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NUCLEAR DATA PROCESSING ON AN IBM-704 COMPUTER WITH THE CONDAC PROGRAM

C. D. Goodman
B. D. Williams

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Electronuclear Research Division

NUCLEAR DATA PROCESSING ON AN IBM-704 COMPUTER WITH THE CONDAC PROGRAM

C. D. Goodman
B. D. Williams
Program Prepared by B. D. Williams

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DEFINITIONS OF SYMBOLS

m_o = Mass of observed particle, in atomic mass units.

m_r = Mass of residual particle, in atomic mass units.

m_i = Mass of incident particle, in atomic mass units.

m_t = Mass of target particle, in atomic mass units.

Z_o = Charge of observed particle, in electronic charge units.

N = Number of electrons per milligram of stopping material.

I = Mean ionization potential of stopping material, in Mev.

e = Energy variable in energy loss expression.

ΔE = Energy lost in stopping material, in Mev.

E_{det} = Energy of particle when it reaches the detector, in Mev.

E_{lab} = Laboratory energy of observed particle in Mev.

ϵ = Kinetic energy of final system.

E = Excitation energy of final system.

Q = Change in kinetic energy from initial system to ground state of final system.

$Y = \epsilon/B$.

θ = Laboratory angle of observation, in degrees.

B = Height of Coulomb barrier, in Mev.

μ = Reduced mass of final system, in atomic mass units.

σ_c = Capture cross section for inverse reaction, in 10^{-26} cm^2.

$N(E_{lab})$ = Corrected counts per Mev of laboratory energy.

$N(\epsilon)$ = Corrected counts per Mev of center-of-mass energy.

x = Absorber thickness variable in energy loss expression.

X = absorber thickness, in mg/cm^2 of aluminum.

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1. PURPOSE OF CONDAC

Many nuclear physics experiments involve measuring the energy distributions of charged particles. The raw data are usually in the form of pulse-height spectra from an energy-sensitive detector such as a scintillation counter or a proportional counter. The point by point reduction of these data to true energy spectra involves a great deal of tedious work which can be performed by automatic computers. CONDAC is a program to perform nuclear data reduction of this type on an IBM-704 Computer.

2. DESCRIPTION OF THE METHOD OF DATA REDUCTION

The data are assumed to be in the form of a sequence of numbers representing the counts in a set of consecutively numbered channels. It is assumed that the channel number is proportional to pulse height.

The data reduction can logically be divided into two parts: (1) The establishment of energies corresponding to each channel number; this makes no use of the counts. (2) The processing of the raw counts into corrected counts.

Energy Scales - The first step in part (1) is to establish the apparent energy at the detector corresponding to each channel number. This is accomplished by multiplying each channel number by a constant channel width specified as Mev/channel. If the response of the detector is linear, this completes the step. Otherwise, each value of the apparent energy must be multiplied by an energy dependent multiplier to obtain the detector energy. For example, if the channel width is 0.12 Mev/channel, the apparent energy corresponding to channel 14 is 1.68 Mev. If the multiplier for 1.68 Mev is 1.3, the detector energy is 1.3 x 1.68 = 2.185 Mev.

The second step is to calculate from the detector energy the laboratory energy of the observed particle. For this calculation the energy lost in the absorbing material between the target and the detector is computed by a numerical integration of the rate of energy loss. The formula used for the rate of energy loss is as follows, which is equivalent to the non-relativlstic limit of the formula

used by Aron, Hoffman, and Williams for their range energy curves[1]:

$$\frac{-de}{dx} = \frac{2\pi m_o Z_o^2 N}{e} \; 3.778 \times 10^{-23} \left[\ln \frac{4e}{0.05488 m_o I} \right] \text{Mev cm}^2\text{mg}^{-1}$$

$$\Delta E = \int_{x=0}^{x=X} \frac{de}{dx} \, dx$$

Z_o is the charge of the observed particle, N is the number of electrons per milligram of the stopping material, e is the energy variable, and x is the thickness variable for the integration. m_o is the mass of the observed particle in atomic mass units.

In the program deck, the numerical values are chosen for aluminum, and I, the mean ionization potential, is taken as 1.664×10^{-4} Mev[2].

The integration of the energy loss is performed starting with $e = E_{det}$ = detector energy. X is the amount of absorbing material in mg/cm^2 between the detector and the target. The laboratory energy, E_{lab} ($= E_{det} + \Delta E$), is computed and printed for each channel following the channel number on the printout sheet.

Nuclear kinematical data are usually referred to the center-of-mass system. It is assumed in this analysis that an incident projectile of mass m_i strikes a target of mass m_t giving rise to an observed particle of mass m_o and a residual particle of mass m_r.

The total kinetic energy, ϵ, in the final center-of-mass system is calculated, as is the difference in kinetic energy between the

---

(1) Aron, Hoffman, and Williams, University of California Radiation Laboratory Report UCRL-121 (unpublished).

(2) Bischel, Moseley, and Aron, Phys. Rev. 105, 1788 (1957).

initial and final systems. The calculations are performed with non-relativistic kinematical formulas. On the printout, a scaling factor, B, is provided for ϵ which is useful in problems involving penetration of a potential barrier, where B is specified in the input data and takes on the significance of the barrier height. $Y = \epsilon/B$ is printed out. If ϵ is desired on the printout, B may be set equal to unity in the input data.

The column labeled "energy" in the printout is the difference in kinetic energy between the initial and final system if Q is set equal to zero in the input data. Q serves as an additive constant; if it is set equal to the Q value for the ground state, the column labeled "energy" becomes excitation energy of the residual nucleus.

The formula used for calculating ϵ from E_{lab} is easily derived from non-relativistic conservation of energy and of momentum, or as the non-relativistic limit of the complete expression(3).

$$-E + Q = E_{lab}(1 + m_o/m_r) - E_i(1 - m_i/m_r) - (2/m_r)(m_o E_{lab} m_i E_i)^{1/2} \cos\theta$$

and

$$E + \epsilon = Q + E_i\left[m_t/(m_i + m_t)\right]$$

where E_i is the incident projectile energy in the laboratory system, and θ is the laboratory angle of observation.

Processing of Counts Data - The counts data are fed into the program as counts per channel. As a first step, each of these numbers is divided by the monitor factor which is read in with the data.

Since neither E_{lab} nor E is a linear function of channel number, transformations are required to convert the data to counts per Mev.

---

(3) See for example: P. Morrison, "A Survey of Nuclear Reactions." Experimental Nuclear Physics, E. Segre, editor, vol. II, John Wiley and Sons, New York (1953).

To obtain a laboratory energy spectrum, the counts in a channel are divided by the channel width at that channel. The channel width is computed from a difference formula which uses the energy values at the channel and for the two channels immediately below and the two immediately above.

