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Data Acquisition from Simultaneous Experiments Using the
MSU Sigma-7 Computer*

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The large size of the nuclear spectroscopy group at Michigan State University and the relative ease and efficiency with which experiments can be performed using the MSU Sector-Focused Cyclotron make it imperative that simultaneous data acquisition and analysis be possible. The Sigma-7 computer at the MSU Cyclotron Laboratory forms the basis of a flexible real-time, time-sharing system that meets the requirements for performing simultaneous spectroscopic experiments or spectroscopic experiments simultaneously with nuclear scattering experiments, all the while allowing data analyses to be performed.

The computer consists of 32K of 32-bit core memory plus a 1.5-megabyte (8 bits = 1 byte) RAD (rapid access disk) for file storage and a 3.0-megabyte RAD for memory swapping during computation. [During this fall a 5.3-megabyte RAD (transfer rate = 3 megabytes/sec) will be added for memory swapping and both current RAD's (transfer rate = 0.19 megabytes/sec) will be used for file storage.] It has standard peripherals such as teletypes (with and without paper tape), card reader, card punch, 600 lines/sec line printer, two 9-track magnetic tape units, and a CalComp plotter. A large general-purpose interface¹ built in this laboratory connects it to two scope displays -- a Fairchild 737A live-display scope and a Tektronix 611 storage scope -- and to the various nuclear instrumentation of the laboratory. This includes four Northern Scientific 13-bit ADC's plus coincidence and routing circuitry and a Nuclear Data 160 analyzer that can dump its memory directly into the computer. Computer control of the cyclotron itself is partially operational and is expected to be completed during the fall of 1969.

At the heart of the flexibility of the system is the time-sharing software, which was written in this laboratory.² This system, called JANUS, permits the simultaneous execution of a set of programs, called "tasks," and performs the swapping in and out of memory which increases the effective size of the computer enormously. Perhaps a list of the currently implemented tasks will give the best idea of the versatility of the system. They can be divided into two classes -- 1) those primarily for real-time use of the system and 2) the monitors for controlling batch programs:

1) *Real-time tasks*

1. POLYPHEMUS Single-parameter data recording from up to four 13-bit ADC's with print, plot, punch, and MOIRAE (see below) analysis. Either whole-word or half-word channels.

2. GEORGE On-line two-dimensional data acquisition and simultaneous display.

3. EVENT Megachannel, multidimensional data collection. Reads ADC's singles, dual coincidence, etc., and lists data on magnetic tape for later analysis.

4. HYDRA External particle identification of up to eight spectra using analog particle identifiers.

5. TOOTSIE Internal on-line data acquisition for digital particle identification. Uses up to four ADC's and can collect many simultaneous spectra.

6. NDDUMP The Nuclear Data analyzer is dumped into the computer and four 1024-channel CPUNCH (compressed binary punch) decks are produced.

7. NDPLOT A set of CPUNCH decks can be read, plotted in various

linear and logarithmic formats, using the CalComp plotter, and listed.

8. PDPTAPE Block binary paper tapes from the PDP-9 computer also in the laboratory are read and converted into CPUNCH decks.

9. MOIRAE Live-scope data analysis program. Discussed below.

10. COPY Any card deck can be copied.

11. LIST Any card deck can be listed on the line printer.

12. CALC Live-display scope can be used as a desk calculator.

13. SPACEWAR Game played with switches on the live-display scope.

14. TOUR Gives visitors a tour of the laboratory on the live-display scope, explaining the construction of the cyclotron, sector-focusing, etc.

2) Monitors

A. JBCM The JANUS basic control monitor, similar to the SDS BCM. Ties up peripherals not essential for real-time use so as to insure faster output of the single program being run under it.

B. JFCM The JANUS file control monitor. Handles up to four programs at once and stores others for later processing. It can be used to "swallow" large calculations such as the DWBA code JULIE so that batch processing can proceed at the same time.

C. JPCM A JANUS file control monitor used to initiate subtasks for cyclotron control.

D. ABS-DEBUG Used to debug new tasks for JANUS.

E. SYSGEN Used to generate a new JANUS system tape.

Multiple "copies" of a number of the tasks can coexist, e.g., several

different TOOTSIE's could be assigned to different sets of ADC's, so the number of simultaneous program possibilities is enormous. Clearly, the number and kinds of peripherals put a practical limit on what programs can be run together, and if too many programs are running at once, the "over-head" time involved in monitoring and memory swapping becomes great enough to lead to diminishing returns. However, there have been numerous occasions in our laboratory when one might have witnessed such scenes as the following. (Each user of the computer is his own operator.)

