TACI—A Code for Interactive Analysis of Neutron Data Produced by a Tissue Equivalent Proportional Counter

F. M. Cummings

June 1984

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TACI - A CODE FOR INTERACTIVE ANALYSIS OF NEUTRON DATA PRODUCED BY A TISSUE EQUIVALENT PROPORTIONAL COUNTER

INTRODUCTION

The TEPC analysis code (TACI) is a computer program designed to analyze pulse height data generated by a tissue equivalent proportional counter (TEPC). It is written in HP BASIC and is for use on an HP-87XM personal computer. The theory of TEPC analysis upon which this code is based is summarized by the International Commission on Radiological Protection (ICRP 1977).

HARDWARE

The hardware necessary to support this code include an HP-87XM personal computer, HP82901M Flexible Disc Drive, and the HP82905B Printer. An HP7470A X-Y Plotter is an optional accessory.

In addition to the aforementioned hardware, the program requires an HP00087-15003 Rev A I/O Rom, an HP00087-15002 Rev A Plotter Rom, an HP00087-15005 Rev A Advanced Programming Rom 1 and the HP00087-15005 Rev A Advanced Programming Rom 2. The Advanced Programming Roms may be omitted if the program is changed to determine the current date and time in another manner.

THEORY OF ANALYSIS

Neutrons interacting within the wall of a TEPC produce recoiling protons and heavier ions which travel through the TE filling gas depositing energy in the gas by ionization. The electronic pulses created by the passage of the charged recoil particle are collected at the counter anode, amplified and stored as a pulse height distribution in a multichannel analyzer. The energy deposited in the gas divided by the mass of the gas is the radiation dose which could be received by an equivalent volume of tissue in air as produced by neutrons.

The TEPC is self-calibrating because the maximum amount of energy a proton can deposit in one micrometer of tissue (stopping power) is roughly 100 keV (Glass and Samsky 1967). The point at which that maximum occurs in each distribution will depend on the gain of the counting system, the gain of the analyzer and to a small part, the size of the equivalent tissue volume. That point is referred to as the proton drop point, or p-drop, and is found by locating the point of inflection in the distribution of proton events times the square of the pulse height, or channel [known as the $y \cdot D(y)$ distribution]. The data are smoothed by a digital filter and the 2nd derivative of $y \cdot D(y)$ is calculated pointwise by:

$$dA(I) = \sum_{L=1}^7 C(L) \times (CGS(I+L) \times (I+L)^2 - CTS(I-L) \times (I-L)^2) \quad (1)$$

where $dA(I)$ = 2nd derivative at channel I

$CTS(I+L)$ = counts in channel I+L

$C(L)$ = weighting coefficients found in Table 1.

TABLE 1. Digital Filter Weighting Coefficients

$C(1)$	0.01136
$C(2)$	0.02075
$C(3)$	0.02656
$C(4)$	0.02777
$C(5)$	0.02418
$C(6)$	0.01641
$C(7)$	0.00581

The p-drop is determined to be the minimum of the 2nd derivative distribution between the proton recoil data and the heavy ion recoil data (refer to Figure 4). After the p-drop channel is determined, the values are calculated for the diameter and volume of an equivalent site size of tissue, the mass of the filling gas, the conversion of channel number to keV/micrometer and the conversion of counts times channel number to radiation dose. The maximum stopping power for protons is a slowly varying function of the tissue site size (Glass and Samsky 1967). The actual conversion for channel number to energy deposited per distance is interpolated from data in Glass and

Samsky (1967). The dose is calculated using equation 3.1-11 in ICRU (1977) and adjusted to account for site size.

The $y \cdot D(y)$ distribution highlights the region where the events from proton recoils overlap the events from the electron recoils. Where there is sufficient data to find the minimum in the $y \cdot D(y)$ distribution between these two regions, then the start of neutron data is taken to be that minimum (refer to Figure 6). That is, events more energetic than the neutron start point are considered to be due to proton recoils entirely and the events less energetic than the neutron start point are considered to be due to electron recoils entirely. If there are not enough data from electron recoils to determine that point, a default value of 7 keV/micrometer may be used (empirically determined from ^{252}Cf irradiations). Variations of a few channels around the actual neutron start channel will not contribute significant error to the measurement.

Integral doses are calculated by the following equations:

$$D_{\text{gamma}} = \text{RADFAC} \times \sum_{I=\text{GS}}^{\text{NST}-1} \text{CTS}(I) \times I \quad (2)$$

$$D_{\text{neutron}} = \text{RADFAC} \times \sum_{I=\text{NST}}^{\text{NC}} \text{CTS}(I) \times I \quad (3)$$

where D_{gamma} = absorbed dose due to gamma-induced events, mrad
 D_{neutron} = absorbed dose due to neutron-induced events, mrad
 RADFAC = conversion factor
 GS = first non-zero channel number
 NST = neutron start channel
 NC = total number of channels.

The integral dose equivalents are calculated by assuming that the average LET for a given channel number is equal to 4/3 the lineal energy equivalent to that channel. (The factor 4/3 comes from (1) the average lineal energy = average energy deposited divided by the mean chord length of the chamber, or, $y = E/(2/3 \cdot D)$ and (2) the average LET is related to the average y at a channel

by $L = 8/9y$ so that $L = 8/9y = 8/9 \times 3/2 \times E/D$.) The quality factor is related to the average L by equation (4) which is a solution of the quality factor curve in ICRP 21, Figure 2.

$$y < 3.5 \text{ keV/micrometer } Q(y) = 1$$

$$3.5 < y < 175 \text{ keV/micrometer } Q(y) = -7.1680 + 13.4095 \times \ln(y) - 7.7259 \times \ln(y)^2 + 1.9651 \times \ln(y)^3 - 0.1500 \times \ln(y)^4$$

$$y > 175 \text{ keV/micrometer } Q(y) = 20$$

where $y = 4/3 \times I \times \text{KEVCH}$

KEVCH = conversion of channel to lineal energy

The dose equivalents for gamma and neutron events are calculated by equations 5 and 6 below:

$$\text{gamma} = \text{RADFAC} \times \sum_{I=GS}^{NST-1} \text{CTS}(I) \times I \times Q(y) \quad (4)$$

$$\text{neutron} = \text{RADFAC} \times \sum_{I=NST}^{NC} \text{CTS}(I) \times I \times Q(y) \quad (5)$$

where gamma = the gamma dose equivalent, mrem

neutron = the neutron dose equivalent, mrem

$Q(y)$ = quality factor for lineal energy of 'y'

LIMITATIONS OF ANALYSIS

There are several limitations on this kind of measurement relating to the assumptions about the slowing down of recoils in the counter, the actual effect of energy straggling and the relationship of the dose from heavy recoils versus the dose from neutron-induced gamma events. Nonetheless, the measurement seems to be sufficiently accurate for occupational dose and dose rate measurements and the determination of neutron dose and dose equivalent.

Limitations imposed on the results by the calculation technique include the following:

- (1) NSTART - the neutron start point is chosen such that the overlapping portions of the $y \cdot D(y)$ distribution between the electron recoil and proton recoil regions are essentially equal. While that situation will not generally be strictly true, the error introduced by the assumption is small (on the order of 2%).
- (2) LET = $8/9 y$ - this assumption is enumerated in depth in Borak and Stinchcomb, 1982. It is a good approximation for equivalent site diameters of 2 micrometers or less (on the order of 5%).
- (3) W factor - it is assumed that the energy necessary to create ion pairs in TE gas will be slowly varying and an average value will suffice for the accuracy of measurement (on the order of 1%).

TACI PROGRAM OPERATION

During this section, refer to Appendix A for line by line listing of the code.

DATA INPUT lines 80:360

Prior to data input, if the computer senses a date of 0 then the operator is queried for the correct date by:

'Enter today's date (MM/DD/YYYY)...'

The operator responds by entering the correct date, e.g. 03/23/1984.

The operator is then queried for the correct time by:

'Enter the current time (HH:MM:SS)...'

The operator responds by entering the current time, e.g. 09:27:30.