To obtain the center-of-mass energy spectrum, the same procedure is followed with the center-of-mass energy scale. However, an additional correction is required because the solid angle subtended by the particle detector is not a constant in the center-of-mass system, but depends on the energy, masses, and angle. The program computes this correction from the following formula and multiplies the counts by $\frac{d\omega_{lab}}{d\omega_{cm}}$

$$\frac{d\omega_{lab}}{d\omega_{cm}} = \left[1 - a^2 \sin^2 \theta\right]^{1/2} \left[a \cos \theta + (1 - a^2 \sin^2 \theta)^{1/2}\right]^{-2}$$

$$a^2 = \frac{m_o m_i}{m_r m_t} \frac{1}{1 + \frac{(Q - E)}{E_i} \frac{(m_i + m_t)}{m_t}}$$

Some energy spectra of particles are analyzed in terms of a statistical model of nuclear reactions. To facilitate this kind of analysis, a feature is incorporated in CONDAC which will divide the corrected counts by $\mu\epsilon\sigma_c$ where μ and ϵ are the reduced mass and the kinetic energy, respectively, of the final system, and σ_c is a function entered with the input data in tabular form, and, in this context, has the significance of a compound nucleus formation cross section for the inverse reaction. (See for example Blatt and Weisskopf[4], Ch. VIII).

---

[4] J. M. Blatt and V. F. Weisskopf, Theoretical Nuclear Physics, (John Wiley and Sons, Inc., New York, 1952).

σ_c is entered as thirty-two values with corresponding thirty-two values of $Y = \epsilon/B$.

If the option of the use of σ_c is selected, the quantity

$$\ln (N(\epsilon)/\mu\epsilon\sigma_c)$$

is printed out for each channel. This form facilitates determinations of nuclear temperatures.

3. PREPARATION OF DATA

The data are entered into the computer from punched 80-column cards. Only the first 64 columns are read into the computer, and these are read as eight, 8-column fields. Each data number is assigned to one 8-column field.

Figure 1 shows a prepared data sheet. Figure 2 shows the first three punched cards corresponding to the first three lines of the data sheet. Note that each row on the data sheet corresponds to one IBM card.

The decimal point is assumed to be at the right-hand edge of each field unless it is written. If it is written, it must be in a column by itself. The sign of a number is assumed to be positive unless a minus sign is written in the column just preceeding the number.

For purposes of explanation, we will break the data into six sections; the keywords, the headings, the maxima and minima for curve plotting, the inverse capture cross-section curve, the non-linear response curve, and the individual run data.

(A) Key Words:

Written in the first five fields of the first card of each run are five numbers which are keywords that control the input-output of the program in the following manner:

1. If the first number is greater than zero, the program will load and use a nonlinear response curve during the current run; if the first number is less than zero, the program will not load a nonlinear response curve but will use the

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650 DATA SHEET

REQUEST 1588 JOB TITLE CONDAC WRITTEN BY C. D. Goodman DATE 3-1-60

1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-72	73-80	
1	1	-1	0	-1					1	Key
1 PALLADIUM	P-ALPHA		CDG	3-1-60	1588				2	Head
.2	.4	.6	.8	1	2	3	4		3	Non-linear response
5	6	7	8	9	10	11	12		4	
13	14	15	16	17	18	19	20		5	
21	22	23	24	25	26	27	28		6	
8.5	4.15	3.5	2.875	2.5	1.75	1.5	1.375		7	
1.3	1.25	1.241	1.188	1.167	1.15	1.136	1.125		8	
1.115	1.107	1.100	1.094	1.088	1.083	1.079	1.075		9	
1.071	1.068	1.065	1.062	1.060	1.058	1.056	1.054		10	
.42	.43	.44	.45	.46	.47	.48	.49		11	σ_c
.50	.55	.60	.65	.70	.75	.80	.85		12	
.90	.95	1.00	1.05	1.10	1.15	1.20	1.25		13	
1.30	1.35	1.40	1.45	1.50	1.60	1.70	1.80		14	
.00008	.00011	.00017	.00025	.00036	.00054	.00080	.0013		15	
.0019	.010	.053	.17	.57	1.6	3.7	7.4		16	
12.3	18.5	25.0	32	34	45	51	56.5		17	
62	68	73	78	82	90	96	102		18	
3	7	58	22.8	0	15.7	2	4		19	Lead
103	1	106	1.036	5	60	1			20	
4	17	1	31	1					21	
13	9	20	35	49	58	50	38		22	
29	22	19	15	12	11	9	7		23	
6									24	
0	0	0	1						25	Key

Fig. 1: IBM-650 Data Sheet with Sample Run.

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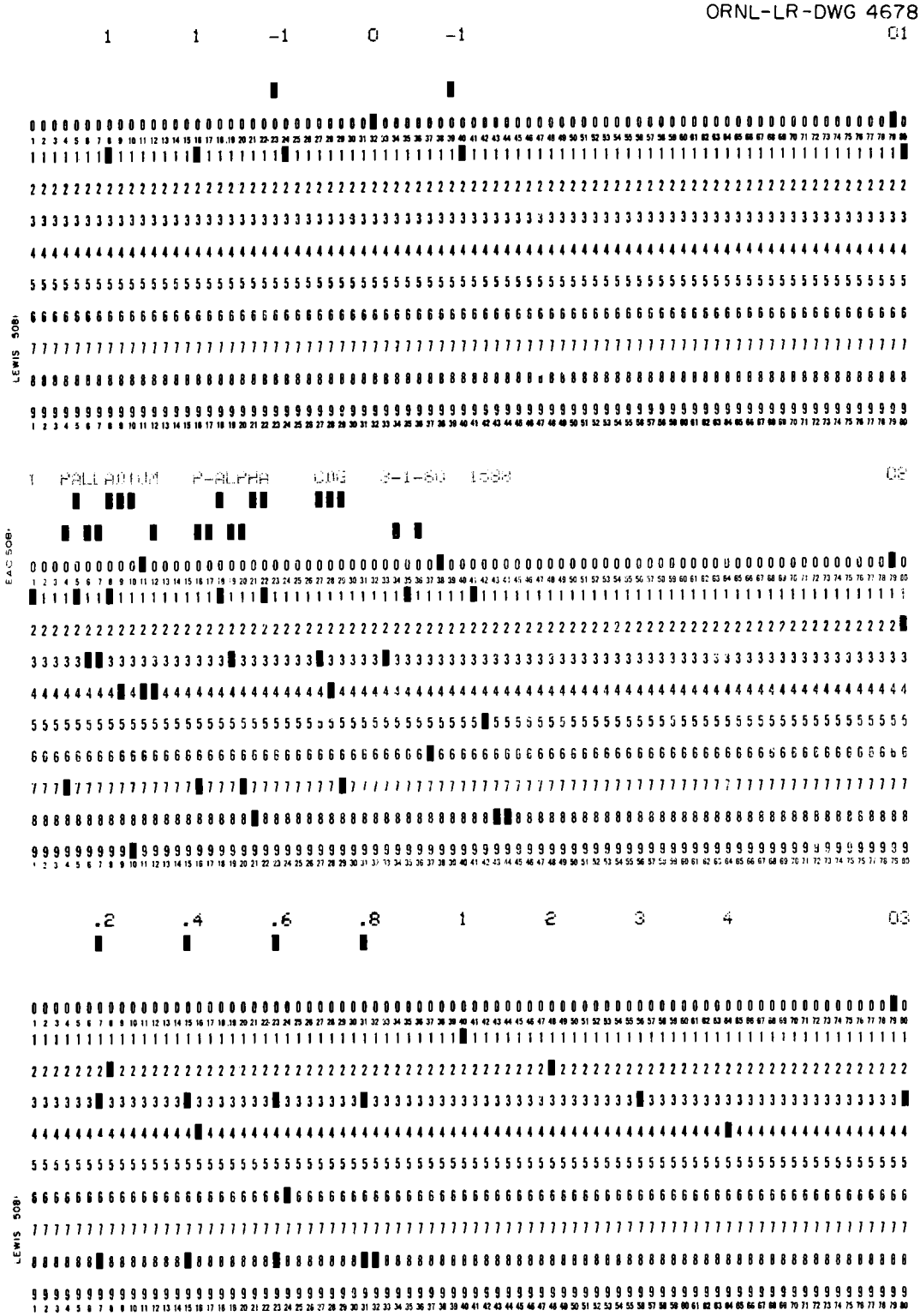

