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A MACHINE-LANGUAGE COMPUTER PROGRAM TO OBTAIN A NEUTRON SPECTRU--ETC(U)

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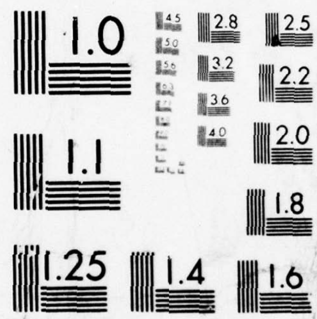

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HDL-TM-77-18

A Machine-Language Computer Program to Obtain a Neutron Spectrum from a Proton-Recoil Spectrum

September 1977

U.S. Army Materiel Development
and Readiness Command
HARRY DIAMOND LABORATORIES
Adelphi, Maryland 20783

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An assembly-language computer program has been written for an ND812 minicomputer. The program allows rapid analysis of proton-recoil data by calculation of the neutron flux directly on the minicomputer. An oscilloscope displays the results. The data may then be examined without their being transferred to an external computer.

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1. INTRODUCTION

Fast-neutron spectrum measurements are important to studies of radiation vulnerability of Army electronic systems. The Harry Diamond Laboratories (HDL) is presently investigating the Bennett[1] neutron spectrometer, which determines the neutron spectrum by analysis of recoil protons in a hydrogen (H_2) or methane (CH_4) gas. The spectrometer is controlled by a minicomputer.

In data analysis, corrections must be made for carbon recoils and wall-and-end effects. The magnitudes of these corrections are not usually large, but are time-consuming to make. It was, therefore, decided to develop a quick method of obtaining preliminary results without these corrections. In this manner, the trend of the data could be followed as the data were taken, and preliminary spectrum results could be evaluated before the time-consuming final analysis of the data was undertaken.

2. STATEMENT OF PROBLEM

When neutrons below 14 MeV scatter from a detector with a gas containing protons, the energy spectrum of recoil protons is related to the energy spectrum of incident neutrons by

$$\phi_p(E) = N * T \int_0^E \frac{\sigma(E')}{E'} \phi_N(E')\, dE, \quad (1)$$

where N is the number density of hydrogen atoms in the detector gas, T is the collection time of the experiment, E is energy, and $\sigma(E)$ is the neutron-proton elastic scattering cross section. The proton flux is $\phi_p(E)$ and $\phi_N(E)$ is the neutron flux. It is necessary to differentiate equation (1) to obtain the desired neutron energy distribution.

As stated in the introduction, the various sources of background noise which are corrections to equation (1) are ignored at this stage of analysis. Of course, these corrections must eventually be made, but they are sufficiently time-consuming that the final results are not available for several weeks after the data have been taken.

3. METHOD OF SOLUTION

The proton-recoil spectrometer is controlled by an ND812 minicomputer. Since the minicomputer is always at the location where the data are taken, it is advantageous to use it for preliminary analysis. An assembly-language computer program to solve equation (1) for $\phi_N(E)$ was written for the ND812. It has the following features:

(a) Since the data are acquired and analyzed by the same computer, there is no need to transfer data from one machine to another. Since the only output device from the ND812 (compatible with other computers) is paper tape, any transfer of data would be time-consuming.

(b) Since the ND812 is owned by HDL, there is no data-processing expense.

[1] E. F. Bennett and T. J. Yule, Techniques and Analyses of Fast-Reactor Neutron Spectroscopy with Proton-Recoil Proportional Counters, Argonne National Laboratory, ANL-7763 (1971).

(c) The system provides a visual display of both neutron and proton spectra on an oscilloscope. A listing of the data is also available.

(d) The analysis is done in a matter of minutes, so that any problems associated with the data may be seen as the data are taken, rather than weeks later. If there are problems, adjustments may be made immediately, without wasting days of valuable reactor running time.

4. PROGRAM DESCRIPTION

The equation relating the neutron spectrum $\phi_N(E)$ to the derivative of the proton-recoil distribution $d\phi_p(E)/dE$ is

$$\phi_N(E) = -\frac{1}{N*T} \frac{E}{\sigma(E)} \frac{d\phi_p(E)}{dE} \quad . \tag{2}$$

The data $\phi_p(E)$ consist of the number of recoil protons detected for each of several energy intervals of equal size. Numerical differentiation is a noise-generating process, and the data contain statistical fluctuations, so a smoothing process is used to obtain the best results. The method used is that of Bennet,[2] who suggests that the slope of a least-squares line—fit through the data surrounding a data point—be used as the slope of the data. The width of the interval over which the least-squares line is fitted is

$$STHW = FUDG* \sqrt{WI**2 + CON/E} \tag{3}$$

where STHW is the half-width of the slope-taking interval. WI is the intrinsic resolution of the detector, and the constant, CON, adds a factor to account for the statistical nature of the gas amplification. FUDG is an arbitrary scale factor which allows more smoothing. Bennett[2] demonstrates that a FUDG factor as large as 3.0 does not significantly affect the area under a peak, although significant line broadening does occur at that value. A value of 2.0 to 3.0 for FUDG is found to give the best compromise between smoothing and loss of resolution.

The program (listed in app A) is written in BASC-12, the assembly language supplied by the computer manufacturer.[3] The program consists of a main control routine, which calls various subroutines as they are needed, and the subroutines. A package[4] supplied by the manufacturer is used to do the floating-point arithmetic since hard-wired floating-point arithmetic is not available.