The internal clock is set and the operator is directed to load a 5-1/4-in. floppy disc which contains the input data on drive 1 of the HP disc drive. The disc is cataloged to display the available input files. The program expects input files which are constructed serially containing (1) the total number of data channels, (2) the run title (80 characters-alpha), and (3) data (see Figure 1). The first two data channels contain the live time and real time, respectively. The operator enters the name of the input file.

PARAMETER INITIALIZATION lines 370:590

During this section of the program, the operator must indicate or enter the physical parameters of the measurement, i.e., the type of filling gas (Figure 2), the temperature of the gas at the time the counter was filled (Figure 3), the gas filling pressure, the gas density and the diameter of the counter. Default values for the gas temperature and counter diameter are 25°C and 12.7 cm respectively. The default values for pressure and density for propane-based TE gas are 7.2 torr and 0.001820 g/cc respectively and for methane-based TE gas: 13 torr and 0.001136 g/cc respectively.

2nd DERIVATIVE CALCULATION lines 600:830

The first calculation in this portion of the code adjusts the gas density to account for temperature and pressure variations. The initial channel for the 2nd derivative calculation is referred to as the KNEE and is determined by setting it as shown:

```
if NC > 1100 and KNEE = 0 then KNEE = INT(NC/20)
NC <= 1100 and KNEE = 0 then KNEE = MIN(NC/5,100)
```

This is done because the p-drop is assumed to be between channel 100 and 400 for most cases where NC = 2048 and between 100 and 300 where NC <= 1024.

The upper boundary of the loop for calculating the 2nd derivative is set as shown below:

```
if NC > 1100 then ANKL = INT(NC/5)
NC <= 1100 then ANKL = MAX(NC/2,300)
```

The 2nd derivative distributions is calculated for this range of channels and then plotted. The operator has the option of recalculating the distribution by introducing new loop boundaries. Figure 4 is a plot of a typical neutron run.

P-DROP DETERMINATION lines 840:1130

The p-drop is determined by finding the minimum in the 2nd derivative distribution. The operator is then allowed to verify the point by viewing the plot, entering new plot boundaries (KNEE and ANKL), entering a value of p-drop or entering the channel corresponding to the alpha peak (Figure 5). At this

time the relationship between the alpha peak and the proton drop point for methane-based TE gas at 2 micrometers equivalent has been established empirically to be: $PDP = .92 \times \text{Alpha channel}$. The same relationship is assumed for propane, but the value could be different.

TISSUE PARAMETER CALCULATION lines 1140:1230

The equivalent site size, gas mass and conversion factors are calculated using this section. The actual calculations are enumerated below:

$$EQDIA = 10000 \times DIA \times RHO \quad (7)$$

$$MASS = 0.5236 \times DIA^3 \times RHO \quad (8)$$

$$RADFAC = 1.602 \times 10^{(-11)} \times KEVCH/MASS \times 1000 \times EQDIA \quad (9)$$

$$KEVCH = RKEVM/PDP \quad (10)$$

where $EQDIA$ = diameter of an equivalent volume of tissue, micrometers
 $MASS$ = mass of the filling gas, grams
 $RADFAC$ = dose conversion factor from ICRU 1977, equation 3.1-11
 $KEVCH$ = converts channel to lineal energy, keV/micrometer/channel
 $RKEVM$ = value of maximum stopping power associated with the particular site size, keV/micrometer
 PDP = channel in which the proton drop point occurs.

NSTART DETERMINATION LINES 1240:1620

The neutron start point is calculated by locating the minimum in the $y \cdot D(y)$ distribution between the proton recoil region and the electron recoil region. If the neutron start point cannot be found between 5 and 15 keV/micrometer then the $y \cdot D(y)$ distribution is plotted for those channels between 3 and the one equivalent to 15 keV/micron. The operator may then interactively select the neutron start point by moving a cursor on the plot, selecting a new range of investigation, by selecting a default value corresponding to 7 keV/micrometer or by entering a neutron start channel.

DOSE AND DOSE EQUIVALENT DETERMINATION lines 1630:1990

The neutron absorbed doses and dose equivalents are calculated as shown in earlier equations. The associated rates are determined by dividing by the

live time of the measurement. Additional distributional parameters are calculated including: number of counts associated with the neutron and gamma portions of the raw data distribution, the number of events of channel number times counts and the integral values in the $y \cdot D(y)$ distribution. From these parameters are calculated the average lineal energies in the frequency and dose distributions and the average linear energy transfer in the dose distribution.

TEPC OUTPUT SUMMARY lines 2000:2410

The data and associated parameters are printed out to the HP Printer and the CRT as shown in Figure 6.

PLOTTING lines 2420:2460

The operator may indicate the necessity of plotting (Figure 7) the different distributions. The plotter must be identified (Figure 8) and the type of plot must also be indicated (Figure 9). The actual plotting is performed in a plotting subroutine contained in lines 3770:4120 and in lines 2720:3610. Examples of input data plots produced on the CRT and on the HP plotter are presented in Figures 10 and 11 for inspection.

PRINT INPUT DATA lines 2470:2510

The operator is given the opportunity to print the input data on the HP printer (an example of the printout is given in Figure 12). The actual print subroutine is contained in lines 4130:4350.

ADDITIONAL ANALYSES lines 2520:2560

The operator is given the opportunity to perform additional analyses using the same parameters as the previous analysis (Figure 13). The advantage of performing multiple analyses is chiefly that the run time is reduced by narrowing the window used to calculate the 2nd derivative distribution.

BENCHMARK MEASUREMENTS

During March 1983, benchmark measurements were performed at the NBS californium-252 irradiation facility using a 5-in. TEPC to test the acceptability of the analysis code. Previous measurements have been performed and

are in good agreement, but not documented at this time. The TEPC was placed 56.36 cm from the center of the D_2O -moderated ^{252}Cf source in the low scatter facility. The emission rate of the source was $8.91E8$ n/s and the dose equivalent rate at 56.35 cm was calculated by using equation 1 in NUREG/CR-2957 (McDonald et al. 1983). The equation was modified by a factor of 0.89 because 11% of the emitted neutrons are below the cadmium cut-off energy (0.5 eV) and the cask containing the D_2O and ^{252}Cf source includes a spherical 0.5-mm cadmium shell (Schwartz and Eisenhauer 1980). The calculated dose equivalent rate was 645 mrem/hr at 56.35 cm. The TEPC output summary is contained in Appendix D along with pertinent plots. The dose equivalent rate determined using the TEPC was $637 \text{ mrem/hr} \pm 37 \text{ mrem/hr}$ (1 standard deviation). The benchmark measurement is included in the document for quality assurance purposes.