Fig. 2: First Three Cards of Run.

curve stored in the memory; and if the first number is zero, the program will not load or use a nonlinear response curve.

2. If the second number is greater than zero, the program will load a cross-section curve; otherwise the program will bypass this load instruction.

3. If the third number is greater than zero, the program will use the cross-section curve and print out log $(N(\epsilon)/\epsilon\sigma_c\mu$. If the third number is zero, the program will not use the cross-section curve and will print out the data in non-log form. If the third number is negative, the program will print out the data in both forms.

4. If the fourth number is greater than zero, the program will stop immediately, otherwise it will continue to load the current run.

5. The fifth keyword is used if curve plotting is desired.
   (a) Plotting will not be done if it is zero. A blank column is equivalent to a punched zero.
   (b) Plotting of all data printed out will be done with automatic scaling on both axes if the fifth keyword is a negative number.
   (c) Plotting will be done with fixed scales on both axes if the fifth keyword is a positive number. In this case, an extra card containing the scale limits must be inserted immediately following the heading card, as described under heading (C).

(B) Heading:

The card following the keywords contains a heading which will be reproduced on the output sheets. The third through 44th characters of the heading will appear on the plotted output. The first column of this card must contain a (1), but the remainder may consist of any combination of capital letters, numbers, and the following symbols: = . $ ( ) / * - + ,. Including spaces, the line must contain no more than sixty-four characters. If the curve plotting feature is used, the heading should contain a name and an identifying number.

(C) Maxima and Minima for Curve Plotting:

AMAX	Largest E desired on plot
AMIN	Smallest E desired on plot
BMAX	Largest $\log_{(10)}$ N desired
BMIN	Smallest $\log_{(10)}$ N desired
CMAX	Largest $\log_{(10)}$ $N/\epsilon\sigma M$ desired
CMIN	Smallest $\log_{(10)}$ $N/\epsilon\sigma M$ desired

All points falling outside the rectangle formed by the maximum and minimum points will be excluded. The maximum and minimum points will be plotted. If $N \leq 0$, Log N will be plotted as zero.

Three numbers are printed along each axis as follows:

1. The value of the variable at the lower left corner of the plot.
2. The increment between grid lines.
3. The value at the last grid line of the axis.

Restrictions and Details - When submitting CONDAC data it will be necessary to state the total number of pictures expected.

Since the pictures and negatives will be sorted it is necessary to have initials and a request number on the plots. For this purpose, characters three through forty-two of the heading will be placed on the plots. In addition, the case and run number will be on the plots as one five-digit number.

(D) Nonlinear Response Curve:

In the event that the energy response of the detector is not linear, a curve must be loaded to show the relationship between the linear response defined by Mev/channel and the nonlinear curve. The relationship fed in as a multiplier. The program computes the energy at each channel by the formula

$$E_{det} = (\text{channel number})(\text{Mev per channel}),$$

then finds the multiplier that corresponds to this energy, and multiplies by it to get the proper energy.

The curve is fed in as thirty-two discreet points. Intermediate values are found by using a four-point Lagrangian interpolation. The points are preferably unevenly spaced. The formula will not extrapolate the curves accurately so it is wise to make the table large enough to include the entire range of energy covered by the data.

The points are written as thirty-two values of energy (four cards) followed by thirty-two values of the corresponding multiplier (four more cards). These eight cards follow the heading card or the plotting limits card if the latter is used.

The program saves this curve until a new one is loaded. If several runs are to be processed using the same response curve, it has to be loaded only once.

(E) Inverse Capture Cross-Section:

The cross-section curve, if it is required, is loaded identically to the nonlinear response curve (thirty-two discreet points). Cross-section curves frequently have a region of steep slope where the accuracy of the Lagrangian interpolation routine will be poor. Best results will be obtained by selecting a large number of points in the region of large slope and fewer points in the region of small slope. The limitations are the same as on the nonlinear response curve, and the curve is saved until another is loaded.

The points are written as thirty-two values of Y followed by thirty-two values of σ_c. The values of σ_c should be written in units of 10^{-26} cm^2. The eight cards for the σ_c curve will follow the non-linear response cards (if used), or the plotting limit card (if used), or the heading card.

(F) Run Data:

After the preceding information is loaded, the program loads the following fifteen numbers, written eight on one card and seven on the next card:

1. Month.
2. Day.
3. Year.
4. Incident energy, in Mev.
5. Q of the reaction, in Mev.
6. B(height of the Coulomb barrier, in Mev). Where an inverse capture cross-section curve is not used, set B = 1.0. $B \neq 0.0$ at any time.
7. Charge of the observed particle, in atomic mass units.

8. Mass of the observed particle, in atomic mass units.

9. Mass of the residual particle, in atomic mass units.

10. Mass of the incident particle, in atomic mass units.

11. Mass of the target particle, in atomic mass units.

12. Mev per channel (energy scale).

13. Absorber thickness, in units of milligrams/cm^2 of aluminum.

14. Laboratory angle of observation (degrees from forward beam path).

15. Number of groups of data. When a twenty-channel pulse-height analyzer is used and the spread of data requires more than twenty channels, the spectrum must be pieced together from several runs with different baseline settings. The number of groups of data is the number of such runs. CONDAC loads each of these runs, normalizes each to its monitor factor, averages the overlap between them, and calculates the results as one curve. All channel numbers must be integers to take advantage of this feature. The groups cannot completely overlap, must be in ascending order of channel numbers, and only two groups may overlap in any one channel. The program will handle up to 512 channels; no channel number can be greater than 512.

