Table 8.2

RANDOM STOPPING POWERS IN DIAMOND

$\bar{E}$ (MeV)	$\frac{dE}{dx}$ (keV/μm)	$\bar{E}$ (MeV)	$\frac{dE}{dx}$ (keV/μm)
Protons (thick crystal)		Protons (thick crystal)	
2.469	40.68	7.786	16.47
2.537	39.68	7.810	16.31
2.633	38.58	7.843	16.50
3.649	30.50	8.809	14.66
3.721	30.22	8.831	14.47
3.749	30.07	8.863	14.45
4.715	24.84	9.827	13.28
4.771	24.66	9.847	13.10
4.797	24.34	9.876	13.09
5.722	21.28	10.837	12.48
5.756	20.93	10.857	12.24
5.801	20.92	10.881	12.51
6.758	18.56	11.844	11.94
6.787	18.28	11.862	11.86
6.830	17.92	11.890	11.62
Protons (thin crystal)		Protons (thin crystal)	
3.897	28.3	7.950	17.6
3.922	27.8	8.942	16.0
5.923	21.1	8.955	16.0
5.942	20.6	9.948	14.2
7.933	18.4	9.961	13.8

$\bar{E}$ (MeV)	$\frac{\bar{E}}{A}$ (MeV/amu)	$\frac{dE}{dx}$ (keV/μm)	$\frac{1}{Z_1^2}\frac{dE}{dx}$ (keV/μm)
Alphas (thick crystal)			
9.867	2.467	162.9	40.72
10.132	2.533	159.9	39.98
10.478	2.620	160.0	40.00
13.326	3.332	127.8	31.96
13.511	3.378	127.5	31.88
13.768	3.442	129.5	32.38
16.565	4.141	109.6	27.40
16.704	4.176	111.0	27.75
16.947	4.237	110.7	27.68
^{7}Li (thick crystal)			
19.606	2.801	336.3	37.37
20.175	2.882	327.5	36.39
20.955	2.994	320.2	35.57

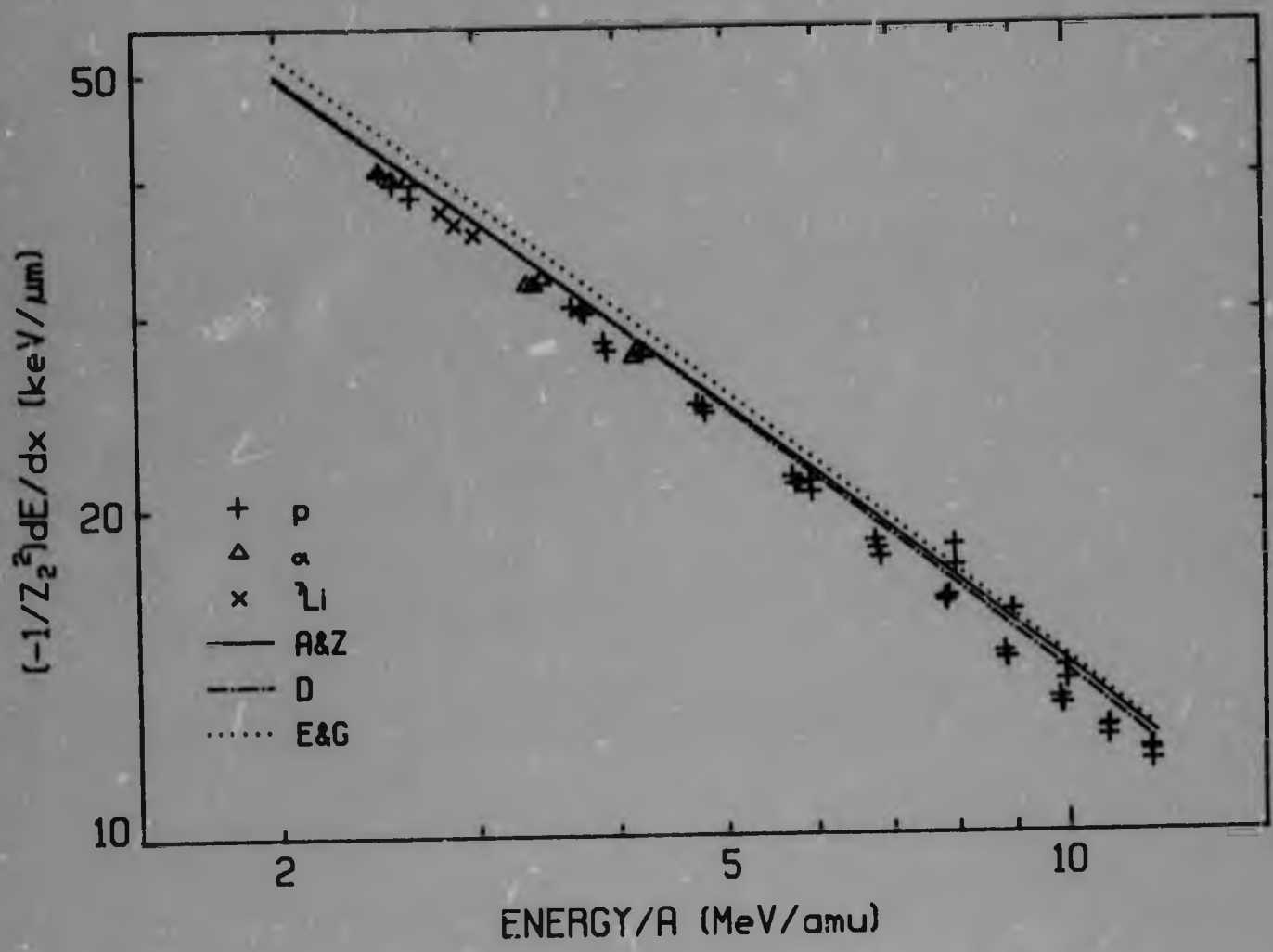


Figure 8.3: Random stopping power of light ions in diamond. A & Z: Andersen and Ziegler, D: Dettmann, E & G: Esbensen and Golovchenko.

