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Control and Data Reduction Software for UMR Neutron Spectrometer

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Introduction

A double-scatter time-of flight neutron spectrometer has been obtained by the Nuclear Engineering department of the University of Missouri-Rolla (UMR). As this device was an experimental prototype which was never brought to full operation, the chance to work with two of the original builders of the spectrometer at EG&G Idaho was an excellent opportunity. Part of the work being done with the detector is the development of a PC-based software package for machine control, data acquisition, and data reduction. It is this part of the project which has been supported by UMR's Opportunities for Undergraduate Research Experience (OURE) program.

History

The device originated at the research facility of Phillips Petroleum in Bartlesville Oklahoma. It was developed by A. M. Preszler, W. A. Millard, and S. E. Walker of Phillips working with T. J. Dolan of UMR, in 1984 and '85. The spectrometer was designed to provide information on the energy and angular characteristics of the neutron flux produced by an experimental fusion device. The project was abandoned when the company was forced to drop its fusion research program due to the combination of a loss of federal funding and the financial strain of hostile takeover attempts. In 1988, the spectrometer was donated to UMR by Phillips Petroleum. The next year Alan Preszler, now working at EG&G Idaho, and Dr. Dolan, on leave at the Idaho National Engineering Laboratory (INEL), proposed a joint project to develop the capabilities of the device. This project is currently underway at EG&G Idaho.

Spectrometer Description

The spectrometer is composed of a two-cell detector, a CAMAC crate containing the necessary electronics modules, and a microcomputer for control and data manipulation. The detector portion is made up of two scintillator cells separated by an adjustable distance. Each cell contains two sheets of NE102 plastic scintillator connected to photomultiplier tubes (PMT's) which collect the light impulses from the scintillators and convert them to electrical signals. These signals are collected, digitized, and processed through the CAMAC electronics for meaningful event data. Many of the CAMAC modules used were straight off the shelf, although some were modified and custom modules were developed for some purposes.[1] The resulting data is transmitted through a GPIB (IEEE 488) link to the microcomputer for evaluation.

The operation of the spectrometer is based on classic elastic scattering kinematics.[2] In an actual double scatter event, an incident neutron of energy Eo collides with a proton (hydrogen nucleus) in the first cell, transferring a portion of its energy to the proton (Ep1). This energy is immediately deposited by the proton, and a light impulse proportional to Ep1 is picked up by the PMT's. This also initiates a timing sequence. The neutron, with remaining energy Etof, then travels to the second cell where it collides with another proton. The PMT pulse resulting from this reaction gives the time of flight from the first cell. Since the kinetic energy Etof of the neutron is proportional to the square of the velocity, it is inversely proportional to the time of flight between the two cells:

Etof = 0.5 * sep^2/TOF^2, (1)

where sep is the distance of separation between the two collisions. This gives us the energy of the incident neutron as the sum of the energy deposited in the first cell and the measured kinetic energy between the two cells:

$$Eo = Ep1 + Etof. \qquad (2)$$

Since the fraction of energy deposited in the first cell is dependent on the incident angle of the neutron, the device can also be used to measure this angle. It is found by taking the arctangent of the square root of the ratio of the energy deposited in the first cell to the kinetic energy between the two cells:

$$\theta = \sqrt{Ep1/Etof} \qquad (3)$$

An illustration of the process is shown in Figure 1.

Certain tradeoffs are inherent in the design of the spectrometer. In order to maximize the efficiency of the detector, the first cell must occupy the largest possible solid angle with respect to the neutron source. Similarly, the second cell should occupy a large solid angle relative to the first cell. Therefore, efficiency demands that the cells be fairly large and relatively close together. Optimizing for efficiency, however, is detrimental to the resolution of the device for both angle and energy measurements. This is due to the larger possible deviation of the path of the scattered neutron from a line parallel to the axis of the detector. The design must balance these two considerations for the circumstances expected in use.

