sources and detector arrive at a new location, the
\ actuator should return the value 16 to the computer. The
\ next statement of a program can then be executed. For no
\ apparent reason, the actuator does not return the value 16
\ after the system has travelled. To avoid a complete crash
\ of a program, a routine should be inserted that takes over
\ the task of the actuator by producing a 16 after a certain
\ time lapse. The colon definitions 'day.determination' and
\ 'time.fetch' are part of this special routine. This
\ routine is part of the 'aston800.status.check' colon
\ definition.
\
\ ***********************************************

: day.determination
1 number.days :=
0 extra :=
hp3497 listener me talker
```

```
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
3 1 do
ascii : "number ?drop
loop
"drop
day :=
month :=
untalk unlisten ;

: time.fetch
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
5 1 do
ascii : "number ?drop
loop
32 "number
?drop "drop
sec :=
min :=
hours :=
days :=
month :=
days day =
if
else
number.days 1 + number.days :=
days day :=
number.days 1 - 86400 *
extra :=
then
hours 3600 * min 60 * + sec + extra +
untalk unlisten ;


\  **********************************************************
\
\ The user has to set up the necessary devices properly in
\ order to determine the relation between the two integral
\ count rates. When this is done, the computer is made the
\ controller of the data acquisition process (me talker).
\ The buffer is the device that accepts command ( gamma
\ listener). A 'control R' (ASCII 18) and a 'control C'
\ (ASCII 3) are sent to the buffer to set the scalers to
\ zero.
\
\  **********************************************************
```

```
: pre.comments
cr
." Turn power to NH85 off." cr
." (to the right of the buffered interface)" cr
 cr ." Press any key when ready." s
." Set stop/count button of TC 535P on 'count'." cr cr
." Press any key when ready." s
." Set .01 min/.1 sec button of TC 535P on '.1 sec'." cr
." This is the 'timebase' of the counting time." cr cr
." Press any key when ready." s
." Preset timer." cr
." (Timer formula: timebase*n*10**m.)" cr
." A counting time of 60 seconds is recommended." cr
." Set timer to '62' if you want a 60 s counting time."
cr cr
." Press any key when ready." s
." Set CH A PRESET to '96'" cr cr
." Press any key when ready." s
." Disconnect the following connections:" cr
." 1: NA-22 from channel A of the TC 535P " cr
." 2: TC 450 from channel B of the TC 535P " cr
." 3: NC-22 from channel C on the back of the TC 535P."
 cr cr
." Press any key when ready." s
." Connect the NC-22 to channel B (pos) and the TC 450" cr
." to channel A (pos) of the TC 535P." cr cr
." Press any key when ready." s
." Set the TC 450 and the NC-22 on integral mode." cr cr
." Press any key when ready." s
." Check the lower level setting on the TC 450 and" cr
." the E-value setting of the NC-22." cr
." The spectrum determinations (calibration program 1)" cr
." should provide the necessary information." cr cr
." Press any key when ready." s
." Make sure the readout mode of the buffer TC 589" cr
." is on auto recycle and that the output format" cr
." is on normal." cr cr
." Press any key when ready." s
." Make sure power of stepper motor indices is on." cr
." System must be able to move freely. Check this." cr cr
." Press any key when ready." s
." Turn power of NH85 on." cr
." Wait till 'Fn' appears on display actuator." cr
." Press any key when ready." s
interface
gamma listener me talker
18 ASCII" 3 ASCII" "CAT TALK ;


\  ****************************************************************
\
\ The following colon definition performs a status test of the
\ Aston 800. The serial poll check gives information on the
```

```
\ status of the actuator and the connected stepper motors.
\ When the actuator returns the value 16, the system has
\ arrived at its destination. The next command of the
\ program can then be executed.
\
\ *************************************************************

: aston800.status.check
untalk unlisten
time.fetch time0 :=
begin
stack.clear
time.fetch
time0 -
60 >
if
16 16
else
1
then
16 =
if
16 =
else
serial.poll.enable
me listener motor talker
stack.listen
serial.poll.disable
16 =
then
until
untalk unlisten
;


\ *************************************************************
\
\ A template is made up for file maintenance. The data
\ output file to be used in this program will contain 3
\ comments and a 33 by 2 array.
\ The first comment is the date. The second comment is
\ the equation of the regression line, while the value
\ of the correlation coefficient is stored in
\ comment 3.
\ The coefficients of the regression equation are stored in
\ position (33,1) and (33,2).
\ The name of the file is assigned to the string 'namefile'
\ The 'file.create' word creates a file according to the
\ latest 'file.template'.
\
\ *************************************************************

: specifications.file
```

```
file.template
3 comments
real dim[ 33 , 2 ] subfile
end
." Enter name of output file (including path)." cr
"input namefile ":=
namefile defer> file.create
namefile defer> file.open p
." Enter date (format: xx/xx/xx)." cr
"input 1 >comment
file.close
p ;


\ **********************************************************
\
\ The counting time as set on the timer has to be entered.
\
\ **********************************************************


: time.count
." Enter counting time in seconds." cr
." (enter this number as an integer)" cr
#input 1000 * counting.time := p
stack.clear ;


\ **********************************************************
\
\ First, the coefficients of the regression line are
\ determined. Then the equation that represents the line
\ is stored as comment 2. An analysis of variance is
\ performed by the 'regress.anova' word. The correlation
\ coefficient is stored as comment 3.
\
\ **********************************************************


: regression.anova
-1 6 fix.format
x sub[ 1 , 32 ] y sub[ 1 , 32 ] 1 leastsq.poly.fit
[ 1 ] lin.coef [ 1 ] :=
lin.coef [ 1 ] res [ 33 , 1 ] :=
x sub[ 1 , 32 ] y sub[ 1 , 32 ] 1 leastsq.poly.fit
[ 2 ] lin.coef [ 2 ] :=
lin.coef [ 2 ] res [ 33 , 2 ] :=
namefile defer> file.open
-1 4 fix.format
" y = " lin.coef [ 2 ] "." "cat "  + " "cat
lin.coef [ 1 ] "." "cat " x" "cat
2 >comment
-1 6 fix.format
y sub[ 1 , 32 ]
```

```
x sub[ 1 , 32 ] lin.coef poly[x]
2 regress.anova
[ 1 , 5 ] "."
-1 6 fix.format
3 >comment
file.close
." Coefficients of the regression line  y=ax + b," cr
." where x is the integral Am count rate via the" cr
." NC-22 s.c.a. and y is the integral Am" cr
." count rate via the TC 450 s.c.a." cr cr
." a = " res [ 33 , 1 ] . cr
." b = " res [ 33 , 2 ] . cr
." Write these numbers down." cr
." You'll need them in the next part of the " cr
." calibration process." cr cr
." Press any key when ready."
pckey drop ?drop screen.clear
;


\ ******************************************************
\
\ Initialization of the plotter.
\
\ ******************************************************

: plotter p
." Press any key when HP is ready to plot data." cr
." Use quality plotter paper only and make sure the" cr
." error indicator is off." s
hp7475 device.init
7.8 10.15 plotter.size
normal.coords ;



\ ******************************************************
\
\ The following colon definition contains all the commands
\ necessary to draw the plot.
\
\ ******************************************************

: graph
horizontal grid.off no.labels label.scale.off
vertical grid.off no.labels label.scale.off
.25 .25 axis.orig
.54 .7 axis.size
normal.coords
.25 .25 axis.point
1. 1. tick.just
.01 .01 tick.size
9 9 axis.divisions
.0 dumx [ 1 ] :=
```

```
44999 dumx [ 2 ] :=
.0 dumy [ 1 ] :=
44999 dumy [ 2 ] :=
"  " symbol dumx dumy xy.auto.plot
" *" symbol
x sub[ 1 , 32 ] y sub[ 1 , 32 ] xy.data.plot
solid
45 ramp 1 - 1000 * dup
lin.coef poly[x] xy.data.plot
normal.coords
.25 .223 position "  0" label
.37 .223 position " 10" label
.486 .223 position " 20" label
.61 .223 position " 30" label
.73 .223 position " 40" label
.217 .25 position "  0" label
.203 .405 position " 10" label
.203 .56 position " 20" label
.203 .715 position " 30" label
.203 .875 position " 40" label
90 label.dir normal.coords
.152 .55 position
" count rate via TC 450 (cps, thousands)"
 centered.label
0 label.dir normal.coords
.52 .18 position
" count rate via NC-22 (cps, thousands)"
 centered.label
.25 .125 position
" RELATION OF THE INTEGRAL AM-241 COUNT "
" RATES MEASURED" "cat label
.25 .1 position
" VIA THE NC-22 SINGLE CHANNEL ANALYZER AND "
" VIA THE" "cat label
.25 .075 position
" TC 450 SINGLE CHANNEL ANALYZER " label
normal.coords
namefile defer> file.open
.3 .9 position 1 comment> label
.69 .62 position " r = " 3 comment> "cat label
.69 .66 position  2 comment> label
file.close
.008 .015 char.size
.703 .635 position " 2" label
;


\ *******************************************************
\
\ The data acquisition is done by this macro.
\ '27 ASCII" ' will cause the scalers to count. The 'P'
\ command stores the string with the measured time and
\ the data from the three scalers.
```

```
\ The word 'gpib.read' reads the string into the computer.
\ A teflon prism is placed between sources and detector.
\ With each measurement the pathlength through the prism,
\ and therefore the attenuation, increases.
\
\ ************************************************************

: rel.loop
 33 1 do
i 1 =
if
." There should be nothing between sources and" cr
." detector during the first measurement." cr cr
." Press any key when system is ready to do measurement." cr
." Wait for the next prompt." s
else
i 2 =
if
." Place teflon prism on a jack on the platform." cr cr
." Press any key when ready." s
." Move sources and detector manually with the stepper" cr
." motor indices or manipulate the jack such that the" cr
." beam travels through the spot on the prism." cr cr
." Press any key when ready." s
." Before continuing make sure to set the stepper" cr
." motor indices back to external mode." cr cr
." Press any key when system is ready to do the 31" cr
." measurements through the teflons prism." s
motor listener me talker
" sm0,za" "cr.lf" "cat talk
50 msec.delay
" sm0,zp" "cr.lf" "cat talk
2500 msec.delay
else
motor listener me talker
" sm0,mr+000100" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
then
." Measurement " i . ." (out of 32)" cr
gamma listener me talker
27 ASCII" TALK
counting.time 2000 + msec.delay
gamma listener me talker
" P" 3 ASCII" "CAT TALK
4 1 do
gamma s1 gpib.read
loop
s1
5 1 do
```

```
32 "number ?drop
loop
dummy :=
ratenc :=
ratetc :=
t :=
"drop
ratenc t / 10. * dup res [ i , 1 ] :=  x [ i ] :=
ratetc t / 10. * dup res [ i , 2 ] :=  y [ i ] :=
p ." Stored data" cr cr
." Count rate NC-22: " res [ i , 1 ] . cr
." Count rate TC-450: " res [ i , 2 ] . cr
5000 msec.delay p
loop
motor listener me talker
" sm0,ma+000000" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
." Reconnect the analyzers to the multiscaler in the" cr
." following way:" cr
." NA-22 to channel A, pos" cr
." TC 450 to channel B, pos" cr
." NC-22 to channel C, pos (on the back)." cr cr
." Press any key when ready." s
." The NA-22 and the NC-22 have to be in integral and" cr
." the TC 450 in differential mode (norm). The" cr
." disable/track switch of the NA-22 has to" cr
." be set on track." cr cr
." Press any key when ready." pckey drop ?drop screen.clear
regression.anova
namefile defer> file.open cr cr
1 subfile
res array>file
file.close
stack.clear
plotter
graph
;


\ ****************************************************
\
\ The main program. By entering 'relation.determination'
\ the program will run.
\
\ ****************************************************

: relation.determination p
interface
day.determination
pre.comments
```

```
specifications.file
time.count
rel.loop
;
```

```
\ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ PROGRAM COMPTON.TXT
\
\ Calibration program 3
\
\ This program determines the relation between the
\ high-energy Cs intensity and the Compton scattering in
\ the Am window. Two brass plates are placed between sources
\ and detector to absorb the radiation emitted by the Am
\ source.
\ The vertical stepper motor is used to send the gamma
\ beam through different positions of a teflon prism.
\ With each step the path length through the prism,
\ and therefore the attenuation, increases.
\
\ Minimum ASYST overlay requirements on custom version:
\ gpib master,
\ type 1 nec gpib drive,
\ data files
\ HP plotter driver
\ statistics and special functions
\ polynomial operations
\ matrix and curve fit functions.
\
\ At the c:\ prompt enter c:\asyst\total. The custom version
\ 'total' contains the overlays specified above.
\ Load this program by entering load c:\asyst\compton.txt.
\ To run the program enter compton.determination.
\
\ 08/01/89
\
\ M.Oostrom
\
\ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

\ ****************************************************************
\
\ Variable declaration.
\
\ ****************************************************************

dp.integer scalar counting.time
\ Counting time set on the timer/multiscaler
real scalar a
real scalar b
\ Scalars a and b are the coefficients of the linear
\ relation of the integral Am count rates via the
\ NC-22 and the TC 450 single channel analyzers.
\ Relation: y = ax + b, where x is the count rate via
\ the NC-22 and y the count rate via the TC 450.
real scalar t
```