In general, the program functions in the following manner. A subroutine INPT is called to obtain the calibration data and constants needed to run the program. The program then locates the proton-recoil data in core and a least-squares line is fitted through the intervals determined by equation (3). For each energy interval, the slope is used in equation (2) to calculate the neutron flux spectrum. The results are stored in the minicomputer memory and may be viewed on the oscilloscope or output to Teletype or tape cassette by use of the ND-1075-01 computer program.[5]

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[2] E. F. Bennett, Fast Neutron Spectroscopy by Proton-Recoil Proportional Counters, Nuclear Science Engineering *27* (1967), 16.
[3] Nuclear Data, Incorporated, Software Instruction Manual, BASC-12 General Assembler, Palatine, IL (1971).
[4] Nuclear Data, Incorporated, ND812 Utilities Manual, Palatine, IL (1971), Ch 9 through 12.
[5] Nuclear Data, Incorporated, Software Instruction Manual, ND4420 Single/Dual Parameter Monitor, Palatine, IL (1972).

4.1 *Description of Main Subroutines*

INPT is the routine which reads the calibration data, along with N, T, WI, and FUDG (See eq (1) and (2).) Also, the IN and OUT groups must be input to INPT. These input numbers tell the computer where in memory to locate the proton-recoil data and where to put the neutron flux results.

INIT takes the calibration data and defines the energy scale.

IOST accepts the input and output group numbers and translates them into locations in core.

BUFRT computes the slope-taking half width and transfers the appropriate proton-recoil data to a buffer location. It is possible for equation (3) to give a width which reaches beyond the data. If this occurs, the slope-taking interval is reduced so that it reaches only to the end of the data.

LSR is the least-squares fitting routine. The sums necessary for the fit are accumulated in integer (as opposed to floating-point) format to save running time. A special routine, TPCHK, converts the sums necessary for least-squares fitting from integer to floating-point format, since they may exceed the normal double-precision 24-bit length of an integer in the computer. The result of program LSR is the slope of the least-squares line.

OPT computes the flux $\phi_N(E)$ from the slope using equation (2). The result is stored as an integer in the memory of the computer, where it may later be accessed by the ND-1075-01.

4.2 *Use of Program*

First, the ND-1075-01 program must be loaded into core. This program is used to load the raw proton-recoil data. The data may be loaded into groups of any size, as the derivative program automatically adjusts itself to fit the group size specified by the ND-1075-01. However, the data may not be loaded into the buffer memory extension, since the derivative program has access only to fields 02 and 03 of core.

Next, the floating-point package is loaded into field 01, along with the SQRT and operate instruction overlays.

The derivative program is loaded in field 01. The starting address is 4000 F01. Field 00 is not altered, so that the functions supported by the 1075-01 located in field 00 are not affected. These functions include all display- and data-acquisition functions but not I/O routines or any functions which use the Teletype.

A sample run of the program is included in appendix B. First, two points and their corresponding energies are input. They set the energy scale of the data. Then, the count time of the experiment, the hydrogen atom concentration of the proton-recoil tube, and mechanical width of the tube are input for use in equations (1) and (2). Next are given the input group and output group, which tell the program where to get and to put the processed data. The input group may not equal the output group, and neither may access the buffer memory extension. Finally, the slope-taking multiplier is input for use in equation (3).

The input data may take various floating-point forms. For example, the number "one" may be input as 1.0, 1, or 1.0E+00. If, after a number is typed, the space bar is pushed to terminate that number, the program will continue typing on the same line. If a carriage return is pushed, the typing will proceed from the beginning of the next line.

When the derivative program is finished, it returns control automatically to the 1075-01. The results may then be viewed on the oscilloscope. If the derivative of another group of data is to be determined, the 1075-01 must be stopped and the address register set again to 4000 F01. In this manner, the derivative program may be run any number of times in succession. However, if the data are to be output, it is necessary to reload and use the 1075-01 program. A typical running time for the program is 15 to 20 s for 256 points.

5. SUMMARY

A rapid, assembly-language computer program has been written to derive neutron spectra from proton-recoil spectra. The program allows a preliminary analysis of data to be made without having to rely on an external computer. The program is an invaluable aid to on-line evaluation of the quality of data during acquisition.

LITERATURE CITED

1. E. F. Bennett and T. J. Yule, Techniques and Analyses of Fast-Reactor Neutron Spectroscopy with Proton-Recoil Proportional Counters, Argonne National Laboratory, ANL-7763 (1971).

2. E. F. Bennett, Fast Neutron Spectroscopy by Proton-Recoil Proportional Counters, Nuclear Science Engineering *27*(1967), 16.

3. Nuclear Data, Incorporated, Software Instruction Manual, BASC-12 General Assembler, Palatine, IL (1971).

4. Nuclear Data, Incorporated, ND812 Utilities Manual, Palatine, IL (1971), Ch 9 through 12.

5. Nuclear Data, Incorporated, Software Instruction Manual, ND4420 Single/Dual Parameter Monitor, Palatine, IL (1972).

This program was written for the ND812 minicomputer language, BASC-12, supplied by the manufacturer.[1] The program consists of a main control routine. The subroutines are called as needed. Since hard-wired floating-point arithmetic is not available, a package is supplied by the manufacturer for the floating-point arithmetic.

```
                    FSIP=1007
                    FCLR=1004
                    FSQRT=7401
                    FSIN=1006
                    FJMP=6000
                    FNEG=1003
                    IFIX=7405
                    EXJK=1374
                    FLOAT=7406
                    XMAX=1131         /REFERS TO ND-1075 GROUP SIZE

                              [FIELD 01

                              *2540

/MODIFY FLOATING POINT PACKAGE OUTPUT ROUTINE SO IT WORKS
/
2540   7413                   TCP      /OUTPUT CHARACTER
2541   7414                   TOS
2542   6101                   JMP .-1  /WAIT TILL READY

                              *4000

/CONTROL PORTION OF PROGRAM
/THIS PORTION CALLS OTHER ROUTINES AS NEEDED
/
4000   0640                   TWJPS
4001   4071                   INPT     /INPUT DATA
4002   0640                   TWJPS
4003   4770                   INIT     /PREPARE EFP
4004   0640                   TWJPS
4005   4371                   IOST     /LOCATE IN AND OUT GROUPS
4006   0504                   TWLDJ FO
4007   1131                   XMAX     /SET COUNTER
```