Since the spectrometer was originally developed for use with a fusion device, it was designed to cope with a very high event rate generated for a very short period of time. This required a relatively high efficiency, and the detector was built using one foot square sheets of scintillator in both the front and rear cells. The resulting resolutions for this configuration with a 100 cm separation were 34 keV and 10 degrees for 2.45 MeV neutrons at 45 degrees.[2]

Project Description

Equipment Configuration

The applications for which the Nuclear Engineering department is interested in using the spectrometer, as well as those in which EG&G is interested, are quite different from the original design purpose. Neutron energy spectra can be used in analysis of fission reactor behavior, determination of the content of nuclear materials, and experiments in radiation shielding and radiography. In each of these cases, the neutron source field is much more long term than in the case of a fusion device. Therefore, efficiency is not as limiting a factor and the configuration of the device can be changed to improve its resolution. This has allowed the design of a new detector with scintillator cells measuring about two inches on a side. While the reduction in efficiency is about 97%, there is about a thirty-fold decrease in the uncertainty of the path length. It is hoped that angular resolutions of one degree and energy resolutions of better than five keV will be obtained.

In addition to the change in the detector configuration, changes are being made in both the electronics packaging and the microcomputer control system. The CAMAC crate containing the instrument's electronics, which was originally mounted in the same structure as the detector, is being installed in a shock-resistant travel case. This affords advantages of portability and protection of the crate modules. The control and data handling of the system is being switched from the Hewlett-Packard Series 200 Model 9816 microcomputer to a Compaq Portable III, which is an IBM compatible 80286 based machine. The Compaq gives the

