AN INTERACTIVE GRAPHICS ANALYSIS SYSTEM FOR
NUCLEAR ENGINEERING APPLICATIONS⁺

by

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ABSTRACT

From working with continuous slowing down theory, the need was recognized for a system which allowed rapid calculation of the theoretical flux, instant comparison with experiment and a simple means of iterating on the slowing down parameters to force flux agreement and reflect cross section modification. Similar requirements exist in other areas of nuclear work for streamlining and simplifying the data analysis process. As a solution, a unique interactive graphics analysis system (RIGAS) was devised to allow a user to calculate, display, compare, manipulate and modify his data without requiring any programming on his part. This was accomplished by establishing human primacy, through extensive human factor considerations, and designing a man-machine dialogue which responds to the mere push of a button. This system results in an instrument which maximizes man's decision making capability and the computer's speed to improve graphic communication and data analysis.

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INTRODUCTION

Nuclear data analysis has become an increasingly complex and time consuming task, involving sophisticated computer codes, large data sets and extremely fast computing machines. One basic ingredient that remains unchanged, however, is the human decision based on graphical representation of the results. Unfortunately, the graphical communications process has not kept pace with technology and forces us to spend greater amounts of time with the mechanics of getting to the decision making point.

Cross section analysis techniques at Rensselaer Polytechnic Institute (RPI) were greatly improved by using Continuous Slowing Down Theory (CSDT), which allows a small number of integral parameters to represent the effects of a large number of cross sections. This theory was refined to include inelastic scattering¹ and extended to finite media² to provide a theoretical flux for comparison with the experimental values measured at RPI. Burns had further shown^{3,4} that one could iterate on the slowing down parameters, ξ and age, to force agreement between the two spectra. The resultant parameters could then be used to regenerate the basic cross sections through the separable kernel technique. Although this required a simple change of these parameters, the computing and plotting times involved with each iteration were inordinate. To make this method practical, a system was needed which allowed rapid calculation, instant evaluation and a simple means of making further changes.

These requirements are by no means unique to CSDT. Throughout all disciplines of science, one is faced with digesting voluminous tabular data generated by modern instrumentation, be it a computer or measuring device. The obvious and traditional

recourse is again some means of graphical representation. Looking at the problem in general, we find certain desires common to all users; the ability to

- (1) Calculate
- (2) Display
- (3) Compare
- (4) Manipulate
- (5) Modify

In order to satisfy these desires at present, anyone doing such analysis work is required to be an accomplished computer programmer, at least in FORTRAN. With this motivation, we proceeded to design the Rensselaer Interactive Graphics Analysis System (RIGAS). The guiding philosophy of this system is to satisfy the five common desires, which also encompasses the CSDT problem, and do this without requiring any programming expertise on the part of the user.

This latter specification describes both the uniqueness and major problem areas of the design. A highly specialized program could easily be devised to solve the CSDT problem, but this would just add to the myriad of other specialized systems now in existence. Generalization of such a system would afford use to others, but still necessitates their having a detailed knowledge of the operations and functioning. To be of real and lasting value, the system should function much like a vending machine - simple input producing complex output at the push of a button. This requires a form of intercourse between the user and the system which is elementary, obvious and highly effective.

THE MAN-MACHINE DIALOGUE

Man and machine can communicate in any number of ways to carry out a desired process. This communication, or dialogue, is the key element to user acceptance and should perform the systems tasks with minimum intrusion on man. Unlike batch processing, where all operations are predetermined, a symbiotic association must exist to bring man and computer together to formulate a scientific problem rather than just a solution. The man-computer dialogue is the only common point between the two entities and is responsible for success or failure of the system. Furthermore, the burden is on the dialogue designer to make the computer seem intelligent and understanding in order to enhance acceptance.

The system design procedure for RIGAS is shown in Figure 1 and follows the recommendations of Martin⁵. The first major task is to evaluate the potential users and choose dialogue types which fit both the user and the problems to be solved. The first two steps have already been specified in that we wish to satisfy those five common desires for RIGAS users - nuclear scientists and engineers intimately familiar with their individual data sets. Additionally, to attain the symbiotic relationship, these users must operate the terminals in an on-line mode to make the necessary decisions for problem formulation.