[1] Nuclear Data, Incorporated, Software Instruction Manual, *BASC-12 General Assembler*, Palatine, IL (1971).

```
4010  2301             SUBL 01 /SKIP FIRST AND LAST POINTS
4011  5422             STJ CNT1
4012  1510             CLR J
4013  2202             ADDL 02 /FIRST POINT WHICH IS DONE
4014  5420             STJ CNT2
4015  5017  CON,       LDJ CNT2         /TAKE DERIV ONE POINT AT A TIME
4016  0540             TWSTJ
4017  4567             PTNO
4020  0640             TWJPS
4021  4575             BUFRT   /PUT DATA INTO BUFFER
4022  0640             TWJPS
4023  5146             LSR     /LEAST SQUARE FIT
4024  0640             TWJPS
4025  4473             OPT     /PUT FLUX IN OUTPUT GROUP
4026  3406             ISZ CNT2
4027  3004             DSZ CNT1         /LAST POINT?
4030  6113             JMP CON /NO
4031  0604             TWJMP FO
4032  0200             0200    /YES,RETURN TO 1075

4033  0000  CNT1,      0000    /COUNTER
4034  0000  CNT2,      0000    /POINT NO

/OUTPUT MESSAGE ROUTINE
4035  0000  OMR,       0000
4036  5301             LDJ@ OMR         /GET START ADRESS OF MESSAGE
4037  3502             ISZ OMR
4040  5411             STJ MESSG
4041  5210  OMR1,      LDJ@ MESSG       /GET CHARACTER
4042  1501             SNZ J   /END OF MESSAGE?
4043  6306             [RETURN OMR     /YES
4044  7413             TCP     /NO, TYPE IT
4045  7414             TOS
4046  6101             JMP .-1
4047  3402             ISZ MESSG
4050  6107             JMP OMR1         /GET NEXT CHAR
4051  0000  MESSG,     0000


4052  0000  ADDR,      0000    /WHERE TO PUT DATA
4053  1400  ADR1,      1400
4054  0000  STT,       0000    /INPUT THRU FLOAT POINT PACK
4055  5102             LDJ ADR1         /PREP TO ENTER FPP
4056  0540             TWSTJ
4057  0402             0402
4060  0640             TWJPS
4061  0400             0400    /ENTER FPP
4062  1400             FINPUT
4063  5711             FSTOR@ ADDR
4064  1001             FEXIT
4065  5113             LDJ ADDR         /NEXT DATA GOES THREE WORDS UP
4066  2203             ADDL 03
```

```
4067  5515          STJ ADDR
4070  6314          [RETURN STT

/WRITE TITLES
/GET DATA THRU FLOATING POINT PACKAGE
/
4071  0000  INPT,   0000
4072  0640  A1,     TWJPS
4073  4035          OMR      /OUTPUT MESSAGE
4074  4232          TITLE    /DERIVATIVE PROGRAM
4075  7103          XCT A1
4076  4211          POINT    /POINT=
4077  5053          LDJ DAT1         /POINT TO START OF DATA BUFFER
4100  5526          STJ ADDR
4101  6525          JPS STT /GET POINT
4102  7110          XCT A1   /PRINT MESSAGE
4103  4221          ENE      /ENERGY =
4104  6530          JPS STT /GET ENERGY
4105  7113          XCT A1
4106  4211          POINT    /POINT=
4107  6533          JPS STT
4110  7116          XCT A1
4111  4221          ENE      /ENERGY=
4112  6536          JPS STT
4113  7121          XCT A1
4114  4257          CTM      /COUNT TIME
4115  6541          JPS STT
4116  7124          XCT A1
4117  4274          H2CO     /H CONCENTRATION
4120  6544          JPS STT
4121  7127          XCT A1
4122  4306          MEW      /ME WIDTH
4123  6547          JPS STT
4124  7132          XCT A1
4125  4322          DFRM     /DATA FROM GRP
4126  6552          JPS STT
4127  7135          XCT A1
4130  4335          DTO      /DATA TO GROUP
4131  6555          JPS STT
4132  7140          XCT A1
4133  4354          FUDG     /MULTIPLIER
4134  6560          JPS STT
4135  5162          LDJ ADR1         /PREP TO ENTER FPP
4136  0540          TWSTJ
4137  0402          0402
4140  0640          TWJPS
4141  0400          0400
4142  5036          FLOAD GF         /CHANGE GF,GT TO INTEGERS
4143  7405          IFIX
4144  5434          FSTOR GF
4145  5036          FLOAD GT
4146  7405          IFIX
4147  5434          FSTOR GT
```