```
\ Counting time transferred to buffer
real scalar ratetc
\ Counts via TC 450 (Am)
real scalar ratena
\ Counts via NA-22 (Cs)
real scalar ratenc
\ Counts via NC-22 (Am)
real dim[ 33 , 2 ] array res
\ The measured count rates are stored in this array. The
\ rates via the NC-22 are placed in the first column;
\ the rates via the TC 450 in the second.
0. res :=
\ initialization of array res
real scalar dummy
\ This dummy variable is used when converting the
\ data string coming from the buffer into numbers.
72 string s1
\ Data string that contains count rates and measured time.
72 string namefile
\ The outputfile (including the path)
2 gpib.device gamma
\ The name 'gamma' is assigned to the buffered interface
3 gpib.device motor
\ The name 'motor' is assigned to the Aston 800 actuator.
real dim[ 33 ] array x
\ Array used in the graphics part of the program.
\ It contains the NC-22 count rates.
real dim[ 33 ] array y
\ Array used in the graphics part of the program.
\ It contains the TC 450 count rates.
real dim[ 2 ] array dumx
\ The use of the arrays 'dumx' and 'dumy' will keep
\ the plot within reasonable boundaries.
real dim[ 2 ] array dumy
real dim[ 2 ] array lin.coef
\ The coefficients of the regression line.
9 gpib.device hp3497
\ The HP 3497 is named hp3497.
integer scalar number.days
\ The number of calender days the program is running.
integer scalar day
integer scalar days
\ Day of the month.
dp.integer scalar extra
integer scalar sec
integer scalar min
integer scalar hours
integer scalar month
dp.integer scalar time0
72 string s2
\ The time string 'month:day:hour:min:sec' is read from
\ the hp3497.
```

```
\ ***************************************************
\
\ The colon definition 's' is used after the prompt 'Press
\ any key when ready'. The 'p' macro clears the screen and
\ the cursor will move to the middle of the screen.
\ Macro 's' will do the same after the user has pressed a
\ key.
\
\ ***************************************************

: s
pckey drop ?drop screen.clear 10 1 do cr loop ;

: p
screen.clear 10 1 do cr loop ;

\ ***************************************************
\
\ The colon definition 'interface' takes care of the GPIB
\ connections.
\ In this program, the three GPIB devices are the buffered
\ interface, defined as 'gamma' ,the Aston 800, defined
\ as 'motor,' and the HP3497, defined as 'hp3497'.
\ The buffered interface requires a 'carriage return'
\ (ASCII character 13) as an EOS (end of string) character.
\ The Aston 800 and the HP3497 require a "cr.lf",
\ catenated with the rest of the string that is sent over
\ as an EOS. The HP3497 accepts capitals only.
\
\ ***************************************************

: interface
bus.init
send.interface.clear
remote.enable.on
gamma eos.on
13 eos.character ;

\ ***************************************************
\
\ The Aston800 actuator is polled frequently when the
\ system moves from one location to the other. The moment
\ the sources and detector arrive at a new location, the
\ actuator should return the value 16 to the computer. The
\ next statement of a program can then be executed. For no
\ apparent reason, the actuator does not return the value 16
\ after the system has travelled. To avoid a complete crash
\ of a program, a routine should be inserted that takes over
\ the task of the actuator by producing a 16 after a certain
\ time lapse. The colon definitions 'day.determination' and
\ 'time.fetch' are part of this special routine. This
\ routine is part of the 'aston800.status.check' colon
```

```
\ definition.
\
\ ********************************************************

: day.determination
1 number.days :=
0 extra :=
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
3 1 do
ascii : "number ?drop
loop
"drop
day :=
month :=
untalk unlisten ;

: time.fetch
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
5 1 do
ascii : "number ?drop
loop
32 "number
?drop "drop
sec :=
min :=
hours :=
days :=
month :=
days day =
if
else
number.days 1 + number.days :=
days day :=
number.days 1 - 86400 *
extra :=
then
hours 3600 * min 60 * + sec + extra +
untalk unlisten ;

\ ********************************************************
\
\ The user has to set up the necessary devices properly in
\ order to determine the relation between the high-energy
\ Cs and the compton scattering in the Am window.
```

```
\ When this is done, the computer is made the controller of
\ the data acquisition process (me talker). The buffer is
\ the device that accepts command ( gamma listener). A
\ 'control R' (ASCII 18) and a 'control C' (ASCII 3) are
\ sent to the buffer to set the scalers to zero.
\
\ ***********************************************************

: pre.comments cr
." Check the following connections:" cr
." NA-22 integral output to channel A (pos) of the TC 535P" cr
." multiscaler;" cr
." TC 450 norm mode output to channel B (pos) of the" cr
." multiscaler;" cr
." NC-22 integral output to channel C (pos) on the" cr
." back of the multiscalar." cr cr
." Press any key when ready." s
." Turn power to NH85 off." cr
." (to the right of buffered interface) "
 cr cr ." Press any key when ready." s
." Set stop/count button of TC 535P on 'count'." cr
." Press any key when ready." s
." Set .01 min/.1 sec button of the TC 535P on '.1 sec'." cr
." This is the 'timebase' of the counting time."
cr cr
." Press any key when ready." s
." Preset timer." cr
." (Timer formula: timebase*n*10**m.)" cr
." A counting time of 60 s is recommended." cr
." Set timer to '62' if you want a 60 s counting time." cr cr
." Press any key when ready." s
." Set CH A PRESET to '96'" cr cr
." Press any key when ready." s
." Make sure the readout mode of the buffer TC 589 is"
cr ." on auto recycle and that the output format is"
cr ." on normal." cr cr
." Press any key when ready." s
." Make sure power of stepper motor indices is on." cr
." System must be able to move freely. Check this." cr cr
." Press any key when ready." s
." The coefficients of the linear relationship"
cr ." ( y = ax + b) between the integral Am-241"
cr ."  count rate via the NC-22 (x) and the integral" cr
." count rate via the TC 450 (y) have to be entered." cr
." Enter a : " cr
#input a := cr
." Enter b : " cr
#input b :=  p
." Place two brass plates between sources and detector."
cr ." Be careful!!!!!!!!!" cr cr
." Press any key when ready." s
." Turn power of NH85 on and wait till the " cr
```

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```
." Aston800 actuator has performed its self test." cr
." The letters 'Fn' appear when the self test has" cr
." been completed." cr cr
." Press any key when counting is finished." s
interface
gamma listener me talker
18 ASCII" 3 ASCII" "CAT TALK ;
```

```
\ ************************************************************
\
\ The following colon definition performs a status test of the
\ Aston 800. The serial poll check gives information on the
\ status of the actuator and the connected stepper motors.
\ When the actuator returns the value 16, the system has
\ arrived at its destination. The next command of the
\ program can then be executed.
\
\ ************************************************************
```

```
: aston800.status.check
untalk unlisten
time.fetch time0 :=
begin
stack.clear
time.fetch
time0 -
60 >
if
16 16
else
1
then
16 =
if
16 =
else
serial.poll.enable
me listener motor talker
stack.listen
serial.poll.disable
16 =
then
until
untalk unlisten
;
```

```
\ ************************************************************
\
\ A template is made up for file maintenance. The data
\ output file to be used in  this program will contain 3
\ comments and a 33 by 2 array. The first comment is
\ the date. The second comment is the equation of the
```

```
\ regression line, while the value of the correlation
\ coefficient is stored in comment 3.
\ The coefficients of the regression equation are
\ stored in position (33,1) and (33,2) of the array.
\ The name of the file is assigned to the string 'namefile'
\ The 'file.create' word creates a file according to the
\ latest 'file.template'.
\
\ ****************************************************

: specifications.file
file.template
3 comments
real dim[ 33 , 2 ] subfile
end
." Enter name of output file (including path)." cr
"input namefile ":=
namefile defer> file.create
namefile defer> file.open p
." Enter date (format: xx/xx/xx)." cr
"input 1 >comment
file.close
p ;

\ ****************************************************
\
\ The counting time as set on the timer has to be entered.
\
\ ****************************************************

: time.count
." Enter counting time in seconds." cr
." (enter this number as an integer)" cr cr
#input 1000 * counting.time := p
stack.clear ;

\ ****************************************************
\
\ The coefficients of the regression line are determined.
\ Subsequently, the equation that represents the line
\ is stored as comment 2. An analysis of variance is
\ performed by the 'regress.anova' word. The correlation
\ coefficient is stored as comment 3.
\
\ ****************************************************

: regression.anova
-1 6 fix.format
x sub[ 1 , 32 ] y sub[ 1 , 32 ] 1 leastsq.poly.fit
[ 1 ] lin.coef [ 1 ] :=
lin.coef [ 1 ] res [ 33 , 1 ] :=
x sub[ 1 , 32 ] y sub[ 1 , 32 ] 1 leastsq.poly.fit
```

```
[ 2 ] lin.coef [ 2 ] :=
lin.coef [ 2 ] res [ 33 , 2 ] :=
." The coefficients of the linear relationship"
cr ." (y = px + q) between the high energy Cs"
cr ." intensity (x) and the Compton scattering in the"
cr ." Am-window (y):" cr
." p = " lin.coef [ 1 ] .  cr
." q = " lin.coef [ 2 ] .  cr
." Write these numbers down. You'll need them in later"
cr ." calibration programs and measurements." cr cr
." Press any key when ready." s
namefile defer> file.open
-1 5 fix.format
" y =" lin.coef [ 1 ] "." "cat
" x" "cat " +" "cat lin.coef [ 2 ] "." "cat 2 >comment
y sub[ 1 , 32 ]
x sub[ 1 , 32 ] lin.coef poly[x]
2 regress.anova
[ 1 , 5 ] "."
3 >comment
file.close ;


\ **********************************************************
\
\ Initialization of the plotter.
\
\ **********************************************************

: hp p
." Press any key when HP is ready to plot data." cr
." Use quality plotted paper only and make sure the"
cr ." error indicator is off." s
hp7475 device.init
7.8 10.15 plotter.size
normal.coords ;


\ **********************************************************
\
\ The following colon definition contains all the commands
\ necessary to draw the plot.
\
\ **********************************************************

: graph
horizontal grid.off no.labels label.scale.off
vertical grid.off no.labels label.scale.off
.25 .25 axis.orig
.54 .7 axis.size
normal.coords
.25 .25 axis.point
1. 1. tick.just
.01 .01 tick.size
```

```
8 4 axis.divisions
.0 dumx [ 1 ] :=
4000 dumx [ 2 ] :=
.0 dumy [ 1 ] :=
1000 dumy [ 2 ] :=
"  " symbol dumx dumy xy.auto.plot
" *" symbol
x sub[ 1 , 32 ] y sub[ 1 , 32 ] xy.data.plot
solid
41 ramp 1 - 100 * dup
lin.coef poly[x] xy.data.plot
normal.coords
90 label.dir normal.coords
.125 .55 position
" Compton scattering in the Am-window, "
centered.label
.152 .55 position " counts per second" centered.label
0 label.dir normal.coords
.25 .21 position " 0" centered.label
.385 .22 position " 1000" centered.label
.52 .22 position " 2000" centered.label
.655 .22 position " 3000" centered.label
.79 .22 position " 4000" centered.label
.22 .25 position " 0" label
.193 .425 position " 250" label
.193 .6 position " 500" label
.193 .775 position " 750" label
.179 .95 position " 1000" label
.52 .17 position
" High-energy Cs intensity, counts per second"
centered.label
.25 .125 position
" COMPTON SCATTERING IN THE Am-WINDOW VERSUS" label
.25 .1 position " HIGH-ENERGY Cs INTENSITY." label
.25 .075 position
" (ALL COUNT RATES ARE CORRECTED FOR DEAD TIME) " label
normal.coords
namefile defer> file.open
.3 .9 position 1 comment> label
.69 .62 position " r =" 3 comment> "cat label
.69 .66 position  2 comment> label
file.close
.008 .015 char.size
.703 .635 position " 2" label
;


\ ********************************************************
\
\ The data acquisition is done by this macro.
\ '27 ASCII" ' will cause the scalers to count. The 'P'
\ command stores the string with the measured time and
\ the data from the three scalers.
```

```
\ The word 'gpib.read' reads the string into the computer.
\ A teflon prism is placed between sources and detector.
\
\ ****************************************************

: compton.loop
33 1 do
i 1 =
if
." There should be nothing between sources and" cr
." detector." cr cr
." Press any key when system is ready to do" cr
." the first measurement." cr
." Wait for the next prompt." s
else
i 2 =
if
." Place teflon prism on a jack on the platform." cr cr
." Press any key when ready." s
." Move sources and detector manually with the stepper" cr
." motor indices or manipulate the jack in such a way" cr
." that the beam travels through the spot on the" cr
." prism." cr cr
." Press any key when ready." s
." Before continuing make sure to set the stepper" cr
." motor indices back to the external mode." cr cr
." Press any key when system is ready to do measurements." s
motor listener me talker
" sm0,za" "cr.lf" "cat talk 50 msec.delay
" sm0,zp" "cr.lf" "cat talk 50 msec.delay
2500 msec.delay
else
motor listener me talker
" sm0,mr+000100" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
then
." Measurement " i . ." (out of 32)"
gamma listener me talker
27 ASCII" TALK
counting.time 2000 + msec.delay
gamma listener me talker
" P" 3 ASCII" "CAT TALK
4 1 do
gamma s1 gpib.read
loop
s1
5 1 do
32 "number ?drop
loop
```

```
ratenc :=
ratetc :=
ratena :=
t :=
"drop
ratetc t / 10. *
ratenc t / 10. * a * b + .0000006 * 1. - / abs
dup res [ i , 2 ] :=  y [ i ] :=
ratena t / 10. * dup
.00000167 * 1. - abs /
dup res [ i , 1 ] :=  x [ i ] :=
p ." Stored data" cr cr
." Dead time corrected Cs count rate : " res [ i , 1 ] . cr
." Dead time corrected Compton scatter in Am-window : "
 res [ i , 2 ] . cr
5000 msec.delay p
loop
motor listener me talker
" sm0,ma+000000" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
regression.anova  p
namefile defer> file.open cr cr
1 subfile
res array>file
file.close
stack.clear
hp
graph
;


\ ********************************************************
\
\ The main program. By entering 'compton.determination',
\ the program will run.
\
\ ********************************************************

: compton.determination p
interface
day.determination
pre.comments
specifications.file
time.count
compton.loop
;
```

```
\ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ PROGRAM ATTEN.TXT
\
\ Calibration program 4
\
\ This program determines mass attenuation coefficients
\ of solutions.
\ A Plexiglas cell with four compartments is
\ used in this part of the calibration process.
\ Count rates will subsequently be obtained on the cell
\ with 0, 1, 2, 3 and 4 compartments filled with the
\ solution. In each case, the count rates are determined
\ at five different locations. A total of 25 measure-
\ ments is done. With a linear regression analysis,
\ the products of the mass attenuation coefficient and
\ the density of the solution are calculated. The
\ variances of these quantities are also computed.
\ For liquids that dissolve Plexiglas, a glass
\ compartmental cell consisting of four French squared
\ bottles, glued to a wooden base, is used.
\
\ Minimum ASYST overlay requirements on custom version:
\ gpib master
\ type 1 nec gpib drive
\ HP plotter driver
\ statistics and special functions
\ polynomial operations
\ matrix and curve fit functions
\
\ At the C:\ prompt, enter c:\asyst\total in order to get
\ into a correct ASYST environment. Then enter
\ load c:\asyst\atten.txt. To run the program, enter
\ determination.attenuation.coef.
\
\ 08/18/89
\
\ M.Oostrom
\
\ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ **************************************************************
\
\ variable declaration
\
\ **************************************************************

integer scalar m
integer scalar l
real scalar a
real scalar b
real scalar r
```