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```

Load data disk on drive #1 and hit [CONT]
[ Volume ]: CLEAN
Name          Type   Bytes   Recs
TA318         DATA   256     65
TL1           DATA   256     65
TH1           DATA   256     65
TL2           DATA   256     65
TH2           DATA   256     65
TL3           DATA   256     65
TH3           DATA   256     65
TCOMH         DATA   256     65
TCOML         DATA   256     65
TPLOT         PROG    256     12
What is the name of the input data file...

```

FIGURE 1.

File: **11**

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

Propane or Methane?

11

ABORT		Propane		Methane		Neither
-------	--	---------	--	---------	--	---------

FIGURE 2.

ETCANE 11

FILE: **TEL1**

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

GAS = PROPANE

Gas Temperature c	Gas Pressure (torr)	Gas Density (g/cc)	Counter Diameter (cm)
25	7.2	.001820	12.7

12

LEONARD CO. 11/18/83

ABORT	Change Gas	Temp	Pressure	Density	Diameter	No Change
-------	------------	------	----------	---------	----------	-----------

FIGURE 3.

VERSION SEPT,1983

PROGRAM TEPC
DATE: 03/22/1984

PAGE 1
TIME: 16:02

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)
INPUT FILE NAME: TL1

FIGURE 4.

FILE: **TL1**

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

The Proton Drop Point was found to be channel 372 between channels 102 & 409

Okay??

ABORT	QUIT	KNEE, ANKLE	PROTON DROP POINT	ALPHA PEAK	VIEW PLOT	PDP OK
-------	------	-------------	----------------------	------------	-----------	--------

FIGURE 5.

VERSION SEPT,1983

PROGRAM TEPC
DATE: 03/22/1984

PAGE 2
TIME: 16:57

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 535B-pg22)
INPUT FILE NAME: TL1

FIGURE 6.

FILE: **741**

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

The Neutron Start Point was found to be channel 31 between channels 18 & 55

16

Okay??

ABORT		X1, X2	NEUTRON ST. POINT	DEFAULT	VIEW PLOT	NST OKAY
-------	--	--------	----------------------	---------	-----------	----------

FIGURE 7.

VERSION MAR,1984

PROGRAM TEPC
DATE: 03/28/1984

PAGE 2
TIME: 13:17

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

INPUT FILE NAME: TL1

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

TE GAS	TE GAS TEMPERATURE (deg-C)	TE GAS PRESSURE (torr)	TE GAS DENSITY (g/cc)	TE GAS MASS (g)
PROPANE	25	7.2	.001820	.016941

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.0 microns
2048 Channels read Live time= 8299 seconds

Proton Drop Point= Channel 372 equivalent to 98.0 keV/micron
Neutron Start Point= Channel 31 equivalent to 8.2 keV/micron
Gamma Start Point= Channel 3 equivalent to .8 keV/micron

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	7.701E+006	2.269E+006	9.970E+006
Counts*Ch	7.736E+007	2.377E+008	3.151E+008
Counts*Ch2	1.091E+009	4.469E+010	4.578E+010
y-bar F	2.6	27.6	8.3
y-bar D	3.7	49.5	38.3
L-bar D	3.3	44.0	34.0

Restricted y-bar D between 8.2 and 115 keV/micron is 40.2

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	3.865E+001	1.188E+002	1.574E+002
Standard Deviation	7.869E+000	6.871E+000	1.045E+001
Quality Factors	1.5	9.9	7.8
Integral DE, mrem	5.929E+001	1.170E+003	1.230E+003
Dose Rate, mrad/hr	1.677E+001	5.152E+001	6.829E+001
DE Rate, mrem/hr	2.572E+001	5.077E+002	5.334E+002

Analysis OK: _____ Date: _____

Verified by: _____ Date: _____

FIGURE 8.

FILE: 7-1

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

Plot distributions?...

FIGURE 9.

FILE: **FILE**

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

HP Plotter or CRT?...

ABORT

FILE

CRT

FILE

HP PLOTTER

FILE

EXIT

FIGURE 10.

FILE:

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

Please select type of plot...

ABORT

Raw Data

Dose Data

92

EXIT

FIGURE 11.

VERSION SEPT, 1983

PROGRAM TEPC
DATE: 03/22/1984

PAGE 1
TIME: 14:34

Low Gain neutron spectrum from moderated
INPUT FILE NAME: TL1

FIGURE 12.

FILE: **LI**

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

Print raw data?...

ABORT

YES

NO

FIGURE 13.

FIGURE 14.

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

Channel	Input Data							
1	8299	8413	796147	305533	1028148	810903	655033	539420
9	452320	384023	329799	288041	252399	223657	199178	178236
17	160327	144375	130531	117333	105856	95885	85844	77565
25	70130	63678	58275	53058	49544	45794	42965	40430
33	38128	36398	35138	33389	32393	31876	30965	29797
41	29038	28646	28193	27435	27071	26732	26283	25238
49	25447	25074	24353	24051	23864	23593	23183	23006
57	22566	22279	21821	21392	20708	20490	20404	20073
65	19908	19368	18822	18809	18511	18040	17630	17567
73	17254	16782	16661	16246	16123	15751	15409	15176
81	14887	14871	14445	14318	14157	13822	13422	13212
89	13088	12712	12703	12201	12091	11823	11941	11453
97	11437	11165	11052	10630	10677	10227	10255	10065
105	9782	9566	9443	9407	9258	9079	8957	8845
113	8576	8500	8352	8238	7911	7818	7935	7768
121	7574	7456	7260	7228	7189	7084	6786	6818
129	6736	6595	6573	6399	6220	6180	6111	6092
137	5992	5868	5622	5654	5605	5631	5549	5537
145	5283	5289	5105	4973	5057	4945	4737	4871
153	4812	4779	4640	4578	4502	4414	4349	4312
161	4289	4274	4183	4161	4091	4026	3869	3944
169	3907	3816	3883	3651	3649	3719	3622	3514
177	3536	3572	3421	3445	3415	3393	3386	3179
185	3276	3179	3141	3070	3124	3076	2973	3003

FIGURE 15.

FILE: **7-1**

Low Gain neutron spectrum from moderated-Cf 11/18/83 (LRB# 5358-pg22)

Another TEPC run?...

ABORT **YES** **NO**

FIGURE 16.

FIGURE 10

UNCLASSIFIED

FOR OFFICIAL USE ONLY (FOUO) - INFORMATION CONTAINED HEREIN IS UNCLASSIFIED EXCEPT WHERE SHOWN OTHERWISE

DATE

APPENDIX A
PROGRAM LISTING

```

10 OPTION BASE 1
20 DIM T$(80),F$(12),A$(7),GAS$(7),X$(30),Y$(24),P$(30),D$(10),REC$(80)
30 DIM CRS$(30),BL$(30),CTS(2048),dA(1024),EOD(7),POS(7),C1(8)
40 DEF FNOF(Y) = -7.168+17.4095*Y-7.7259*Y^2+1.9651*Y^3-.15*Y^4
50 PRINTER IS 701,80
60 ENABLE KBD 173 @ REMOTE 706,710 @ LOCAL LOCKOUT 7
70 GOSUB IN1
80 PN=1
90 ! *****
100 !           Read in data from disk
110 ! *****
120 IF DATE > 0 THEN GOTO 180
130 CLEAR @ DISP "Enter today's date (MM/DD/YYYY)..." @ INPUT D$
140 D=MDY (D$) @ DA=MDY ("12/31/1987") @ D=B4000+D-DA
150 CLEAR @ DISP "Enter the current time (HH:MM:SS)..." @ INPUT H$
160 T=3600*VAL (H$(1,2))+60*VAL (H$(4,5))+VAL (H$(7,8))
170 SETTIME T,D
180 D1=INT (DATE /1000)*1000 @ D2=MDY ("12/31/19")@VAL$ (INT (D1/1000)-1))
190 D$=MDY$ (DATE -D1+D2)
200 IF KNEE#0 THEN GOTO 230
210 CLEAR @ DISP USING "6/" @ DISP "Load data disk on drive #1 and hit [CONT]"
220 PAUSE
230 CAT ":D701"
240 DISP "What is the name of the input data file..." @ INPUT T$
250 T$=LEN (T$)
260 F$(1,T)=T$(1,T) @ T$="" @ ASSIGN# 1 TO F$":D701"
270 FOR I=1 TO LEN (F$) @ B$(1,I)=CHR$ (NUM (F$(1,I))+128) @ NEXT I
280 CLEAR @ DISP USING 4380 : "Reading data from file \"%B$%\" ..."
290 READ# 1 : NC,T$
300 IF NC=2048 THEN READ# 1 : CTS()@ GOTO 320
310 FOR I=1 TO NC @ READ# 1 : CTS(I)@ NEXT I
320 IF KNEE=0 THEN GOTO GAS
330 CLEAR @ OFF KEY# @ ON KEY# 1,A$ GOTO ABORT
340 ON KEY# 3," YES" GOTO CALC @ ON KEY# 5," NO" GOTO GAS
350 DISP USING 4410 : "File: ",B$,T$,"Same parameters as last time?..."
360 KEY LABEL
370 GOTO 370
380 ! *****
390 !           Enter counter parameters
400 ! *****
410 GAS: CLEAR @ OFF KEY#
420 ON KEY# 1,A$ GOTO ABORT @ ON KEY# 3," Propane" GOTO PRO
430 ON KEY# 5," Methane" GOTO MET @ ON KEY# 7," Neither" GOTO NEI
440 DISP USING 4410 : "File: ",B$,T$,"Propane or Methane?" @ KEY LABEL
450 GOTO 450
460 PRO: CLEAR @ GAS$="PROPANE" @ TEMP=25 @ PRESS=7.2 @ RHO=.00182 @ DIA=12.7 @
GOTO DIS
470 MET: CLEAR @ GAS$="METHANE" @ TEMP=25 @ PRESS=7 @ RHO=.001136 @ DIA=12.7 @ G
OTO DIS
480 NEI: DISP "Enter filling gas..." @ INPUT GAS$@ TEMP,PRESS,RHO,DIA=0
490 DIS: CLEAR @ DISP USING 4410 : "File: ",B$,T$,"GAS = \"%GAS%
500 DISP USING 4390 : "Gas Temperature","Gas Pressure","Gas Density","Counter Di
ameter","c","(torr)","(g/cc)","(cm)"
510 DISP USING 4400 : TEMP,PRESS,RHO,DIA
520 ON KEY# 2,"Change Gas" GOTO GAS @ ON KEY# 3," Temp" GOTO CTEM
530 ON KEY# 4," Pressure" GOTO CPRE @ ON KEY# 5," Density" GOTO CRHO
540 ON KEY# 6," Diameter" GOTO CDIA @ ON KEY# 7,"No Change" GOTO CALC
550 KEY LABEL
560 GOTO 560

