

Evaluation, storage, and retrieval of neutron cross-section data are of major concern to the international community of low-energy physicists. Discussed is an experimentally evolving program, called SCORE, designed to perform these services.

The overall concept of the SCORE program and the programming environment are presented. Cross-section data entry, evaluation, and curve generation are discussed.

INTERACTIVE GRAPHICS IN DATA PROCESSING Neutron cross-section evaluation

by R. J. Creasy

One of the major activities of many nuclear research centers is the deriving of meaning from experimental data produced by nuclear particle accelerators and nuclear event detectors. H. Horstman suggests the magnitude of the volume of data produced at an accelerator center by citing the output of the one at Geel, Belgium. "If cross section data accumulated . . . were punched into cards, we might get about 100 kg of punched cards per day."¹

A routine output of a large number of accelerator centers is neutron cross-section data. A nuclear *cross section* is the ratio of target nuclei reacting per second to a flux of incident particles. For any particular reaction, the nuclear cross section is dependent upon the target material, the energy of the incident particles, and the particle type. Nuclear cross-section has the dimension of area, the unit being termed the *barn* (10^{-24} cm² per nucleus), and is a measure of the probability of the occurrence of nuclear reactions (events). When measuring a large number of events, each reaction type is present in proportion to its cross-section value. Large quantities of cross-section data are produced because of the number of variables present: particle type and energy, target material and observed events.

This paper relates primarily to cross-section calculations wherein the incident bombarding beam consists of neutrons. Typical nuclear events might be the production of alpha particles by

incident neutrons or the production of scattered neutrons (at a certain scattering angle and energy) by incident neutrons. All experiments are limited, by practical considerations, to the production of data over a small region of the energy spectrum. Therefore, data from many sources must be correlated to produce a complete set of cross sections for a given isotope.

This paper first introduces an experimental computer program, called SCORE, which allows an evaluator to correlate data and calculate neutron cross sections interactively through a display console. Next, there is a brief description of the computing environment—the computing system and its relation to the SCORE program. Finally, system operation is discussed and exemplified by showing the steps necessary to perform data evaluation and curve generation. The paper concludes by suggesting capabilities that could usefully be added to SCORE.

The SCORE program

Low-energy physics research is continuously producing large volumes of data. If this data is not distributed in a convenient form as fast as it is generated, a potential data user may base his work on experimental results that do not reflect current knowledge either completely or accurately. A user attempting to select and coordinate the significant parts of the experimental data pertinent to a problem in which he is interested is called an *evaluator*. The inspection of data, the application of statistical tests, the production of cross-section versus neutron-energy plots, and the use of various theoretical models compose the evaluation cycle. The process is repeated until the evaluator is satisfied that his data are consistent. Although traditional data processing techniques are presently used, the basic methods are unable to cope with the volume of data produced. A simple task, such as data plotting, typically may require hours or days.

program description

A prototype program to assist in the evaluation of this data has been designed and implemented for the IBM SYSTEM/360.² This program, called SCORE, is the result of a joint study by Atomic International (funded by the Atomic Energy Commission) and the International Business Machines Corporation. The evaluator uses the IBM 2250 display console via SCORE to rapidly perform operations on data, thereby greatly reducing cross-section evaluation time. The first version of SCORE provided a minimal capability, allowing only a few operations to be performed on the data base. As experience with the system increased, the design was modified—new functions were added and old ones were changed—and the version of the system described in this paper evolved. Program evolution is a continuing process, permitting the evaluation of alternatives in an operational environment. Until more is known about the design of interactive systems, such evolution is required to improve the man-machine interface.