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```
real scalar q
\ The coefficients of the linear relation
\ between  the integral count rates via the NC-22 and
\ the TC 450 are a and b.
\ (calibration program 2)
\ The coefficients r and q determine the linear relation
\ between the high energy Cs count rate and the Cs
\ Compton scattering in the Am-window.
\ (calibration program 3)
real scalar ratenc
\ Raw integral Am count rate measured via the NC-22.
real scalar ratetc
\ Raw differential Am count rate measured via the TC 450.
real scalar ratena
\ Raw integral Cs count rate measured via the NA-22.
real dim[ 25 ] array yam
\ Natural log values of the corrected Am count rates of
\ the twenty five measurements.
real scalar yamav
\ Average value of the array yam
real dim[ 25 ] array ycs
\ Natural log values of the corrected Cs count rates of
\ the twenty five measurements.
real scalar ycsav
real dim[ 25 ] array x
\ Cumulative travel distances through the cells.
: init
6 1 do 0. x [ i ] := loop
11 6 do 1.505 x [ i ] := loop
16 11 do 2.975 x [ i ] := loop
21 16 do 4.445 x [ i ] := loop
26 21 do 5.95 x [ i ] := loop ;
\ Initialization of the x array.
real scalar xav
\ The average value of array x.
real scalar counting.time
\ Counting time entered by the user.
real scalar count.time
\ Counting time send over from buffer to computer.
real scalar rateam
\ Dead time and compton scattering corrected Am count rate.
real scalar ratecs
\ Dead time corrected Cs count rate.
72 string s1
\ String with the counting time and total counts stored in
\ the buffered interface and send over to the computer.
2 gpib.device gamma
\ The buffered interface is named gamma.
3 gpib.device motor
\ The buffered interface TC 589 is called motor.
real dim[ 2 ] array am.coef
\ Coefficients of the linear relation between the path
```

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```
\ length through the compartmental cell and the natural
\ log of count rate of Am.
real dim[ 2 ] array cs.coef
\ Coefficients of the linear relation between the path
\ length through the compartmental cell and the natural
\ log of count rate of Cs.
real dim[ 2 ] array dumx
\ Dummy array used in the graphics part of the program.
real dim[ 2 ] array dumy
\ Dummy array used in the graphics part of the program.
10 string rsquaredam
10 string rsquaredcs
\ String containing the r² value of the linear
\ relation mentioned above for Am and Cs, respectively.
real dim[ 2 ] array cs.coef
20 string information
\ Information on the solution that has to appear
\ on the plot.
real scalar varuwam
real scalar varuwcs
\ The variance of the product of the attenuation
\ coefficient and the density of the solution.
\ (Am and Cs, respectively)
real scalar pp
real scalar qq
real scalar rr
real scalar ss
real scalar tt
\ The temporary variables pp,qq,rr,ss, and tt are used
\ during the calculation of the variances.
9 gpib.device hp3497
\ The HP 3497 is named hp3497.
integer scalar number.days
\ The number of calender days the program is running.
integer scalar day
integer scalar days
\ Day of the month.
dp.integer scalar extra
integer scalar min
integer scalar sec
integer scalar hours
integer scalar month
dp.integer scalar time0
72 string s2
\ The time string 'month:day:hour:min:sec' is read from
\ the hp 3497


\ ************************************************************
\
\ This colon definition takes care of the GPIB connections.
\ In this program, the three GPIB devices are the buffered
\ interface, defined as 'gamma', the Aston 800, defined
```

```
\ as 'motor', and the HP 3497, defined as 'hp3497'.
\ The buffered interface requires a 'carriage return'
\ (ASCII character 13) as an EOS (end of string) character.
\ The Aston 800 and the HP 3497 require a "cr.lf",
\ catenated with the rest of the string that is sent over
\ as an EOS. The HP 3497 accepts capitals only.
\
\ ********************************************************

: interface
bus.init
send.interface.clear
remote.enable.on
gamma eos.on
13 eos.character ;


\ ********************************************************
\
\ The Aston800 actuator is polled frequently when the
\ system moves from one location to the other. The moment
\ the sources and detector arrive at a new location, the
\ actuator should return the value 16 to the computer. The
\ next statement of a program can then be executed. For no
\ apparent reason, the actuator does not always return the
\ value 16 after the system has travelled. To avoid a
\ complete crash of a program, a routine should be inserted
\ that takes over the task of the actuator by producing a
\ 16 after a certain time lapse. The colon definitions
\ 'day.determination' and 'time.fetch' are part of this
\ special routine. This routine is part of
\ the 'aston800.status.check' colon definition.
\
\ ********************************************************

: day.determination
1 number.days :=
0 extra :=
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
3 1 do
ascii : "number ?drop
loop
"drop
day :=
month :=
untalk unlisten ;

: time.fetch
hp3497 listener me talker
```

```
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
5 1 do
ascii : "number ?drop
loop
32 "number
?drop "drop
sec :=
min :=
hours :=
days :=
month :=
days day =
if
else
number.days 1 + number.days :=
days day :=
number.days 1 - 86400 *
extra :=
then
hours 3600 * min 60 * + sec + extra +
untalk unlisten ;
```

```
\ ************************************************************
\
\ The colon definition 's' is used after the prompt
\ 'Press any key when ready'. The 'p' macro clears the
\ screen and moves the cursor to the middle of the screen.
\ Macro 's' does the same after the user has pressed a key.
\
\ ************************************************************
```

```
: s
pckey drop ?drop screen.clear 10 1 do cr loop ;
```

```
: p
screen.clear 10 1 do cr loop ;
```

```
\ ************************************************************
\
\ Before the actual measurements can take place, the user has
\ to check a number of connections and settings. He also has
\ to enter coefficients of relations determined in previous
\ calibration programs.
\
\ ************************************************************
```

```
: instructions
." Preset timer TC 535P to '1,1'" cr cr
```

." Press any key when ready." s
." Check the following connections with the multiscaler:" cr
." NA-22 integral output to channel A,pos;" cr
." TC 450 norm mode output to channel B,pos;" cr
." NC-22 integral output to channel C,pos." cr cr
." Press any key when ready." s
." Check E and delta E settings of the " cr
." single channel analyzers and the NA-22." cr cr
." Press any key when ready." s
." Turn power to NH85 off." cr
." (to the right of the buffered interface)" cr
cr ." Press any key when ready." s
." Set stop/count button of TC 535P on 'count' and" cr
." set .01 min/.1 sec button on '.1 sec'." cr
." This is the 'timebase' of the counting time." cr cr
." Press any key when ready." s
." Make sure the readout mode of the buffered inter-" cr
." face TC 589 is on auto recycle and that the output " cr
." format is on normal." cr cr
." Press any key when ready." s
." The coefficients of the linear relation (y=ax+b)" cr
." between the integral Am count rate via the NC-22" cr
." (x) and via the TC 450 (y) must be entered." cr cr
-1 6 fix.format
." Enter a:" cr
#input a := cr
." Enter b:" cr
#input b := p
." The coefficients of the linear relation (y=rx+q)" cr
." between the high energy Cs count rate (x) and the" cr
." Compton scattering in the Am-window (y) must be" cr
." entered." cr cr
." Enter r:" cr
#input r := cr
." Enter q:" cr
#input q := p
." Make sure power of stepper motors is on." cr
." System must be able to move freely. Check this." cr cr
." Press any key when ready." s
." Turn power of NH85 on." cr
." Wait till 'Fn' appears on the display of" cr
." the Aston actuator." cr cr
." Press any key when ready." s
interface
gamma listener me talker
18 ASCII" 3 ASCII" "CAT TALK
." Preset timer (minimum 200 sec)." cr
." Timer formula: timebase*n*10**m." cr
." A counting time of 200 s is recommended." cr
." Set the timer to '2,3' if you want a counting time" cr
." of 200 s." cr cr
." Press any key when ready." s

```
."  Set CH A PRESET to '96'. " cr cr
."  Press any key when ready." s
."  Enter counting time in seconds." cr
."  (enter as a real)" cr
#input 1000. * counting.time := p
stack.clear ;


\  ***************************************************
\
\ The colon definition 'aston800.status.check' performs a
\ status test of the Aston 800. The serial poll check
\ gives information on the status of the actuator and the
\ connected stepper motors. When the actuator returns
\ the value 16, the system has arrived at its destination.
\ The next command of the program can then be executed.
\
\  ***************************************************

: aston800.status.check
untalk unlisten
time.fetch time0 :=
begin
stack.clear
time.fetch
time0 -
60 >
if
16 16
else
1
then
16 =
if
16 =
else
serial.poll.enable
me listener motor talker
stack.listen
serial.poll.disable
16 =
then
until
untalk unlisten
;


\  ***************************************************
\
\ The determination of the attenuation coefficient is done
\ with a four-compartment Plexiglas calibration cell.
\ First, the count rate through the empty cell is determined.
\ Then the user is prompted four times to fill up a
\ compartment. In each case, a measurement is done at five
```

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```
\ different locations.
\ By fitting a line through all 25 data points,
\ the product of the attenuation coefficient and the
\ density of the solution can be determined. This
\ product is the absolute value of the slope of the line.
\ (see next colon definition)
\
\ ****************************************************

: measurement
0 l :=
6 1 do
i l =
if
." Place the calibration cell between sources and detector."
 cr
." The radiation should go through compartment 1 first."
 cr
." Make sure the long side of the calibration cell" cr
." is parallel to the radiation beam." cr cr
." Press any key when ready for measurement." s
else
." Some action is required after the tune!" cr
10000 1000 tune
p
." Fill up compartment " i 1 - . " with the solution."
cr cr
." Press any key when ready for next measurement." s
then
6 1 do
l 1 + l :=
i m :=
m 1 =
if
motor listener me talker
" sm0,za" "cr.lf" "cat talk 50 msec.delay
" sm0,zp" "cr.lf" "cat talk 50 msec.delay
" sm1,za" "cr.lf" "cat talk 50 msec.delay
" sm1,zp" "cr.lf" "cat talk
2500 msec.delay
then
m 2 =
if
motor listener me talker
" sm1,mr+000500" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
m 3 =
if
motor listener me talker
```

```
"  sm1,mr-001000" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
m 4 =
if
motor listener me talker
"  sm1,mr+000600" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
motor listener me talker
"  sm1,mr-000100" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
motor listener me talker
"  sm0,mr+000500" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
m 5 =
if
motor listener me talker
"  sm0,mr-001000" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
." Measurement " i . ." (out of 5) for this set up" cr
gamma listener me talker
27 ASCII" TALK
\ This command starts the scalers and the timer.
counting.time 2000 + msec.delay
gamma listener me talker
" P" 3 ASCII" "CAT TALK
\ This command transfers the data string with the information
\ on counts and time from the multiscaler to the buffered
\ interface.
4 1 do
gamma s1 gpib.read
loop
\ The previous loop transfers the data string
\ from the buffer to the computer.
\ The next loop converts the data string into the counts and
\ counting time.
s1
5 1 do
32 "number ?drop
loop
```