User capabilities can be summarized by stating that RIGAS is intended for use by casual operators, possessing relatively high IQ's, some programming skills, operating in the active-intercept mode but having little system indoctrination. A casual operator is one who approaches the terminal on an "as needed" basis and is contrasted with the dedicated operator whose full-time duties involve system operation. Above average intelligence can greatly simplify a dialogue by assuming

that the learning and retention processes will quickly improve system performance. Programming skills are included to ensure familiarity with basic computer terminology not expected of laymen. The capability of operating in the active-intercept mode is again a result of symbiotic association and is essential for decision making. The active-intercept operator can initiate data entry and enquiries and can intervene should an unprocessable or questionable transaction be relayed by the computer. In other words, the operator can make an on-line decision.

From the stated purpose of this dialogue and the capabilities of the potential users, it is obvious that a system is desired which is extremely easy to use and yet encourages information exchange. The inherently high information capacity of graphs is a major motivating force for using such representation. However, the mechanics of obtaining it must be simplified and streamlined. The methods of accomplishing this, through the man-machine dialogue, must now be specified.

One would think the ideal dialogue, from the human standpoint, would be the same as between humans - natural language. This is true if the computer had a verbal Input/Output (I/O) capability, but technology has not progressed that far. Typing the conversation is possible but the length of time required would soon frustrate the average user. Additionally, the English language is fraught with so many ambiguities that programming the dialogue would be a nearly impossible task. As a replacement, we have devised a "natural response" dialogue which elicits a natural reaction to various choices presented and utilizes three modes of I/O. The first two are the conventional teletype and lightpen-CRT devices. In both these cases, the computer asks a question and the user responds by typing information or makes a selection with the lightpen. The third involves building

the dialogue into a hardware device in the form of labeled pushbuttons. While this limits the flexibility of the system, the labels describe the action to make it totally unambiguous.

Selecting a man-machine dialogue implies the existence of an integrated hardware-software package which accomplishes that dialogue in the intended manner. Although both contribute equally to the success of the system, the hardware actually determines the performance limits. We can generalize by saying the hardware determines the feasibility of the dialogue and defines a broadband region for ease of use. The software must operate within this region to develop the design to its fullest potential. Since the interplay of hardware and software directly affects the speed with which the system responds, the time response criteria must be specified prior to selecting the terminal equipment.

As with man-man communications, certain points of etiquette must be observed in the dialogue to avoid frustration⁶. The system must respond quickly to input to signify receipt and long pauses must be avoided during calculation which causes the user to lose attention. This latter criterion can be satisfied by returning interim responses during the operation which are of the informative nature. Error messages, however, should be delayed to allow man to achieve psychological closure, which means to complete his current thought. To summarize, we state that response time shall, on the average, be between 2 and 4 seconds, with modifications allowed providing closure is adhered to and interim responses used. Error messages shall be delayed until 2 seconds after closure, if possible.

Specification of the actual hardware is fairly straightforward, once the dialogue and time responses are chosen. We wish to maintain a complementary mixture of I/O devices natural response, but still provide a wide information

bandwidth and flexibility . The main portion of the work will be done by the graphics terminal which allows great flexibility and high information transfer rates. Teletypes (TTY), although more restricted in capacity, still retain generality. These devices are nicely balanced by the specialized hardware which has the dialogue built in. This takes the form of 32 lighted and labeled push-buttons and is referred to as the Hardware Dialogue Unit.