Even though the programmed techniques are general in nature, such as the scaling of data for plotting, all functions of SCORE are programmed with cross-section data and other aspects of the nuclear interaction process in mind. The specialized design of SCORE limits its use in other fields, but has simplified system problems. For example, some flow of control can be implicit for certain functions, while it can be explicit for others. Not only is specialization convenient for the user, the restriction limits the anticipated functional requirements during the design phases. An advantage to the user is the minimal knowledge outside of his field required to operate the system. Although hundreds of parameters may be involved, the evaluator need only concern himself with those pertinent to the immediate problem.

simplifying
system
problems

Computing environment

Using a main storage partition under the SYSTEM/360 Operating System (OS/360) with basic graphics support, SCORE uses the 2250 Model 1 display console with a 4K-byte buffer, character generator, alphanumeric keyboard, and light pen. The program is written in FORTRAN IV as implemented in the FORTRAN H-size compiler. There are two exceptions: (1) the FORTRAN G compiler is used to support direct-access data files on the IBM 2311 disk units, and (2) some graphics routines that were originally written in assembler language are being converted to FORTRAN IV. SCORE also uses the multiprogramming provided by OS/360.

A typical session using SCORE on a SYSTEM/360 Model 50 requires less than 165K bytes of main storage and CPU time of about ten percent of the session time. Therefore, a 512K-byte memory allows concurrent batch processing with good efficiency. In this multiprogramming environment, SCORE's interaction with the evaluator is very fast, ranging from a tenth of a second for a trivial request to a minute for the computation of a complicated theoretical model.

System operation

Normally, SCORE is waiting for the user to interact with the picture on the 2250 display screen, and the CPU is released for other uses. When an attention signal is generated by striking either of two special keys or by using the light pen, the executive program of SCORE decodes the action and initiates functions within the system in combinations inferred from the context of the user action. When a new decision point is reached, or more information is required, SCORE again waits for the user to resume the interaction cycle.

Each function can manipulate both flags and values contained in the data base via common arrays. For example, the point deletion function sets a flag attached to a data element, and point correction requires both changing data and setting an update flag. Other functions bring information into memory from magnetic tape or from direct-access data sets. A major operation that the evaluator

Figure 1 Initial request

LABORATORY:	IBM PALO ALTO
EVALUATOR:	R J CREASY
DATE:	MAY 1, 1968
PROBLEM I.D.:	1
ELEMENT:	11
MASS NUMBER:	23
REACTION:	NA
MINIMUM ENERGY (MEV):	6.
MAXIMUM ENERGY (MEV):	22.
LEVEL ENERGY (MEV):	

cannot perform is the alteration of his original set of data, which must be performed outside of the domain of the system by change cards produced by SCORE. The system need not inspect combinations of functions for validity because full protection of the original data is assured.

