Computer Automated Data Acquisition and Control for Measurement of Scintillation Materials and Scintillating Fibers

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Abstract

Scintillation materials, and scintillating fibers are being developed for potential use as tracking detectors at the SSC (Superconducting Super Collider). These fibers will need high scintillation efficiency, short decay time constants, and good transmission characteristics. This paper will discuss the combined use of the Apple Macintosh family of micro-computers and custom built and commercially available hardware and software used at Notre Dame to aid in determining suitable materials and production characteristics for long scintillating fibers or capillaries. This system includes the use of a Hitachi model F-2000 Fluorescence Spectrophotometer, LeCroy model 3001 qVt multichannel analyzer, LeCroy 8901A CAMAC to GPIB (General Purpose Interface Bus) interface, LeCroy 4604 scaler, and a Centent CN0170 Micro-Stepping motor controller. The software for the system is written primarily in Microsoft QuickBASIC, and will be discussed in detail. The potential use of a DigiKrom 240 monochromator for understanding attenuation as a function of wavelength and for reflection coefficient measurements will also be discussed.

I. INTRODUCTION

The purpose for design and construction of data acquisition and control systems and for the development of appropriate software for our laboratory was to speed up and standardize the process of evaluation of scintillants and scintillating fibers (or scintillation filled capillaries). The Apple Macintosh was chosen as the micro computer for this system based on price/performance, user friendly environment, and the NuBus architecture. NuBus allows for the implementation of custom interfaces and the Macintosh operating system allows for easy, user friendly, program development. Since many people will use the system, this was an important consideration. The laboratory equipment was chosen to be as versatile and standard in the field of High Energy Physics as possible. The choice of CAMAC and GPIB is based on the wide variety of devices available in these two standards, and the wide use of both in a research environment. The software has been developed locally using compiled Microsoft QuickBASIC. This is easy to debug and modify, and permits us to add custom features as we see the need.

II. TESTING PROCEDURES

The process of selection of a scintillation material suitable for drawing into fibers or for use in liquid filled capillaries occurs in several stages. The first measurements are performed on samples either in the form of small boules of plastic or in quartz cuvettes in the case of liquids. Small quantities of scintillant are dissolved into a liquid solvent or polymerized to form a plastic. Fluorescence measurements are made to get a rough determination of light output and emission wavelengths. Samples are then taken to the Notre Dame Radiation Laboratory where transmission characteristics, decay constants, and radiation damage are measured. Light yields using a radioactive beta source are then carried out to determine scintillation efficiency relative to other samples. Finally the attenuation length of samples drawn into fibers (or liquid filled capillaries) is then measured.

The data from all the measurements made in our laboratory are read into the same micro-computer using the same basic file format of a header containing comments and other information, followed by the data. This allows a single program to be used to look at and print the data from any of the measurements. This paper will focus on the hardware and software used to make the measurements in our laboratory.

Fluorescence measurements

The Hitachi F-2000 fluorescence spectrophotometer is a stand alone or computer controllable unit that is used to perform spectroscopic measurements on samples (see Figure 1). It can store up to 20 "tests" and 3 sample results locally in its memory. The tests are basically arrays of parameters used in a measurement. Parameters include excitation wavelength, spectral emission range to be studied, integration time, sensor tube voltage, upper and lower scale limits, and bandpass. Tests stored in such a manner are retained for later use even if power is removed, and only change when written over. The F-2000 can perform a prescan to determine best excitation wavelength and peak emission wavelength to aid in setting parameters.