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570 CTEM: DISP "Gas Temperature?..." @ INPUT TEMPE @ GOTO DIS
580 CPRE: DISP "Gas Pressure?..." @ INPUT PRESSE @ GOTO DIS
590 CRHO: DISP "Gas Density?..." @ INPUT RHOE @ GOTO DIS
600 CDIA: DISP "Counter diameter?..." @ INPUT DIAE @ GOTO DIS
610 ! *****
620 ! Calculate 2nd derivatives of y*D(y) distribution
630 ! *****
640 CALC: CLEAR @ OFF KEY# @ ON KEY# 1 GOTO ABORT
650 RHO=RHO*(PRESS/760)*(273/(TEMP+273))
660 LT=CTS(1) @ RT=CTS(2) @ CTS(1),CTS(2)=0
670 IF NC<1100 THEN KNEE=MIN (NC/5,100) @ ANKL=MAX (NC/2,300)
680 IF KNEE=0 THEN KNEE=INT (NC/20) @ ANKL=INT (NC/5)
690 X1=MAX (KNEE,15) @ X2=MAX (MIN (ANKL,NC-15),X1+20)
700 DISP USING 4410 : "File: ",B$,T$,"Calculating 2nd derivatives..."
710 T,JJ=1 @ LY=1.E20 @ HY=-1.E20
720 FOR I=X1 TO X2
730 dA(JJ)=C1(I)*CTS(I)*I*I
740 FOR L=2 TO 8
750 dA(JJ)=dA(JJ)+C1(L)*(CTS(I+L)*(I+L)^2-CTS(I-L)*(I-L)^2)
760 NEXT L
770 LY=MIN (LY,dA(JJ)) @ HY=MAX (HY,dA(JJ)) @ JJ=JJ+1
780 NEXT I
790 RANGE=(X2-X1) MOD 100 @ LO=INT (X1-RANGE/2) @ HI=INT (X2+RANGE/2)
800 RANGE=(HY-LY) MOD 100 @ LY=INT (LY-RANGE/2) @ HY=INT (HY+RANGE/2)
810 XT=INT (HI-LO)/20 @ YTIC=INT (HY-LY)/10 @ XD,YD=0 @ XN=2 @ YTN=1 @ TYPE=1
820 X$="Channel Number" @ P$="2nd Deriv's in y2" @ Y$="2nd Deriv"
830 XA=X1 @ XB=X2 @ X1=1 @ X2=JJ-1 @ PLTR=1 @ GOSUB PLT
840 CLEAR @ OFF KEY# @ ON KEY# 1,A$ GOTO ABORT @ GOTO FFIND
850 ! *****
860 ! Determine Proton Drop Point
870 ! The Pdrop is equivalent to the minimum in the 2nd derivative curve of
880 ! the y*D(y) distribution....
890 ! *****
900 PDROP: CLEAR @ OFF KEY# @ ON KEY# 1,A$ GOTO ABORT
910 ON KEY# 3,"KNEE,ANKLE" GOTO PCAL @ ON KEY# 4,"DROP POINT" GOTO PGIV
920 ON KEY# 5,"ALPHA PEAK" GOTO AGIV @ ON KEY# 6,"VIEW PLOT" GOTO VIEW
930 ON KEY# 7," PDP OK " GOTO OK @ ON KEY# 11," PROTON" GOTO PGIV
940 DISP USING 4420 : "FILE: ",B$,T$,"The Proton Drop Point was found to be chann
e1 "%VAL$ (PDP)% between channels "%VAL$ (KNEE)% & "%VAL$ (ANKL)
950 KEY LABEL
960 GOTO 960
970 VIEW: GRAPH @ WAIT 10000 @ GOTO PDROP
980 PCAL: DISP "Enter the Knee and Ankle..." @ INPUT X1,X2 @ GOTO 700
990 PGIV: DISP "Enter the Proton Drop Point..." @ INPUT PDP @ GOTO PDROP
1000 AGIV: DISP "Enter the Alpha Peak Channel..." @ INPUT AL
1010 IF GAS$="METHANE" THEN PDP=.92*AL @ GOTO PDROP
1020 ! The relationship between the alpha peak and proton drop point was
1030 ! determined for methane at 1 micron equivalent. The value for propane
1040 ! will be assumed to be the same until verified experimentally...FMC
1050 IF GAS$="PROPANE" THEN PDP=.92*AL @ GOTO PDROP
1060 FFIND: CLEAR @ DISP USING 4410 : "FILE: ",B$,T$,"Calculating PDROP..."
1070 T=1
1080 FOR I=X1 TO X2
1090 IF dA(I)<= dA(T) THEN T=I
1100 NEXT I
1110 PDP=XA-1+T
1120 IF T#X1 AND T#X2 THEN GOTO PDROP
1130 IF T=X1 AND X1>15 THEN X1=MAX (15,INT (X1-.2*X1)) @ GOTO 710
1140 IF T=X2 AND X2<NC/2 THEN X2=MIN (NC-15,INT (X2+.2*X2)) @ GOTO 710
1150 ! *****