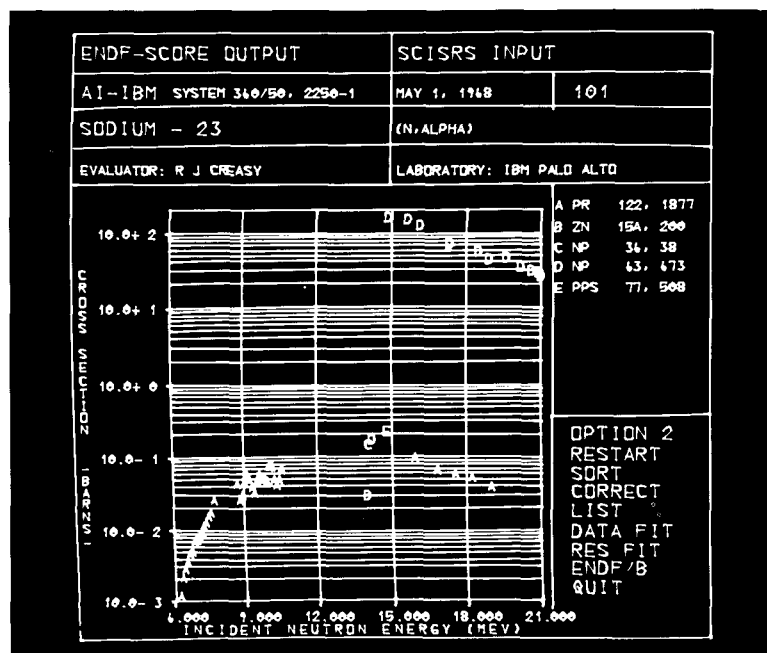
data
entry

The Sigma Center at Brookhaven National Laboratory acts as a distribution agency for neutron cross-section data. Upon request, data is written on magnetic tape as card images and forwarded to the evaluator. A SCORE utility program, the Sigma Center Information Storage and Retrieval System Adaptation Program (SAP), reads these tapes and produces entries in the SCORE isotope library. Initial processing by SAP produces on other tapes a compact representation of the several hundred thousand data bytes composing the cross sections for a typical isotope. In addition, SAP creates directory information to identify the energy range for all reaction types for each isotope, which SCORE uses to load isotope data into a direct-access data set and to locate the data requested by the evaluator.

data
evaluation

Figure 1 shows an example of the information the evaluator enters when initially using the system. Here, he identifies himself to SCORE and requests data for the isotope with mass number 23 of the element with atomic number 11 (sodium 23). The system automatically locates the proper library file, requests mounting of the tape, and moves the isotope information to the disk. The requested isotope data set is used for all transactions until a different isotope is selected. Since SCORE is aware of the disk contents, many

Figure 2 Typical cross-section plot



operations may be accomplished on data for one isotope without further tape handling.

Data from the disk file are selected for reaction type and energy range as specified in Figure 1, and are placed in main storage. This data can be sorted into a subset on the basis of experimental identification tags or neutron energy. To select a new group of data, the RESTART option must be used. Changes can be made to data in memory, but no updating of the disk file (or the tape library) can occur directly. As a convenience, whenever a data element is changed, its last value is stored by the system until another change is entered. Except for operations that affect multiple data elements, the evaluator can erase the effect of his last change.

Figure 2 shows the displayed data for a neutron-in-alpha-particle-out type of interaction (n, α) with the neutron energy between the limits of 6 and 22 million electron volts (MeV). SCORE has selected axis types and scaling values appropriate to the data; textual information is also displayed. This picture shows the output format of the system; all information necessary to completely identify the data and evaluator is present in a form convenient for publication. Also, a serial record of every transaction is kept in a sequential data set, which can be correlated with the picture number for a specific session. All sequences of operations leading to a desired evaluation are preserved for later use.

Each datum in Figure 2 is shown plotted with a letter. Data points are identified with particular experiments by keying the letters with the publications codes listed in the middle righthand