The computing power required of the system depends on the sophistication of the application and the ease with which it can be done. The analysis and modification of nuclear data involves large data files and complex mathematical manipulation. This would indicate the need for a processor much larger than the standard minicomputer associated with intelligent terminals. Time response, however, dictates criteria which may not be available in current time-sharing systems. This conflict is resolved by a compromise using a "super-intelligent" terminal which has sufficient memory, speed and peripherals to provide local calculation and display. Instances requiring more computing power can be satisfied with a communications link to a large remote system through time-sharing. A minimum system configuration would then consist of a minicomputer, magnetic disk (and a disk operating system), magnetic tape, a data communications link, a graphics terminal with lightpen and a multiple pushbutton unit. The actual RIGAS configuration is somewhat more elegant, being comprised of a DEC PDP-15 minicomputer with 32K words of core, 2 disk surfaces, 4 tape drives, a variable rate asynchronous communications interface, a VT04 graphics terminal and the Hardware Dialogue Unit.

Although any multiple pushbutton system can enter data into the computer, a specialized button layout was required for RIGAS to satisfy human factor con-

siderations. As will be described shortly, this layout enhances the obviousness of the operation selected and therefore requires a unique piece of equipment. This unit, along with the communications link, TTY and CRT required extensive software development to achieve maximum flexibility of the dialogue within hardware constraints. From inception, through design, to completion required approximately two man years. This includes many false starts, hardware design and construction and human factors research in addition to both FORTRAN and assembler level programming.

With the dialogue and hardware criteria specified, we can now proceed with the description of the resulting analysis system and its functioning. To reiterate the guiding principles, this system allows the user to calculate, display, compare, manipulate and modify his data without requiring programming on his part. The natural response dialogue establishes a symbiotic relationship between man and machine to both formulate the problem and provide its solution.

RIGAS OPERATION AND FUNCTIONING

The sequence of operations of RIGAS is controlled entirely from the Hardware Dialogue Unit (HDU), shown in Figure 2. The function buttons labeled ENTER, TEXT, SELECT, and DISPLA control entry to routines which accomplish the major tasks of the system. Entry is possible only when a CRT monitor display instructs the user to select a function. Within two of these functions (SELECT and DISPLA) are options which operate on the data being displayed, but still keeps the user in that function. Options are called by pressing the appropriate button on the option area of the HDU.

The ENTER function allows the user to enter data into RIGAS and is usually the first function performed. The standard CSISR data format⁷ is used, which

consists of a file and multiple subfiles. Each subfile contains both textual and numerical data pertaining to the general file. TEXT provides a means of displaying the bibliographic portions of each subfile entered and may be called at any time after entry. The SELECT button accesses a routine which displays the data portion of a subfile and generates a working file from all or part of that data for use in the DISPLA function. The EXPAND/CONTRACT and SCROLL options are available in SELECT to inspect the selected data for suitability. DISPLA, the actual analysis section of RIGAS, creates displays of one or two working files and has three additional options; EXACT VALUE, MODIFY DATA and USER ROUTINE. Once a user selects a function, he cannot perform another without returning to the monitor display.

The options are operations which effect the display in a manner indicated by their names. EXPAND/CONTRACT expands or contracts the selected axis while SCROLL moves the curve left or right. EXACT VALUE allows one to obtain the abscissa and ordinate values of any point on the display. MODIFY DATA affords a means of shifting the entire curve in the vertical direction (normalizing) or changing the value of a single point. If the user has specialized operations he wishes to perform on the data, he may "plug in" up to five such programs and call them using the USER ROUTINE option.

The function portion of the HDU contains seven additional buttons; HELP, SYMPATHY, ACCEPT, REJECT, CONT., BKSPC and ABORT. The HELP button brings in detailed instructions for the operation of the system should a user not understand what is required from the display. If confusion still reigns, pressing SYMPATHY allows one to enter the cause of frustration for review by systems personnel and possible modification. ACCEPT/REJECT is a confirmation response

asked for when selections are made to ensure both man and machine understand the request. CONT. allows the user to continue with the function sequence while BKSPC returns him to the previous display. Finally, if the user wishes to terminate the function being performed, he presses ABORT and is instructed to select another. If ABORT is pressed while in the monitor display, the entire system is terminated.

Physical positioning and color of the buttons further adds to the dialogue. The ENTER through DISPLA buttons form a natural top to bottom progression, indicating the normal flow of data. A double HELP button, with different orientation, makes this stand out from all others. The REJECT/ACCEPT alternatives, as well as ABORT/CONT., use the familiar "traffic light" positioning and color to draw an analogy to the button meanings. BKSPC is placed in the intermediate position to indicate an intermediate response to either of these alternatives.