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1160 ' Calculate the channel to kev/micron conversion
1170 ' *****
1180 ON: EODIA=10000*DIA*RHO @ MASS=.5234*DIA^3*RHO
1190 FOR I=1 TO 6
1200 IF EODIA< EOD(I+1) THEN GOTO 1220
1210 NEXT I
1220 REVM=PDS(I)+(PDS(I+1)-PDS(I))*(EODIA-EOD(I))/(EOD(I+1)-EOD(I))
1230 KEVCH=REVM/PDP @ RADFAC=1.602E-11*KEVCH/MASS*1000*EODIA
1240 CLEAR @ OFF KEY# @ ON KEY# 1,A$ GOTO ABORT
1250 ' *****
1260 ' Calculate the Neutron Start Point
1270 ' The neutron start point is determined to be the minimum in the
1280 ' y*D(y) distribution...
1290 ' *****
1300 X1=MAX (C,INT (5/KEVCH)) @ X2=MIN (INT (15/KEVCH),INT (NC*.9))
1310 NSTART: CLEAR
1320 DISP USING 4410 : "FILE:".B$,T$,"Calculating Neutron Start Point..."
1330 T=X1 @ HY=-1.E20 @ LY=1.E20
1340 FOR I=X1 TO X2
1350 A=CTS(T)*T*T @ B=CTS(I)*I*I
1360 IF A< B THEN T=I
1370 HY=MAX (HY,B) @ LY=MAX (LY,B)
1380 NEXT I
1390 NST=T
1400 IF T=X1 AND T=X2 THEN GOTO NCHECK
1410 P$="y2 Plot for NSTART" @ X$="Channel #" @ Y$="Counts*ch*ch"
1420 HIGH=HY/.9 @ XD,LO,LY=0 @ YD,HY,XT,FLTR=1 @ YTN,TYPE=2
1430 HI=X2+(10-X2 MOD 10) @ XN=HI/10 @ YTIC=.1
1440 CLEAR @ DISP USING "6/.80A" ; " To determine the neutron start point, m
ove the cursor in the next plot"
1450 DISP "to the minimum point (or the middle of the flat part) in the "
1460 DISP "plotted distribution. It should be somewhere around channel number"
1470 DISP VAL$ (INT (7/KEVCH))$ " ..... we will start plotting in 15 seconds..."
1480 WAIT 15000
1490 GOSUB FLT
1500 NCHECK: CLEAR
1510 ON KEY# 1,A$ GOTO ABORT @ ON KEY# 3," X1,X2" GOTO XGIV
1520 ON KEY# 11," NEUTRON" GOTO NGIV @ ON KEY# 4," ST. POINT" GOTO NGIV
1530 ON KEY# 5," DEFAULT" GOTO DVAL @ ON KEY# 6," VIEW PLOT" GOTO VUE
1540 ON KEY# 7," NST DRAY" GOTO NOK
1550 DISP USING 4420 : "FILE:".B$,T$,"The Neutron Start Point was found to be ch
annel "&VAL$ (NST)$" between channels "&VAL$ (X1)$" & "&VAL$ (X2)
1560 KEY LABEL
1570 GOTO 1570
1580 XGIV: CLEAR @ DISP USING 4410 : "FILE:".B$,T$,"Enter x1 and x2...(X1,X2)"
1590 INPUT X1,X2@ GOTO NSTART
1600 NGIV: CLEAR @ DISP USING 4410 : "FILE:".B$,T$,"Enter NSTART channel..."
1610 INPUT NST@ GOTO NCHECK
1620 DVAL: NST=INT (7/KEVCH) @ GOTO NCHECK
1630 VUE: GRAPH @ WAIT 10000 @ GOTO NCHECK
1640 ' *****
1650 ' Calculate doses and dose equivalents
1660 ' *****
1670 NOK: FOR I=1 TO NST
1680 IF CTS(I)#0 THEN GS=I @ GOTO 1700
1690 NEXT I
1700 CLEAR @ DISP USING 4410 : "FILE:".B$,T$,"Calculating doses..."
1710 NG,DG,YG,NN,DN,YN,gamma,neutron,SG,SN=0
1720 IF GS=NST THEN GOTO 1790
1730 FOR I=GS TO NST-1

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1740 y=I*KEVCH*4/3 ! Korah & Stinchcomb, Health Physics #8/1982, pg 20
1750 D=CTS(I)*I @ NG=NG+CTS(I) @ DG=DG+D @ YG=YG+D*I @ SG=SG+D*D
1760 IF y = 3.5 THEN D=1 ELSE D=FNDF(LOG (y))
1770 gamma=gamma+D*D
1780 NEXT I
1790 FOR I=NST TO NC
1800 IF CTS(I)=0 THEN GOTO 1860
1810 y=I*KEVCH*4/3
1820 IF I<INT (115/KEVCH) THEN RSTD=DN @ RSTY=YN
1830 D=CTS(I)*I @ NN=NN+CTS(I) @ DN=DN+D @ YN=YN+D*I @ SN=SN+D*D
1840 IF y>= 175 THEN D=20 ELSE D=FNDF(LOG (y))
1850 neutron=neutron+D*D
1860 NEXT I
1870 T=LT/3600
1880 IF NG#0 THEN YDG=DG/NG*KEVCH @ YYG=YG/DG*KEVCH
1890 NT=NG+NN @ DT=DG+DN @ YT=YG+YN
1900 YDN=DN/NN*KEVCH @ YYN=YN/DN*KEVCH
1910 YDT=(DG+DN)/(NG+NN)*KEVCH @ YYT=(YG+YN)/(DG+DN)*KEVCH
1920 LBG=YYG*8/9 @ LBN=YYN*8/9 @ LBT=YYT*8/9
1930 Dgamma=DG*RADFAC @ Dneutron=DN*RADFAC @ Dtotal=Dgamma+Dneutron
1940 ST=SOR (SG+SN)*RADFAC @ SG=SOR (SG)*RADFAC @ SN=SOR (SN)*RADFAC
1950 gamma=gamma*RADFAC @ neutron=neutron*RADFAC @ total=gamma+neutron
1960 IF DG#0 THEN DFG=gamma/DG
1970 DFG=gamma/Dgamma @ DFN=neutron/Dneutron @ DFT=total/Dtotal
1980 DRG=Dgamma/T @ DFN=Dneutron/T @ DRT=Dtotal/T
1990 DEGR=gamma/T @ DENR=neutron/T @ DETR=total/T
2000 RHO=RHO*760/PRESS*(TEMP+273)/273
2010 ! *****
2020 ! Output data to CRT and HP Printer
2030 ! *****
2040 FOR PTR=2 TO 701 STEP 699
2050 PRINTER IS PTR
2060 PRINT USING 4430 : "PROGRAM TPC", "PAGE "&VAL$ (PN) @ PN=PN+1
2070 PRINT USING 4440 : "VERSION MAR.1984", "DATE: "&D$, "TIME: "&TIME$
2080 PRINT @ PRINT TAB (40-LEN (T$)/2):T$ @ PRINT
2090 PRINT USING 4450 : "INPUT FILE NAME: "&F$
2100 PRINT USING 4460 : "TEPC OUTPUT SUMMARY"
2110 PRINT USING 4470 : "----TEPC OPERATING PARAMETERS----"
2120 PRINT USING 4480 : "TE GAS", "TE GAS", "TE GAS", "TE GAS", "TE GAS", "TEMPERATUR
E", "PRESSURE", "DENSITY", "MASS"
2130 PRINT USING 4490 : "(deg-C)", "(torr)", "(g/cc)", "(g)"
2140 PRINT USING 4500 : GAS$, TEMP, PRESS, RHO, MASS
2150 PRINT USING 4510 : "CHAMBER DIAMETER= ", DIA, " cm", "SITE EQUIVALENT DIAMETER
= ", EDDIA, " microns"
2160 PRINT USING 4520 : NC, " Channels read", "Live time= ", LT, " seconds"
2170 PRINT USING 4530 : "Proton Drop Point= Channel ", FDP, " equivalent to ", KEVC
H*FDP, " keV/micron"
2180 PRINT USING 4530 : "Neutron Start Point= Channel ", NST, " equivalent to ", KE
VCH*NST, " keV/micron"
2190 PRINT USING 4530 : "Gamma Start Point= Channel ", GS, " equivalent to ", KEVCH
*GS, " keV/micron"
2200 PRINT USING 4540 : "----DISTRIBUTION PARAMETERS----"
2210 PRINT USING 4550 : "gamma", "neutron", "total"
2220 PRINT USING 4560 : "Counts/Ch", NG, NN, NT
2230 PRINT USING 4560 : "Counts*Ch", DG, DN, DT
2240 PRINT USING 4560 : "Counts*Ch2", YG, YN, YT
2250 PRINT USING 4570 : "y-bar F", YDG, YDN, YDT
2260 PRINT USING 4570 : "y-bar D", YYG, YYN, YYT
2270 PRINT USING 4570 : "L-bar D", LBG, LBN, LBT
2280 PRINT USING 4580 : "Restricted y-bar D between ", NST*KEVCH, " and 115 keV/mi