Figure 3 Data correction

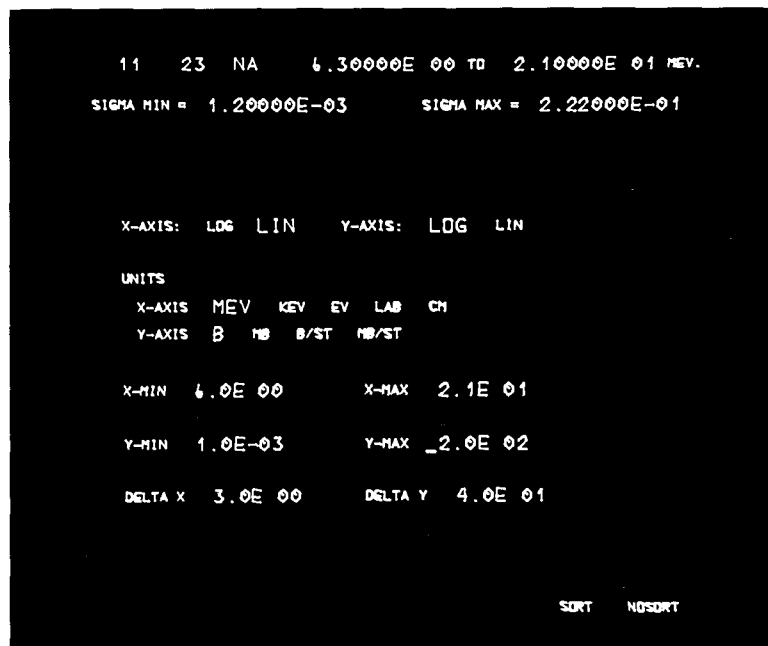
SODIUM - 23		(N, ALPHA)	NO. 101	
LIGHT PEN DATA		TIMES .001	PLUS 0.00 +00	
INCORRECT DATA		CORRECTED DATA		
ENERGY	SIGMA	ENERGY	SIGMA	
(MEV)	(BARN)	(MEV)	(BARN)	
1.48100E 01	1.44000E 02	1.48100E 01	1.44000E-01	
1.54700E 01	1.53000E 02	1.54700E 01	1.53000E-01	
1.61500E 01	1.34000E 02	1.61500E 01	1.34000E-01	
1.73300E 01	7.55000E 01	1.73300E 01	7.55000E-02	
1.84100E 01	4.00000E 01	1.84100E 01	4.00000E-02	
1.81200E 01	4.54000E 01	1.81200E 01	4.54000E-02	
1.74100E 01	4.10000E 01	1.74100E 01	4.10000E-02	
2.01100E 01	3.40000E 01	2.01100E 01	3.40000E-02	
2.04300E 01	3.07000E 01	2.04300E 01	3.07000E-02	
2.01000E 01	2.10000E 01	2.01000E 01	2.10000E-02	
2.10000E 01	2.58000E 01	2.10000E 01	2.58000E-02	

portion of the display. If all codes do not fit into the allotted space, new code groups can be displayed by touching any item in the list with the light pen.

The utility of the SCORE system may be illustrated by the following example procedure. Most of the data identified by the letter D (*Nuclear Physics*, Volume 63, page 673) appears in millibarns instead of barns. This difference introduces an apparent error of a factor of one thousand in the magnitude of the cross section. Using the light pen, corrective system options can be selected from the list in the lower right of the display. (This list can also be paged, by touching the first option with the light pen.) After selecting the CORRECT option, points may be selected with the light pen and tabulated, as shown to the left of Figure 3. A multiplicative or additive factor, set from the keyboard, can be applied to any value selected by the light pen. Also, the 2250 cursor can be used for changing any datum. The list to the left shows the data as first displayed; the new values are on the right, wherein the original data has been corrected by multiplying the cross section by 0.001.

Continuing the example, before the picture is displayed again, the NOSORT option is selected by SCORE to allow the use of new axis limits or types. The top of Figure 4 shows the range of each variable to assist the evaluator in the selection of plotting parameters by means of either light pen or keyboard. In this example, the vertical scale is expanded by reducing the maximum value of the upper limit of the ordinate, and the data are displayed as shown

Figure 4 New axis limits and types



in Figure 5. Using options not shown, error bars are added to Figure 5. Other options can

- Delete and restore points
- Sort data by reference or energy range
- Apply an energy-shifting transformation to experimental data
- Restart to change initial parameters
- Quit the session

The results of an evaluation are usually the parameters of a curve or a mathematical expression that closely approximates the raw data. These results provide a convenient method for computations involving isotopes in such engineering applications as the design of nuclear reactors. Methods are currently available to the evaluator, under the SCORE program, for producing curves that fit his data. Also, the ENDF/B option permits superimposing, on the display data points, a curve that has been generated from data distributed to the industry. If the evaluator feels the industry curve represents the data well in his region of interest, he may use it; otherwise, he must produce the necessary curve himself.