1. A two-dimensional, "megachannel" Ge(Li)-Ge(Li) coincidence experiment on γ -rays from Pb^{200} decay is entering its third day under the task EVENT. The storage scope was used to set up this experiment, but, once the experiment was running, this scope was given over to other programs. The scope is brought back to EVENT periodically to check on how things are progressing, but a separate one-dimensional analyzer and several scalars are the only continuous monitors. The 21-h Pb^{200} is replenished every few days by a $\text{Tl}^{203}(p,4n)\text{Pb}^{200}$ bombardment using the proton beam of the cyclotron. The task EVENT does get stopped several times per day when the tape unit being used is needed for another program, but the tapes are protected by automatic ends-of-file, and if the ADC's, amplifiers, etc., are not altered, EVENT can easily pick up where it left off.

2. The group operating the cyclotron for the night sets up the task TOOTSIE to collect the (p,d) and (p,t) spectra simultaneously from a single bombardment of Ne^{20} with 40-MeV protons. They use the storage scope to set gates for the digital identification of deuteron and triton pulses from the ΔE and E counters. Because generating displays is one of the most time-

consuming operations for the central processor (that is why a storage scope was selected as the second display unit), they find it necessary to terminate (usually politely) the game of SPACEWAR that was proceeding on the live-display scope. Otherwise, they may have to wait five or ten seconds for each update of their own display, which can be annoying when one is setting up. (Incoming data always have the highest priority, so there is no danger of losing these because of other tasks, but displays have much lower priority, even when part of on-line tasks such as TOOTSIE or POLYPHEMUS, so the human element is left to control them.) Once their gates are set in the two-dimensional mode, ΔE vs $\Delta E + E$, they then monitor the progress of their experiments by periodic updatings of one-dimensional displays on the storage scope. From time to time they punch (CPUNCH) out their accumulated spectra and plot them (all part of TOOTSIE). In the event that the card punch or plotter is in use, the spectra go into a buffer memory to await the availability of the proper device.

3. A student brings in previously collected spectra of γ -rays from Bi^{204} decay. He uses the task MOIRAE to analyze them for energies and intensities. This is done with the live-display scope, using switches to select input information as described below.

4. Several other students have been following the decay of Sm^{141} , using the PDP-9 computer as an analyzer. They bring in some output paper tapes in block binary form, feed them into the Sigma-7, using the task FDP-TAPE, and receive CPUNCH decks in return.

5. One of us is completing a paper on the decay of Cd^{149} and needs "fresh" plots of his spectra for the draftsman. He cleans the India

ink pens for the CalComp plotter, and, using the task MOPIOT, proceeds to run off a number of spectra from CTTCOM decks.

6. Three FORTRAN programs are being run under the task JFCM.

Running continually throughout the night is the DWBA code JULIE, being used to calculate ten cases for inelastic proton scattering from some of the Ni isotopes. Through memory swapping, the Sigma-7 can handle programs requiring as much as 128K words of memory. Although programs such as JULIE run much more slowly than they would on a larger computer, we have found it no great inconvenience to load a deck in the evening and pick up the print-out the next morning.

Running more sporadically are the two other programs. The program TASK RECOVERY is being used to sort spectra from the tapes that resulted from a previous megachannel spectrum of Bi^{205} γ -rays taken with the task EVENT. And the spectrum-analysis program SAMPO,³ which one of us brought back from Berkeley, is being modified, debugged, and tested as a complementary program to the task MOIRAE.

More detailed information about the programs of most interest to nuclear spectroscopists follows, together with some specific examples of their use:

The task EVENT and the FORTRAN program EVENT RECOVERY. The task EVENT, when used in a two-dimensional mode, accepts the input from two of the 13-bit ADC's. This means that two-dimensional spectra as large as 8192 $\times$ 8192 can be run, but we usually find, say, 1024 $\times$ 2048 or 4096 $\times$ 4096 to be more than adequate. When a coincidence event is detected, its x and y ad-

addresses are listed in the two halves of a single computer word, which is fed into a dedicated buffer memory. There are two of these buffers, each with a capacity of 240 words. When one buffer fills, the listing is shifted to the other, while the contents of the first one are written on magnetic tape. The upper limit on the counting rate is set by the speed with which data can be written on the tape, and this is approximately 3000 words/sec. A standard 2400-ft tape completely filled will hold some 1.1 million events.

Most of our Ge(Li)-Ge(Li) spectra, especially of longer-lived activities, are taken with the detectors placed at an angle of 90° to each other and with shielding inserted between them to minimize Compton coincidences. For shorter-lived activities, however, when it is often necessary to collect a full spectrum by repeated bombardments during one night, one needs the most efficient counting geometry possible. For these we place the detectors 180° to each other with little or no shielding between them. Offsetting the source from the central axis helps to reduce $\gamma^\pm$ coincidences, but the Compton edges can sometimes be quite large when this geometry is used. Thus, although these spectra are reduced in quality from the 90° spectra, they are still quite valuable.