```
ratenc :=
ratetc :=
ratena :=          ·
count.time :=
"drop
\ The raw data are corrected for dead time. The Am count
\ rate is also corrected for low energy Cs in the Am window.
ratetc count.time / 10. *
ratenc count.time / 10. * a * b + .0000006 * 1. - / abs
rateam :=
ratena count.time / 10. * dup
.00000167 * 1. - abs /
dup ratecs :=
r * q + rateam swap - rateam :=
ratecs ln ycs [ l ] :=
rateam ln yam [ l ] :=
p
m 5 =
if
motor listener me talker
" sm0,mr+000600" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
motor listener me talker
" sm0,mr-000100" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
loop
loop ;


\ ***********************************************************
\
\ The determination of the TCE attenuation coefficient is done
\ with a setup consisting of four French square glass
\ bottles glued on a wooden base.
\ First, the count rate through the empty setup is determined.
\ Then the user is prompted four times to fill up a
\ bottle. In each case, a measurement is done five times.
\ By fitting a line through all 25 data points,
\ the product of the attenuation coefficient and the
\ density of the solution can be determined. This
\ product is the absolute value of the slope of the line.
\ (see next colon definition)
\
\ ***********************************************************

: measurement.tce
0 l :=
6 1 do
```

```
i 1 =
if
." Place the calibration cell between sources and detector."
 cr
." The radiation should go through bottle 1 first."
 cr cr ." Press any key when ready for measurement." s
else
." Some action is required after the tune!" cr
10000 1000 tune
p
." Fill up bottle " i 1 - . " with the NAPL."
cr cr
." Press any key when ready for next measurement." s
then
6 1 do
l 1 + 1 :=
." Measurement " i . ." (out of 5) for this set up" cr
gamma listener me talker
27 ASCII" TALK
\ This command starts the scalers and the timer.
counting.time 2000 + msec.delay
gamma listener me talker
" P" 3 ASCII" "CAT TALK
\ This command transfers the data string with the information
\ on counts and time from the multiscaler to the buffered
\ interface.
4 1 do
gamma s1 gpib.read
loop
\ The previous loop transfers the data string
\ from the buffer to the computer.
\ The next loop converts the data string into the counts and
\ counting time.
s1
5 1 do
32 "number ?drop
loop
ratenc :=
ratetc :=
ratena :=
count.time :=
"drop
\ The raw data are corrected for dead time. The Am count
\ rate is also corrected for low energy Cs in the Am window.
ratetc count.time / 10. *
ratenc count.time / 10. * a * b + .0000006 * 1. - / abs
rateam :=
ratena count.time / 10. * dup
.00000167 * 1. - abs /
dup ratecs :=
r * q + rateam swap - rateam :=
ratecs ln ycs [ 1 ] :=
```

```
rateam ln yam [ 1 ] :=
p
loop
loop ;

\ ************************************************************
\
\ This macro calculates the coefficients of the linear
\ relation between path length and the natural log of
\ the corrected count rates of Am and Cs.
\ The r² of the relations and the variance of the
\ product of the mass attenuation coefficient and the
\ solution density are also determined.
\
\ ************************************************************

: regression
x yam 1 leastsq.poly.fit
[ 1 ] am.coef [ 1 ] :=
x yam 1 leastsq.poly.fit
[ 2 ] am.coef [ 2 ] :=
x ycs 1 leastsq.poly.fit
[ 1 ] cs.coef [ 1 ] :=
x ycs 1 leastsq.poly.fit
[ 2 ] cs.coef [ 2 ] :=
yam
x am.coef poly[x]
2 regress.anova
[ 1 , 5 ] "." rsquaredam ":=
ycs
x cs.coef poly[x]
2 regress.anova
[ 1 , 5 ] "." rsquaredcs ":=
\ Calculation of the variances.
0. yamav :=
0. ycsav :=
0. xav :=
26 1 do
yamav yam [ i ] + yamav :=
ycsav ycs [ i ] + ycsav :=
xav x [ i ] + xav :=
loop
yamav 25. / yamav :=
ycsav 25. / ycsav :=
xav 25. / xav :=
0. pp :=
0. qq :=
0. rr :=
0. ss :=
0. tt :=
26 1 do
yam [ i ] yamav - 2 ** tt + tt :=
```

```
ycs [ i ] ycsav - 2 ** ss + ss :=
x [ i ] xav - 2 ** rr + rr :=
yam [ i ] yamav -
x [ i ] xav - * qq + qq :=
ycs [ i ] ycsav -
x [ i ] xav - * pp + pp :=
loop
qq 2 ** qq :=
pp 2 ** pp :=
tt qq rr / - 23 / rr / varuwam :=
ss pp rr / - 23 / rr / varuwcs :=
screen.clear
." Linear relations:" cr cr
." Ln( Am count rate ) = " am.coef [ 1 ] . ." x + "
am.coef [ 2 ] . cr
." Volumetric attenuation coefficient: "
am.coef [ 1 ] abs . " /cm" cr
-1 10 fix.format
." Variance: " varuwam . cr cr
-1 6 fix.format
." Ln( Cs count rate ) = " cs.coef [ 1 ] . ." x + "
cs.coef [ 2 ] . cr
." Volumetric attenuation coefficient: "
cs.coef [ 1 ] abs . " /cm" cr
-1 10 fix.format
." Variance: " varuwcs . cr cr
." Write this information down." cr cr
." Press any key when ready to proceed." s ;

\ ************************************************************
\
\ Initialization of the plotter
\
\ ************************************************************

: plotter
." Use only quality paper to plot graphs." cr
." Make sure error indicator is off." cr
." Press any key when plotter is ready to plot data." s
hp7475
device.init
7.8 10.15 plotter.size
normal.coords ;

\ ************************************************************
\
\ This colon definition contains the statements
\ necessary to plot the two linear relations in one graph.
\
\ ************************************************************

: graph
```

```
." Enter information on the tested solution" cr
." that has to appear on the graph." cr
." ( maximum 20 characters )" cr cr
"input information ":= p
horizontal grid.off no.labels label.scale.off
vertical grid.off no.labels label.scale.off
.25 .25 axis.orig
.54 .7 axis.size
normal.coords
.25 .25 axis.point
1. 1. tick.just
.01 .01 tick.size
6 3 axis.divisions
.0 dumx [ 1 ] :=
5.99 dumx [ 2 ] :=
7. dumy [ 1 ] :=
9.99 dumy [ 2 ] :=
"  " symbol dumx dumy xy.auto.plot
" +" symbol
x yam xy.data.plot
solid
62 ramp 1 - 10 / dup
am.coef poly[x] xy.data.plot
" *" symbol
x ycs xy.data.plot
.02 .02 .02 .02 dashed
62 ramp 1 - 10 / dup
cs.coef poly[x] xy.data.plot
normal.coords
.217 .25 position " 7.0" centered.label
.217 .483 position " 8.0" centered.label
.217 .717 position " 9.0" centered.label
.203 .95 position " 10.0" centered.label
.25 .223 position " 0.0" centered.label
.43 .223 position " 2.0" centered.label
.61 .223 position " 4.0" centered.label
.79 .223 position " 6.0" centered.label
normal.coords
.52 .97 position information centered.label
.7 .9 position " Am (solid line):" label
-1 5 fix.format
.7 .86 position
" y=" am.coef [ 1 ] "." "cat " x +" "cat
am.coef [ 2 ] "." "cat label
.7 .82 position
" r =" rsquaredam "cat label
.7 .78 position " Cs (dashed line):" label
.7 .74 position
" y=" cs.coef [ 1 ] "." "cat " x +" "cat
cs.coef [ 2 ] "." "cat label
.7 .70 position
" r =" rsquaredcs "cat label
```

```
90 label.dir
normal.coords
.152 .6 position " LN ( count rate )" centered.label
0 label.dir
normal.coords
.52 .18 position " PATH LENGTH THROUGH FILLED"
"   COMPARTMENTS (CM)" "cat centered.label
.25 .125 position
" RELATION BETWEEN PATH LENGTH THROUGH A SOLUTION"
label
.25 .1 position
" AND THE NATURAL LOG OF THE CORRECTED COUNT RATES."
label
.25 .075 position
" THE ABSOLUTE VALUE OF THE SLOPE IS THE"
label
.25 .05 position
" VOLUMETRIC ATTENUATION COEFFICIENT."
label
.008 .015 char.size
normal.coords
.713 .835 position " 2" label
.713 .715 position " 2" label ;

: graph.tce
." Enter information on the tested solution" cr
." that has to appear on the graph." cr
." ( maximum 20 characters )" cr cr
"input information ":= p
horizontal grid.off no.labels label.scale.off
vertical grid.off no.labels label.scale.off
.25 .25 axis.orig
.54 .7 axis.size
normal.coords
.25 .25 axis.point
1. 1. tick.just
.01 .01 tick.size
4 5 axis.divisions
.0 dumx [ 1 ] :=
7.99 dumx [ 2 ] :=
5. dumy [ 1 ] :=
9.99 dumy [ 2 ] :=
"   " symbol dumx dumy xy.auto.plot
" +" symbol
x yam xy.data.plot
solid
82 ramp 1 - 10 / dup
am.coef poly[x] xy.data.plot
" *" symbol
x ycs xy.data.plot
.02 .02 .02 .02 dashed
82 ramp 1 - 10 / dup
```

```
cs.coef poly[x] xy.data.plot
normal.coords
.217 .25 position " 5.0" centered.label
.217 .39 position " 6.0" centered.label
.217 .53 position " 7.0" centered.label
.217 .67 position " 8.0" centered.label
.217 .81 position " 9.0" centered.label
.203 .95 position " 10.0" centered.label
.25 .223 position " 0.0" centered.label
.385 .223 position " 2.0" centered.label
.52 .223 position " 4.0" centered.label
.655 .223 position " 6.0" centered.label
.79 .223 position " 8.0" centered.label
normal.coords
.52 .97 position information centered.label
.7 .9 position " Am (solid line):" label
-1 5 fix.format
.7 .86 position
" y=" am.coef [ 1 ] "." "cat " x +" "cat
am.coef [ 2 ] "." "cat label
.7 .82 position
" r =" rsquaredam "cat label
.7 .78 position " Cs (dashed line):" label
.7 .74 position
" y=" cs.coef [ 1 ] "." "cat " x +" "cat
cs.coef [ 2 ] "." "cat label
.7 .70 position
" r =" rsquaredcs "cat label
90 label.dir
normal.coords
.152 .6 position " LN ( COUNT RATE )" centered.label
0 label.dir
normal.coords
.52 .18 position " PATH LENGTH THROUGH FILLED"
"  COMPARTMENTS (CM)" "cat centered.label
.25 .125 position
" RELATION BETWEEN PATH LENGTH THROUGH A NAPL"
label
.25 .1 position
" AND THE NATURAL LOG OF THE CORRECTED COUNT RATES."
label
.25 .075 position
" THE ABSOLUTE VALUE OF THE SLOPE IS THE"
label
.25 .05 position
" VOLUMETRIC ATTENUATION COEFFICIENT."
label
.008 .015 char.size
normal.coords
.713 .835 position " 2" label
.713 .715 position " 2" label ;
```

```
\ *******************************************************
\
\ The main program.
\ After this program is loaded into the right Asyst
\ environment, entering 'determination.attenuation.coef'
\ will run the program.
\
\ *******************************************************

: determination.attenuation.coef p
init
day.determination
instructions p
." Enter 'y' if you want to use the Plexiglass" cr
." compartmental cell." cr cr
"input p
" y" "=
if
measurement
regression p
." Enter 'y' if you want to plot the relation" cr
." Enter 'n' if you want to quit" cr
"input  p
" y" "=
if
plotter
graph
then
" y" "=
if
plotter
graph
else
quit
then
else
measurement.tce
regression p
." Enter 'y' if you want to plot the relation" cr
." Enter 'n' if you want to quit" cr
"input  p
" y" "=
if
plotter
graph.tce
then
" y" "=
if
plotter
graph.tce
else
quit
```

```
then
then ;
```

```
\ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ PROGRAM SAT5A.TXT
\
\ Calibration program 5a
\
\ This program determines, together with program 5b,
\ mass attenuation coefficients of soils by using a cell
\ with 4 compartments.
\ Program 5a takes care of the data acquisition and
\ correction of the raw data for dead time and
\ Compton scattering. Before executing program 5b,
\ which carries out the linear regression anlysis,
\ the volumetric water content and the bulk density
\ of each of the four compartments must be determined
\ gravimetrically.
\
\ Before starting the determination, all compartments
\ of the cell must be filled with soil. Count rates
\ on 5 different positions will subsequently be obtained
\ on the cell with 4, 3, 2, 1, and 0 compartments filled.
\ This results in 25 data pairs for each source (Am and
\ Cs).
\
\ Minimum ASYST overlay requirements on custom version:
\ gpib master
\ type 1 nec gpib drive
\ data files
\
\ At the C:\ prompt, enter c:\asyst\total in order to get
\ into a correct ASYST environment. Then enter
\ load c:\asyst\sat5a.txt. To run the program, enter
\ count.rate.acquisition.
\
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\
\ M.Oostrom
\
\ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

\ ******************************************************************
\
\ variable declaration
\
\ ******************************************************************

dp.integer scalar l
real scalar a
real scalar b
real scalar r
real scalar q
\ The coefficients of the linear relation
```

```
\ between  the integral count rates via the NC-22 and
\ the TC 450 are a and b.
\ (calibration program 2)
\ The coefficients r and q determine the linear relation
\ between the high energy Cs count rate and the Cs
\ Compton scattering in the Am-window.
\ (calibration program 3)
real scalar ratenc
\ Raw integral Am count rate measured via the NC-22
real scalar ratetc
\ Raw differential Am count rate measured via the TC 450
real scalar ratena
\ Raw integral Cs count rate measured via the NA-22
real dim[ 25 ] array yam
\ Natural log values of the corrected Am count rates of
\ the twenty five measurements
real dim[ 25 ] array ycs
\ Natural log values of the corrected Cs count rates of
\ the twenty five measurements
real scalar counting.time
\ Counting time entered by the user
real scalar t
\ Counting time send over from buffer to computer
real scalar rateam
\ Dead time and compton scattering corrected Am count rate
real scalar ratecs
\ Dead time corrected Cs count rate
72 string s1
\ String with the counting time and total counts stored in
\ the buffered interface and send over to the computer
2 gpib.device gamma
\ The buffered interface is named gamma
real dim[ 2 ] array am.coef
\ Coefficients of the linear relation to be determined
\ for Am
real dim[ 2 ] array cs.coef
\ Coefficients of the linear relation to be determined
\ for Cs
72 string namefile
\ String containing the path and name of data file
\ with natural log values of corrected Am and Cs count
\ rates.
3 gpib.device motor
\ The Aston 800 is named motor
9 gpib.device hp3497
\ The HP 3497 is named hp3497.
integer scalar number.days
\ The number of calender days the program is running.
integer scalar day
integer scalar days
\ Day of the month.
dp.integer scalar extra
```

```
integer scalar sec
integer scalar min
integer scalar hours
integer scalar month
dp.integer time0
72 string s2
\ The time string 'month:day:hour:min:sec' is read from
\ the hp3497.