The options occupy a separate panel, have two word labels and are isolated from each other by an outline. These buttons are functionally arranged to make the operation more obvious. For example, pressing EXPAND X expands the curve in the X direction and makes it seem as if the curve moves to the right. This button is therefore placed at the right of this option outline. Likewise, if one wishes to increase the value of a point, he presses either COARSE or FINE INCREASE, which are positioned above the MODIFY DATA button.

Taking a typical operating sequence, the first function performed is to enter data by pressing ENTER. Since this function requires entering unique information, such as filenames, all further I/O is done through the TTY. The entered data may take two forms; raw data or previously processed data. The first is a file in CSISR card image format, stored on magnetic tape, and is the prime input for the analysis. When this type file is entered, the information

is copied to a second tape, in binary form, and called a previously processed file. Subsequent entries of the same data can be made from these previously processed tapes, which protects the valuable raw data and accelerates data entry. Upon pushing ENTER, the user is advised of the contents of each of these tapes and is asked to type the name of the desired file. If he does not have the raw data in CSISR format, he types a name different from those listed and the system creates the format from his data through teletype queries. Since data entry is a rather lengthy process, interim responses are displayed on the CRT to retain the user's attention.

TEXT allows the user to view the bibliographic portions of the subfiles entered. After selecting the appropriate file, a directory is presented, Figure 3, which gives pertinent information for each subfile of the selected file and asks the user to specify the desired subfile. Selection is made by touching one of the underlined and intensified filenames with the lightpen. This name then blinks and the selection must be confirmed with ACCEPT/REJECT. The bibliography shown in Figure 4 then appears. At this time the user may press CONT. to view other bibliographies or he may ABORT this function and select another.

SELECT performs a parallel operation for the data portion of the subfiles. Once again the user selects the file and the directory is displayed. This time, however, the data filenames are underlined and intensified. The appropriate subfile is selected, confirmed and the entire data subfile appears as shown in Figure 5. If the number of data points is less than 200, the entire subfile is displayed. If the number exceeds this, the system generates what we call a distorted average. An average is computed and each point contributing to that

average is inspected to determine if it differs from this by more than one standard deviation. If so, that value is used as the average to preclude "washing out" strong local variations. The user may select the entire curve or specify a limited range by moving the arrows with the lightpen. The figure shows that only the region between the arrow boundaries is desired. The user then pushes ACCEPT, selects the data format from the display of Figure 6 and the selected data is then read. While accessing the data, the user is given an interim response which has the filename, range limits and format displayed. The requested data, Figure 7, may be inspected, using the options listed there, to determine if this is the data he wishes to work with or not. Figure 8 shows this same curve scrolled left and expanded in both the X and Y directions. If this is suitable, he presses CONT. and gives the display a unique working file name through the TTY. If not, he can press CONT., not save the file and get another or backspace the same to change the format or range.

Once all working files are established, the user selects the DISPLA function to carry out the actual analysis. A number of displays may be set up, containing one or two curves per display, by selecting the desired working file names shown in Figure 9. As illustrated in this figure, the same curve may appear in various displays. Selecting a Display Designation in the right hand column brings in the two curves shown in Figure 10. Once again the user is advised of the displayed filenames and the options available. The arrow under these names appears later, when an option is selected. These curves may be simultaneously scrolled and expanded in addition to the three new options.

To keep the display as clean as possible, only minimal data is included on the axes. If one desires the exact value of a point, he pushes this option button

and selects the file with the lightpen, as shown in Figure 10. An arrow then appears which can be moved to the general area of the point and its position accepted. A blinking indicator appears on a point and this may be shifted with the STEP LEFT/STEP RIGHT buttons. Once the desired point is reached, the user presses ACCEPT and the values are shown below the names, Figure 11. If another value is needed, he pushes CONT. and moves the blinking indicator as before. The new value is then displayed after pressing ACCEPT. The user terminates this, and all options, by pressing BKSPC.