The Hitachi is not capable of running under complete computer control. Test parameters must be set up manually first. This isn't a problem, because the specific test for a set of measurements can be stored in the unit, and the Macintosh can

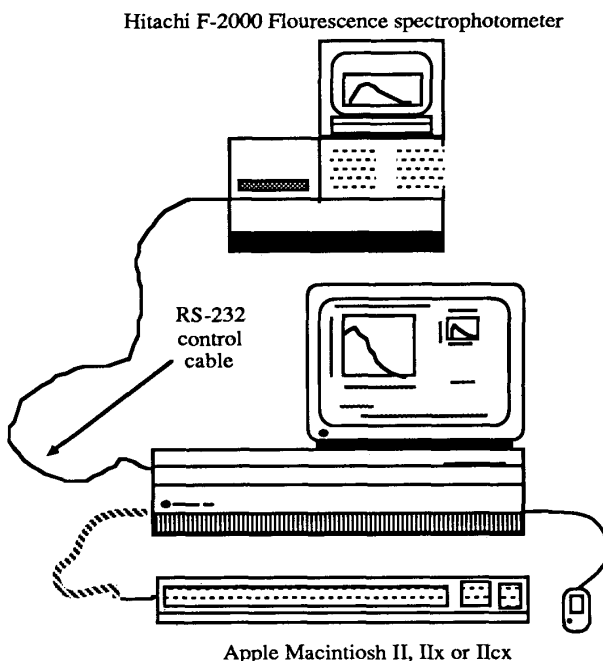select the appropriate test list to be executed for a given sample.

Hitachi F-2000 Flourescence spectrophotometer

Figure 1. Hitachi F-2000 setup.

Source excitation measurements

The testing of the samples using a beta source (^{90}Sr or ^{106}Ru) gives us a relative measurement of light output from ionizing radiation. The setup for these tests, shown in figure 2, is straight forward. A sample is placed against the face of the PMT using optical grease to maximize coupling. The collimated source is aimed at the sample as shown. The PMT, sample, and source are all contained in a small light-tight
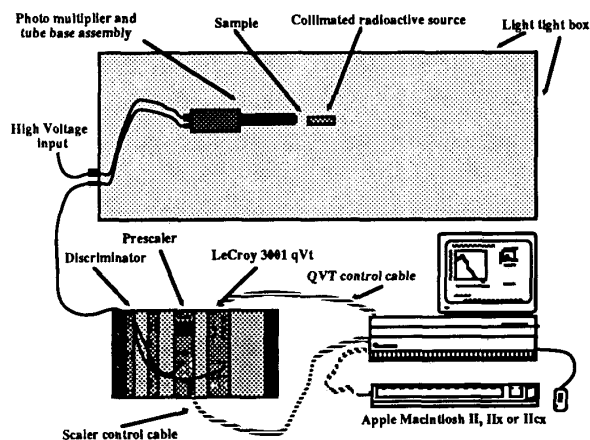

Figure 2. Source excitation setup.

enclosure. The qVt then acquires data for a specified amount of time or a preset number of counts, which can be determined by the optional scaler.

The results yield a histogram that can be compared with other samples to optimize scintillant concentration, or solvent type. The "endpoint" of the spectrum is the value we use to determine the ultimate merit of the sample. This endpoint is the point at which the logarithmic plot of the data falls to "0", representing the largest number of photons reaching the PMT.

The Macintosh has in it a NuBus card designed and built at Notre Dame that controls the scaler and qVt. This interface uses the rear connector on the qVt nominally designed for a printer or CAMAC interface to read and control the qVt. The LeCroy model 4604 scaler is controlled using the front panel ECL input connector.

Attenuation length

After evaluating the results from the previous tests to determine the best scintillant/solvent/concentration combination, samples are selected to be drawn into plastic fibers or dissolved into solvents such as 1-phenylnaphthalene, and drawn into capillaries using a low vacuum. Both types are butted against the face of the R-1104 PMT. The setup is all contained in a large light-tight enclosure. The liquid filled capillaries are placed against the PMT without any optical grease because the solvent may attack it. Instead an excess of the liquid is allowed to come in contact with the PMT directly to allow a good optical coupling. Fibers and capillaries are currently of the order of 1-2 meters in length. The setup for this system is shown in figure 3. The system can measure fibers up to 2 meters long, with a 4 meter long test station under development.