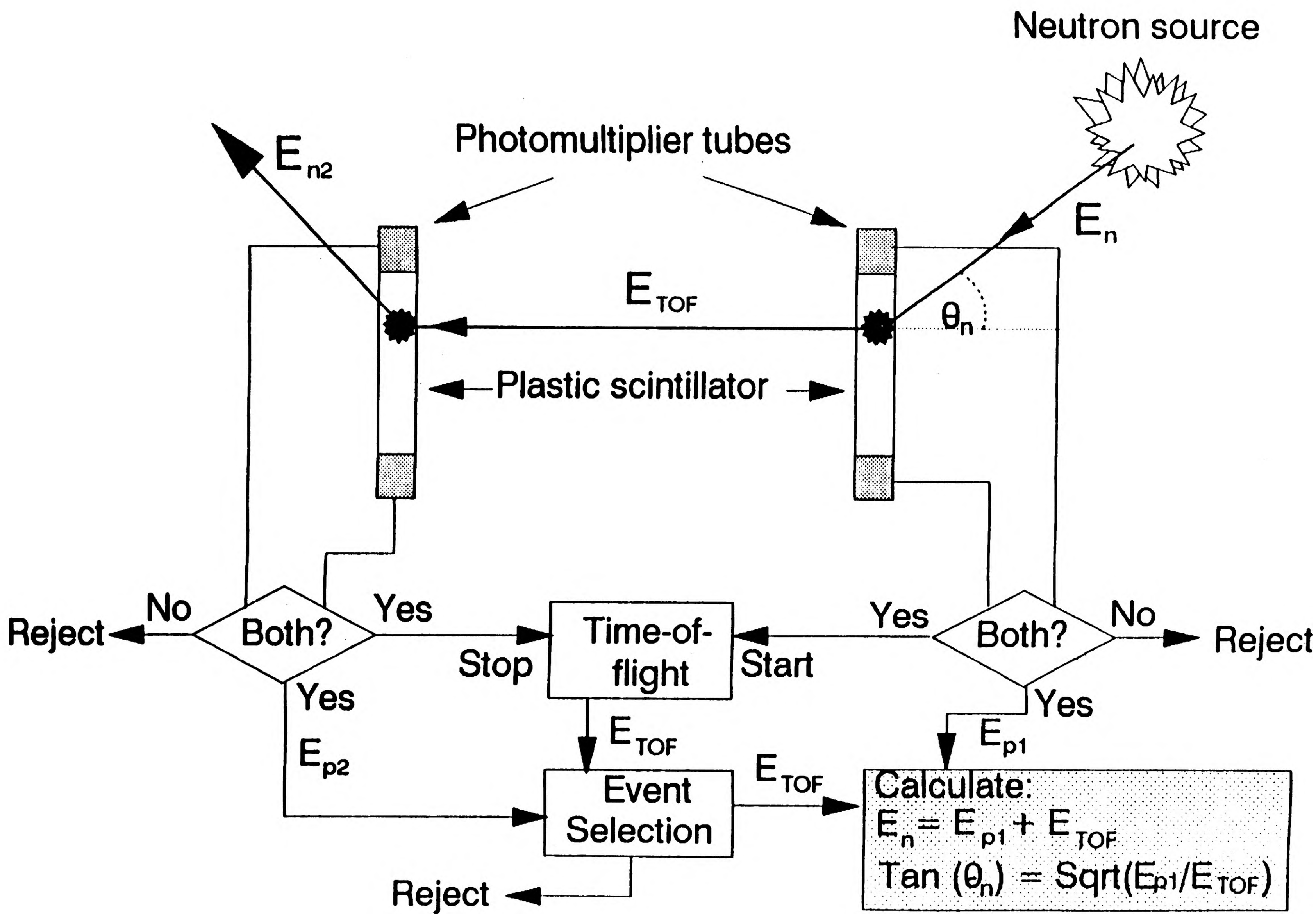

Figure 1: Spectrometer Operation

advantage of having the CPU, monitor, and hard disk all in a single easily portable unit, where the older HP machine consisted of four separate components which are not designed to be moved around.

The flexibility gained by the reconfiguration of the instrument will be substantial. In addition to the increased portability, the department will have available both the old and the new detector configurations, giving the option of using whichever is more suitable for a given project. Figures 2 and 3 illustrate the old and new configurations of the spectrometer.

Software Upgrade

In replacing the control computer, it has become necessary to rewrite the software which controls the instrument. This is being done in the C language, the old code having been written in BASIC. Writing the code in C will result in a faster and more efficient program. Additionally, it will make the program more easily portable to other machines. This is particularly important with the data reduction end of the program, where the need to run numerous variations on the analysis of the same data might make it worthwhile to work on a larger and faster machine. The version of C being used is Microsoft C 6.0. Care is being taken, however, to keep the program compatible with the ANSI C standard to ensure portability of the code.

Project Status

The building of the new detector is in progress at EG&G. It is expected to be completed in the summer of 1991. Work was started on the software in the summer of 1990 and the first version should be completed for the summer 1991 trial runs of the instrument.

Software

There are two major goals to meet in writing the software. The first is to improve on the efficiency of the code and reduce the time necessary for calculations and genarl operation. This includes changing the way in which the data is stored, changing the user interface, and including the ability to work with one set of data while monitoring the clock for collection of another data set. The second, and at least as important, is to write a program which can be readily maintained. Since this device is a prototype and of an experimental nature, it is very probable that the program will continue to evolve for some time. From working with the original program, it is very obvious how important this is. Additionally, the fact that the code is to be used in Idaho but written here in Missouri makes it imperative that it be as easy to use as possible.

There are effectively three main parts of the program. They are data handling, the user interface, and the CAMAC interface. Figure 4 is a basic flowchart of the program. The data which the program handles is actually rather straightforward. For each data point stored in memory records are kept for seven associated values. These are:

the time of the event,
the scintillator sheets involved,
the energy deposited in the first cell,
the time of flight between cells,
the energy deposited in the second cell,
the scaler rate of the first cell,
and the scaler rate of the second cell.