If one wishes to modify the displayed data, he presses the option button labeled MODIFY DATA. After specifying the file name, as in Figure 10, a query appears at the top of the CRT asking if this is a normalization or a modification. If normalize is selected with the lightpen, the instruction "normalize" appears and the entire curve may be shifted vertically using the INCREASE/DECREASE buttons. Figure 12 shows a normalization in progress. The results may be deleted (DELETE MOD.) or saved (SAVE MOD.) If it is to be saved, one can assign the same or different name from the TTY. This also provides a convenient way to duplicate curves. A normalization is requested, but no changes made. The curve can then be saved with a different name.

A modification involves changing a single point rather than the entire curve. Upon selecting this, a sequence similar to EXACT VALUE is followed to get the desired point and value. This is then changed using the same INCREASE/DECREASE buttons and the modification continued by pressing CONT., moving the blinking indicator and making further changes. Figure 13 shows such a modification being done around 200 Kev. These modifications may also be deleted or saved, as with the normalization. Often one must modify a curve generated by

an integral function, that is, the preceeding or succeeding values depend on each other. Prior to making a modification, the user is asked if changing the blinking point effects the value of others. If so, he specifies the direction and these are changed automatically when the blinking point is changed.

The final option available under the DISPLA function is USER ROUTINE. As stated previously, this allows the user to perform operations not accounted for in the general design and are supplied by the individual. Upon pressing USER ROUTINE, a display is presented allowing the selection of one or a sequence of these routines with the lightpen. To execute this sequence, the user presses CONT. and the routine name in the left column of Figure 14 currently being executed blinks. Once complete, the user presses BKSPC to return to Figure 9 or ABORT to terminate the function.

The entire system was tested on totally untrained subjects having the stated user capabilities. Left on their own with the system and a short user's manual, they were able to operate the system with little difficulty. The main advice given was to experiment with the buttons if a question arose, since RIGAS is insensitive to illogical choices. In any event, the design is such that data can never be accidentally destroyed by pressing a wrong button.

The success of RIGAS holds much promise for future data analysis at RPI. A system is finally available which allows the user to enter his data and perform operations in an on-line mode by the mere press of a button. In a companion paper⁸, the application of this system to the CSDT problem is described, along with the resultant recommendations for cross section modifications for depleted uranium (ENDF/B-II) and iron-1124. This application shows that RIGAS provides a new and valuable tool to the reactor physicist and indicates the shape of things to come using on-line interactive graphics.

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FIGURE CAPTIONS

- Figure 1 Procedure for the design of the man-machine dialogue used in the Rensselaer Interactive Graphics Analysis System (RIGAS).
- Figure 2 Hardware Dialogue Unit (HDU) that controls the operating sequence of RIGAS. The four functions: ENTER, TEXT, SELECT and DISPLA call the major tasks of the system and are augmented by the five option areas.
- Figure 3 Directory resulting from pushing the TEXT button of the HDU. A summary of each available file is presented and allows the user to select a bibliographic file for display from the underlined and intensified names.
- Figure 4 Bibliography display resulting from selection of the Bibliographic File Name J. W. M. BIB in Figure 3.
- Figure 5 Display resulting from the selection of a Data File Name in the function SELECT. The user specifies the portion of the data file he wishes to inspect by setting the boundaries.
- Figure 6 Display affording the user four different formats to display the specified data of Figure 5.
- Figure 7 Display of the specified data from Figure 5. The data file name and format are given along with the options one may call from the HDU of Figure 2.
- Figure 8 Display of Figure 7 which has been acted upon by both available options. The curve has been scrolled left and expanded once in both the X and Y directions.
- Figure 9 Selection of working files to display one or two curves in the function DISPLA. The same curve may occur in any number of displays and viewed by selecting the Display Designator from the right hand column.
- Figure 10 Final display of working files selected from Figure 9. The file names and format are presented along with available options called from the HDU, Figure 2.
- Figure 11 Display resulting from calling the EXACT VALUE option in the DISPLA function. Prior to getting the values, the user specifies the point by moving an arrow to the area with the light pen and presses ACCEPT on the HDU. The specified part blinks and is either accepted or changed using the STEP buttons of the HDU.