The Macintosh can perform a test automatically at up to 200 positions along a given fiber. Each position has a file associated with it that contains the data collected at that location. Data for the entire series of tests is also saved and appended to a single file that contains the endpoint data for each location.

The motor is a 200 step/revolution, 2 amp/phase stepping motor (Oriental Motor model PH229-02), and the controller drives a 10 microstep-per-full-step drive (Centent model CN0142) with anti-resonance circuitry to lessen low speed vibration and mid-band instability. The motor drive is connected to a 2:1 pulley that turns a 20 thread/inch threaded rod. This gives a linear accuracy of 31,500 steps per cm (80,000 steps per inch), but play in the threaded shaft, etc., makes the overall accuracy much less. Currently the accuracy is fine for the tests we are running ($\approx$.025 cm or $\approx$.010"), but to increase the accuracy in the future if we desire to do so, a constant unidirectional tension can be added to keep the pressure against one face of the threads. We also have rotary encoders that can be added to check and verify position. Currently the encoders do not seem necessary, as we have not

300

h voltage
inputs

Light tight enclosure

LeCroy Prescaler

Dicriminator   LeCro 3001 QVT
                      QVT control cable

Stepping Motor

Scaler control cable

RS-232
cable   Power Supply
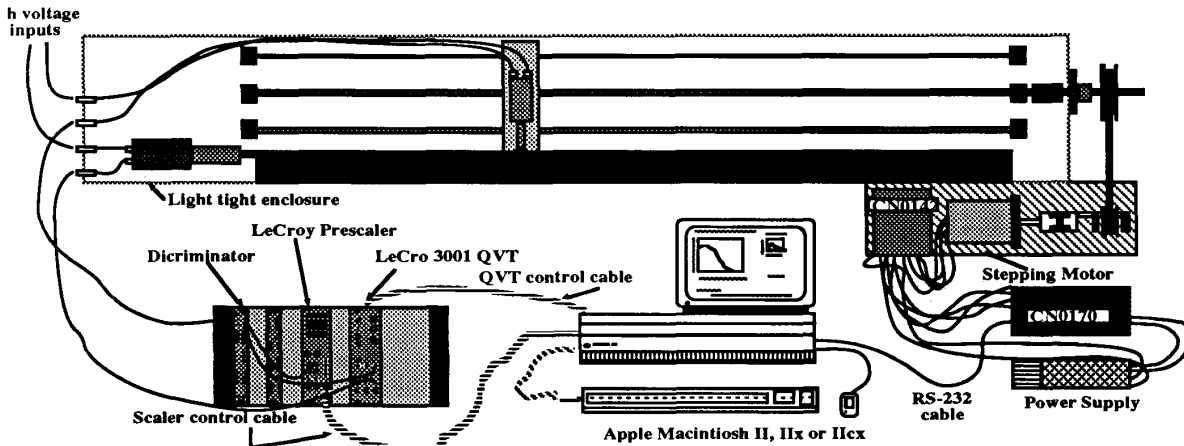
Apple Macintiosh II, IIx or IIcx

Figure 3. Attenuation measurement.

noticed any stalling of the motor, and the position has remained accurate.

During attenuation measurements the motor controller routines are used. These are selected via a pull down menu on the Macintosh. Once this menu has been selected, a prompt is issued to determine whether or not the motor controller should be initialized. This is only necessary if a power failure or a manual move of the slide has occurred since the last initialization.

The motor controller is a microprocessor-based 2-axis microstepping controller. It allows full control of velocity, acceleration curves, torque curves, and standby currents. It has limit switch inputs for safety, and a home position input to verify starting location. There are analog inputs for joy sticks or other controls, and digital outputs available for user programming. Communication is via RS-232 at 1200 baud to the host computer. The standby current is set with an external resistor. In this case the standby current is allowed to go to 0, since there is no tension on the slide (the slide being the source/trigger combination) once it is in position.