Current Arrangement

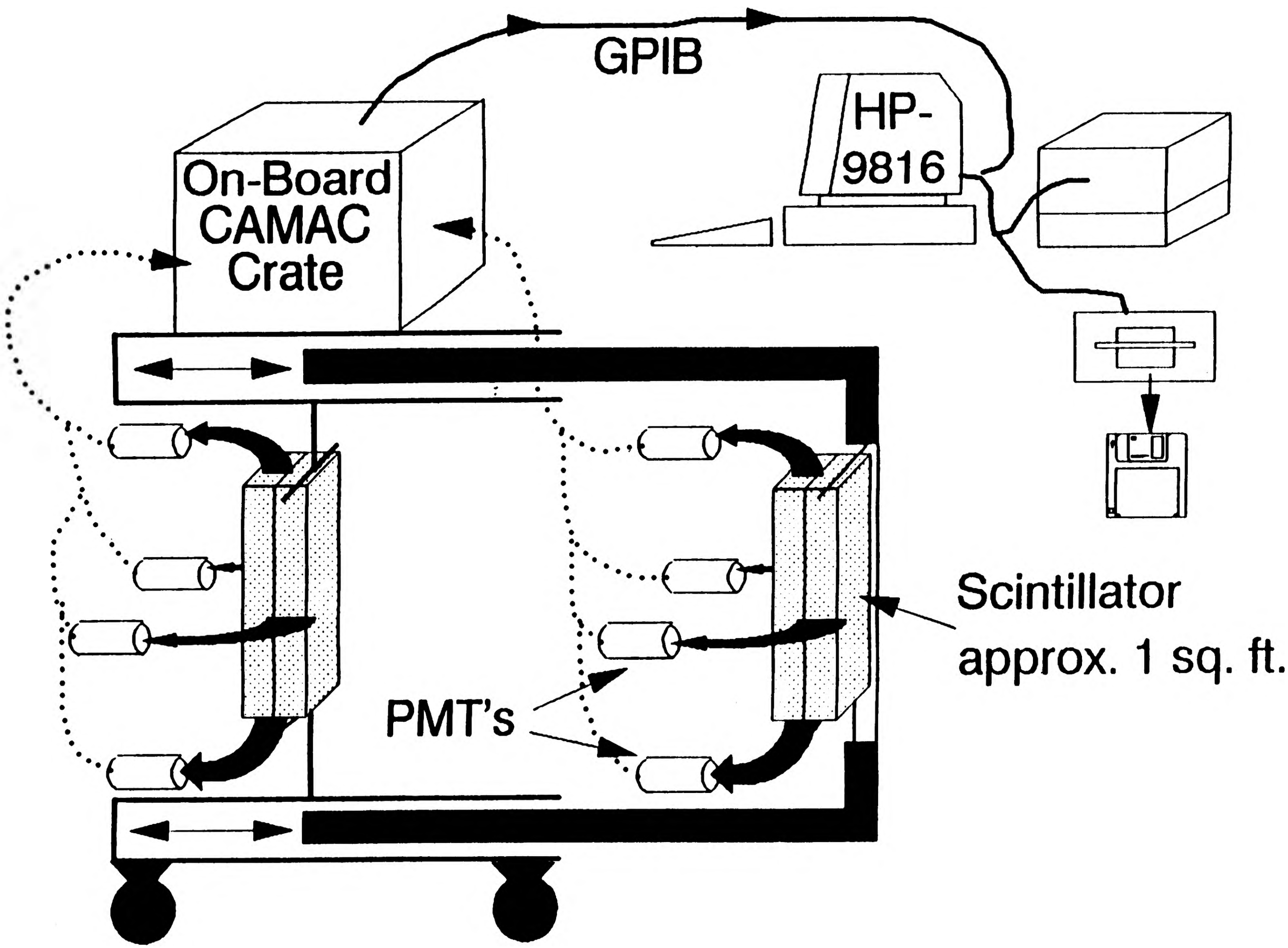

Figure 2: Original Configuration

Proposed Arrangement

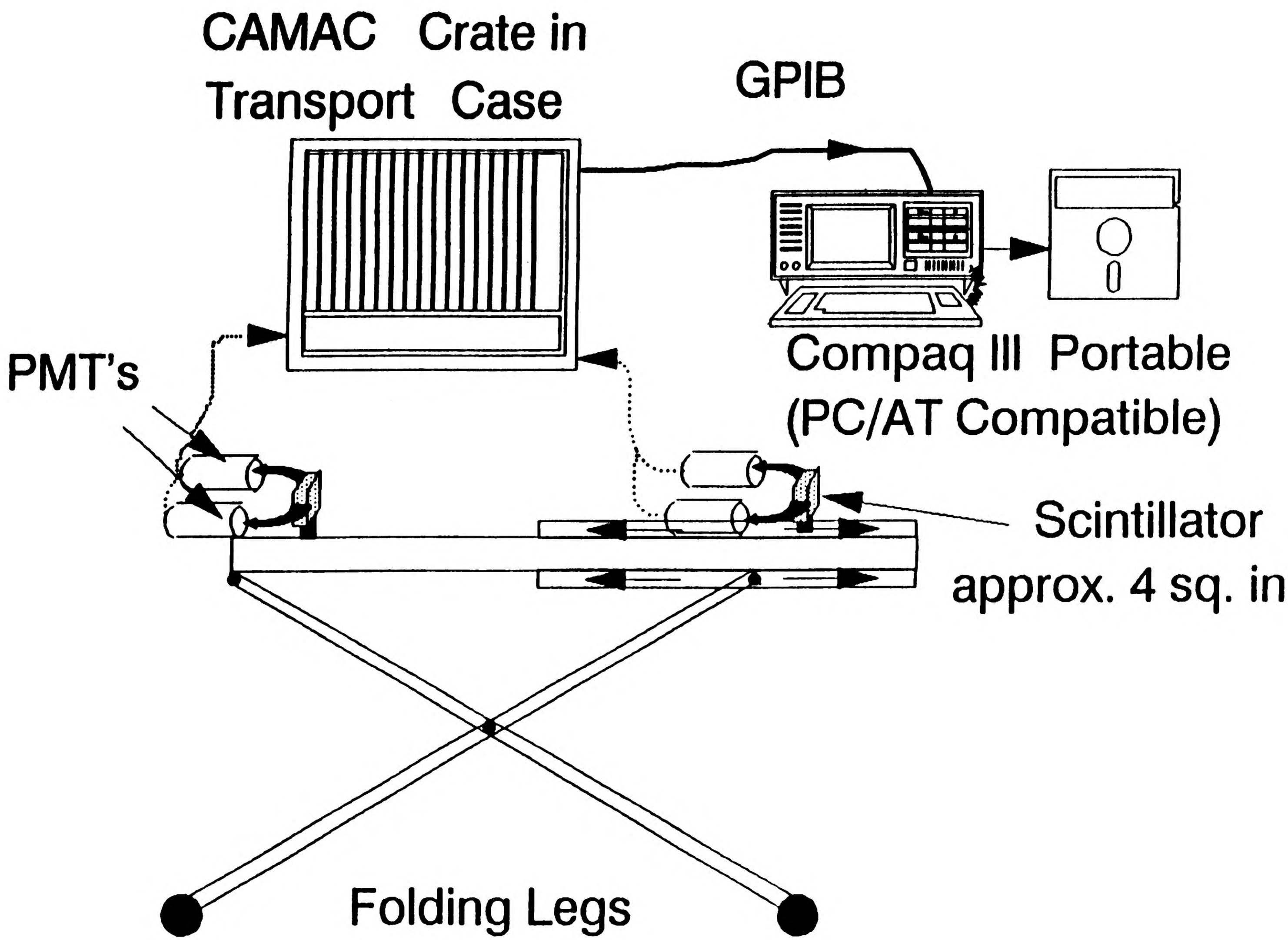

Figure 3: Updated Configuration

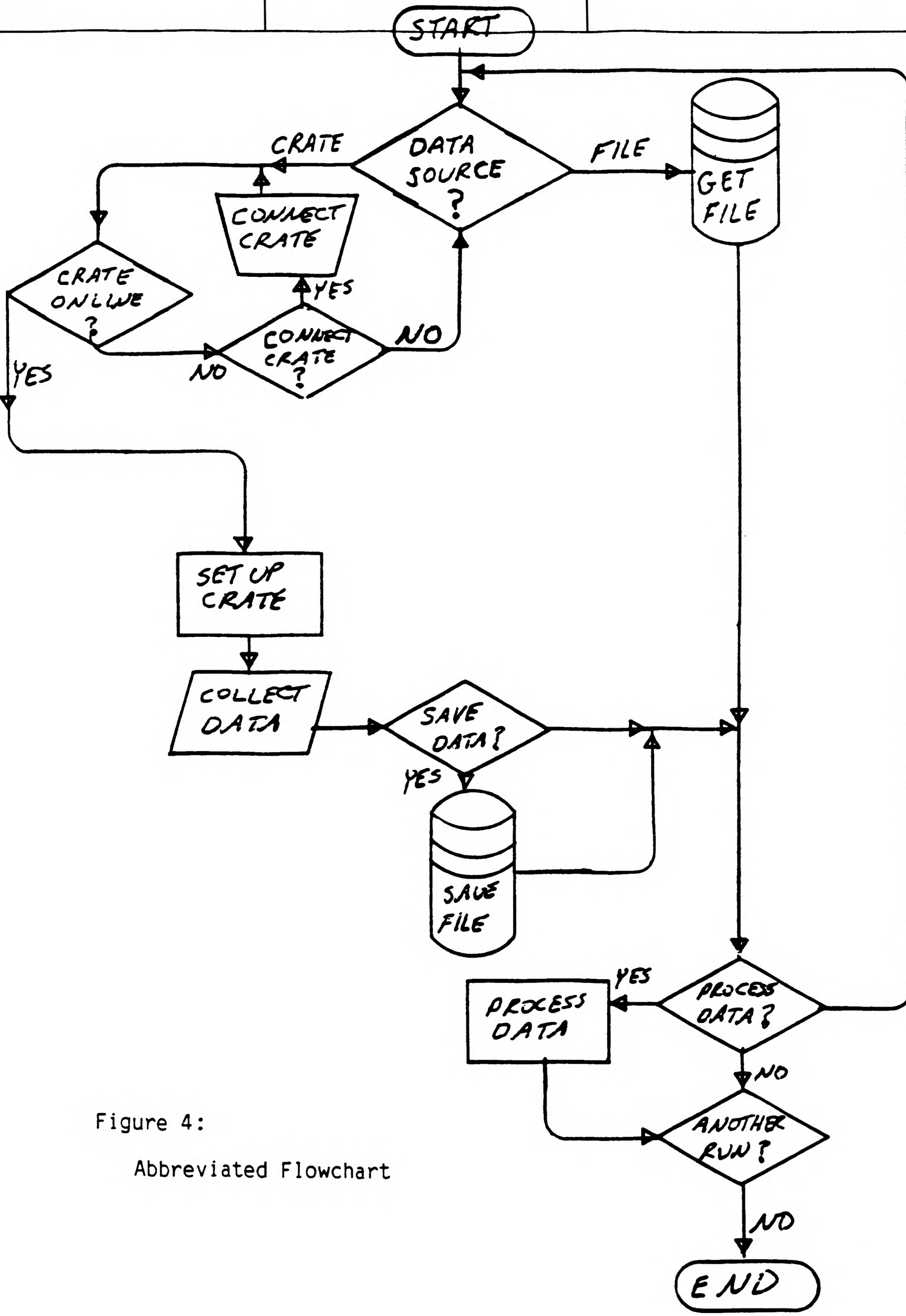

Figure 4:

Abbreviated Flowchart

These values are stored for each of up to 8184 events, and saved to a file if requested. Using this information, a wide variety of plots are produced, including polynomial fits and statistical distributions.

As it turned out, the data handling area showed the most room for improvement. In order to improve the efficiency, the most obvious areas to look for were those in which a time consuming operation was being performed repetitively. It became evident that one area in which time could be saved was the event selection routine. Since events are catagorized by what sheets they deposit energy in, this information is recorded for each event. What the old program did was to determine which events were required, check each event (a maximum of 8184) against that requirement, and determine whether or not to include it in the data set to be worked with. If the requirements changed, even if just adding another set to the existing group, the entire process was repeated. This was necessary because the data points are kept in memory in the same order that they were read in from the digitizer.