APPENDIX A

```
4150  1001            FEXIT
4151  6360            [RETURN INPT

/END OF BLOCK 1
//

IC AT 4153
IC AT 4153
##
4152  4153  DAT1,     P1
4153  0000  P1,       0000      /INPUT DATA BUFFER
4154  0000            0000
4155  0000            0000
4156  0000  E1,       0000
4157  0000            0000
4160  0000            0000
4161  0000  P2,       0000
4162  0000            0000
4163  0000            0000
4164  0000  E2,       0000
4165  0000            0000
4166  0000            0000
4167  0000  CT,       0000      /COUNT TIME
4170  0000            0000
4171  0000            0000
4172  0000  HC,       0000      /H CONCENTRATION
4173  0000            0000
4174  0000            0000
4175  0000  MW,       0000      /MECH WIDTH
4176  0000            0000
4177  0000            0000
4200  0000  GF,       0000      /INPUT GROUP
4201  0000            0000
4202  0000            0000
4203  0000  GT,       0000      /OUTPUT GROUP
4204  0000            0000
4205  0000            0000
4206  0000  FDGE,     0000      /WI MULTIPLIER
4207  0000            0000
4210  0000            0000

4211  0320  POINT,    0320      /POINT
4212  0317            0317
4213  0311            0311
4214  0316            0316
4215  0324            0324
4216  0240            0240
4217  0275            0275
4220  0000            0000

4221  0305  ENE,      0305      /ENERGY
4222  0316            0316
4223  0305            0305
```

```
4224  0322          0322
4225  0307          0307
4226  0331          0331
4227  0240          0240
4230  0275          0275
4231  0000          0000

4232  0304  TITLE,  0304    /TITLE
4233  0305          0305
4234  0322          0322
4235  0311          0311
4236  0326          0326
4237  0301          0301
4240  0324          0324
4241  0311          0311
4242  0326          0326
4243  0305          0305
4244  0240          0240
4245  0320          0320
4246  0322          0322
4247  0317          0317
4250  0307          0307
4251  0322          0322
4252  0301          0301
4253  0315          0315
4254  0215          0215
4255  0212          0212
4256  0000          0000

4257  0303  CTM,    0303    /COUNT TIME
4260  0317          0317
4261  0325          0325
4262  0316          0316
4263  0324          0324
4264  0240          0240
4265  0324          0324
4266  0311          0311
4267  0315          0315
4270  0305          0305
4271  0240          0240
4272  0275          0275
4273  0000          0000

4274  0310  H2CO,   0310    /H CONCEN
4275  0240          0240
4276  0303          0303
4277  0317          0317
4300  0316          0316
4301  0303          0303
4302  0305          0305
4303  0316          0316
4304  0275          0275
4305  0000          0000
```