The user then uses the menus to turn on the automatic motion option, and "builds" a test setup. This setup is the array of locations at which the measurements are to take place. Since the increments along the fiber need not be uniform (i.e. the user may wish to measure every centimeter for the first 50 cm, then every 2cm for the next 50 cm, then every 5 cm out to 2 meters), the program allows one to divide the fiber into as many "segments" as one wishes. Each segment has its own incremental value used to locate measurement positions within that section. Once the test setup is built, the absolute positions for each measurement are displayed to verify the test before it begins. This same setup can be repeated on consecutive fibers until a new setup is "built". This allows multiple fiber samples to undergo exactly the same tests without making any changes.

When a measurement is initiated the system first checks the location of the slide, and moves it to the selected position if needed. There are two options that can be selected for automatic motion of the slide. The first is "semi" automatic, in that after each qVt reading the user is prompted to clear the qVt and scaler, and then strike any key when a new measurement is ready. In this way the the user can look at each reading as it is made, and continue when ready. The slide is moved immediately following a qVt reading.

The second method for moving the slide is completely automatic. The user "builds" a test pattern as before, then starts. The Macintosh asks the Centent Motor controller for its position, and moves to the start location if necessary. The test then begins, and runs through the entire set of locations. At the start of each measurement, the pre-scaler and qVt are cleared, then started. The pre-scaler will then stop the qVt automatically after the selected number of events. The Macintosh constantly polls a register to see if the pre-scaler has reached its selected value. Once the Macintosh senses that the scaler has stopped, the qVt data is read. Each new file has the position appended to the name of the file (example: MOPOM.Naphthalene.10cm), and placed in the comment record in the header of the file.

Since measurement of attenuation length is the objective of this test, a method of determining this value had to be selected. We determine an endpoint for each location based on the slope of the logarithmic plot of the histogram. For this calculation a line fitting routine was built into the program, and the "endpoint" is written to a separate file. The algorithm for this calculation is discussed in the software section. Once the test is complete, the "endpoint" file is saved with the same name as the sample, but without a length extender, and with an added ".epm" extension. This file contains a record for each position which represents the endpoint for that location.

III. Software

The programs developed for this system were designed for two levels of operation. The first is the data acquisition and control level which allows the user to run the tests and observe the results. The second allows for more extensive analysis, such as data manipulation and printing for comparisons.

The qVt program

The same program is used for source excitation tests and attenuation measurements. The user can select the use of the motor controller at any point in the running of the program. If the motor control is selected, the program automatically selects the storage of the endpoint data. For source excitation measurements the endpoint file storage is optional and must be initiated before reading the qVt. The endpoint is calculated and displayed even if the file isn't saved.

Figure 4 is an example display of the qVt data. The selection of display format, display of previously stored files, overlays, data expansion, and color plots are the same for all measurements. The plots are set to either linear or logarithmic scales. We use primarily logarithmic scales, but for some tests the linear mode proves useful. The vertical scale is automatically set to allow the full display of the data with the peak as high as possible. If the displayed number of counts per bin are much lower than the peak counts per bin (such as with a large pedestal), then the scale can be set manually to an appropriate value.
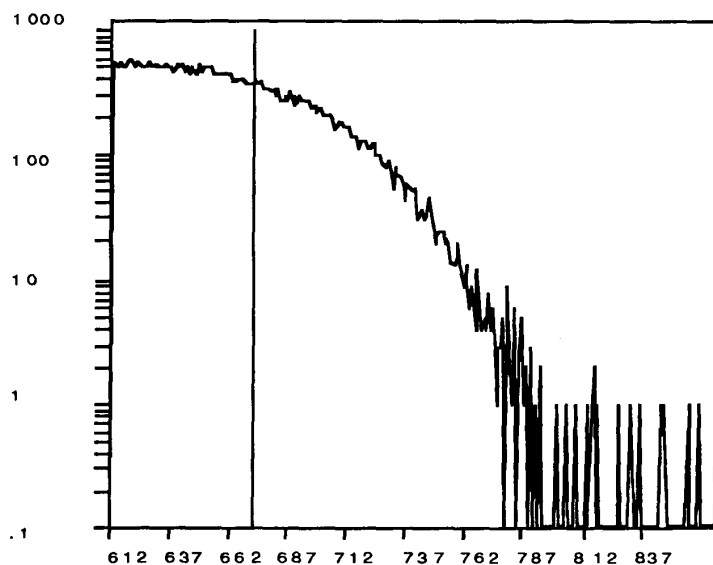
While making measurements, previously recorded data files can be displayed as if they were being read from the qVt. This allows for an easy comparison of samples. The color of each plot can be selected when overlaying multiple histograms. In the overlay mode, previous files and new qVt data can be continually overlaid on the same screen. This makes it easier to see each histogram separately when many are overlaid, preventing confusion as to which plots belong to which measurement.