The program EVENT RECOVERY is used to scan the tapes and to assemble one-dimensional spectrum "slices" from various gates. Gates can be set on either the x or the y side, and one has the option of setting gates by themselves or of setting gates having selected background gates on either side. For the latter, the program subtracts the background according to the weighted size of the background gates. When a single gate is used, sorting through a 2400-ft tape takes approximately 10 min, depending, of course, on

the particular spectrum and on what else the computer is doing at the same time. Up to about five gates can be sorted simultaneously with relatively little increase in time, perhaps a total of 15 min for sorting one tape. When more than five gates are sorted simultaneously, the memory swapping involved starts slowing down the process markedly, so, although the program can accept an indefinite number of gates, rarely do we use more than five at a time.

The data analysis task MOIRAE. Most of our spectrum analysis is done using this task. Up to 25 spectra can be introduced into the computer by cards, tape, or a data acquisition task. They can then be called up on the live-display scope and manipulated by a set of 32 switches. Some of the switches control the display of the spectrum, such as linear or log display, expansion of vertical and/or horizontal axes, shifting portions of a spectrum from left to right, etc. The others control various routines used to determine the centroids and intensities of the peaks displayed. Some typical spectrum analyses are shown in the following figures.

Fig. 1 shows a portion of the γ -ray spectrum from the decay of Bi^{204} with the background fit to a second-order polynomial. The switches are used to move the tall pointer to the positions of points in the spectrum to be used in calculating the background. Up to 50 points can be used, and the background can be fit up to the ninth degree. The shorter lines show the points that have been accepted. Alternatively, one can select up to 25 pairs of points enclosing regions of up to 512 spectrum points (total) for calculating the background.

Fig. 2 shows the same spectrum, this time with the background

fit to a third-order polynomial. In this and the previous figure, the region of background fit is about as large as one can use and expect to get reasonable results with a low-order polynomial.

Fig. 3 shows a fifth-order fit to the same spectrum. Note that the region of background fit is almost doubled from the previous figures.

Fig. 4 is a display of the data of fig. 3 with the (fifth-order) background subtracted. To obtain the areas of these peaks, one then selects the peak limits with the large pointer and chooses to calculate the peak position either by the full peak or that portion of the peak higher than one-third peak (meaning higher than one-third peak defined within the limits selected). The task then finds the centroid, the area, the sum of raw data plus background, and the square root of that sum.

In fig. 5 we see the above fifth-order background fit with more of the spectrum included for perspective. The fit in question was to a Compton edge.

Once one is satisfied with the display on the scope, he can punch, plot, or print out any information contained on it. After accumulating all the analyses he desires, he can have the computer calculate a calibration curve if he chooses, by making a least-squares fit to an n th degree polynomial. Or he can calculate his peak energies by a similar least-squares fit to a previously generated calibration curve. In each case all the statistical quantities, such as standard deviation of each peak energy from the curve, are also calculated.

Although MOIRAE has proven to be a very satisfactory task, we are continually improving it. For example, it is now in the process of being

modified to add a Gaussian fit with exponential tails to determine the peak area. MOIRAE, however, has proven to be the biggest bottleneck in our work, simply because of the amount of time involved in sitting in front of the scope performing fits. For this reason we are starting to perform some of our analyses with the program SAMPO,³ which searches out peaks on its own. We hope that it will shortly be able to perform much of the more routine analysis and that MOIRAE will be reserved for quality control and for fits to more complicated regions that require on the spot inspections. We are also updating the data analysis programs on the PDP-9 to make them more or less comparable to MOIRAE.

The task TOOTSIE. Most of the particle identification from scattering reactions performed in the laboratory is now done by TOOTSIE, but, because of its extreme flexibility, this task is also of interest to spectroscopists. In fig. 6 we show a set-up for collecting tritons from the (p,t) reaction on a Pr^{141} target. It is a plot of ΔE vs $\Delta E + E$, and we are looking at a slice in the xy plane. The tritons lie in the region between the two curves, each of which was generated by a fifth-order fit to points like those still showing on the upper curve. The tritons can thus be separated digitally from the deuterons and protons, which lie below and to the left. The order of fit can be changed at will, and TOOTSIE can collect multiple spectra, such as (p,d) and (p,t) , simultaneously. TOOTSIE also offers numerous other modes of identification, such as those including time as a second or third co-ordinate. This makes it a potentially powerful tool for the spectroscopist performing on-line experiments.

Acknowledgments:

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- ³Written by J. Routti, whom we thank for its availability.

Figure Captions:

- Fig. 1 Portion of Bi^{204} γ -ray spectrum with second-order background fit. The analyses in figs. 1-5 were performed by J. B. Cross.
- Fig. 2 Same as fig. 1, with third-order fit.
- Fig. 3 Same as fig. 1, with fifth-order fit.
- Fig. 4 Fig. 3 with background subtracted.
- Fig. 5 Larger portion of Bi^{204} γ -ray spectrum showing the fifth-order background fit in better perspective.
- Fig. 6 ΔE vs $\Delta E+E$ display of particles resulting from a proton bombardment of a Pr^{141} target. The tritons lie between the two curves drawn by the task TOOTSIE. From an experiment of R. W. Coles.