APPENDIX A

```
4306  0315  MEW,    0315    /ME WIDTH
4307  0305          0305
4310  0303          0303
4311  0310          0310
4312  0240          0240
4313  0327          0327
4314  0311          0311
4315  0304          0304
4316  0324          0324
4317  0310          0310
4320  0275          0275
4321  0000          0000

4322  0311  DFRM,   0311    /INPUT GROUP
4323  0316          0316
4324  0240          0240
4325  0307          0307
4326  0322          0322
4327  0317          0317
4330  0325          0325
4331  0320          0320
4332  0240          0240
4333  0275          0275
4334  0000          0000

4335  0317  DTO,    0317    /OUT GROUP
4336  0325          0325
4337  0324          0324
4340  0000          00
4341  0325          0325
4342  0324          0324
4343  0240          0240
4344  0307          0307
4345  0322          0322
4346  0317          0317
4347  0325          0325
4350  0320          0320
4351  0240          0240
4352  0275          0275
4353  0000          0000

4354  0327  FUDG,   0327    /WI MULT
4355  0311          0311
4356  0240          0240
4357  0315          0315
4360  0325          0325
4361  0314          0314
4362  0324          0324
4363  0275          0275
4364  0240          0240
4365  0000          0000
```

```
/END OF BLOCK 2
//

IS [%       AT 4366
4366  0000  ;%
/TRANSLATE IN GROUP AND OUT GROUP NUMBERS
/ INTO ACTUAL LOCATION IN CORE
/
4367  0604  RETN,    TWJMP FO
4370  0200           0200

4371  0000  IOST,    0000     /LOCATE GROUPS IN CORE
4372  0500           TWLDJ
4373  4202           GF+2
4374  0510           TWLDK    /IN GROUP = OUT GROUP?
4375  4205           GT+2
4376  1131           NSJK J
4377  1501           SNZ J
4400  6111           JMP RETN           /YES,RETURN
4401  0514           TWLDK FO           /NO,SET INPUT DATA
4402  1131           XMAX
4403  1604           INC K    /NO OF PTS PER GROUP
4404  0500           TWLDJ
4405  4202           GF+2
4406  2301           SUBL 01 /NO OF GROUPS - 1
4407  1161           ROTD J 01          /DOUBLE PRECISION
4410  1000           MPY
4411  1302           LJKFRS
4412  0540           TWSTJ
4413  4572           INST     /LOCATION OF INPUT GROUP
4414  1604           INC K
4415  1604           INC K    /DATA STARTS IN FIELD 2
4416  0550           TWSTK
4417  4573           INST+1   /FIELD
4420  0514           TWLDK FO           /DO SAME FOR OUTPUT GROUP
4421  1131           XMAX
4422  1604           INC K
4423  0500           TWLDJ
4424  4205           GT+2
4425  2301           SUBL 01
4426  1161           ROTD J 01
4427  1000           MPY
4430  1302           LJKFRS
4431  0540           TWSTJ
4432  4462           OUST     /LOCATION OF OUTPUT GROUP
4433  1604           INC K
4434  1604           INC K
4435  0550           TWSTK
4436  4463           OUST+1
4437  6346           [RETURN IOST

/CONSTANTS FOR HYDROGEN CROSS SECTION
4440  0016  CON1,    0016     /11010.
```

```
4441  2540          2540
4442  2000          2000
4443  0014  CON2,   0014      /4041.
4444  3744          3744
4445  4000          4000
4446  0014  CON3,   0014      /2387.
4447  2251          2251
4450  4000          4000
4451  0010  CON4,   0010      /135.5
4452  2074          2074
4453  0000          0000

4454  0000  STR1,   0000      /GENERAL STORAGE
4455  0000          0000
4456  0000          0000
4457  0000  STR2,   0000      /GENEL STORAGE
4460  0000          0000
4461  0000          0000
4462  0000  OUST,   0000      /WHERE TO PUT OUTPUT DATA
4463  0000          0000      /FIELD
4464  0000  FLUX,   0000
4465  0000          0000
4466  0000          0000

4467  1400  CON5,   1400
4470  0000  SIG,    0000      /CROSS SECTION
4471  0000          0000
4472  0000          0000

/CONVERT SLOPE TO FLUX AND
/  PUT INTO CORRECT OUTPUT LOCATION
/
4473  0000  OPT,    0000
4474  5105          LDJ CON5          /COMPUTE FLUX
4475  0540          TWSTJ
4476  0402          0402
4477  0640          TWJPS
4500  0400          0400      /ENTER FLOAT POINT PACK
4501  0500          FTWLD     /COMPUTE H CROSS SECTION
4502  5034          E
4503  4540          FADD CON2
4504  5530          FSTOR STR1
4505  0500          FTWLD
4506  5034          E
4507  4536          FADD CON4
4510  5531          FSTOR STR2
4511  5151          FLOAD CON1
4512  6536          FDIV STR1
4513  5537          FSTOR STR1
4514  5146          FLOAD CON3
4515  6536          FDIV STR2
4516  4542          FADD STR1
4517  5527          FSTOR SIG         /STORE IT
```

```
4577  0540           TWSTJ
4600  5033           P+2
4601  0640           TWJPS
4602  5045           EFP      /FIND ENERGY
4603  0640           TWJPS
4604  4734           WIN      /FIND WIDTH
4605  0500           TWLDJ
4606  4724           WIP+2    /SLOPE TAKING HALF INTERVAL
4607  5516           STJ PTWTH
4610  4121           SBJ PTNO
4611  2301           SUBL 01
4612  1502           SIP J    /INTERVAL TOO WIDE (LOW)?
4613  6004           JMP .+4 /NO
4614  5125           LDJ PTNO          /YES,
4615  2301           SUBL 01
4616  5525           STJ PTWTH         /DO FROM FIRST POINT
4617  0504   PT2,    TWLDJ F0
4620  1131           XMAX
4621  4132           SBJ PTNO
4622  4131           SBJ PTWTH
4623  1506           SIN J    /TOO WIDE(HIGH)?
4624  6004           JMP .+4 /NO
4625  7106           XCT PT2 /YES, DO TO MAX
4626  4137           SBJ PTNO
4627  5536           STJ PTWTH
4630  5141           LDJ PTNO          /FIND PFST
4631  4140           SBJ PTWTH
4632  5542           STJ PFST
4633  5142           LDJ PTWTH         /FIND NO OF POINTS IN INTERVAL
4634  1161           ROTD J 01
4635  1504           INC J
4636  5542           STJ CNTR
4637  0540           TWSTJ
4640  5230           NPTS     /FOR LSR
4641  5013           LDJ PT4 /SET FIELD BITS
4642  2004           ANDF MASK
4643  4550           ADJ INST+1
4644  5410           STJ PT4
4645  6002           SKIP
4646  7774   MASK,   7774
4647  0640           TWJPS
4650  4673           PFSET    /TRANSLATE PFST TO LOCATION IN CORE
4651  0500           TWLDJ
4652  4566           BUFF
4653  5400           STJ FIRST
4654  0524   PT4,    TWLDJ@ F0         /LOAD DATA - DOUBLE PRECISION
4655  4570           PFST
4656  5600           STJ@ FIRST        /PUT INTO BUFFER
4657  3567           ISZ PFST
4660  6002           SKIP
4661  3505   PT5,    ISZ PT4
4662  7106           XCT PT4
4663  5600           STJ@ FIRST
```

```
4520  0500            FTWLD   /COMPUTE FLUX
4521  5034            E       /FLUX=-(E/(N*SIG*CT)) * (SLOPE/DEPP)
4522  6532            FDIV SIG
4523  0700            FTWMT
4524  5416            SLOPE
4525  0640            FTWDV
4526  4172            HC
4527  0640            FTWDV