Because of the resolution of the standard Macintosh color display, the results are averaged to allow display with a width of 256 pixels. This averaging is done by adding 4 bins together, and dividing by 4. This "averaged" display can be expanded to view any 256 bin sub-section of the possible 1024 channels of qVt data with a 1:1 display. After expanding a section, the address and data for each location in that section can be examined easily by using the mouse and cursor (a custom cursor with a cross hair is used to aid in positioning). Once the section of interest has been selected, the screen can be spooled to a LaserWriter for printing (see Figure 4.).

The motor control software is built into the rest of the program. The controller accepts commands and issues responses when prompted. It keeps track of absolute position, freeing the Macintosh of that task. The controller can be programmed to issue ASCII commands when certain events occur, such as the motor stopping or reaching the programmed position. Commands from the host can be stored locally in the controller and repeated as desired. Commands sent to the controller are either stacked up and issued in sequence by a single command, or executed separately as they are received, depending on the way the controller has been setup .

File :Q V T D A T A :blcro n .plastic.sample. R EF O pened
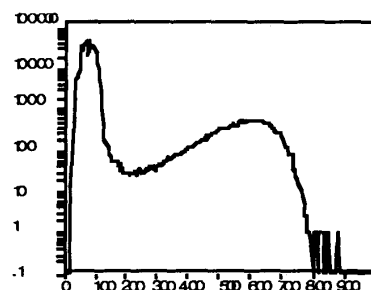
Channel = 673
Data = 376

Total count = 2 041 043

Figure 4. Example qVt display.

302

The controller contains a register which can be polled by the Macintosh to determine the location of the motor as it is in motion. The response indicates the position and direction of motion at the time of the request.

The Fluorescence Measurement program

This program is very simple. It sends and receives ASCII codes to and from the Hitachi F-2000 unit. The data is displayed in essentially the same format as it is on the screen of the spectrophotometer itself, and can be manipulated in much the same way as the attenuation length data described above. Since the Hitachi has its own display screen which works quite well, the main purpose here is to store the data in a file for future use. This is necessary because the Hitachi has only three local storage files.

Communication to and from the F-2000 is via RS-232 at 4800 baud using the modem port on the Macintosh. Because of the low transmission speed, reading a file takes a few seconds, but this hasn't been a major drawback.

The Laser Printing program

The Laser printing program allows the user to obtain graphic plots of the data. It takes the files created by any of the data acquisition programs, and generates histograms that can be spooled to the Apple LaserWriter.

The plots are scaled automatically, and have x and y axis labels. All the information needed for these plots is stored in the header of the file created by the various programs. The display limitations mentioned earlier are not an issue here, as the LaserWriter has much higher resolution. This means each bin is plotted accurately. The size of the display printed out can be changed using one of the menus allowing expansion or compression of the image. The image can also be cut to the "clipboard" file to be exported to other applications, such as a word processing program.