\ *******************************************************
\
\ The colon definition 's' is used after the prompt
\ 'Press any key when ready'. The 'p' macro clears the
\ screen and moves the cursor to the middle of the screen.
\ Macro 's' does the same after the user has pressed a key.
\
\ *******************************************************

: s
pckey drop ?drop screen.clear 10 1 do cr loop ;


: p
screen.clear 10 1 do cr loop ;


\ *******************************************************
\
\ The colon definition 'interface' takes care of the GPIB
\ connections.
\ In this program, the three GPIB devices are the buffered
\ interface, defined as 'gamma' ,the Aston 800, defined
\ as 'motor', and the HP3497, defined as 'hp3497'.
\ The buffered interface requires a 'carriage return'
\ (ASCII character 13) as an EOS (end of string) character.
\ The Aston 800 and the HP3497 require a "cr.lf",
\ catenated with the rest of the string that is sent over
\ as an EOS. The HP3497 accepts capitals only.
\
\ *******************************************************

: interface
bus.init
send.interface.clear
remote.enable.on
gamma eos.on
13 eos.character ;


\ *******************************************************
\
\ The Aston800 actuator is polled frequently when the
\ system moves from one location to the other. The moment
\ the sources and detector arrive at a new location, the
\ actuator should return the value 16 to the computer. The
```

```
\ next statement of a program can then be executed. For no
\ apparent reason, the actuator does not return the value 16
\ after the system has travelled. To avoid a complete crash
\ of a program, a routine should be inserted that takes over
\ the task of the actuator by producing a 16 after a certain
\ time lapse. The colon definitions 'day.determination' and
\ 'time.fetch' are part of this special routine. This
\ routine is part of the 'aston800.status.check' colon
\ definition.
\
\ *****************************************************

: day.determination
1 number.days :=
0 extra :=
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
3 1 do
ascii : "number ?drop
loop
"drop
day :=
month :=
untalk unlisten ;

: time.fetch
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
5 1 do
ascii : "number ?drop
loop
32 "number
?drop "drop .
sec :=
min :=
hours :=
days :=
month :=
days day =
if
else
number.days 1 + number.days :=
days day :=
number.days 1 - 86400 *
extra :=
then
```

```
hours 3600 * min 60 * + sec + extra +
untalk unlisten ;

\ *****************************************************
\
\ Before the actual measurements can take place, the user has
\ to check a number of connections and settings. He also has
\ to enter coefficients of relations determined in previous
\ calibration programs.
\
\ *****************************************************

: instructions
." Preset timer to '1,1'" cr cr
." Press any key when ready." s
." Check the following connections with the multiscaler:" cr
." NA-22 integral output to channel A,pos;" cr
." TC 450 norm mode output to channel B,pos;" cr
." NC-22 integral output to channel C,pos." cr cr
." Press any key when ready." s
." Check E and delta E settings of the " cr
." single channel analyzers and the NA-22." cr cr
." Press any key when ready." s
." Turn power to NH85 off." cr
." (to the right of buffered interface TC 589)" cr
cr ." Press any key when ready." s
." Set stop/count button of TC 535P on 'count' and" cr
." set .01 min/.1 sec button on '.1 sec'." cr
." The .1 sec is the 'timebase' of the counting time."
cr cr ." Press any key when ready." s
." Make sure the readout mode of the buffered inter-" cr
." face is on auto recycle and that the output " cr
." format is on normal." cr cr
." Press any key when ready." s
." The coefficients of the linear relation (y=ax+b)" cr
." between the integral Am count rate via the NC-22" cr
." (x) and via the TC 450 (y) must be entered." cr cr
-1 6 fix.format
." Enter a:" cr
#input a := cr
." Enter b:" cr
#input b := p
." Make sure power to the stepper motor indices is on." cr
." System must be able to move freely. Check this." cr cr
." Press any key when ready." s
." The coefficients of the linear relation (y=rx+q)" cr
." between the high energy Cs count rate (x) and the" cr
." Compton scattering in the Am-window (y) must be" cr
." entered." cr cr
." Enter r:" cr
#input r := cr
." Enter q:" cr
```

```
#input q := p
." Turn power of NH85 on." cr
." Wait till 'Fn' appears on display Aston 800." cr cr
." Press any key when ready." s
interface
untalk unlisten
gamma listener me talker
18 ASCII" 3 ASCII" "CAT TALK
." Preset timer (minimum 300 sec)." cr
." Timer formula: timebase*n*10**m." cr
." If you want a counting time of 300 sec, set the timer" cr
." to '3,3'." cr cr
." Press any key when ready." s
." Set CH A PRESET to '96'. " cr cr
." Press any key when ready." s
." Enter counting time in seconds (enter as a real)." cr
#input 1000 * counting.time := p
stack.clear ;


\  ******************************************************
\
\ The following colon definition performs a status test of the
\ Aston 800. The serial poll check gives information on the
\ status of the actuator and the connected stepper motors.
\ When the actuator returns the value 16, the system has
\ arrived at its destination. The next command of the
\ program can then be executed.
\
\  ******************************************************


: aston800.status.check
untalk unlisten
time.fetch time0 :=
begin
stack.clear
time.fetch
time0 -
60 >
if
16 16
else
1
then
16 =
if
16 =
else
serial.poll.enable
me listener motor talker
stack.listen
serial.poll.disable
16 =
```

```
then
until
untalk unlisten
;


\ ***********************************************************
\
\ A file template is made up for file maintenance. The data
\ file will contain two subfiles, each with a storage
\ capacity of a 25 element array.
\ The name of the file is assigned to the string 'namefile'.
\ The 'file.create' word creates a file according to the
\ latest 'file.template'.
\
\ ***********************************************************

: specifications.file
file.template
real dim[ 25 ] subfile
2 times
end
." Enter name of data file (including path)." cr
"input namefile ":=
namefile defer> file.create
p
;


\ ***********************************************************
\
\ The determination of the attenuation coefficient is done
\ with a four-compartment Plexiglas calibration cell.
\ First, the count rate through the cell with all
\ compartments filled with soil is determined. These
\ count rates are obtained five times at different positions.
\ Source and detector are moved to the new positions under
\ computer control. This procedure is repeated four more
\ times, each time the user is prompted to empty one of the
\ compartments into a moisture can.
\ The corrected count rates are stored in a data
\ file. This data file will be used in program 5b to
\ determine the attenuation coefficient of the soil.
\
\ ***********************************************************

: measurement
26 1 :=
6 1 do
i 1 =
if
." Place the calibration cell between sources and detector."
cr
." All 4 compartments have to be filled with soil." cr
```

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```
." Have four moisture cans ready." cr cr
." Press any key when ready." s
." The radiation should go through compartment 1 first."
 cr
." Make sure the long side of the calibration cell" cr
." is parallel to the radiation beam." cr cr
." Press any key when ready for measurement." s
else
." Some action is required after the tune!" cr
10000 1000 tune
p
." Empty compartment " 6 i - . ." into a moisture can,"
cr ." and return Plexiglas cell." cr cr
." Press any key when ready for next measurement." s
then
6 1 do
1 1 - 1 :=
i 1 =
if
motor listener me talker
" sm0,za" "cr.lf" "cat talk 50 msec.delay
" sm0,zp" "cr.lf" "cat talk 50 msec.delay
" sm1,za" "cr.lf" "cat talk 50 msec.delay
" sm1,zp" "cr.lf" "cat talk 50 msec.delay
2500 msec.delay
then
i 2 =
if
motor listener me talker
" sm1,mr+000500" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
i 3 =
if
motor listener me talker
" sm1,mr-001000" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
i 4 =
if
motor listener me talker
" sm1,mr+000600" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
motor listener me talker
2500 msec.delay
" sm1,mr-000100" "cr.lf" "cat talk
50 msec.delay
```

```
aston800.status.check
motor listener me talker
2500 msec.delay
" sm0,mr+000500" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
motor listener me talker
2500 msec.delay
then
i 5 =
if
motor listener me talker
" sm0,mr-001000" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
then
." Measurement " i . ." (out of 5) for this set up" cr
gamma listener me talker
27 ASCII" TALK
\ This command starts the scalers and the timer.
counting.time 2000 + msec.delay
gamma listener me talker
" P" 3 ASCII" "CAT TALK
\ This command transfers the data string with the
\ information on counts and time from the multiscalar
\ to the buffered interface.
4 1 do
gamma s1 gpib.read
loop
\ The previous loop transfers the data string
\ from the buffer to the computer.
\ The next loop converts the data string into the counts and
\ counting time.
s1
5 1 do
32 "number ?drop
loop
ratenc :=
ratetc :=
ratena :=
t :=
"drop
\ The raw data are corrected for dead time. The Am count
\ rate is also corrected for low energy Cs in the Am window.
ratetc t / 10. *
ratenc t / 10. * a * b + .0000006 * 1. - / abs
rateam :=
ratena t / 10. * dup
.00000167 * 1. - abs /
dup ratecs :=
r * q + rateam swap - rateam :=
```

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```
ratecs ln ycs [ 1 ] :=
rateam ln yam [ 1 ] :=
p
i 5 =
if
motor listener me talker
" sm0,mr+000600" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
motor listener me talker
" sm0,mr-000100" "cr.lf" "cat talk
50 msec.delay
aston800.status.check
2500 msec.delay
motor listener me talker
then
loop
loop
namefile defer> file.open
1 subfile
ycs array>file
2 subfile
yam array>file
file.close ;


\ ********************************************************
\
\ The main program.
\ After this program is loaded into the right ASYST
\ environment, entering 'count.rate.acquisition'
\ will run the program.
\
\ ********************************************************

: count.rate.acquisition p
interface
day.determination
instructions
specifications.file
measurement p
." Array of corrected Cs count rates:" cr
." (count rates through empty cell first)" cr cr
ycs exp . cr
." Press any key to continue." s
." Array of corrected Am count rates:" cr
." (count rates through empty cell first)" cr cr
yam exp .
;
```

```
\ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ PROGRAM SAT5B.TXT
\
\ Calibration program 5b
\
\ This program determines, together with program 5a,
\ mass attenuation coefficients of soils.
\ In program 5a, the corrected count rates through the
\ compartmental cell are acquired. In program 5b, the
\ values of the volumetric water contents and dry bulk
\ densities of the four compartments are entered.
\ These data are necessary to calculate the mass
\ attenuation coefficient of the soil. The absolute
\ value of the slope, obtained with a linear regression,
\ equals the mass attenuation coefficient of the soil.
\ Finally, the variances of the mass attenuation
\ coefficients are calculated.
\
\ Minimum ASYST overlay requirements on custom version:
\ data files
\ statistics and special functions
\ polynomial functions
\ matrix and curve fit functions.
\
\ At the c:\ prompt enter c:\asyst\total. The custom version
\ 'total' contains the overlays specified above.
\ Load this program by entering load c:\asyst\sat5b.txt.
\ To run the program, enter soil.att.calculation.
\
\ 09/20/89
\
\ M.Oostrom
\
\ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

\ ***********************************************************
\
\ variable declaration
\
\ ***********************************************************

dp.real scalar uwam
dp.real scalar uwcs
\ The products of the mass attenuation coefficients and
\ the density of deionized water.
\ ( Am and Cs, respectively)
dp.real scalar v
\ The sum of the products of the dry bulk density and the
\ travel distance through the soil filled compartments.
dp.real scalar z
\ The sum of the products of the volumetric water content
```

```
\ and the travel distance through the soil filled
\ compartments.
real dim[ 25 ] array x
\ Array containing the sum of the products of the dry bulk
\ density and the travel distance through the soil filled
\ compartments.
real dim[ 25 ] array ycs
real dim[ 25 ] array yam
\ Arrays containing the natural log values of the corrected
\ count rates, obtained in program 5a. In this program the
\ product of the mass attenuation coefficient, density of
\ water and z are added to do the linear regression.
\ ( Cs and Am, respectively ).
real scalar yamav
real scalar ycsav
\ The average of the arrays yam and ycs, respectively.
real scalar xav
\ The average of the array x.
real scalar varusam
real scalar varuscs
\ The variance of the mass attenuation coefficients.
\ (Am and Cs, respectively)
real scalar p
real scalar q
real scalar r
real scalar s
real scalar t
\ The temporary variables p,q,r,s and t are used during the
\ calculation of the variances.
real dim[ 4 ] array y
\ Travel distance through a compartment.
real dim[ 4 ] array bulk
\ The dry bulk densities of the compartments.
real dim[ 4 ] array theta
\ The volumetric water contents of the compartments.
72 string namefile
\ Name of data file (including path) used in 5a.
real dim[ 2 ] array am.coef
real dim[ 2 ] array cs.coef
\ Coefficients of the regression relation for Am and
\ Cs, respectively.