4530  4167            CT
4531  0640            FTWDV
4532  5037            DEPP
4533  1003            FNEG
4534  1007            FSIP    /FLUX < 0 ?
4535  1004            FCLR    /YES, FLUX = 0
4536  7405            IFIX
4537  5553            FSTOR FLUX
4540  1001            FEXIT
4541  5017            LDJ PT3 /GET FIELD
4542  4557            ADJ OUST+1
4543  5402            STJ PT1
4544  5156            LDJ FLUX+2        /GET FLUX (LOW ORDER)
4545  0564  PT1,      TWSTJ@ FO         /STORE IT
4546  4462            OUST
4547  3565            ISZ OUST
4550  6002            SKIP
4551  6410            JPS INCR
4552  5165            LDJ FLUX+1        /GET FLUX (HIGH ORDER)
4553  7106            XCT PT1           /STORE IT
4554  3572            ISZ OUST
4555  6002            SKIP
4556  6403            JPS INCR
4557  6364            [RETURN OPT
4560  0564  PT3,      TWSTJ@ FO

4561  0000  INCR,     0000    /INCREMENT FIELD
4562  0340            TWISZ
4563  4463            OUST+1
4564  3517            ISZ PT1
4565  6304            [RETURN INCR


4566  7000  BUFF,     7000    /BUFFER LOCATION
4567  0000  PTNO,     0000    /NO OF POINT IN QUESTION
4570  0000  PFST,     0000    /FIRST POINT OF SLOPE-TAKING INTERVAL
4571  0000  PTWTH,    0000    /HALF WIDTH
4572  0000  INST,     0000    /DATA LOCATION IN MEMORY
4573  0000            0000    /FIELD
4574  0000  CNTR,     0000    /NO OF POINTS TO TRANSFER

/TRANSFER POINTS IN SLOPE-TAKING INTERVAL INTO BUFFER
/
4575  0000  BUFRT,    0000
4576  5107            LDJ PTNO
```

```
4664  3574            ISZ PFST
4665  6002            SKIP
4666  3512            ISZ PT4
4667  3173            DSZ CNTR         /LAST PT?
4670  6114            JMP PT4          /NO
4671  6374            [RETURN BUFRT    /YES


4672  4661  ADR5,     PT5
4673  0000  PFSET,    0000    /CONVERT POINT NO TO CORE LOCATION
4674  1710            CLR JK
4675  0500            TWLDJ
4676  4570            PFST    /GET NUM OF FIRST POINT
4677  2301            SUBL 01
4700  1361            ROTD JK 01       /DOUBLE PRECISION
4701  1450            CLR 0
4702  0440            TWADJ
4703  4572            INST    /CONVERT TO CORE LOCATION
4704  0540            TWSTJ
4705  4570            PFST    /FIRST CORE LOCATION TO GET
4706  1445            SIZ 0   /CHECK FIELD
4707  7315            XCT@ ADR5
4710  1605            SIZ K
4711  7317            XCT@ ADR5
4712  6317            [RETURN PFSET

/END OF BLOCK 3
//

IC AT 4714
IS [       AT 4713
4713  0000  #;

4714  7776  CONST1, 7776    /0.17
4715  2560            2560
4716  5076            5076
4717  0000  WI,       0000    /INTRINSIC WIDTH (KEV)
4720  0000            0000
4721  0000            0000
4722  0000  WIP,      0000    /WI IN POINTS (HALF WIDTH)
4723  0000            0000
4724  0000            0000
4725  0000  WMSQ,     0000    /WM*WM
4726  0000            0000
4727  0000            0000
4730  1400  FPCON1, 1400
4731  0002  TWO,      0002    /FLOATING POINT 2.0
4732  2000            2000
4733  0000            0000

/FIND SLOPE TAKING HALF INTERVAL
/
4734  0000  WIN,      0000    /WI=SQRT(WM**2+CONST1/E)
4735  5105            LDJ FPCON1
```

```
4736  0540           TWSTJ
4737  0402           0402
4740  0640           TWJPS
4741  0400           0400     /ENTER FLOAT POINT PACK
4742  5126           FLOAD CONST1
4743  0640           FTWDV
4744  5034           E
4745  0440           FTWAD
4746  4725           WMSQ
4747  7401           FSQRT
4750  0700           FTWMT
4751  5034           E
4752  5533           FSTOR WI              /WI IN KEV
4753  0640           FTWDV
4754  5037           DEPP     /WI IN POINTS
4755  0700           FTWMT
4756  4206           FDGE
4757  6526           FDIV TWO              /HALF INTERVAL
4760  7405           IFIX
4761  5537           FSTOR WIP             /WIDTH IN POINTS
4762  1001           FEXIT
4763  6327           [RETURN WIN


4764  0000  STOR1,   0000
4765  0000           0000     /FLOAT NO TEMP STORAGE
4766  0000           0000
4767  1400  ADR6,    1400


4770  0000  INIT,    0000     /INITIALIZE SO
4771  5102           LDJ ADR6              /FLOATING CONSTANTS
4772  0540  EN1,     TWSTJ
4773  0402           0402
4774  0640  EN2,     TWJPS
4775  0400           0400
4776  0500           FTWLD    /FIND DEPP FROM CALIBRATION POINTS
4777  4161           P2
5000  0400           FTWSB
5001  4153           P1
5002  5516           FSTOR STOR1
5003  0500           FTWLD
5004  4164           E2
5005  0400           FTWSB
5006  4156           E1
5007  6523           FDIV STOR1
5010  5427           FSTOR DEPP
5011  0500           FTWLD    /FIND B FOR E=PT*DEPP+B
5012  4153           P1
5013  7024           FMULT DEPP
5014  5530           FSTOR STOR1
5015  0500           FTWLD
5016  4156           E1
```

```
5017  4133           FSUB STOR1
5020  5422           FSTOR B
5021  0500           FTWLD    /INITIALIZE WMSQ
5022  4175           MW
5023  0700           FTWMT
5024  4175           MW
5025  0540           FTWST
5026  4725           WMSQ
5027  1001           FEXIT
5030  6340           [RETURN INIT

5031  0000  P,       0000     /POINTER STORAGE
5032  0000           0000
5033  0000           0000
5034  0000  E,       0000     /ENERGY RESULT
5035  0000           0000
5036  0000           0000
5037  0000  DEPP,    0000     /E=DEPP X P + B
5040  0000           0000
5041  0000           0000
5042  0000  B,       0000
5043  0000           0000
5044  0000           0000


5045  0000  EFP,     0000     /FIND ENERGY FROM POINT
5046  5157           LDJ ADR6
5047  7155           XCT EN1
5050  7154           XCT EN2 /ENTER FPP
5051  5120           FLOAD P
5052  7406           FLOAT
5053  7114           FMULT DEPP
5054  4512           FADD B
5055  5521           FSTOR E /E=DEPP*P+B
5056  1001           FEXIT
5057  6312           [RETURN EFP

/XCLR STORES ZEROS IN SUCCESSIVE LOCATIONS
/CALL: JPS XCLR
/       START- FIRST WORD CLEARED
/       NO    - NO OF WORDS CLEARED
/       RETURN POINT
/
5060  0000  XCLR,    0000
5061  5301           LDJ@ XCLR
5062  3502           ISZ XCLR
5063  5406           STJ AD1 /FIRST WD TO BE ZEROED
5064  5304           LDJ@ XCLR
5065  5411           STJ XC2 /NO OF WDS TO BE ZEROED
5066  3506           ISZ XCLR        /SET RETURN ADRESS
5067  1510           CLR J
5070  0540           TWSTJ
5071  0000  AD1,     0000
```

```
5072  3501            ISZ AD1
5073  3003            DSZ XC2
5074  6104            JMP .-4
5075  6315            [RETURN XCLR
5076  0000  XC2,      0000

/END OF BLOCK 4
//

IC AT 5100
5077  0003  #3
/CONVERT DOUBLE OR TPLE PRECISION INTEGER
/TO FLOATING POINT
/
5100  0000  TPCHK,    0000
5101  0500            TWLDJ