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from is ",RSTY/RSTD*PEVCH
2290 PRINT USING 4600 : "----DOSE AND DOSE EQUIVALENT DATA----"
2300 PRINT USING 4620 : "Integral Dose, mrad",Dgamma,Dneutron,Dtotal
2310 PRINT USING 4610 : "Standard Deviation",SG,SN,ST
2320 PRINT
2330 PRINT USING 4590 : "Duality Factors",DFG,DFN,OFT
2340 PRINT USING 4610 : "Integral DE, mrem",gamma,neutron,total
2350 PRINT
2360 PRINT USING 4610 : "Dose Rate, mrad/hr",DRG,DRN,DRT
2370 PRINT USING 4610 : "DE Rate, mrem/hr",DEGR,DENR,DETR
2380 IF PTR=2 THEN GOTO 2420
2390 PRINT USING 4630 : "Analysis OK: ", "Date: "
2400 PRINT USING 4630 : "Verified by: ", "Date: "
2410 IF PTR=701 THEN PRINT CHR$(12)
2420 NEXT PTR
2430 NEX0: OFF KEY# @ CLEAR @ ON KEY# 1,A$ GOTO ABORT
2440 ON KEY# 3," YES" GOTO NEX1 @ ON KEY# 5," NO" GOTO NEX2
2450 DISP USING 4410 : "FILE: ",B$,T$,"Plot distributions?... " @ KEY LABEL
2460 GOTO 2460
2470 NEX1: GDSUB PLOTS @ GOTO NEX0
2480 NEX2: OFF KEY# @ CLEAR @ ON KEY# 1,A$ GOTO ABORT
2490 ON KEY# 3," YES" GOTO NEX3 @ ON KEY# 5," NO" GOTO NEX4
2500 DISP USING 4410 : "FILE: ",B$,T$,"Print raw data?... " @ KEY LABEL
2510 GOTO 2510
2520 NEX3: GDSUB PRNTDAT @ GOTO NEX4
2530 NEX4: CLEAR @ OFF KEY# @ ON KEY# 1,A$ GOTO ABORT
2540 ON KEY# 3," YES" GOTO NEX5 @ ON KEY# 5," NO" GOTO NEX6
2550 DISP USING 4410 : "FILE: ",B$,T$,"Another TEPC run?... " @ KEY LABEL
2560 GOTO 2560
2570 NEX5: I=INT (PDF*.25) @ KNEE=PDP-I @ ANKL=PDP+I @ GOTO 80
2580 NEX6: CHAIN "Autost"
2590 ! *****
2600 ! * INITIALIZE ROUTINE *
2610 ! *****
2620 IN1:
2630 FOR I=1 TO 7 @ READ EQD(I),PDS(I) @ NEXT I
2640 DATA 0.104,.13.104,.15.103,1.101,2.98,5.90,1.E20,90
2650 FOR I=1 TO 30 @ CRS$(I)=CHR$(128) @ NEXT I
2660 FOR I=1 TO 30 @ BL$(I)=CHR$(0) @ NEXT I
2670 KNEE,ANKL,PDP=0
2680 HY=-1.E20 @ LY=1.E20 @ FN=1
2690 FOR I=1 TO 8 @ READ C1(I) @ NEXT I
2700 DATA 0,.01136,.02075,.02656,.02777,.02418,.01641,.00581
2710 A$=" ABORT"
2720 RETURN
2730 ! *****
2740 ! * Plotting Routine *
2750 ! *****
2760 PLT: PLOTTER IS PLTR
2770 IF PLTR=705 THEN LOCATE 0.130,0.100 @ XMIN=15 @ XMAX=130 @ GOTO 2800
2780 IF PLTR=1 THEN GCLEAR @ LIMIT 0.125,0.75 @ LOCATE 0.160,0.100
2790 XMIN=20 @ XMAX=160
2800 IF PLTR=1 THEN GOTO 2830
2810 CLEAR @ DISP USING "6/,20X,40A" : "L O A D P L O T T E R"
2820 DISP USING "1/,24X,40A" : "and hit CONTINUE" @ PAUSE
2830 DEG @ CSIZE 6 @ LDIR 0 @ LORG 6 @ PEN 1
2840 XDIM=XMAX-XMIN @ XLOC=XMIN+XDIM/2
2850 MOVE XLOC,100 @ LABEL P$ @ MOVE XLOC,6.5 @ LABEL X$

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2860 MOVE 0.50 @ LDIR 90 @ LABEL Y*
2870 CSIZE 4 @ LDIR 0 @ FXD XD,YD @ LORG 5
2880 SETGU @ LOCATE XMIN,XMAX,15,95
2890 SCALE LO,HI,LY,HY @ LAXES -XT,YTIC,LO,LY,XN,YTN,5
2900 ON TYPE GOTO T1,T2,T3,T4
2910 T1: ! CRT plot of 2nd derivative curve in y2 dist for pdp determination
2920 FOR I=X1 TO X2
2930 T=XA-1+I @ MOVE T,DA(I) @ LABEL "+" @ PEN UP
2940 NEXT I
2950 GOSUB NX
2960 RETURN
2970 T2: ! CRT plot of y2 distribution for nstart determination
2980 FOR I=X1 TO X2
2990 PLOT I,CTS(I)*I*HIGH @ PEN UP
3000 NEXT I
3010 GOSUB CURS @ GOSUB NX
3020 RETURN
3030 T3: ! Plot of log of counts vs channel number
3040 IF PLTR=705 THEN SV=10 ELSE SV=14
3050 LORG 9 @ SETGU
3060 FOR I=LY TO HY
3070 IF I<0 THEN SY=SV-2 ELSE SX=SV
3080 MOVE SX,(I-LY)*80/(HY-LY)+15 @ LABEL "10" @ PEN UP
3090 NEXT I
3100 SETUU @ LORG 5
3110 FOR I=1 TO NC STEP 10
3120 IF CTS(I)≠0 THEN PLOT I,LGT (CTS(I)) @ PEN UP
3130 NEXT I
3140 IF PLTR=1 THEN GOSUB NX @ RETURN
3150 GOTO RSET
3160 T4: ! Plot of Fraction of dose and y*D(y) events vs lineal energy
3170 IF PLTR=705 THEN SV=14 ELSE SV=18
3180 XDIM=XMAX-XMIN
3190 LORG 9 @ SETGU
3200 FOR I=LO TO HI
3210 IF I<0 THEN SX=SV-2 ELSE SX=SV
3220 MOVE (I-LO)*XDIM/(HI-LO)+SX,12 @ LABEL "10" @ PEN UP
3230 NEXT I
3240 SETUU
3250 FOR I=LO TO HI-1
3260 FOR L=1 TO 9
3270 SX=LGT (L*10-1) @ IF L=5 THEN SY=.03 ELSE SY=.015
3280 MOVE SX,SY @ DRAW SX,0 @ PEN UP
3290 NEXT L
3300 NEXT I
3310 HIGH=0
3320 FOR I=INT (10/KEVCH) TO INT (100/KEVCH)
3330 HIGH=MAX (HIGH,CTS(I)*I-EX)
3340 NEXT I
3350 HIGH=HIGH/.9 @ SETUU @ LORG 5
3360 FOR I=65 TO INT (100/KEVCH*3/2)
3370 PLOT LGT (I*KEVCH*3/2),CTS(I)*I-EX/HIGH @ PEN UP
3380 NEXT I
3390 FOR I=INT (100/KEVCH*3/2)+1 TO INT (300/KEVCH*3/2) STEP 8
3400 PLOT LGT (I*KEVCH*3/2),CTS(I)*I-EX/HIGH @ PEN UP
3410 NEXT I
3420 FOR I=INT (300/KEVCH*3/2)+1 TO NC STEP 20
3430 PLOT LGT (I*KEVCH*3/2),CTS(I)*I-EX/HIGH @ PEN UP
3440 NEXT I
3450 IF PLTR=1 THEN GOSUB NX @ RETURN