(G) Five Word Lead Card:

For each group of data, write a card with the five following numbers in the first five fields:

1. First channel number in the group. This must be an integer if (15) above is greater than one. It may have two digits to right of decimal point if (15) above equale one. First channel

number must be ≥ 4.

2. Number of channels in this group.

3. Monitor factor (program divides the data by this number).

4. Case Number (less than 32 if curve plotting, 3 digits otherwise).

5. Run number (any 3 digits).

If several groups are combined, only the last case and run number will be printed and placed on the plots (when used).

On the cards following the above five numbers, write the data eight numbers to a card, except the last card which may have any number less than or equal to eight.

Follow with a new five-word card and the next group of data, if there is another group to be combined, or a new keyword card and the next run.

At the end of the deck, insert a card with 1 (digit one) punched in the fourth field. This stops the loading.

4. INSTRUCTIONS FOR OPERATOR

(A) Equipment Required:

This program may be used on any IBM-704 which has the following units:

Card reader.

8192-word core memory, or larger.

Two tape units.

Ability to print data from magnetic tape on a line printer either off line, or through a simulator on-line.

A good time estimate has not been made, but the time may be approximated by using one minute plus one second for each channel of output data.

Two sample output sheets are shown in Figs. 3 and 4. The E after the numbers in two columns on the non-log printout stands for exponent and indicates that the preceding number should be multiplied by ten to the power as indicated by the number immediately following the E.

Two sample curve plots are shown in Figs. 5 and 6. The three numerical labels on the axes are (from left to right and bottom to top):

1. The value at the lower left corner.
2. The increment between grid lines.
3. The value on the far right or top grid lines.

The number on the right end of the curve plot heading is the case number times one thousand plus the run number.

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PALLADIUM P-ALPHA CDG 3-1-60 1588 CASE 31 RUN 1 3- 7-58

E(I)= 22.800 Q= 0. B= 15.700 Z= 2.000 M(0)= 4.00 M(R)= 103.00 M(I)= 1.00 M(T)= 106.00

MEV/CHANNEL= 1.0360 ABSORBER= 5.0000 ANGLE= 60.0000

CHANNEL	LAB ENERGY	N(LAB)	N(E)	ENERGY	Y = EPSILON/B
4.00	8.1568	0.3752E 01	0.3556E 01	14.3699	0.5234
5.00	8.9778	0.1055E 02	0.1001E 02	13.5300	0.5769
6.00	9.8716	0.2068E 02	0.1963E 02	12.6150	0.6352
7.00	10.8613	0.4031E 02	0.3829E 02	11.6011	0.6997
8.00	11.6208	0.5928E 02	0.5633E 02	10.8226	0.7493
9.00	12.5530	0.6133E 02	0.5831E 02	9.8667	0.8102
10.00	13.4858	0.5324E 02	0.5064E 02	8.9096	0.8712
11.00	14.4329	0.3986E 02	0.3793E 02	7.9375	0.9331
12.00	15.3910	0.3018E 02	0.2873E 02	6.9537	0.9957
13.00	16.3546	0.2269E 02	0.2161E 02	5.9639	1.0588
14.00	17.3300	0.1939E 02	0.1847E 02	4.9616	1.1226
15.00	18.3121	0.1528E 02	0.1455E 02	3.9522	1.1869
16.00	19.2929	0.1224E 02	0.1166E 02	2.9437	1.2512
17.00	20.2754	0.1112E 02	0.1060E 02	1.9334	1.3155
18.00	21.2718	0.9009E 01	0.8590E 01	0.9084	1.3808
19.00	22.2698	0.7046E 01	0.6719E 01	-0.1185	1.4462
20.00	23.2606	0.6025E 01	0.5747E 01	-1.1381	1.5111

Fig. 3: Sample Non-Log Printout.

PALLADIUM P-ALPHA CDG 3-1-60 1588 CASE 31 RUN 1 3- 7-58

E(I)= 22.800 Q= 0. B= 15.700 Z= 2.000 M(0)= 4.00 M(R)= 103.00 M(I)= 1.00 M(T)= 106.00

MEV/CHANNEL= 1.0360 ABSORBER= 5.0000 ANGLE= 60.0000

CHANNEL	LAB ENERGY	LOGE N(LAB)	LOGE N(E)/EPSILONSIGMAM*	ENERGY	Y = EPSILON/B
4.00	8.1568	1.322	63.299	14.3699	0.5234
5.00	8.9778	2.357	62.258	13.5300	0.5769
6.00	9.8716	3.029	61.358	12.6150	0.6352
7.00	10.8613	3.697	60.336	11.6011	0.6997
8.00	11.6208	4.082	59.628	10.8226	0.7493
9.00	12.5530	4.116	58.574	9.8667	0.8102
10.00	13.4858	3.975	57.596	8.9096	0.8712
11.00	14.4329	3.685	56.678	7.9375	0.9331
12.00	15.3910	3.407	55.932	6.9537	0.9957
13.00	16.3546	3.122	55.277	5.9639	1.0588
14.00	17.3300	2.965	54.833	4.9616	1.1226
15.00	18.3121	2.726	54.371	3.9522	1.1869
16.00	19.2929	2.505	53.961	2.9437	1.2512
17.00	20.2754	2.409	53.695	1.9334	1.3155
18.00	21.2718	2.198	53.329	0.9084	1.3808
19.00	22.2698	1.952	52.949	-0.1185	1.4462
20.00	23.2606	1.796	52.683	-1.1381	1.5111

Fig. 4: Sample Log Printout.