5102  5407            POSST
5103  5437            STJ POS /LOCATION OF NUMBER
5104  2302            SUBL 02
5105  5434            STJ POS2
5106  0500            TWLDJ   /PREPARE FPP
5107  5254            IDCON1
5110  0540            TWSTJ
5111  0402            0402
5112  0640            TWJPS
5113  0400            0400    /ENTER IT
5114  0520            FTWLD@  /GET LOW ORDER TWO WORDS OF NUMBER
5115  5142            POS
5116  7406            FLOAT
5117  5424            FSTOR STOR5
5120  1006            FSIN    /IF NEG, NO WANTER=PREC+NO FOUND
5121  6004            FJMP .+4        /SINCE ND ASSUMES DOUBLE PREC INTEGE
5122  5014            FLOAD PREC      /WITH HIGH ORDER BIT SET TO BE NEG
5123  4420            FADD STOR5
5124  5417            FSTOR STOR5
5125  0520            FTWLD@
5126  5141            POS2    /GET HIGH ORDER PART OF NUM
5127  7406            FLOAT
5130  7006            FMULT PREC      /CORRECT MAGNITUDE
5131  4412            FADD STOR5      /ADD LOW ORDER PART
5132  0560            FTWST@  /STORE FLOATING NUMBER
5133  5142            POS
5134  1001            FEXIT
5135  6335            [RETURN TPCHK

5136  0031  PREC,     0031    /4096*4096
5137  2000            2000
5140  0000            0000
5141  0000  POS2,     0000
5142  0000  POS,      0000
5143  0000  STOR5,    0000
5144  0000            0000
5145  0000            0000
```

```
/LINEAR LEAST SQUARES FIT ROUTINE
/ACCUMULATE SUMS IN INTEGER FORMAT TO SAVE TIME
/
/
5146  0000  LSR,    0000
5147  0640          TWJPS
5150  5060          XCLR    /CLEAR SUMS
5151  5231          ICON1
5152  0021          0021
5153  1504          INC J   /INIT POINTERS
5154  5477          STJ ACNT2          /AND COUNTERS
5155  5053          LDJ NPTS
5156  5474          STJ ACNT1
5157  5472          STJ N+2
5160  0500          TWLDJ
5161  4566          BUFF
5162  5400          STJ FIRST
5163  5070  CONTN2, LDJ ACNT2          /SUM OF I
5164  1450          CLR 0
5165  4446          ADJ ICON1+2
5166  5445          STJ ICON1+2
5167  1445          SIZ 0   /OVERFLOW?
5170  3442          ISZ ICON1+1        /YES
5171  5062          LDJ ACNT2          /NO, SUM I X I
5172  1204          LKFJ
5173  1000          MPY     /I X I
5174  1302          LJKFRS
5175  1450          CLR 0
5176  4440          ADJ ICON2+2        /LOW ORDER
5177  5437          STJ ICON2+2
5200  1445          SIZ 0   /OVERFLOW?
5201  1604          INC K   /YES
5202  1374          EXJK    /NO
5203  4432          ADJ ICON2+1
5204  5431          STJ ICON2+1
5205  5200          LDJ@ FIRST         /Y LOW
5206  1374          EXJK
5207  5200          LDJ@ FIRST         /Y HIGH
5210  1374          EXJK
5211  1301          LRSFJK  /STORE DATA
5212  1450          CLR 0
5213  4433          ADJ Y+2            /SUM ON Y
5214  5432          STJ Y+2
5215  1445          SIZ 0   /CHECK FOR CARRIES TO HIGHER PRECISION
5216  3427          ISZ Y+1
5217  6002          SKIP
5220  3424          ISZ Y
5221  1450          CLR 0
5222  1374          EXJK
5223  4422          ADJ Y+1
5224  5421          STJ Y+1
5225  1445          SIZ 0
5226  3416          ISZ Y
5227  6030          JMP CONTN1
```

```
5230  0000  NPTS,    0000      /NO OF POINTS
5231  0000  ICON1,   0000      /SUM OF I
5232  0000           0000
5233  0000           0000
5234  0000  ICON2,   0000      /SUM OF I X I
5235  0000           0000
5236  0000           0000
5237  0000           0000
5240  0000  IY,      0000      /SUM OF I X Y
5241  0000           0000
5242  0000           0000
5243  0000           0000
5244  0000  Y,       0000      /SUM OF Y
5245  0000           0000
5246  0000           0000
5247  0000  N,       0000      /NO OF POINTS
5250  0000           0000
5251  0000           0000
5252  0000  ACNT1,   0000      /COUNTER
5253  0000  ACNT2,   0000      /I
5254  1400  IDCON1,  1400
5255  0600  CJMP,    TWJMP
5256  5163           CONTN2

5257  1302  CONTN1,  LJKFRS  /RESTORE Y
5260  0550           TWSTK   /FIND I X Y
5261  5410           STOR6   /HIGH ORDER LAST
5262  0510           TWLDK
5263  5253           ACNT2   /I
5264  1000           MPY     /I X LOW ORDER - DOUBLE PRECISION
5265  1302           LJKFRS
5266  1450           CLR 0
5267  4525           ADJ IY+2          /ADD IT (LOW)
5270  5526           STJ IY+2          /STORE IT
5271  1374           EXJK
5272  1445           SIZ 0   /CHECK FOR CARRIES
5273  3532           ISZ IY+1
5274  6002           SKIP
5275  3535           ISZ IY
5276  1450           CLR 0
5277  4536           ADJ IY+1          /ADD IT (HIGH)
5300  5537           STJ IY+1
5301  1445           SIZ 0
5302  3542           ISZ IY
5303  0510           TWLDK
5304  5410           STOR6
5305  5132           LDJ ACNT2
5306  1000           MPY     /I X HIGH ORDER - DOUBLE PRECISION
5307  1302           LJKFRS
5310  1450           CLR 0
5311  4550           ADJ IY+1          /ADD IT (LOW)
5312  5551           STJ IY+1
5313  1374           EXJK
```

```
5314  1445        SIZ 0    /CHECK FOR CARRY
5315  1504        INC J
5316  4556        ADJ IY   /ADD IT (HIGH)
5317  5557        STJ IY
5320  3545        ISZ ACNT2
5321  3147        DSZ ACNT1          /LAST?
5322  7145        XCT CJMP           /NO
5323  0640        TWJPS    /YES, FLOAT SUM OF Y
5324  5100        TPCHK    /CHECK FOR
5325  5062        LDJ POSST          /  TRIPLE PRECISION
5326  2304        SUBL 04
5327  5460        STJ POSST          /FLOAT SUM OF I X Y
5330  0640        TWJPS    /MAY BE TRIPLE PRECISION
5331  5100        TPCHK
5332  5055        LDJ POSST
5333  2204        ADDL 04
5334  5453        STJ POSST
5335  5161        LDJ IDCON1         /START PART OF ROUTINE TO FIND SLOPE
5336  0540        TWSTJ
5337  0402        0402
5340  0640        TWJPS
5341  0400        0400     /ENTER FPP
5342  0500        FTWLD
5343  5231        ICON1
5344  7406        FLOAT
5345  0540        FTWST
5346  5231        ICON1
5347  0700        FTWMT
5350  5244        Y
5351  5437        FSTOR STOR6        /STOR6=(SUM I)*(SUM Y)
5352  0500        FTWLD
5353  5247        N
5354  7406        FLOAT
5355  0540        FTWST
5356  5247        N
5357  0700        FTWMT
5360  5240        IY
5361  4027        FSUB STOR6
5362  5431        FSTOR STOR2        /STOR2=N*(SUM IY) - STOR6
5363  0500        FTWLD
5364  5231        ICON1
5365  0700        FTWMT
5366  5231        ICON1
5367  5421        FSTOR STOR6        /STOR6=(SUM I)**2
5370  0500        FTWLD
5371  5234        ICON2
5372  7406        FLOAT
5373  0700        FTWMT
5374  5247        N                  /ACCUMULATOR=(SUM I*I)*N
5375  4013        FSUB STOR6
5376  0700        FTWMT
5377  5037        DEPP
5400  5410        FSTOR STOR6        /STOR6=DEPP*( (SUM I*I)*N-(SUM I)**2
```