The Attenuation plotter program

The data in the endpoint file can then be opened with a program written to calculate the attenuation length. This program allows the user to select a section along the length of the fiber for data fitting. Typical data are not well described by a simple exponential, but have rather a multiple exponential character. Figure 5 shows two distinct regions of behavior for a typical sample with a sharp fall for x<25 cm and flat behavior for x>30 cm. Since no method is perfect for determining the endpoint, the file can be edited to change values that don't appear correct by eye, or data for a complete file can be entered manually.

The plot routines allow the selection of anything from a small section of the data to the entire array to be used in the calculations. This allows determining the curves at the early part to be fit, as well as after the point where the data flattens out, as was shown in figure 5. The program fits a line to the

data, and calculates the attenuation length based on the section of data that has been selected.

Sample: DP9_sr90_t3
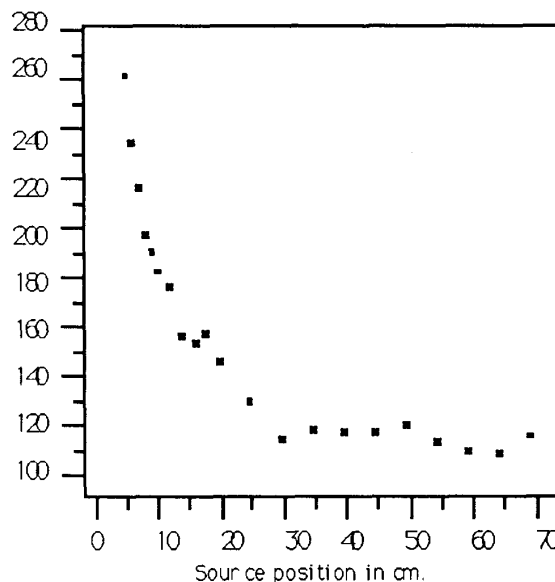
Figure 5. Example endpoint plot.

The calculations performed by the qVt program to determine the endpoint data used by this program were chosen pick the point at which the logarithmic plot of the data reaches zero as follows:

$$y = b_0 + b_1 x$$

$$b_1 = \frac{n\sum x_i y_i - \left(\sum x_i\right)\left(\sum y_i\right)}{n\sum x_i^2 - \left(\sum x_i\right)^2}$$

$$b_0 = \frac{\sum y_i}{n} - b_1 \frac{\sum x_i}{n}$$

where x_i= bin number; y_i= log(bin value); b_0= y intercept; b_1= slope. Hence the x intercept, or endpoint is:

$$\text{endpoint} = -\frac{b_0}{b_1}$$

The plots generated can be printed on an ImageWriter or LaserWriter. The histograms can also be sent to the "Clipboard" file for transfer to other applications, such as Microsoft Word 4.0, MacPaint, and MacDraw.

IV. Future additions

Monochromator

We intend to use a DigiKrom 240 monochromator for two additional types of tests. These are to measure the spectral attenuation length, and the reflection coefficient of the fibers. This requires special reflective optics capable of collecting all the light that exits the fiber. Since fibers with a large

numerical aperture are desired, this requirement puts constraints on the types of optics that may be used. Reflective optics have the advantage of flat spectral response across their surface, while refractive optics will attenuate some wavelengths nonuniformly across the surface due to the thickness of lens that the light must pass through.

The basic idea of the reflection coefficient measurements is to determine the actual numerical aperture, and collection efficiency as the reflected angle increases. An iris with an aperture that can be remotely controlled is located between the output of the fiber and the first focussing mirror to control the opening angle (numerical aperture) for the measurement.

Since the surface qualities of fibers and capillaries will affect the final characteristics of any device, we want to be able to determine the effects of these values. By calculating the ideal numerical aperture, and comparing this value to the measured results, the reflection coefficient can be calculated. This may be important in the choice of fiber cross sectional shape (i.e. circular, hex, square, etc.), and surface quality requirements of the core and clad materials before fiber drawing in the case of solid core fibers.