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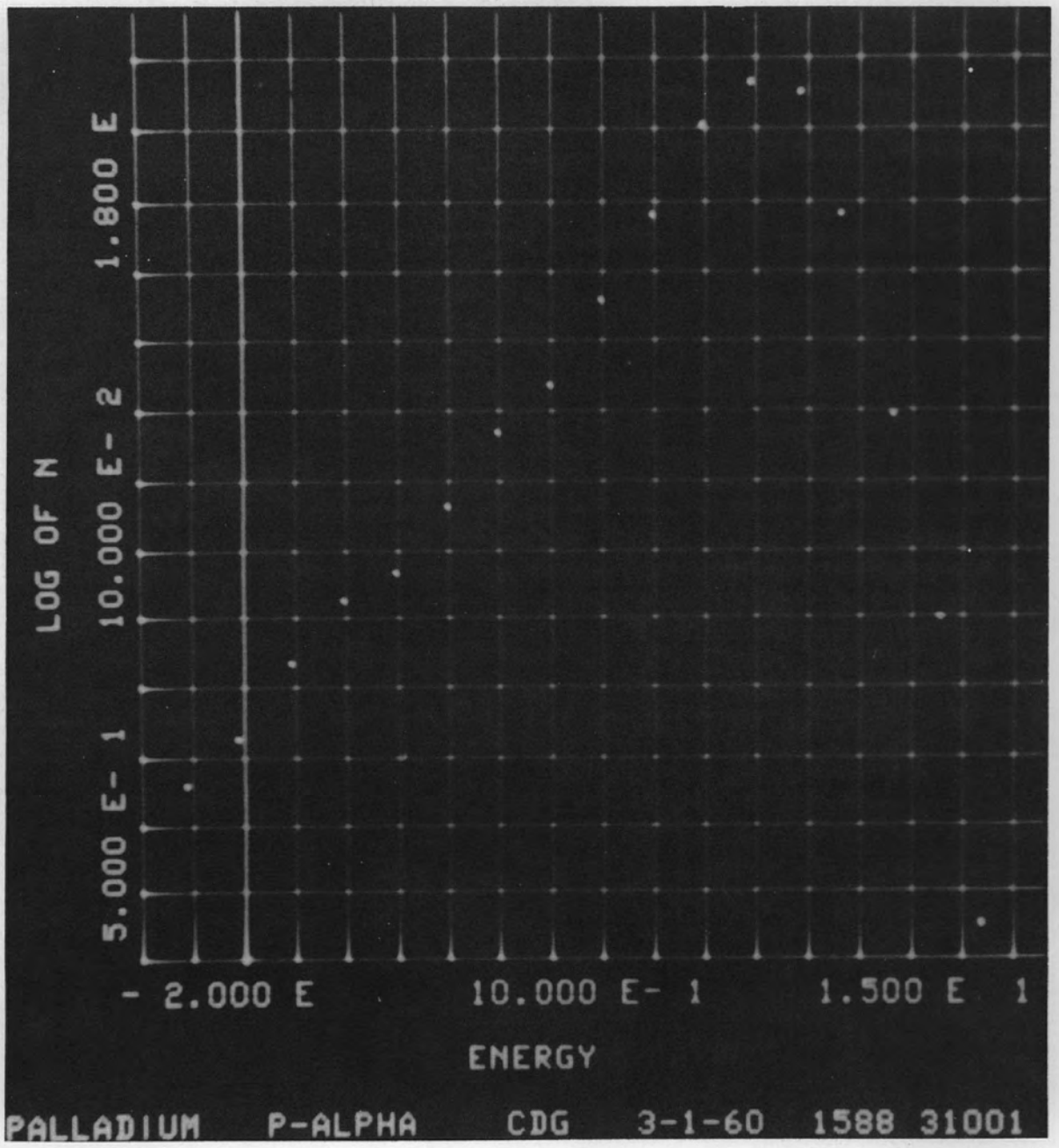

Fig. 5: Sample Curve-Plotter Output Corresponding to Data of Fig. 3.

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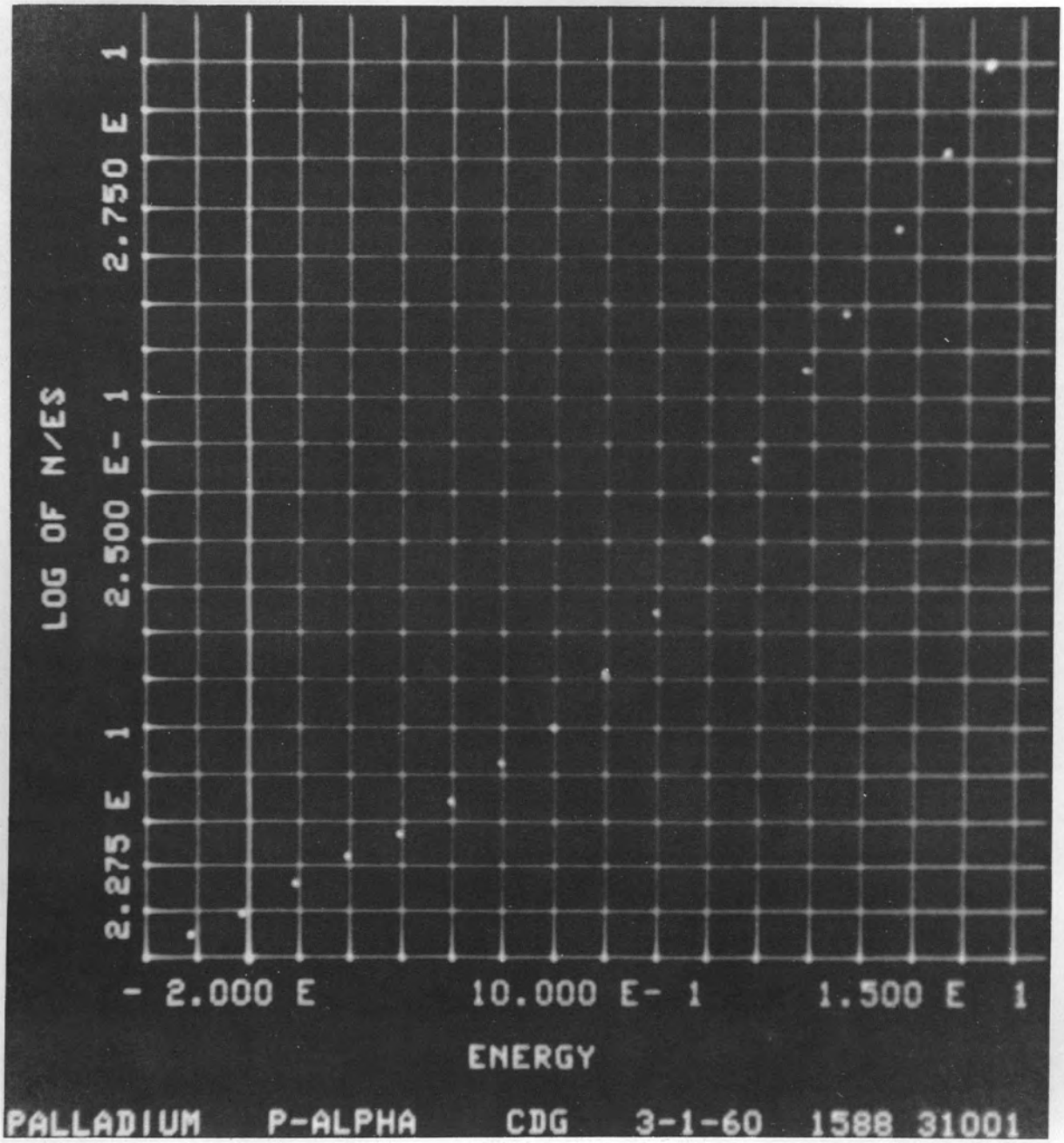

Fig. 6: Sample Curve-Plotter Output Corresponding to Data of Fig. 4.