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3460 GOTO RSET
3470 RSET: ' Resets paper and returns pen to fount...
3480 SETGU @ LOCATE 0,100,0,100 @ MOVE 0,0 @ PEN 0 @ RETURN
3490 ' *****
3500 '          *      Hard Copy Routine      *
3510 ' *****
3520 NX: CLEAR @ OFF KEY# @ ON KEY# 3," YES" GOTO HC
3530 ON KEY# 5," NO" GOTO NO @ ON KEY# 1,A$ GOTO ABORT
3540 ON KEY# 7,"VIEW PLOT" GOTO VUE1
3550 DISP USING 4380 : "Want a hard copy of the plot?..." @ KEY LABEL
3560 GOTO 3560
3570 VUE1: GRAPH @ WAIT 15000 @ GOTO NX
3580 HC: PRINT USING 4430 : "PROGRAM TERC". "PAGE " & VAL$ (PN)
3590 PRINT USING 4440 : "VERSION SEPT,1983". "DATE: " & D$."TIME: " & TIME$
3600 PRINT USING 4450 : T$,"INPUT FILE NAME: " & F$
3610 DUMP GRAPHICS @ PRINT CHR$ (12) @ PN=PN+1
3620 NO: OFF KEY# @ ON KEY# 1 GOTO ABORT @ RETURN
3630 ' *****
3640 '          CURSOR CONTROL ROUTINE
3650 ' *****
3660 CURS: SETGU @ CSIZE 4 @ LORG 3 @ MOVE 145,100 @ LABEL "K1=ABORT"
3670 MOVE 145,96 @ LABEL "K3=LEFT" @ MOVE 145,92 @ LABEL "K5=RIGHT"
3680 MOVE 145,88 @ LABEL "K7=MARK" @ LORG 5
3690 OFF KEY# @ ON KEY# 1 GOTO ABORT
3700 ON KEY# 3 GOTO LEFT @ ON KEY# 5 GOTO RIGHT @ ON KEY# 7 GOTO MARK
3710 SETUU @ L=INT (7/KEYCH) @ C=CTS(L)*L*H/HIGH @ MOVE L,C @ BPLOT CRS$,1
3720 GOTO 3720
3730 LEFT: MOVE L,C @ BPLOT BL$,-1 @ PLOT L,C @ L=L-1 @ C=CTS(L)*L^2/HIGH
3740 MOVE L,C @ BPLOT CRS$,1 @ GOTO 3720
3750 RIGHT: MOVE L,C @ BPLOT BL$,-1 @ PLOT L,C @ L=L+1 @ C=CTS(L)*L^2/HIGH
3760 MOVE L,C @ BPLOT CRS$,1 @ GOTO 3720
3770 MARK: NST=L @ RETURN
3780 ' *****
3790 '          PLOTTING CONTROL ROUTINE
3800 ' *****
3810 PLOTS:
3820 OFF KEY# @ ON KEY# 1,A$ GOTO ABORT @ ON KEY# 3," CRT" GOTO CRT
3830 ON KEY# 5,"HP PLOTTER" GOTO HP @ ON KEY# 7," EXIT" GOTO RET1
3840 CLEAR @ DISP USING 4410 : "FILE: ",B$,T$,"HP Plotter or CRT?..."
3850 KEY LABEL
3860 GOTO 3860
3870 CRT: PLTR=1 @ GOTO PTYPE
3880 HP: PLTR=705 @ GOTO PTYPE
3890 RET1: RETURN
3900 PTYPE: CLEAR @ OFF KEY#
3910 ON KEY# 1,A$ GOTO ABORT @ ON KEY# 3,"Raw Data" GOTO RAW
3920 ON KEY# 4,"Dose Data" GOTO DOS @ ON KEY# 5," v2" GOTO YDY
3930 ON KEY# 7," EXIT" GOTO RET
3940 DISP USING 4410 : "FILE: ",B$,T$,"Please select type of plot..."
3950 KEY LABEL
3960 GOTO 3960
3970 RAW:
3980 LY=-1 @ HY=INT (LGT (NT)+1) @ LO=0 @ HI=NC+10-NC MOD 10
3990 XT=INT (HI/20) @ XN=2 @ YTIC, YTN=1 @ XD,YD=0 @ TYPE=3
4000 X$="Channel Number" @ Y$="Counts" @ F$="Input Spectrum for " & F$
4010 GOSUB FLT
4020 GOTO PTYPE
4030 DOS:
4040 EX=1 @ Y$="Dose Event Fraction" @ F$="Dose Distribution for " & F$
4050 LO=INT (LGT (GS*KEVCH)) @ HI=INT (LGT (NC*KEVCH))+1