To improve on the time spent sorting, the data is completely sorted when it is first read in and saved in that form. Since the sheet id's are simply yes or no for each of 4 sheets, there are sixteen possible permutations. This makes it possible to perform a simple sort on the entire set, leaving the events grouped according to which scintillator sheets fired. Coupled with this data array is a sixteen-element index array which tells how many events fall under each permutation. With all of the events in a contiguous array, these values can act as offsets which are added to the base address of the data array. This allows the use of pointer arithmetic to quickly access those events which are requested for a given plot. It also allows the use of a mask to identify qualifying events. For instance, if all events which deposited energy in the first sheet of the rear cell are wanted (sheet #3), only the third bit of the mask is set. A logical AND operator is then used to select the applicable elements of the index array.

Although the data reduction portion of the code is not complete, it does not appear that implementation of simultaneous control of a data run will be a large problem. The skeleton code which has been written for this portion includes all of the necessary function calls with time checks nested in between. Since the computer is not capable of multitasking, the strategy is to look at the time left on the data run, ensure that it is enough to complete the requested operation, and only then to execute the request. If the data run finishes in between two function call, the existing data will be written to a temporary file and the new data will be read from the crate and sorted. The new data will then be saved to disk, the old data recovered, and the operation completed. The problem with this part is estimating how long a given operation will take, which will not be possible until that part of the code is working.

The user interface is still primitive. Dr. Edwards has supplied a set of programs which allows the inclusion of windows and pull-down menus in a program. It is written for PC's, which limits its portability. The X-windows system, which is supposed to be a standard for graphics handling in C, is another possibility. This, in fact, would be preferable in order to make the graphics of the program available on other classes of computers. In the meantime, if the window and menu programs are used on the PC, the more primitive interfaces will be maintained for use with other machines. Since the program would have to be recompiled for use with another machines, this can be accomplished through standard structured programming practice, using different program modules for use with different machines. Of course, this will have to be well documented to prevent confusion.

The CAMAC interface portion of the code is essentially complete. A National Instruments GPIB-PCIII interface card is being used to interface the PC to the GPIB bus. A C language driver was included with the card. Although a header file for function prototypes was not included and there was a problem with the functions being listed in lower case and programmmed in upper case, the driver worked fine after these problems were fixed. The most difficult part was figuring out just what the problems were. Once the GPIB functions were prototyped and working, it was simply a matter of writing the CAMAC crate calls in terms of the GPIB functions. As soon as a simple framework is written around it for interface and data storage, it will be sent to Idaho for its first round of tests.

The documentation consideration largely becomes a discussion of lessons learned. Since this is the first time that the author has attempted a programming project of this magnitude, there have been many learning opportunities. One of the simplest to spot was the value of structured programming. The original code is all in one file, with innumerable calls to subroutines spread throughout. Care is being taken to write the code in a number of files. For instance, one file contains all CAMAC crate function calls and another the data manipulation routines. The code is also being heavily commented as to why things are done a given way. The old program is not very strong in this regard, and a lot of time has been spent chasing data trails to figure out what is going on.

Conclusion

Overall, this project has been a very rewarding experience. The experience working with research labs and writing programs that other people will be using will be invaluable in future work. Additionally, it has been an opportunity to make valuable contacts with professional researchers. Although still in progress, the program promises to be complete by the end of this summer, at which time a final report will be submitted.

References

1. W. A. Millard, A. M. Preszler, and S. E. Walker, "Electronics Implementation of a Double Scatter Neutron Time-Of-Flight Spectrometer for Fusion Plasma Measurements", Proc. 11th Symp. on Fusion Energy, Nov. 1985, 3C05.

2. A. M. Preszler, W. A. Millard, and S. E. Walker, "Double Scatter Neutron Time-of-Flight Spectrometer for Fusion Plasma Measurements", Proc. 11th Symp. on Fusion Energy, Nov. 1985, 3C04.

3. Ibid.