- Figure 12 Normalization in progress, called by the MODIFY DATA, option in the function DISPLA. The curve being normalized is moved through the INCREASE/DECREASE buttons and the final normalization saved or deleted.
- Figure 13 Modification in progress, called by the MODIFY DATA option in the function DISPLA. An individual point may be modified using the same buttons as described in Figure 12.
- Figure 14 Response to pressing the USER ROUTINE button while in the DISPLA function. The specialized sequence established in right hand column is executed by pressing the CONT. button and the routine name in the left column blinks 23 each is being executed.

SYSTEM DESIGN STEPS

Figure 1

Figure 2

DIRECTORY

SELECT A FILE WITH THE LIGHTPEN

AVAILABLE
MAINFILES

IDENT <J H MEADOWS, J F WHALEN>
 TITLE THE TOTAL NEUTRON CROSS SECTION OF LITHIUM-7 AND CARBO
 CIRCULOGRAPHY FILE NAME J H M 818 DATA FILE NAME J H M DAT
 ASCISSA RANGE 0 5000E+00 0 1498E+01 MEV
 INFO AVAILABLE EN EN-RSL DATA DATA-CP

CSISR

IDENT <J F WHALEN, J H MEADOWS>
 TITLE 5-LI-6 TOT
 CIRCULOGRAPHY FILE NAME J F W 818 DATA FILE NAME J F W DAT
 ASCISSA RANGE 0 5000E+00 0 1498E+01 MEV
 INFO AVAILABLE EN EN-RSL DATA DATA-CP

Figure 3

BIBLIOGRAPHY

INSTITUTE <IUSANL>
REFERENCE <J.NSC.41.351.7009>
<H.WHALEN.7002>
AUTHOR <J.H.MEADOWS,J.F.WHALEN>
TITLE THE TOTAL NEUTRON CROSS SECTION OF LITHIUM-7 AND CARBO
FROM 100 TO 1500 KEV
FACILITY <HOC> 3 S-MEV VAN-DE-GRAAFF
N-SOURCE <P-LI2> LI2 (P,N) REACTION AT 0 DEGREES
INC-SPECT MONOENERGETIC SOURCE ENERGY RESOLUTION = 2.5 TO 5.0
KEV. DETERMINED MAINLY BY TARGET THICKNESS
SAMPLE <COM1> 99.991 PER-CENT LI-7 SAMPLES ENCASED IN
STAINLESS STEEL CANS. SAMPLE THICKNESSES 0.0708,
0.1165, AND 0.1633 ATOMS/G
METHOD <TRAN> TRANSMISSION
STANDARD <ACOL> ABSOLUTE ENERGY CALIBRATED USING LI2 (P,N) AN
C11 (P,N) REACTION THRESHOLDS AT 1001 AND 3016 KEV
DETECTOR <LSCIN,CF3> CONCENTRIC RINGS OF CF3 COUNTERS USED BELO
650-KEV. ABOVE 650-KEV NEUTRON ENERGY. THESE WERE
REPLACED BY A 5 X 5-CM DIAMETER LIQUID SCINTILLATOR
WITH PULSE-HEIGHT DISCRIMINATION
FLUX MONITORED BY CF3 COUNTERS
PART-LET (N) NEUTRON
EXP-ANALYSIS ERRORS GIVEN ARE STATISTICAL ERRORS ONLY
CORRECTION CORRECTED FOR BACKGROUND AND FOR TARGET THICKNESS
STATUS APPROV. APPROVED BY AUTHOR
HISTORY <701010C>

AVAILABLE
MAINFILES

CS15P

Figure 4

Figure 5

THIS DATA MAY BE DISPLAYED AS:

- ✓ LINEAR X/LINEAR Y
- ✓ NATLOG X/LINEAR Y
- ✓ LINEAR X/NATLOG Y
- ✓ NATLOG X/NATLOG Y

CHOOSE ONE WITH LIGHTPEN

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14