One method of curve generation, selected by the DATA FIT option, enables the operator to enter, move, and list inflection points by the light pen using options indicated in the lower right corner in Figure 6. The LINEAR option connects the inflection points with straight line segments. By pointing to the SPLINE option, cubic-curve segments, continuous in their second derivatives, are caused to join the inflection points, as the example in

curve
generation

Figure 5 Expanded cross-section plot

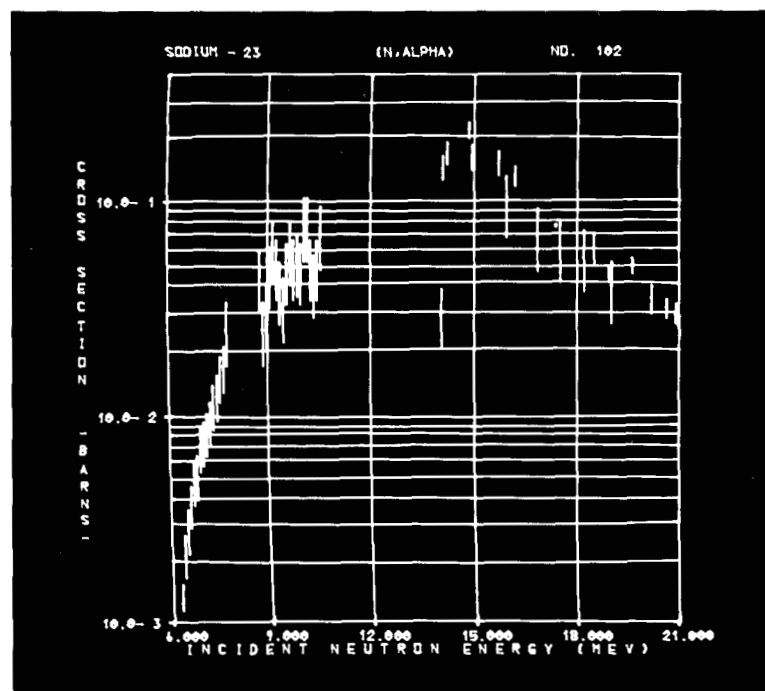


Figure 6 Spline curve

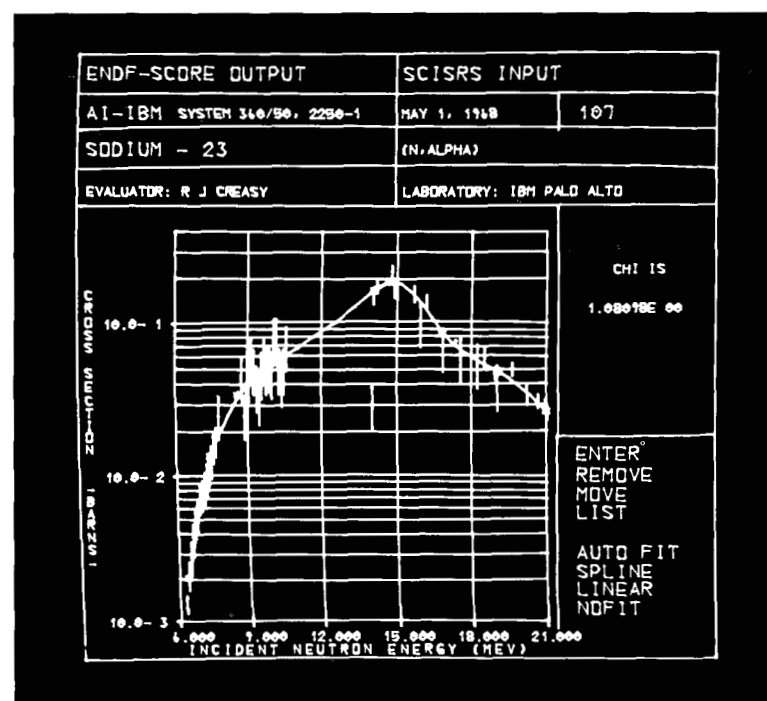


Figure 7 M-and S-level curves

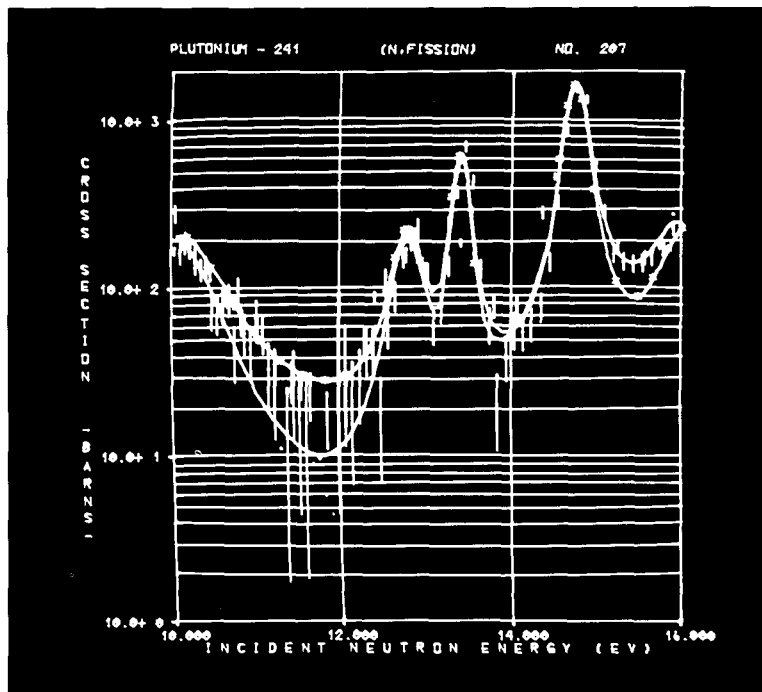


Figure 6 shows.³ The AUTO FIT option adjusts the ordinate values of each node to achieve the best least squares fit between the data and a cubic spline connecting the nodes. For all three options, the CHI value is displayed on the right side of the screen, giving the evaluator a quantitative measure of the goodness-of-fit between the curve and data (chi-square test).

Two models that use parameters to describe resonance regions provide a second method of curve production. The M-LEVEL option invokes the two channel Reich-Moore multilevel model calculation, which requires about one minute of computation time on the SYSTEM/360 Model 50. Less time is required for the simpler Breit-Wigner model, invoked by the S-LEVEL option. In addition, resolution and Doppler broadening are used in these functions.⁴ The several hundred parameters can be loaded from secondary storage by the LOAD RES option, and can be modified by the MOD RES option for resonance parameters or by the MOD PARM option for resolution and broadening. New data can be added by the ADD RES option and stored for later retrieval by the STORERES.

Figure 7 shows curves generated by both models for plutonium 241 data. The next to last curve generated is identified by asterisks on the curve. (In Figure 7, the output of the S-LEVEL model is so marked.) The last curve calculated by SCORE can be displayed alone or compared with the next to last curve. Pictures of the screen must be taken to compare the shapes of more than two curves or curves computed out of sequence.

Concluding remarks

SCORE is an experimental prototype program that has proved the feasibility of computer-aided neutron cross-section evaluation. Additional curve generation and statistical functions, such as the ability to do a least squares fit on data, should be added to make SCORE practical for operational use. An improved system structure is necessary to facilitate future system additions and to make the linkage editor overlay representation more compact. For better modeling and evaluation of data, the evaluator should be able to display parametric information abstracted from published experiment descriptions. Finally, some data handling techniques should be available for storing and retrieving picture data efficiently and conveniently.

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3. R. F. Berland, C. L. Dunford, and R. J. Creasy, "Computer graphics for automated neutron cross-section evaluation," *Transactions for the American Nuclear Society* 10, 2, 584 (1967).
4. These features were added to SCORE by M. S. Moore and N. Marshall of the Idaho Nuclear Corporation.