\ ***********************************************************
\
\ Initialization of the variables.
\
\ ***********************************************************

: initialization
." Enter the product of the mass attenuation coefficient"
cr ." and the density of deionized water, for Am:" cr
#input uwam := screen.clear 10 1 do cr loop
```

```
." Enter the product of the mass attenuation coefficient"
cr ." and the density of deionized water, for Cs:" cr
#input uwcs := screen.clear 10 1 do cr loop
5 1 do
." Enter dry bulk density of compartment " i . cr
#input bulk [ i ] := screen.clear 10 1 do cr loop
." Enter volumetric water content of compartment " i . cr
#input theta [ i ] := screen.clear 10 1 do cr loop
loop
0. x :=
0. z :=
0. v :=
1.505 y [ 1 ] :=
1.47 y [ 2 ] :=
1.47 y [ 3 ] :=
1.505 y [ 4 ] :=
;

\ ***********************************************************
\
\ In the following colon definition, the data file with the
\ corrected count rates (program 5a) is retrieved. The 2
\ subfiles are assigned to the arrays ycs and yam,
\ respectively.
\
\ ***********************************************************

: retrieve.file
." Enter name of data file (including path)," cr
." containing the corrected count rates." cr
." This data file was created with program 5a."
cr "input namefile ":= screen.clear 10 1 do cr loop
namefile defer> file.open
1 subfile
ycs file>array
2 subfile
yam file>array
file.close
;

\ ***********************************************************
\
\ The arrays ycs, yam, and x are adapted according to the
\ volumetric water contents and dry bulk densities
\ of the soil in the four compartments.
\ The changed arrays are stored in the same data file.
\
\ ***********************************************************

: change.arrays
y [ 1 ] bulk [ 1 ] * v + v :=
theta [ 1 ] y [ 1 ] * z + z :=
```

```
11 6 do
v x [ i ] :=
uwcs z * ycs [ i ] + ycs [ i ] :=
uwam z * yam [ i ] + yam [ i ] :=
loop
y [ 2 ] bulk [ 2 ] * v + v :=
theta [ 2 ] y [ 2 ] * z + z :=
16 11 do
v x [ i ] :=
uwcs z * ycs [ i ] + ycs [ i ] :=
uwam z * yam [ i ] + yam [ i ] :=
loop
y [ 3 ] bulk [ 3 ] * v + v :=
theta [ 3 ] y [ 3 ] * z + z :=
21 16 do
v x [ i ] :=
uwcs z * ycs [ i ] + ycs [ i ] :=
uwam z * yam [ i ] + yam [ i ] :=
loop
y [ 4 ] bulk [ 4 ] * v + v :=
theta [ 4 ] y [ 4 ] * z + z :=
26 21 do
v x [ i ] :=
uwcs z * ycs [ i ] + ycs [ i ] :=
uwam z * yam [ i ] + yam [ i ] :=
loop
namefile defer> file.open
1 subfile
ycs array>file
2 subfile
yam array>file
file.close
;

\ ***************************************************
\
\ The following colon definition calculates the mass
\ attenuation coefficients. The absolute values of the
\ slope of the linear relation between x and ycs or yam
\ are the mass attenuation coefficients of the soil
\ for Cs and Am, respectively.
\ The r² of the relations and the variance of the mass
\ attenuation coefficients are also determined.
\
\ ***************************************************

: regression
\ Determination of the regression coefficients.
-1 6 fix.format
x yam 1 leastsq.poly.fit
[ 1 ] am.coef [ 1 ] :=
x yam 1 leastsq.poly.fit
```

```
[ 2 ] am.coef [ 2 ] :=
x ycs 1 leastsq.poly.fit
[ 1 ] cs.coef [ 1 ] :=
x ycs 1 leastsq.poly.fit
[ 2 ] cs.coef [ 2 ] :=
\ Calculation of the variances.
0. yamav :=
0. ycsav :=
0. xav :=
26 1 do
yamav yam [ i ] + yamav :=
ycsav ycs [ i ] + ycsav :=
xav x [ i ] + xav :=
loop
yamav 25. / yamav :=
ycsav 25. / ycsav :=
xav 25. / xav :=
0. p :=
0. q :=
0. r :=
0. s :=
0. t :=
26 1 do
yam [ i ] yamav - 2 ** t + t :=
ycs [ i ] ycsav - 2 ** s + s :=
x [ i ] xav - 2 ** r + r :=
yam [ i ] yamav -
x [ i ] xav - * q + q :=
ycs [ i ] ycsav -
x [ i ] xav - * p + p :=
loop
q 2 ** q :=
p 2 ** p :=
t q r / - 23 / r / varusam :=
s p r / - 23 / r / varuscs :=
\ Determination of r squared and print out on screen.
am.coef [ 1 ] abs
screen.clear
." Am mass attenuation coefficient: " .
cr
yam
x am.coef poly[x]
2 regress.anova
[ 1 , 5 ]
." r squared of linear relation: " . cr
-1 10 fix.format varusam
." Variance of mass attenuation coefficient: " . cr cr
-1 6 fix.format cs.coef [ 1 ] abs
." Cs mass attenuation coefficient: " .
cr
ycs
x cs.coef poly[x]
```

```
2 regress.anova
[ 1 , 5 ]
." r squared of linear relation: " . cr
-1 10 fix.format varuscs
." Variance of mass attenuation coeffient: " . cr
." Write this information down."
-1 6 fix.format
;


\ *******************************************************
\
\ The main program.
\ After this program is loaded into the right ASYST
\ environment, entering 'soil.att.calculation' will run
\ the program.
\
\ *******************************************************

: soil.att.calculation
screen.clear 10 1 do cr loop
initialization
retrieve.file
change.arrays
regression
;
```

```
\ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ PROGRAM X.TXT
\
\ Calibration program 6
\
\ This program determines the path lengths (x) at
\ positions along a vertical column where measurements
\ will be taken during an experiment.
\ Count rate determinations are done five times at a
\ maximum of 15 locations along the empty and water-filled
\ column. The locations are evenly spaced.
\ The average count rates through the empty column are
\ stored for future use.
\ An overshooting technique is used to overcome the
\ hysteresis of the stepper motors and to assure that the
\ locations where the measurements are taken are the
\ same for each loop.
\
\ Minimum ASYST overlay requirements on custom version:
\ gpib master
\ type 1 nec gpib drive
\ data files
\
\ At the C:\ prompt, enter c:\asyst\total in order to get
\ into a correct ASYST environment. Then enter
\ load c:\asyst\x.txt. To run the program, enter
\ path.length.determination.
\
\ 09/22/89
\
\ M.Oostrom
\
\ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

\ ***************************************************************
\
\ variable declaration
\
\ ***************************************************************

integer scalar l
integer scalar k
integer scalar m
integer scalar n
\ l,k and m are counters in loops
real scalar a
real scalar b
real scalar r
real scalar q
\ The coefficients of the linear relation
\ between  the integral count rates via the NC-22 and
```

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```
\ the TC 450 are a and b.
\ (calibration program 2)
\ The coefficients r and q determine the linear relation
\ between the high energy Cs count rate and the Cs
\ Compton scattering in the Am-window.
\ (calibration program 3)
real scalar ratenc
\ Raw integral Am count rate measured via the NC-22
real scalar ratetc
\ Raw differential Am count rate measured via the TC 450
real scalar ratena
\ Raw integral Cs count rate measured via the NA-22
real dim[ 75 ] array yam.empty
real dim[ 75 ] array yam.filled
\ Natural log values of the corrected Am count rates
\ (with a maximum of 75) for the empty and filled
\ column, respectively.
real dim[ 75 ] array ycs.empty
real dim[ 75 ] array ycs.filled
\ Natural log values of the corrected Cs count rates
\ (with a maximum of 75) for the empty and filled
\ column, respectively.
dp.integer scalar counting.time
\ Counting time entered by the user
real scalar t
\ Counting time sent over from buffer to computer
real scalar rateam
\ Dead time and Compton scattering corrected Am count rate
real scalar ratecs
\ Dead time corrected Cs count rate
72 string s1
\ String with the counting time and total counts stored in
\ the buffered interface and send over to the computer
2 gpib.device gamma
\ The buffered interface is named gamma
72 string namefile
\ String consisting of the path and name of a data file.
\ This data file will contain the natural log values
\ of the corrected count rates through the empty column
\ at the specified locations, the calculated path lengths
\ and the dry bulk densities. The dry bulk densities will
\ be determined in calibration program 7.
real dim[ 15 ] array path.length.am
real dim[ 15 ] array path.length.cs
\ Arrays with the calculated path lengths at a maximum
\ of fifteen locations along the column.
real dim[ 15 ] array am.empty
real dim[ 15 ] array cs.empty
\ Arrays containing the average corrected count rates
\ through the empty column. (Am and Cs, respectively)
real dim[ 15 ] array am.filled
real dim[ 15 ] array cs.filled
```

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```
\ Arrays containing the average corrected count rates
\ through the water filled column. (Am and Cs, resp.)
3 gpib.device motor
\ The Aston 800 is named motor.
9 gpib.device hp3497
\ The HP 3497 is named hp3497.
integer scalar number.days
\ The number of calender days the program is running.
integer scalar day
integer scalar days
\ Day of the month.
dp.integer scalar extra
integer scalar sec
integer scalar min
integer scalar hours
integer scalar month
dp.integer time0
72 string s2
\ The time string 'month:day:hour:min:sec' is read from
\ the hp3497.
dp.real scalar uwam
dp.real scalar uwcs
\ Product of mass attenuation coefficient and density of
\ deionized water. (Am and Cs, respectively)
integer scalar step.size
\ Step size between two locations. All locations are
\ evenly spaced.
6 string step.size2
\ Step between two locations expressed as a six letter
\ string
6 string step.size3
\ Step used in overshooting procedure
integer scalar number.locations
\ Total number of locations.


\ ********************************************************
\
\ The Aston800 actuator is polled frequently when the
\ system moves from one location to the other. The moment
\ the sources and detector arrive at a new location, the
\ actuator should return the value 16 to the computer. The
\ next statement of a program can then be executed. For no
\ apparent reason, the actuator does not return the value 16
\ after the system has travelled. To avoid a complete crash
\ of a program, a routine should be inserted that takes over
\ the task of the actuator by producing a 16 after a certain
\ time lapse. The colon definitions 'day.determination' and
\ 'time.fetch' are part of this special routine. This
\ routine is part of the 'aston800.status.check' colon
\ definition.
\
\ ********************************************************
```

```
: day.determination
1 number.days :=
0 extra :=
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
3 1 do
ascii : "number ?drop
loop
"drop
day :=
month :=
untalk unlisten ;

: time.fetch
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
5 1 do
ascii : "number ?drop
loop
32 "number
?drop "drop
sec :=
min :=
hours :=
days :=
month :=
days day =
if
else
number.days 1 + number.days :=
days day :=
number.days 1 - 86400 *
extra :=
then
hours 3600 * min 60 * + sec + extra +
untalk unlisten ;

\ **********************************************************
\
\ The colon definition 's' is used after the prompt
\ 'Press any key when ready'. The 'p' macro clears the
\ screen and moves the cursor to the middle of the screen.
\ Macro 's' does the same after the user has pressed a key.
\
\ **********************************************************
```

```
: s
pckey drop ?drop screen.clear 10 1 do cr loop ;

: p
screen.clear 10 1 do cr loop ;

\ **********************************************************
\
\ The colon definition 'interface' takes care of the GPIB
\ connections.
\ In this program, the three GPIB devices are the buffered
\ interface, defined as 'gamma' ,the Aston 800, defined
\ as 'motor', and the HP3497, defined as 'hp3497'.
\ The buffered interface requires a 'carriage return'
\ (ASCII character 13) as an EOS (end of string) character.
\ The Aston 800 and the HP3497 require a "cr.lf",
\ catenated with the rest of the string that is send over
\ as an EOS. The HP3497 accepts capitals only.
\
\ **********************************************************

: interface
bus.init
send.interface.clear
remote.enable.on
gamma eos.on
13 eos.character ;

\ **********************************************************
\
\ Before the actual measurements can take place, the user has
\ to check a number of connections and settings. He also has
\ to enter coefficients of relations determined in previous
\ calibration programs.
\
\ **********************************************************