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4060 LY=0 @ HY,XT,XN,YD=1 @ YTIC=.1 @ YTN=2 @ XD=0 @ TYPE=4
4070 X$="Lineal Energy, keV/micron"
4080 GOSUB FLT
4090 GOTO PTYPE
4100 YDY:
4110 EX=2 @ Y$="Y*D(y) Event Fraction" @ P$="Y*D(y) Distribution for "&F$
4120 GOTO 4050
4130 RET: GOTO PLOTS
4140 ! *****
4150 !           Print out input data
4160 ! *****
4170 PRINTDAT:
4180 PRINT CHR$(27)&"811L"
4190 PN=PN+1 @ LN=1,E20 @ CTS(1)=LT @ CTS(2)=RT
4200 FOR I=1 TO NC STEP 8
4210 IF LN<56 THEN GOTO 4240
4220 PRINT CHR$(12) @ PRINT USING 4640 : "TEPC Input Data from file: ",F$,PN
4230 PRINT USING 4650 : D$,T$,"Channel","Input Data" @ LN=9 @ PN=PN+1
4240 REC$="" @ REC$(6-LEN (VAL$ (I)),5)=VAL$ (I)
4250 FOR L=1 TO 8
4260 J=I-1+L @ RE=L*9+B @ RS=RE-LEN (VAL$ (CTS(J)))
4270 REC$(RS,RE)=VAL$ (CTS(J))
4280 NEXT L
4290 PRINT REC$ @ PRINT @ LN=LN+2
4300 NEXT I
4310 IF LN+8<56 THEN GOTO 4330
4320 PRINT CHR$(12) @ PRINT USING 4640 : "TEPC Input Data from file: ",F$,PN
4330 PRINT USING 4630 : "Raw Data Of: _____". "Date: _____"
4340 PRINT USING 4630 : "Verified by: _____". "Date: _____"
4350 PRINT CHR$(12)
4360 RETURN
4370 ABORT: END
4380 IMAGE 6/,22X,35A
4390 IMAGE 2X,15A,6X,12A,8X,11A,7X,16A,/,9X,1A,16X,6A,14X,6A,15X,4A
4400 IMAGE /,8X,DD,17X,DD,D,14X,.,6D,15X,DD,D
4410 IMAGE 5A,8A,/,80A,2/,15X,50A,2/
4420 IMAGE 3/,5A,8A,/,80A,2/,80A,2/, "Okay?"
4430 IMAGE 34X,12A,26X,7A
4440 IMAGE 1X,18A,13X,16A,20X,11A
4450 IMAGE /,80A,40A
4460 IMAGE /,31X,19A
4470 IMAGE /,24X,33A
4480 IMAGE /,16X,5(5X,6A,5X),2X,11A,7X,8A,8X,7A,11X,4A
4490 IMAGE 20X,7A,10X,6A,10X,6A,11X,3A
4500 IMAGE 4X,7A,12X,2D,13X,2D,D,10X,.,6D,9X,.,6D
4510 IMAGE /,7X,19A,DD,D,3A,8X,27A,D,D,8A
4520 IMAGE 11X,4D,14A,20X,12A,5D,8A
4530 IMAGE /,9X,28A,4D,15A,3D,D,11A
4540 IMAGE 2/,25X,31A
4550 IMAGE 27X,5A,14X,7A,14X,7A
4560 IMAGE 5X,10A,5X,3(5X,D,3DE,5X)
4570 IMAGE 6X,7A,7X,3(8X,DD,D,8X)
4580 IMAGE 27A,DD,D,23A,DD,D
4590 IMAGE 4X,15A,1X,3(8X,DD,D,8X)
4600 IMAGE /,23X,40A
4610 IMAGE 1X,18A,1X,3(5X,D,3DE,5X)
4620 IMAGE 1X,19A,3(5X,D,3DE,5X)
4630 IMAGE 4/,2(35A,5X)

```

4640 IMAGE 21X,264,2X,8A,10X,"PAGE ",1X,2D
4650 IMAGE 35X,10A,27,80A,37,7A,32X,10A,2/
4660 END

APPENDIX B

GLOSSARY OF VARIABLES

A\$ 'ABORT' used to allow program abort function
 AL Alpha peak channel
 ANKL Final channel in the loop used to find the position of the K-drop
 I\$ Inverse video of the input file name
 BL\$ Null string used to erase the interactive plotting cursor
 C1 Smoothing coefficients used to determine 2nd derivatives
 CR\$ String which is used to plot (binarily) the interactive cursor
 CTS Input data array
 D\$ String containing current date
 dA array of 2nd derivatives
 DEGR Gamma dose equivalent rate
 DENR Neutron dose equivalent rate
 DETR Total dose equivalent rate
 DG Integral number of dose events between GS and NST-1
 Dgamma Integral gamma absorbed dose
 DIA Diameter of counter in centimeters
 DN Integral number of dose events between NST and NC
 Dneutron Integral neutron absorbed dose
 DRG Gamma absorbed dose rate
 DRN Neutron absorbed dose rate
 DRT Total absorbed dose rate
 DT Integral number of dose events
 Dtotal Integral absorbed dose from gammas and neutrons
 EQD Array of equivalent diameters used to define maximum stopping power
 EQDIA Diameter of tissue volume equivalent to volume of counter
 EX Exponent used to differentiate between dose and y*D(y) distributions
 F\$ Input file name
 gamma Gamma absorbed dose equivalent
 GAS\$ Type of filling gas
 GS Gamma start point, taken as first non-zero data point
 H\$ Current time
 HI Maximum 'x' value used for plotting

HIGH Maximum 'y' value in the dose or $\mu\text{B}(y)$ distribution
 HY Maximum 'y' value used for plotting
 KEVCH Conversion factor for channel to keV/micrometer
 KNEE Initial channel in loop used to calculate 2nd derivative array
 LBG Average LET in gamma frequency distribution
 LBN Average LET in neutron frequency distribution
 LBT Average LET in total frequency distribution
 LN Line number... used to control the form feed on output
 LO Minimum 'x' value... used for plotting
 LT Live time
 LY Minimum 'y' value... used for plotting
 MASS Mass of the TE filling gas
 NC Number of data channels
 neutron Neutron dose equivalent
 NG Integral number of counts between GS and NST-1
 NN Integral number of counts between NST and NC
 NST Neutron start channel
 NT Total number of counts
 P% Plot title
 PDP Position of proton drop point
 PDS Stopping power array
 PLTR Type of plotter to be used... (1=CRT, 705=HP Plotter)
 PN Page number... used for printed output
 PRESS Pressure to which the counter was filled
 Q Quality factor
 QFG Average quality factor for gamma events
 GFN Average quality factor for neutron events
 QFT Average quality factor for all events
 RADFAC Conversion factor for dose events to absorbed dose
 RANGE Numerical range of the 'x' axis
 REC% String variable used to print one line of input data
 RHD TE gas density
 RKEVM Maximum stopping power

HT	Elapsed counting time
SG	Standard deviation of gamma absorbed dose
SN	Standard deviation of neutron absorbed dose
ST	Standard deviation of absorbed dose
SV	Relative location on axis used for axis labelling
SX	Relative location on 'x' axis used for axis labelling
SY	Relative location on 'y' axis used for axis labelling
T#	Run title
TEMP	Temperature at the time the counter is filled with TE gas
total	Total absorbed dose
TYPE	Variable used for control in the plotting routine 1=2nd derivative vs channel (P-drop determination) 2=y*D(y) vs channel (NATART determination) 3=log of Raw data vs channel 4=fraction of dose or y*d(y) distribution vs log of lineal energy
X#	Title of 'x' axis
X1,X2	Plotting loop boundaries
XD	Number of decimal points used for labelling 'x' axis
XDIM	Range of the plotting area
XLOC	Horizontal center of the plotting area
XMAX	Maximum location of the plotting area
XMIN	Minimum location of the plotting area
XN	Number of tic marks between major tics on 'x' axis
XT	Number of values between tic marks
Y#	Title of 'y' axis
YD	Number of decimal points used for labelling 'y' axis
YDG	Average event size in the gamma frequency distribution
YDN	Average event size in the neutron frequency distribution
YDT	Average event size in the total frequency distribution
YG	Integral number of y*D(y) events between GS and NST-1
YN	Integral number of y*D(y) events between NST and NC
YT	Integral number of y*D(y) events
YTIC	Number of values between tic marks on the 'y' axis
YTN	Number of tic marks between major tic marks on the 'y' axis
YVG	Average event size in the gamma dose distribution

YYN Average event size in the neutron dose distribution
YYT Average event size in the dose distribution

APPENDIX C
GLOSSARY OF SUBROUTINES

CALC: Calculates the 2nd derivative distribution in $y \# D(y)$
 CURS Controls the position of the cursor on the NSTART plot
 DIS Allows manual input of counting parameters
 GAS Sets default operating parameters for the operator chosen filling gas
 INI Initializes variables
 NOK Calculates the output parameters (e.g. dose, ybar, etc)
 NSTART Used to determine the position of the neutron start channel
 NX: Hard copy routine dumps CRT graphics to printer
 OK Calculates the conversions factors necessary to determine neutron absorbed dose, etc.
 PROCP Used to determine the position of the proton drop point
 PLOTS Used to determine the type of plot to be created
 PLT Plotting routine - CRT and HP plotter
 PRNTDAT Prints input data on HP printer

APPENDIX D
BENCHMARK MEASUREMENT

VERSION SEPT.1987

PROGRAM TEPC
DATE: 03/26/1984

PAGE 1
TIME: 12:44

LOW GAIN TEPC Moderated Cf252 CG=50 FG=.885 ST=1WS HV=-650v 3/28/83
INPUT FILE NAME: NBS8

VERSION MAR, 1984

PROGRAM TEPC
DATE: 03/26/1984

PAGE 2
TIME: 12:54

LOW GAIN TEPC Moderated Cf252 CG=50 FG=.885 ST=1WS HV=-650v 3/28/83

INPUT FILE NAME: NWSB

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

TE GAS	TE GAS TEMPERATURE (deg-C)	TE GAS PRESSURE (torr)	TE GAS DENSITY (g/cc)	TE GAS MASS (g)
PROPANE	25	3.7	.001820	.008706

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 1.0 microns
2048 Channels read Live time= 6118 seconds

Proton Drop Point= Channel 351 equivalent to 100.9 keV/micron
Neutron Start Point= Channel 35 equivalent to 10.1 keV/micron
Gamma Start Point= Channel 3 equivalent to .9 keV/micron

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	7.571E+006	1.773E+006	9.344E+006
Counts*Ch	9.462E+007	1.904E+008	2.850E+008
Counts*Ch ²	1.509E+009	3.557E+010	3.707E+010
y-bar F	3.6	30.9	8.8
y-bar D	4.6	53.7	37.4
L-bar D	4.1	47.7	33.2

Restricted y-bar D between 10.1 and 115 keV/micron is 43.1

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	5.160E+001	1.008E+002	1.554E+002
Standard Deviation	1.069E+001	6.126E+000	1.232E+001
Quality Factors	1.7	10.4	7.5
Integral DE, mrem	8.990E+001	1.082E+003	1.172E+003
Dose Rate, mrad/hr	3.036E+001	6.111E+001	9.147E+001
DE Rate, mrem/hr	5.290E+001	6.366E+002	6.895E+002

Analysis Ok: _____ Date: _____

Verified by: _____ Date: _____

VERSION SEPT.1983

PROGRAM TEPC
DATE: 03/26/1984

PAGE 2
TIME: 12:56

LOW GAIN TEPC Moderated Cf252 CG=50 FG=.885 ST=1wS HV=-650v 3/28/83
INPUT FILE NAME: NBS8

VERSION SEPT,1983

PROGRAM TEPC
DATE: 03/26/1984

PAGE 3
TIME: 13:03

LOW GAIN TEPC Moderated Cf252 CG=50 FG=.885 ST=1WS HV=-650v 3/28/83
INPUT FILE NAME: NBS8

g*DCY) Distribution for NBS8

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