The set up for the spectral attenuation measurement is shown in figure 6. Since the attenuation length is not constant across the spectra, and the sensitivity of most detectors is wavelength dependent, we intend to use a monochromator at the output of the fiber to measure the wavelength dependence of the attenuation length. We have seen by eye that as a UV light source is moved along the fiber the light output will shift from green to red in some samples as the source moves farther along the fiber. Since the photomultiplier does not have a flat

response spectrally, this can cause misleading results.

With the possibility of using Solid State Photo Multipliers (SSPM's)[1,2] as detectors, the red sensitivity is important. The R-1104 will indicate almost no light output, when in fact a large red component may be there. For this reason we would like to be able to hold the output wavelength at a constant as the source is moved along the fiber.

The amount of light generated by an ionizing particle would in all likelihood be too low to be detected, so for these tests a UV light source would be used, and the detector may be a photomultiplier, PIN photodiode, or a solid state photomultiplier. The solid state device would be the detector of choice because of it's sensitivity and spectral response. Care must be taken when making these measurements as the decay constant of various samples is not constant with respect to wavelength. The blue or green component may be very fast, but the red may be long. With a detector sensitive to all wavelengths, this would cause severe rate dependency problems.

The DigiKrom is a Z80 based system. Commands are issued to, and responses received from the monochromator using serial RS-232. We have developed a program to allow full control of the system, and this is being added into the existing program to allow full spectral measurements, and reflection coefficients for the fiber samples.

CAMAC

A CAMAC data acquisition system has been configured to enhance the measurements. This system uses the SCSI

Figure 6. Monochromatic attenuation studies

interface on any Macintosh II or SE series computer to run a GPIB controller (IOtech model MacSCSI488). This controller comes with a set of drivers that allow the user to read and write to the GPIB through the SCSI bus.

The GPIB can then be used for acquiring data and controlling instruments (such as digitized oscilloscope outputs, micro-stepping motor controllers, etc.). We use the GPIB to control a CAMAC crate via a LeCroy 8901A GPIB CAMAC controller. This allows us to simultaneously measure multiple channels (such as the output of both ends of a fiber), and gives us access to all the instrumentation available for CAMAC.

A LeCroy 2249W 12 channel CAMAC ADC (Analog to Digital Converter) will be used for many of the measurements. This unit has a wide gate width, allowing measurement of samples with both fast and slow decay components (up to 10 μsec). The SSC requires scintillators with very short decay times, so systematic measurement of decay constants over extended time intervals is important.

When reading multiple fibers, such as with the solid state photomultiplier, this unit will be essential. This is intended for use where the data comes from more than one device with a common gate. Because this is an SCSI device, the same Macintosh could be used for the qVt, monochromator, and CAMAC. This would make for a versatile lab system.

CAMAC software

Much of the software for this system is preliminary. The crate can be read and displayed in the same way as the qVt data. One major drawback so far has been the slow transfer rate using this set up. It appears that there is a lot of overhead in the SCSI to GPIB or GPIB to CAMAC controller which slows data taking somewhat. For testing purposes, and as a general laboratory device, this is no problem. Work is being done to speed up the data transfers by using C for the program language and building Assembly language library routines. Since the work is preliminary the problems are not completely understood.

V. OPERATIONAL EXPERIENCE

The qVt system has been used to make many measurements, the results of which can be found in two papers presented in other sections of this symposium [3,4]. The automatic attenuation measurements were useful in speeding up repetitive procedures, such as the large number of measurements required in determination of attenuation length.

Some of the early tests that used manual motion of the slide had an error caused by miscalculation of "turns-per-cm", leading to an accumulated error as the slide was moved along the fiber. The computer controlled motion has been checked, and rechecked for accuracy and has no such problem.

The overall system performance seems to be robust and reliable. It has been useful not only for the fiber measurements, but as a lab data acquisition system for other areas of research we are currently involved in.

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