: instructions
." Preset timer to '1,1'" cr cr
." Press any key when ready." s
." Check the following connections with the multiscaler:" cr
." NA-22 integral output to channel A,pos;" cr
." TC 450 norm mode output to channel B,pos;" cr
." NC-22 integral output to channel C,pos." cr cr
." Press any key when ready." s
." Check E and delta E settings of the " cr
." single channel analyzers and the NA-22." cr cr
." Press any key when ready." s
." Turn power to NH85 (next to buffered interface) off." cr
cr ." Press any key when ready." s
." Move sources and detector manually to the first location"
cr
```

```
." where you want to know the path length. This point" cr
." has to be the highest of all locations." cr cr
." Press any key when ready." s
." Write down the coordinates of this location." cr cr
." Press any key when ready." s
." Determine the step size between two locations." cr cr
." Press any key when ready." s
." The stepper motor indexers should be on external mode" cr
." before you can continue. " cr
." Both stepper motor indexers should read zero." cr cr
." Press any key when ready." s
." Set stop/count button of TC 535P on 'count' and" cr
." set .01 min/.1 sec button on '.1 sec'." cr cr
." Press any key when ready." s
." Make sure the readout mode of the buffered inter-" cr
." face is on auto recycle and that the output " cr
." format is on normal." cr cr
." Press any key when ready." s
." The coefficients of the linear relation (y=ax+b)" cr
." between the integral Am count rate via the NC-22" cr
." (x) and via the TC 450 (y) must be entered." cr cr
-1 6 fix.format
." Enter a:" cr
#input a := cr
." Enter b:" cr
#input b := p
." The coefficients of the linear relation (y=rx+q)" cr
." between the high energy Cs count rate (x) and the" cr
." Compton scattering in the Am-window (y) must be" cr
." entered." cr cr
." Enter r:" cr
#input r := cr
." Enter q:" cr
#input q := p
." Enter product of mass attenuation coefficient and" cr
." density of deionized water, for Am:" cr
#input uwam := p
." Enter product of mass attenuation coefficient and" cr
." density of deionized water, for Cs:" cr
#input uwcs := p
." Enter the # of steps between two locations:" cr
#input step.size := p
." Enter the number of steps again, but now as a six digit"
cr
." number with leading zero's. For instance, 1000" cr
." steps has to be entered as 001000." cr
"input step.size2 ":= p
." Multiply the # of steps between two locations" cr
." by (number of locations - 1) and add 1000." cr
." Enter this number as a six digit number" cr
." with leading zero's" cr cr
"input step.size3 ":= p
```

```
." Enter the total number of locations:" cr
." (maximum of 15)" cr
#input number.locations := p
." Place the empty column at exactly the same position" cr
." as during the actual experiment." cr
cr ." Press any key when ready." s
." System must be able to move freely. Check this." cr cr
." Press any key when ready." s
." Turn power of NH85 on." cr
." Wait till the Aston 800 actuator has performed" cr
." its self test. The letters 'Fn' appear when" cr
." when the self test has been completed." cr cr
." Press any key when ready." s
interface
untalk unlisten
gamma listener me talker
18 ASCII" 3 ASCII" "CAT TALK
." Preset timer (minimum 200 sec)." cr
." Timer formula: timebase*n*10**m." cr
." A counting time of 200 sec. is recommended." cr
." Set timer to '2,3' if you want a 200 sec." cr
." counting period." cr cr
." Press any key when ready." s
." Set CH A PRESET to '96'. " cr cr
." Press any key when ready." s
." Enter counting time in seconds (200 sec. minimum)." cr
#input 1000 * counting.time := p
stack.clear ;


\  ********************************************************
\
\ The following colon definition performs a status test of the
\ Aston 800. The serial poll check gives information on the
\ status of the actuator and the connected stepper motors.
\ When the actuator returns the value 16, the system has
\ arrived at its destination. The next command of the
\ program can then be executed.
\
\  ********************************************************

: aston800.status.check
untalk unlisten
time.fetch time0 :=
begin
stack.clear
time.fetch
time0 -
60 >
if
16 16
else
1
```

```
then
16 =
if
16 =
else
serial.poll.enable
me listener motor talker
stack.listen
serial.poll.disable
16 =
then
until
untalk unlisten
;


\ ***********************************************************
\
\ If the program execution is delayed (by using the word
\ msec.delay) past midnight, the program will crash. The
\ following colon definition will prevent this.
\
\ ***********************************************************

: no.crashes
86000000. rel.time <
if
begin
rel.time 500. <
until
then ;


\ ***********************************************************
\
\ A file template is made up for file maintenance. The data
\ file will contain six subfiles, each with a storage
\ capacity of a 15-element array.
\ The first subfile contains the natural log values of the
\ count rates through the empty column at the specified
\ locations for Am. The second subfile contains these data
\ for Cs.
\ The third subfile is used for path length storage,
\ determined with the Am source.
\ Subfile 4 contains the path lengths determined with Cs.
\ Subfile 5 will be used to store the dry bulk densities,
\ while subfile 6 will contain the volumetric water
\ contents, to be determined with calibration program 7.
\ The name of the file is assigned to the string 'namefile'.
\ The 'file.create' word creates a file according to the
\ latest 'file.template'.
\
\ ***********************************************************
```

```
: specifications.file
file.template
real dim[ 15 ] subfile
6 times
end
." Enter name of data file (including path)." cr
"input namefile ":=
namefile defer> file.create
p
;


\ ***********************************************************
\
\ Five measurements are done at each location for the
\ empty and deionized water filled column, respectively.
\
\ ***********************************************************

: measurement
0. ycs.filled :=
0. ycs.empty :=
0. yam.filled :=
0. yam.empty :=
0 k := 0 m := 0 n :=
3 1 do
0 l :=
i m :=
m 2 =
if
p ." Some action required after this tune!" cr
10000 1000 tune
p
." Fill column up with deionized water." cr
." It is better not to remove the column." cr
." If this is unavoidable, be sure the column is" cr
." replaced at exactly the same position." cr cr
." Press any key when ready." s
then
6 1 do
i k :=
number.locations 1 + 1 do
i n :=
l 1 + l :=
n 1 =
if
no.crashes
motor listener me talker
" sm0,za" "cr.lf" "cat talk
" sm0,zp" "cr.lf" "cat talk
2500 msec.delay
else
no.crashes
```

```
motor listener me talker
" sm0,mr+" step.size2 "cat "cr.lf" "cat talk
aston800.status.check
2500 msec.delay
then
." Loop " k . ." (out of 5)." cr
." Location " i . ." (out of " number.locations .
." )"  cr
gamma listener me talker
27 ASCII" TALK
\ This command starts the scalers and the timer.
counting.time 2000 + msec.delay
gamma listener me talker
" P" 3 ASCII" "CAT TALK
\ This command transfers the data string with the
\ information on counts and time from the multiscaler
\ to the buffered interface.
4 1 do
gamma s1 gpib.read
loop
\ The previous loop transfers the data string
\ from the buffer to the computer.
\ The next loop converts the data string into the counts and
\ counting time.
s1
5 1 do
32 "number ?drop
loop
ratenc :=
ratetc :=
ratena :=
t :=
"drop
\ The raw data are corrected for dead time. The Am count
\ rate is also corrected for low energy Cs in the Am window.
ratetc t / 10. *
ratenc t / 10. * a * b + .0000006 * 1. - / abs
rateam :=
ratena t / 10. * dup
.00000167 * 1. - abs /
dup ratecs :=
r * q + rateam swap - rateam :=
m 1 =
if
ratecs ln ycs.empty [ 1 ] :=
rateam ln yam.empty [ 1 ] :=
p
else
ratecs ln ycs.filled [ 1 ] :=
rateam ln yam.filled [ 1 ] :=
p
then
```

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```
n number.locations =
if
motor listener me talker
" sm0,mr-" step.size3 "cat "cr.lf" "cat talk
aston800.status.check
2500 msec.delay
motor listener me talker
" sm0,mr+001000" "cat "cr.lf" "cat talk
aston800.status.check
2500 msec.delay
then
loop
loop
loop
;


\ *******************************************************
\
\ In the colon definition 'calculations', the average count
\ rates through the empty column and the path lengths
\ at the specified locations are calculated. The data are
\ stored in a data file created with the colon definition
\ 'specifications.file'.
\
\ *******************************************************

: calculations
0. k := 0. m :=
0. am.empty :=
0. am.filled :=
0. cs.empty :=
0. cs.filled :=
0. path.length.am :=
0. path.length.cs :=
number.locations m :=
i 1 :=
m 1 + 1 do
yam.empty [ i ] i m + k := yam.empty [ k ] +
k m + k := yam.empty [ k ] +
k m + k := yam.empty [ k ] +
k m + k := yam.empty [ k ] + 5. /
am.empty [ i ] :=
ycs.empty [ i ] i m + k := ycs.empty [ k ] +
k m + k := ycs.empty [ k ] +
k m + k := ycs.empty [ k ] +
k m + k := ycs.empty [ k ] + 5. /
cs.empty [ i ] :=
yam.filled [ i ] i m + k := yam.filled [ k ] +
k m + k := yam.filled [ k ] +
k m + k := yam.filled [ k ] +
k m + k := yam.filled [ k ] + 5. /
am.filled [ i ] :=
```

```
ycs.filled [ i ] i m + k := ycs.filled [ k ] +
k m + k := ycs.filled [ k ] +
k m + k := ycs.filled [ k ] +
k m + k := ycs.filled [ k ] + 5. /
cs.filled [ i ] :=
loop
m 1 + 1 do
am.empty [ i ] am.filled [ i ] - uwam /
path.length.am [ i ] :=
cs.empty [ i ] cs.filled [ i ] - uwcs /
path.length.cs [ i ] :=
loop
screen.clear
." Path lengths determined with the Am source: " cr
." (upper location first)" cr cr
m 1 + 1 do
path.length.am [ i ] . cr
loop cr cr
." Write this information down!" cr cr
." Press any key if you want to continue." s screen.clear
." Path lengths determined with the Cs source: " cr
." (upper location first)" cr cr
m 1 + 1 do
path.length.cs [ i ] . cr
loop cr cr
namefile defer> file.open
1 subfile
am.empty array>file
2 subfile
cs.empty array>file
3 subfile
path.length.am array>file
4 subfile
path.length.cs array>file
file.close
;


\ *****************************************************
\
\ The main program.
\ After this program is loaded into the right ASYST
\ environment, entering 'path.length.determination'
\ will run the program.
\
\ *****************************************************

: path.length.determination p
interface
day.determination
instructions
specifications.file
measurement
```