APPENDIX A

```
5401  5012            FLOAD STOR2
5402  6406            FDIV STOR6
5403  5413            FSTOR SLOPE      /SLOPE=STOR2/STOR6
5404  1001            FEXIT
5405  0620
5406  5146            [RETURN LSR
5407  5244  POSST,    Y
5410  0000  STOR6,    0000      /TEMP STORAGE
5411  0000            0000
5412  0000            0000
5413  0000  STOR2,    0000
5414  0000            0000
5415  0000            0000
5416  0000  SLOPE,    0000
5417  0000            0000
5420  0000            0000
```

```
SE 6203
A1      = 4072
ACNT1   = 5252
ACNT2   = 5253
AD1     = 5071
ADDR    = 4052
ADR1    = 4053
ADR5    = 4672
ADR6    = 4767
B       = 5042
BUFF    = 4566
BUFRT   = 4575
CJMP    = 5255
CNT1    = 4033
CNT2    = 4034
CNTR    = 4574
CON     = 4015
CON1    = 4440
CON2    = 4443
CON3    = 4446
CON4    = 4451
CON5    = 4467
CONST1  = 4714
CONTN1  = 5257
CONTN2  = 5163
CT      = 4167
CTM     = 4257
DAT1    = 4152
DEPP    = 5037
DFRM    = 4322
DTO     = 4335
E       = 5034
E1      = 4156
E2      = 4164
EFP     = 5045
```

```
EN1     = 4772
EN2     = 4774
ENE     = 4221
EXJK    = 1374
FCLR    = 1004
FDGE    = 4206
FJMP    = 6000
FLOAT   = 7406
FLUX    = 4464
FNEG    = 1003
FPCON1  = 4730
FSIN    = 1006
FSIP    = 1007
FSQRT   = 7401
FUDG    = 4354
GF      = 4200
GT      = 4203
H2CO    = 4274
HC      = 4172
ICON1   = 5231
ICON2   = 5234
IDCON1  = 5254
IFIX    = 7405
INCR    = 4561
INIT    = 4770
INPT    = 4071
INST    = 4572
IOST    = 4371
IY      = 5240
LSR     = 5146
MASK    = 4646
MESSG   = 4051
MEW     = 4306
MW      = 4175
N       = 5247
NPTS    = 5230
OMR     = 4035
OMR1    = 4041
OPT     = 4473
OUST    = 4462
P       = 5031
P1      = 4153
P2      = 4161
PFSET   = 4673
PFST    = 4570
POINT   = 4211
POS     = 5142
POS2    = 5141
POSST   = 5407
PREC    = 5136
PT1     = 4545
PT2     = 4617
PT3     = 4560
PT4     = 4654
PT5     = 4661
PTNO    = 4567
PTWTH   = 4571
RETN    = 4367
SIG     = 4470
SLOPE   = 5416
STOR1   = 4764
STOR2   = 5413
STOR5   = 5143
STOR6   = 5410
STR1    = 4454
STR2    = 4457
STT     = 4054
TITLE   = 4232
TPCHK   = 5100
TWO     = 4731
WI      = 4717
WIN     = 4734
WIP     = 4722
WMSQ    = 4725
XC2     = 5076
XCLR    = 5060
XMAX    = 1131
Y       = 5244
ER 0002
```

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APPENDIX B.—SAMPLE PROGRAM RUN

This appendix provides a sample run of the computer program BASC-12.

```
   DERIVATIVE PROGRAM
POINT =1 ENERGY =1.1
POINT =2.0 ENERGY =.2E+01
COUNT TIME =1.E+03 H CONCEN=.1E-02
MECH WIDTH=.1
IN GOUP =1 OUTPUT GROUP =2
WI MULT= 3.

*  DERIVATIVE PROGRAM
POINT =1 ENERGY =1
POINT =2 ENERGY =2
COUNT TIME =1 H CONCEN=1
MECH WIDTH=.1
IN GOUP =1 OUTPUT GROUP =2
WI MULT= 3.

* 0
```

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