(B) Loading Instructions for Program on Cards:

1. Preliminary steps

   (a) Place data deck behind program deck.

2. Operating

   (a) An output tape 2 is used.

   (b) One tape 6 for intermediate processing.

   (c) Ready curve plotter.

   (d) For normal use all sense switches UP.

   (e) With deck in card reader, clear and load cards.

   (f) At normal program stop in location 2500 write end-of-file on drive 2.

   (g) Remove tape 2, program finished.

3. Listing of tape 2

   (a) 14 x 11 paper.

   (b) One file.

   (c) Program control.

   (d) Return results and data to sender.

4. Error stops

Location	ACC	
1014	1	Incorrect data Get off machine.

5. FORTRAN LISTING

```
C  BDW          1588          CONDAC 3      NUCLEAR REACTIONS ANALYSIS
 1000 DIMENSIONSIGMA(4,32),YOBS(32),CPC(512),                          14760201
     1CBC(512),CCC(512),EOI(512),ELAB(512),EFIN(512),                  14760203
     2GLAB(512),GNAB(512),GEN(512),GNET(512),                          14760205
     3AL(2,32),EPSN(512),Y(512),APLOT(512),BPLOT(512)                  15882001
 1001 READ1002,TE1,TE2,TE3,TE4,TE5                                     15882003
      IF(TE4)901,901,1256                                              15882005
  901 READ1242                                                         15882007
      KAP=0                                                            15882009
      KRT=0                                                            15882011
      IF(TE5)905,905,903                                               15882013
  903 READ1002,AMAX,AMIN,BMAX,BMIN,CMAX,CMIN                           15882015
  905 IF(TE1)1005,1005,1003                                            15882017
 1002 FORMAT(0P8E8.0)
 1003 READ1002,(AL(1,J),J=1,32)                                        14760115
 1004 READ1002,(AL(2,J),J=1,32)                                        14760117
 1005 IF(TE2)1009,1009,1007                                            15882107
 1006 FORMAT(26P8F8.0)
 1007 READ1002,(YOBS(J),J=1,32)                                        1476
      READ1006,(SIGMA(1,L),L=1,32)                                     1476
 1009 READ1002,(SD,TD,UD,EI,QA,BA,ZA,AMO,                              14760201
     1AMR,AMI,AMT,AMEV,ABSORB,THETA,SG)                                14760203
      ID=SD+0.001                                                      14760205
      JD=TD+0.001                                                      14760207
      KD=UD+0.001                                                      14760209
      ITYPE=AMO+0.001                                                  15882515
      IG=SG+0.001                                                      14760213
      THETA=THETA/57.2958                                              15882105
      IF(IG-1)1256,1012,1013                                           14760217
 1012 READ1002,(SCFB,SPFB,TAE,SCASE,SRUN)                              14760219
      NCFB=SCFB+0.001                                                  14760221
      NPFB=SPFB+0.001                                                  14760223
      ICASE=SCASE+0.001                                                14760225
      IRUN=SRUN+0.001                                                  14760301
      IMN=NCFB+NPFB-1                                                  14760303
      READ1002,(CPC(KA),KA=NCFB,IMN)                                   14760305
      GOTO1050                                                         14760307
 1013 READ1002,(SCFB,SPBB,TAB,SCASE,SRUN)
      NCBB=SCFB+0.001
      NPBB=SPBB+0.001                                                  14760313
      ICASE=SCASE+0.001                                                14760315
      IRUN=SRUN+0.001                                                  14760317
      IMK=NCBB+NPBB-1                                                  14760319
      READ1002,(CBC(JA),JA=NCBB,IMK)                                   14760321
      NCFB=NCBB                                                        14760401
      DO1014JA=NCBB,IMK                                                14760403
 1014 CBC(JA)=(CBC(JA))/TAB                                            14760405
      IG=IG-1                                                          14760407
 1021 READ1002,(SCCB,SPCB,TAC,SCASE,SRUN)                              14760409
      NCCB=SCCB+0.001                                                  14760411
      NPCB=SPCB+0.001                                                  14760413
      ICASE=SCASE+0.001                                                14760415
      IRUN=SRUN+0.001                                                  14760417
      IMO=NCCB+NPCB-1                                                  14760419
      READ1002,(CCC(JB),JB=NCCB,IMO)                                   14760421
      DO1015JB=NCCB,IMO                                                14760515
```

```
1015 CCC(JB)=(CCC(JB))/TAC                                          14760517
     IMP=NCCB-1                                                     14760519
     DO1018JC=NCBB,IMP                                              14760521
1018 CPC(JC)=CBC(JC)                                                14760523
     DO1020JD=NCCB,IMK                                              14760525
1020 CPC(JD) = (CBC(JD)+CCC(JD))/2.0                                14760601
     IMQ = NCBB+NPBB                                                14760603
     DO 1022 JE=IMQ,IMO                                             14760607
1022 CBC(JE) = CCC(JE)                                              14760609
     NCBB=IMQ
     NPBB=IMO-IMQ+1
     IMK=IMO
     IG = IG-1                                                      14760615
     IF(IG) 1030,1031,1021                                          14760617
1030 STOP 1                                                         14760619
1031 DO 1032 JF=IMQ,IMO                                             14760622
1032 CPC(JF) = CCC(JF)                                              14760625
     NPFB = NCCB+NPCB-NCFB                                          14760701
     TAE = 1.0                                                      14760703
1050 DAP=0.688525E-01*AMO                                           14760801
     IMN=NCFB+NPFB-1                                                15882517
     DAI=0.302452*AMO                                               14760803
     LI=IMN+3                                                       14760805
     LO=NCFB-3                                                      14760807
     IF(LO)1053,1053,1054                                           14760809
1053 LO=1                                                           14760811
1054 ZO=SCFB-3.0                                                    15882019
     EOI(LO)=ZO*AMEV                                                14760815
     LP=LO+1                                                        14760818
     DO1055JL=LP,LI                                                 14760820
1055 EOI(JL)=EOI(JL-1)+AMEV                                         14760822
     IF(TE1)1058,1100,1058                                          14760005
1058 DO1080JM=LO,LI                                                 14760905