calculations
;

```
\ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
\
\ PROGRAM BULK.TXT
\
\ Calibration program 7a
\
\ This program determines the dry bulk densities at the
\ same locations where the gamma measurements will be taken
\ during the experiments. The dry bulk density values
\ are determined on a water saturated soil.
\ An overshooting technique is used to overcome the
\ hysteresis of the stepper motors and to assure that the
\ locations where the measurements are taken are the
\ same for each loop.
\
\ Minimum ASYST overlay requirements on custom version:
\ gpib master
\ type 1 nec gpib drive
\ data files
\
\ At the C:\ prompt, enter c:\asyst\total to create
\ a correct ASYST environment. Then enter
\ load c:\asyst\bulk.txt. To run the program, enter
\ bulk.density.determination.
\
\ 09/26/89
\
\ M.Oostrom
\
\ +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

\ ****************************************************************
\
\ variable declaration
\
\ ****************************************************************

integer scalar l
integer scalar m
integer scalar k
integer scalar n
\ l,k,m and n are counters in loops
real scalar a
real scalar b
real scalar r
real scalar q
\ The coefficients of the linear relation
\ between the integral count rates via the NC-22 and
\ the TC 450 are a and b.
\ (calibration program 2)
\ The coefficients r and q determine the linear relation
\ between the high energy Cs count rate and the Cs
```

```
\ Compton scattering in the Am-window.
\ (calibration program 3)
real scalar ratenc
\ Raw integral Am count rate measured via the NC-22
real scalar ratetc
\ Raw differential Am count rate measured via the TC 450
real scalar ratena
\ Raw integral Cs count rate measured via the NA-22
dp.integer scalar counting.time
\ Counting time entered by the user
real scalar t
\ Counting time send over from buffer to computer
real scalar rateam
\ Dead time and compton scattering corrected Am count rate
real scalar ratecs
\ Dead time corrected Cs count rate
72 string s1
\ String with the counting time and total counts stored in
\ the buffered interface and send over to the computer
2 gpib.device gamma
\ The buffered interface is named gamma
72 string namefile
\ String consisting of the path and name of a data file.
\ This data file will contain the natural log values
\ of the corrected count rates through the empty column
\ at the specified locations, the calculated path lengths
\ and the dry bulk densities. The dry bulk densities are
\ determined in this program.
real dim[ 15 ] array bulk.density
\ The dry bulk density values at a maximum of 15 locations.
real dim[ 15 ] array bd
\ Average bulk density
real dim[ 15 ] array theta
\ The volumetric water contents at a maximum of 15
\ locations.
real dim[ 15 ] array th
\ Average theta
real dim[ 15 ] array path.length.am
real dim[ 15 ] array path.length.cs
\ Arrays with the calculated path lengths at a maximum
\ of 15 locations along the column. The path lengths are
\ determined in program 6 and stored in a data file.
real dim[ 15 ] array am.empty
real dim[ 15 ] array cs.empty
\ Arrays containing the average corrected count rates
\ through the empty column. (Am and Cs, respectively)
\ These data are also determined in program 6.
real dim[ 15 ] array am.filled
real dim[ 15 ] array cs.filled
\ Arrays containing the average corrected count rates
\ through the water saturated soil column. (Am and Cs, resp.)
3 gpib.device motor
```

```
\ The Aston 800 is named motor
dp.real scalar uwam
dp.real scalar uwcs
\ Volumetric attenuation coefficient of
\ deionized water. (Am and Cs, respectively)
dp.real scalar usam
dp.real scalar uscs
\ Soil mass attenuation coefficients. (Am and Cs,
\ respectively)
integer scalar step.size
\ Step size between two locations. All locations are
\ evenly spaced.
6 string step.size2
\ Number of steps between locations expressed as a
\ six letter string
6 string step.size3
\ String used in overshooting process
integer scalar number.locations
\ Total number of locations.
9 gpib.device hp3497
\ The HP 3497 is named hp3497.
integer scalar number.days
\ The number of calender days the program is running.
integer scalar day
integer scalar days
\ Day of the month.
dp.integer scalar extra
integer scalar sec
integer scalar min
integer scalar hours
integer scalar month
dp.integer scalar time0
72 string s2
\ The time string 'month:day:hour:min:sec' is read from
\ the hp3497.

\ *****************************************************
\
\ The colon definition 's' is used after the prompt
\ 'Press any key when ready'. The 'p' macro clears the
\ screen and moves the cursor to the middle of the screen.
\ Macro 's' does the same after the user has pressed a key.
\
\ *****************************************************

: s
pckey drop ?drop screen.clear 10 1 do cr loop ;

: p
screen.clear 10 1 do cr loop ;

\ *****************************************************
```

```
\
\ The colon definition 'interface' takes care of the GPIB
\ connections.
\ In this program the three GPIB devices are the buffered
\ interface, defined as 'gamma' ,the Aston 800, defined
\ as 'motor', and the HP3497, defined as 'hp3497'.
\ The buffered interface requires a 'carriage return'
\ (ASCII character 13) as an EOS (end of string) character.
\ The Aston 800 and the HP3497 require a "cr.lf",
\ catenated with the rest of the string that is send over
\ as an EOS. The HP3497 accepts capitals only.
\
\ ********************************************************

: interface
bus.init
send.interface.clear
remote.enable.on
gamma eos.on
13 eos.character ;


\ ***********************************************************
\
\ The Aston800 actuator is polled frequently when the
\ system moves from one location to the other. The moment
\ the sources and detector arrive at a new location, the
\ actuator should return the value 16 to the computer. The
\ next statement of a program can then be executed. For no
\ apparent reason, the actuator does not return the value 16
\ after the system has travelled. To avoid a complete crash
\ of a program, a routine should be inserted that takes over
\ the task of the actuator by producing a 16 after a certain
\ time lapse. The colon definitions 'day.determination' and
\ 'time.fetch' are part of this special routine. This
\ routine is part of the 'aston800.status.check' colon
\ definition.
\
\ *********************************************************

: day.determination
1 number.days :=
0 extra :=
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
3 1 do
ascii : "number ?drop
loop
"drop
day :=
```

```
month :=
untalk unlisten ;

: time.fetch
hp3497 listener me talker
" TD" "CR.LF" "CAT TALK
hp3497
s2 gpib.read
s2
5 1 do
ascii : "number ?drop
loop
32 "number
?drop "drop
sec :=
min :=
hours :=
days :=
month :=
days day =
if
else
number.days 1 + number.days :=
days day :=
number.days 1 - 86400 *
extra :=
then
hours 3600 * min 60 * + sec + extra +
untalk unlisten ;

\ *********************************************************
\
\ Before the actual measurements can take place, the user has
\ to check a number of connections and settings. He also has
\ to enter coefficients of relations determined in previous
\ calibration programs.
\
\ *********************************************************

: instructions
." Turn power to NH85 (next to buffered interface) off." cr
cr ." Press any key when ready." s
." Preset timer to '1,1'" cr cr
." Press any key when ready." s
." Check the following connections with the multiscaler:" cr
." NA-22 integral output to channel A,pos;" cr
." TC 450 norm mode output to channel B,pos;" cr
." NC-22 integral output to channel C,pos." cr cr
." Press any key when ready." s
." Check E and delta E settings of the " cr
." single channel analyzers and the NA-22." cr cr
." Press any key when ready." s
```

```
." Set stop/count button of TC 535P on 'count' and" cr
." set .01 min/.1 sec button on '.1 sec'." cr cr
." Press any key when ready." s
." Make sure the readout mode of the buffered inter-" cr
." face is on auto recycle and that the output " cr
." format is on normal." cr cr
." Press any key when ready." s
." The coefficients of the linear relation (y=ax+b)" cr
." between the integral Am count rate via the NC-22" cr
." (x) and via the TC 450 (y) must be entered." cr cr
-1 6 fix.format
." Enter a:" cr
#input a := cr
." Enter b:" cr
#input b := p
." The coefficients of the linear relation (y=rx+q)" cr
." between the high energy Cs count rate (x) and the" cr
." Compton scattering in the Am-window (y) must be" cr
." entered." cr cr
." Enter r:" cr
#input r := cr
." Enter q:" cr
#input q := p
." Enter volumetric attenuation coefficient" cr
." of deionized water, for Am:" cr
#input uwam := p
." Enter volumetric attenuation coefficient" cr
." of deionized water, for Cs:" cr
#input uwcs := p
." Enter Am soil mass attenuation coefficient:" cr
#input usam := p
." Enter Cs soil mass attenuation coefficient:" cr
#input uscs := p
." Enter the step size between two locations:" cr
#input step.size := p
." Enter the step size again, but now as a six digit" cr
." number with leading zero's. For instance, a step " cr
." size of 1000 has to be entered as 001000." cr
"input step.size2 ":= p
." Multiply step size between locations by" cr
." (number of locations - 1) and add 1000." cr
." Enter this number as a six letter digit with." cr
." leading zero's." cr cr
"input step.size3 ":= p
." Enter the total number of locations:" cr
." (maximum of 15)" cr
#input number.locations := p
." Place column exactly the way it was during" cr
." the executing of program 6." cr cr
." Press any key when ready." s
." System must be able to move freely. Check this." cr cr
." Press any key when ready." s
```

```
." Move stepper motors manually to the location where" cr
." you want to do the first measurement." cr
." The coordinates of the stepper motors for this" cr
." position were written down during program 6." cr cr
." Press any key when ready." s
." Both stepper motor indexers should be on external mode" cr
." before you can continue. All the counters on" cr
." both stepper motor indexers should read zero." cr cr
." Press any key when ready." s
." Turn power of NH85 on." cr
." Wait till 'Fn' appears on the display of the actuator." cr
 cr
." Press any key when ready." s
interface
untalk unlisten
gamma listener me talker
18 ASCII" 3 ASCII" "CAT TALK
." Preset timer (minimum 200 sec)." cr
." Timer formula: timebase*n*10**m." cr
." If you want to use a counting time of 200 sec.," cr
." set timer to '2,3'." cr cr
." Press any key when ready." s
." Set CH A PRESET to '96'. " cr cr
." Press any key when ready." s
." Enter counting time in seconds (200 sec. minimum)." cr
#input 1000 * counting.time := p
stack.clear ;


\ ***************************************************
\
\ The following colon definition performs a status test of the
\ Aston 800. The serial poll check gives information on the
\ status of the actuator and the connected stepper motors.
\ When the actuator returns the value 16, the system has
\ arrived at its destination. The next command of the
\ program can then be executed.
\
\ ***************************************************

: aston800.status.check
untalk unlisten
time.fetch time0 :=
begin
stack.clear
time.fetch
time0 -
60 >
if
16 16
else
1
then
```

```
16 =
if
16 =
else
serial.poll.enable
me listener motor talker
stack.listen
serial.poll.disable
16 =
then
until
untalk unlisten
;


\ ***********************************************************
\
\ If the program execution is delayed (by using the word
\ msec.delay) past midnight the program will crash. The
\ following colon definition will prevent this.
\
\ ***********************************************************

: no.crashes
86000000. rel.time <
if
begin
rel.time 500. <
until
then ;


\ ***********************************************************
\
\ Data collected with program x.txt are retrieved
\ from the data file. This data file consists of six
\ subfiles. The contents of each subfile are assigned to an
\ array.
\ The first subfile contains natural log values of the count
\ rates through the empty column at the specified locations
\ for Am. The second subfile contains these data for Cs.
\ The third subfile is used for path length storage,
\ determined with the Am source. Subfile 4 contains the
\ path lengths determined with Cs. Subfile 5 will be used
\ to store the dry bulk density values and subfile 6 the
\ volumetric water content values, to be determined with
\ this program.
\ The name of the file is assigned to the string 'namefile'.
\
\ ***********************************************************

: retrieve.data
." Enter name of data file (including path)." cr
"input namefile ":=
```

```
namefile defer> file.open
1 subfile
am.empty file>array
2 subfile
cs.empty file>array
3 subfile
path.length.am file>array
4 subfile
path.length.cs file>array
file.close
p
;


\ ***********************************************************
\
\ Count measurements are taken at all the locations. This
\ loop can be repeated 50 times.
\ The data are stored temporarely in the arrays 'yam.filled'
\ and 'ycs.filled'.
\
\ ***********************************************************

: measurement
0 bd :=
0 th :=
0 k := 0 l := 0 n :=
51 1 do
i k :=
number.locations 1 + 1 do
i n :=
n 1 =
if
no.crashes
motor listener me talker
" sm0,za" "cr.lf" "cat talk
" sm0,zp" "cr.lf" "cat talk
2500 msec.delay
else
no.crashes
motor listener me talker
" sm0,mr+" step.size2 "cat "cr.lf" "cat talk
aston800.status.check
2500 msec.delay
then
." Location " i . ." (out of " number.locations .
." )" cr
gamma listener me talker
27 ASCII" TALK
\ This command starts the scalers and the timer.
counting.time 2000 + msec.delay
gamma listener me talker
" P" 3 ASCII" "CAT TALK
```

```
\ This command transfers the data string with the information
\ on counts and time from the multiscalar to the buffered
\ interface.
4 1 do
gamma s1 gpib.read
loop
\ The previous loop transfers the data string
\ from the buffer to the computer.
\ The next loop converts the data string into the counts and
\ counting time.
s1
5 1 do
32 "number ?drop
loop
ratenc :=
ratetc :=
ratena :=
t :=
"drop
\ The raw data are corrected for dead time. The Am count
\ rate is also corrected for low energy Cs in the Am window.
ratetc t / 10. *
ratenc t / 10. * a * b + .0000006 * 1. - / abs
rateam :=
ratena t / 10. * dup
.00000167 * 1. - abs /
dup ratecs :=
r * q + rateam swap - rateam :=
ratecs ln cs.filled [ n ] :=
rateam ln am.filled [ n ] :=
p
n number.locations =
if
motor listener me talker
" sm0,mr-" step.size3 "cat "cr.lf" "cat talk
100000 msec.delay
motor listener me talker
" sm0,mr+001000" "cr.lf" "cat talk
aston800.status.check
2500 msec.delay
number.locations 1 + 1 do
i 1 :=
uwcs am.empty [ 1 ] am.filled [ 1 ] - *
uwam cs.empty [ 1 ] cs.filled [ 1 ] - * -
usam uwcs * uscs uwam * - path.length.am [ 1 ] * /
bulk.density [ 1 ] :=
bulk.density [ 1 ] bd [ 1 ] + bd [ 1 ] :=
usam cs.empty [ 1 ] cs.filled [ 1 ] - *
uscs am.empty [ 1 ] am.filled [ 1 ] - * -
usam uwcs * uscs uwam * - path.length.am [ 1 ] * /
theta [ 1 ] :=
theta [ 1 ] th [ 1 ] + th [ 1 ] :=
```

```
loop
." Loop" k . cr cr
." Bulk density values: " cr
." (upper location first)" cr cr
number.locations 1 + 1 do
bulk.density [ i ] . cr
loop cr cr
screen.print
." Press any key when ready." s screen.clear
." Volumetric water content values: " cr
." (upper location first)" cr cr
number.locations 1 + 1  do
theta [ i ] . cr
loop cr cr
screen.print
." Enter 'y' if you want to do another run" cr
." Enter 'n' if you want to quit" cr
"input " y" "= p
if
else
bd k / bd :=
th k / th :=
." Average bulk density values: " cr
." (upper location first)" cr cr
number.locations 1 + 1 do
bd [ i ] . cr
loop cr cr
screen.print
." Press any key when ready." s screen.clear
." Average volumetric water content values: " cr
." (upper location first)" cr cr
number.locations 1 + 1  do
th [ i ] . cr
loop cr cr
screen.print
." Press any key when ready." s screen.clear
quit
then
then
loop
loop
namefile defer> file.open
5 subfile
bd array>file
6 subfile
th array>file
file.close
screen.clear
;

\ ****************************************************************
\
```

```
\ The main program.
\ After this program is loaded into the right Asyst
\ environment, entering 'bulk.density.determination'
\ will run the program.
\
\ ******************************************************

: bulk.density.determination p
interface
day.determination
instructions
retrieve.data
measurement
;
```