     DO1060JN=3,31                                                  14760907
     IF(AL(1,JN)-EOI(JM))1060,1062,1062                             14760909
1060 CONTINUE                                                       14760911
1062 ALP1 = EOI(JM)-AL(1,JN-2)                                      14761001
     ALP2 = EOI(JM)-AL(1,JN-1)                                      14761003
     ALP3 = EOI(JM)-AL(1,JN)                                        14761005
     ALP4 = EOI(JM)-AL(1,JN+1)                                      14761007
     ALD1 = AL(1,JN-2)-AL(1,JN-1)                                   14761009
     ALD2 = AL(1,JN-2)-AL(1,JN)                                     14761011
     ALD3 = AL(1,JN-2)-AL(1,JN+1)                                   14761013
     ALD4 = AL(1,JN-1)-AL(1,JN)                                     14761015
     ALD5 = AL(1,JN-1)-AL(1,JN+1)                                   14761017
     ALD6 = AL(1,JN)-AL(1,JN+1)                                     14761019
     ALS1 = ALP2*ALP3*ALP4*AL(2,JN-2)/(ALD1*ALD2*ALD3)              14761021
     ALS2 = ALP1*ALP3*ALP4*AL(2,JN-1)/(ALD1*ALD4*ALD5)              14761023
     ALS3 = ALP1*ALP2*ALP4*AL(2,JN)/(ALD2*ALD4*ALD6)                14761025
     ALS4 = ALP1*ALP2*ALP3*AL(2,JN+1)/(ALD6*ALD5*ALD3)              14761101
1080 EOI(JM) = EOI(JM)*(ALS1-ALS2+ALS3-ALS4)                        14761103
1100 DO 1108 JN=LO,LI                                               14761111
     ELAB (JN) = EOI(JN)                                            14761113
     DO 1108 JO=1,20                                                14761115
     DELTA = (DAP*(ZA**2.0)*(ABSORB/20.0)*LOGF(4.0*ELAB(JN)/        14761117
    1DAI))/ELAB(JN)                                                 14761119
```

```
1108 ELAB(JN) = ELAB(JN)+DELTA                                          14761121
1114 DO1116JP=LO,LI                                                     14761203
1116 EFIN(JP)=QA-ELAB(JP)*(1.0+AMO/AMR)+EI*                             14761205
    1(1.0-AMI/AMR)+(2.0*(COSF(THETA))*SQRTF(AMO                         14761207
    2*AMI*EI*ELAB(JP)))/AMR                                             14761209
1130 DO 1135 JQ=NCFB,IMN                                                14761315
     GLAB(JQ) = CPC(JQ)/(TAE*(ELAB(JQ-2)/12.0-2.0*ELAB(JQ-1)/3.0        14761317
    1+2.0*ELAB(JQ+1)/3.0-ELAB(JQ+2)/12.0))                              14761319
1135 GNAB(JQ) = CPC(JQ)/(-TAE*(EFIN(JQ-2)/12.0-2.0*EFIN(JQ-1)/3.0       14761321
    1+2.0*EFIN(JQ+1)/3.0-EFIN(JQ+2)/12.0))                              14761323
1140 DO1144JR=NCFB,IMN                                                  14761411
     ANT=SQRTF(AMO*AMI*EI/((AMR*EI*AMT)                                 14761413
    1+AMR*(AMI+AMT)*(QA-EFIN(JR))))                                     14761415
1144 GEN(JR)=GNAB(JR)*(SQRTF(1.0-(ANT**2.0)*                            14761417
    1(SINF(THETA))**2.0))/((ANT*(COSF(THETA))+                          14761419
    2SQRTF(1.0-(ANT**2.0)*((SINF(THETA))**2.0)))**2.0)                  14761421
     BAD=AMO*AMR/(AMO+AMR)                                              14760221
     ITYPE=1                                                            15882521
1155 DO 1210 JS=NCFB,IMN                                                14761503
     EPSN(JS)=QA+(AMT*EI)/(AMT+AMI)-EFIN(JS)                            14761506
     YCALC=EPSN(JS)/BA                                                  14761507
     Y(JS)=YCALC                                                        14761508
1158 DO1170JT=3,31                                                      1476
     IF (YCALC-YOBS(JT)) 1175,1175,1170                                 14761511
1170 CONTINUE                                                           14761513
1175 ALP1 = YCALC-YOBS(JT-2)                                            14761515
     ALP2 = YCALC-YOBS(JT-1)                                            14761517
     ALP3 = YCALC-YOBS(JT)                                              14761519
     ALP4 = YCALC-YOBS(JT+1)                                            14761521
     ALD1 = YOBS(JT-2)-YOBS(JT-1)                                       14761523
     ALD2 = YOBS(JT-2)-YOBS(JT)                                         14761525
     ALD3 = YOBS(JT-2)-YOBS(JT+1)                                       14761601
     ALD4 = YOBS(JT-1)-YOBS(JT)                                         14761603
     ALD5 = YOBS(JT-1)-YOBS(JT+1)                                       14761605
     ALD6 = YOBS(JT)-YOBS(JT+1)                                         14761607
     ALS1=ALP2*ALP3*ALP4*SIGMA(ITYPE,JT-2)/(ALD1*ALD2*ALD3)             14761609
     ALS2 = ALP1*ALP3*ALP4*SIGMA(ITYPE,JT-1)/(ALD1*ALD4*ALD5)           14761611
     ALS3 = ALP1*ALP2*ALP4*SIGMA(ITYPE,JT)/(ALD2*ALD4*ALD6)             14761613
     ALS4 = ALP1*ALP2*ALP3*SIGMA(ITYPE,JT+1)/(ALD6*ALD5*ALD3)           14761615
1210 GNET(JS)=GEN(JS)/(EPSN(JS)*BAD*(ALS1-ALS2+ALS3-ALS4))              14760223
     IF(TE3)1244,1244,1215                                              15882111
1215 DO1241JU=NCFB,IMN                                                  15882021
     IF (GNET(JU)) 1218,1218,1219                                       14761701
1218 GNET(JU) = 0.0                                                     14761703
     GO TO 1220                                                         14761705
1219 GNET(JU) = LOGF(GNET(JU))                                          14761707
1220 IF (GLAB(JU)) 1221,1221,1223                                       14761709
1221 GLAB(JU) = 0.0                                                     14761711
     GOTO1241                                                           15882103
1223 GLAB(JU) = LOGF(GLAB(JU))                                          14761715
1241 CONTINUE                                                           15882107
1242 FORMAT(64H1                                                        15882207
    1         )                                                         15882209
1243 FORMAT(79H+                                                        14760213
    1                    CASE I3,6H  RUN I3,                            14761805
    25H      I2,1H-I2,1H-I2)                                            14761807
```

```
1244 WRITEOUTPUTTAPE2,1242                                                14761811
     WRITEOUTPUTTAPE2,1243,ICASE,IRUN,ID,JD,KD                            14761813
1245 FORMAT(119H0CHANNEL            LAB ENERGY        LOGE N(LAB)       LO14761909
    1GE N(E)/EPSILONSIGMAM*           ENERGY           Y = EPSILON/B    ) 15882519
1246 FORMAT(1H0F6.2,10H           F12.4,11H            F6.3,             15882111
    119H                    F6.3, 14H                F12.4,               14761915
    29H          F12.4)                                                   14761917
1247 FORMAT  (9H0  E(I)= F8.3, 5H  Q= F8.3, 5H  B= F8.3,                  14761919
    15H  Z= F8.3, 8H  M(0)= F6.2, 8H  M(R)= F6.2, 8H  M(I)= F6.2,         14761921
    28H  M(T)= F6.2 / / 15H  MEV/CHANNEL= F8.4,                           14761923
    312H  ABSORBER= F8.4, 9H  ANGLE= F8.4)                                14761925
     THETA=57.2958*THETA                                                  14762001
1248 WRITEOUTPUTTAPE2,1247,(EI,QA,BA,ZA,AMO,                              14762003
    1AMR,AMI,AMT,AMEV,ABSORB,THETA)                                       14762005
     IF(TE3)1260,1260,1250                                                15882113
1260 WRITEOUTPUTTAPE2,1261                                                14760303
     GOTO1300                                                             14760305
1250 WRITEOUTPUTTAPE2,1245                                                14760307
1300 MAGE=4                                                               14760309
     DO1320KO=NCFB,IMN                                                    14760401
     PIKE=KO-NCFB                                                         15882113
     PIKE=SCFB+PIKE                                                       15882115
     IF(TE3)1301,1301,1251                                                15882115
1251 WRITEOUTPUTTAPE2,1246,(PIKE,ELAB(KO),                                15882117
    1GLAB(KO),GNET(KO),EFIN(KO),Y(KO))                                    14760411
     GOTO1302                                                             14760415
1301 WRITEOUTPUTTAPE2,1262,(PIKE,ELAB(KO),                                15882119
    1GLAB(KO),GEN (KO),EFIN(KO),Y(KO))                                    14760419
1302 MAGE=MAGE+1                                                          14760421
     IF(MAGE-30)1320,1304,1304                                            14760423
1304 WRITEOUTPUTTAPE2,1242                                                14760425
     WRITEOUTPUTTAPE2,1243,ICASE,IRUN,ID,JD,KD                            14760501
     MAGE=2                                                               14760503
     IF(TE3)1310,1310,1312                                                15882117
1310 WRITEOUTPUTTAPE2,1261                                                14760507
     GOTO1320                                                             14760509
1312 WRITEOUTPUTTAPE2,1245                                                14760511
1320 CONTINUE                                                             14760513
     GOTO1622                                                             15882121
1321 IF(TE3)1252,1001,1001                                                15882123
1252 TE3=1.0                                                              15882121
     THETA=THETA/57.2958                                                  15882123
     KRT=1                                                                15882201
     GOTO1215                                                             15882125
1256 IF(KAP)1258,1258,1257                                                15882205
C    CHANGE FILM FRAME AT 1257
1257 KAP=1                                                                15882207
1258 STOP0000                                                             15882209
1261 FORMAT(120H0CHANNEL            LAB ENERGY          N(LAB)            14762118
    1            N(E)                  ENERGY           Y = EPSILON/B   )14762120
1262 FORMAT(1H0F6.2,10H           F12.4,9H          E12.4,                15882211
    112H             E12.4,9H          F12.4,9H          F12.4)           14760215
     EQUIVALENCE(CBC,EOI,ELAB,BPLOT),
    1(GNET,EPSN,CCC),(GNAB,GEN),(CPC,Y,APLOT)
1400 K=1
     DO1415J=NCFB,IMN
```

```
      TIM=EFIN(J)
      APLOT(K)=TIM
      IF(AMAX-AMIN)2000,1401,2000
 2000 IF(TE3)1402,1402,2001
 1402 IF((AMAX-TIM)*(TIM-AMIN))1415,1401,1401                          14760004
 2001 IF((      (AMAX)-TIM)*(TIM-      (AMIN)))1415,1401,1401
 1401 IF(TE3)1407,1407,1413                                            14760006
 1407 TIM=GEN(J)
      IF(TIM)1408,1408,1409
 1409 BPLOT(K)=0.43429448*LOGF(TIM)
      TIM=BPLOT(K)
      GOTO1410
 1408 TIM=0.0
      BPLOT(K)=0.0
 1410 IF(BMAX-BMIN)1411,1414,1411                                      14760009
 1411 IF((BMAX-TIM)*(TIM-BMIN))1415,1414,1414                          14760011
 1413 TIM=0.43429448*GNET(J)
      BPLOT(K)=TIM
      IF(CMAX-CMIN)1701,1414,1701                                      14760013
 1701 IF((CMAX-TIM)*(TIM-CMIN))1415,1414,1414                          14760015
 1414 K=K+1
 1415 CONTINUE
      K=K-1
      IF(TE3)1417,1417,1501                                            14760017
 1417 APLOT(K+1)=AMAX                                                  15881417
      APLOT(K+2)=AMIN                                                  15881419
      BPLOT(K+1)=BMAX                                                  15881421
      BPLOT(K+2)=BMIN                                                  15881423
      GOTO1509                                                         15881425
 1501 APLOT(K+1)=      (AMAX)                                          15881501
      APLOT(K+2)=      (AMIN)                                          15881503
      BPLOT(K+1)=CMAX                                                  15881505
      BPLOT(K+2)=CMIN                                                  15881507
 1509 MB1=1000*ICASE+IRUN                                              15881509
      CALLBURP                                                         15881510
      CALLTITLE(48HCONDAC LOG OF COUNTS VS ENERGY                    )
      CALLCALCN(MB1)                                                   15881513
      MB2=K+K53
      CALLSCALE(APLOT,BPLOT,MB2)                                       15881517
      IF(TE3)1521,1521,1605                                            14760019
 1521 CALLCRT(1.0,0.0,0.1,1.0,0.0,0.1,                                 15881521
     142H                                          ,                   15881523
     242H                                          ,                   15881524
     348H                                                ,             15881525
     412HENERGY       ,12HLOG OF N     )                               15881601
      GOTO1612                                                         15881603
 1605 CALLCRT(1.0,0.0,0.1,1.0,0.0,0.1,                                 15881605
     142H                                          ,                   15881607
     242H                                          ,                   15881608
     348H                                                ,             15881609
     412HENERGY       ,12HLOG OF N/ES )                               15881610
 1612 MB3=2                                                            15881612
      DO1618JACK=1,MB2                                                 15881614
      CALLPLOT(APLOT(JACK),BPLOT(JACK),MB3)                            15881616
 1618 CONTINUE                                                         15881618
      KAP=1.0                                                          15881619
```

```
      READTAPE6,Y
      READTAPE6,ELAB
      REWIND6
 1620 GOTO1321                                                    15881620
 1622 REWIND6
      WRITETAPE6,Y
      WRITETAPE6,ELAB
      REWIND6
      IF(TE5)1623,1620,1624
 1623 BMAX=0.0
      BMIN=0.0
      AMAX=0.0
      AMIN=0.0
      CMAX=0.0
      CMIN=0.0
      K53=0
      GOTO1400
 1624 K53=2
      GOTO1400
      END(0,1,0,0,1)                                              15882103
```

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