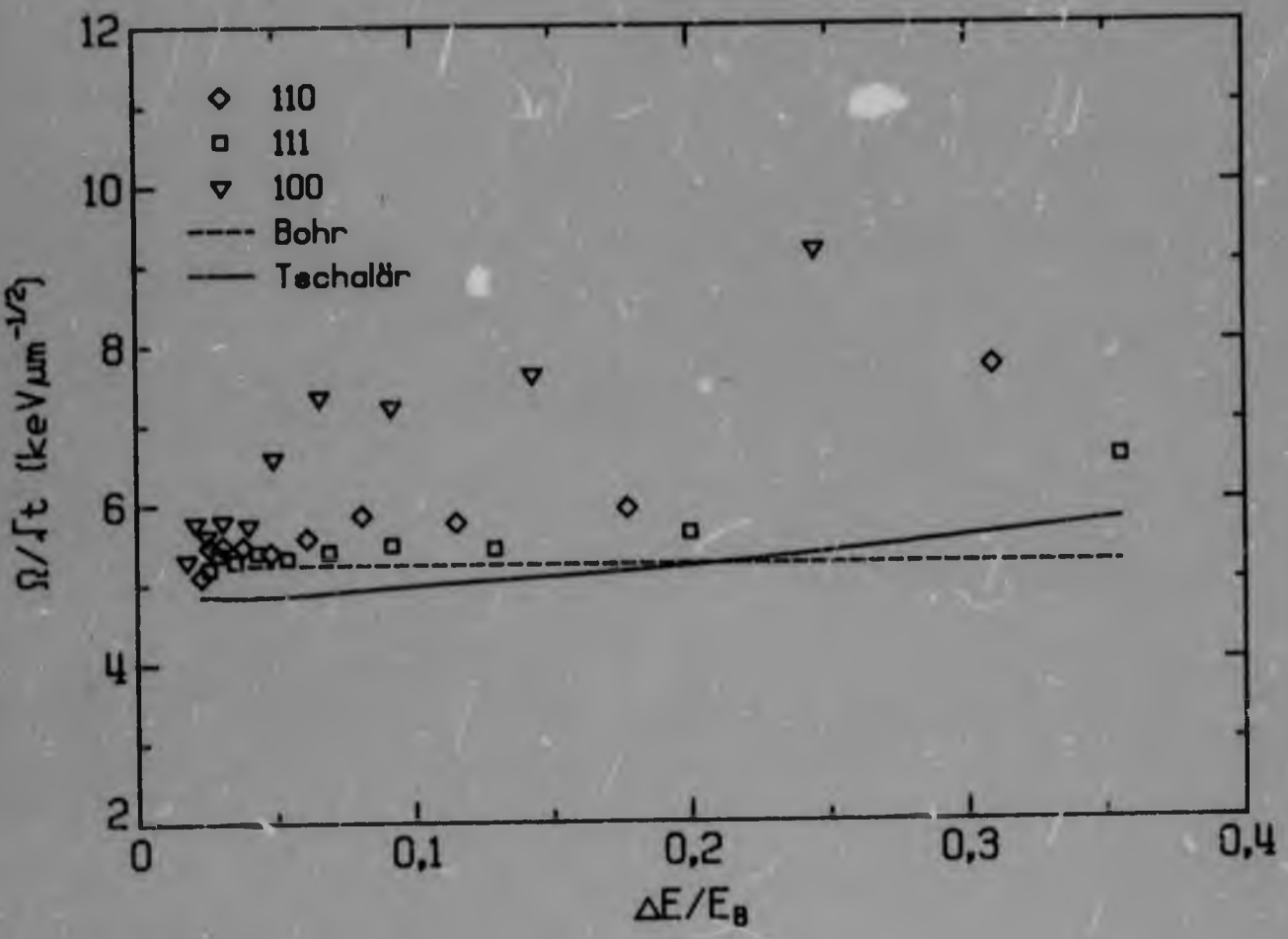


Figure 8.4: Straggling of protons transmitted through thin diamond in random orientations.

and the rate of increase. It is possible that this is due to approximations in the theory, but it is more probable that the experimental points are perturbed by the crystal structure of the target. It was observed that the random peak tended to be skewed toward higher energies, especially for larger relative energy losses in the target, and more so in <100> where the points lie above the other axes in Figure 8.4. It is probable that some feeding into channels is occurring; this would be expected to be more probable in targets where more multiple scattering can occur, that is, at larger energy loss. This then leads to a lower energy loss for some ions and a skewing of the peaks to higher energies, with a consequent apparent increase in straggling. This is likely to occur in any crystalline target: it can be concluded that crystals are not the ideal target in which to study straggling at larger relative energy losses. Nevertheless it can be concluded that the Bohr approximation is valid at smaller energy losses, in the Gaussian energy loss distribution regime. Straggling in carbon has also been examined by Langley and Brice [Lal 78] who determined it from the broadening of the resonances at 459 keV and 1.7 MeV in elastic proton scattering. A value close to that predicted by the Bohr theory was found at 1.7 MeV.

8.4.3 Channelled Ion Stopping Power

The ratio of channelled to random stopping is given in Table 8.3 and is plotted in Figure 8.5 for the three axes <110>, <111> and <100>. There was no evidence for any ion dependence of these values, and the points in Figure 8.5 are not distinguished according to the ion. It is interesting that the peak values for the <110> axis in the thin diamond are close to the leading <110> values for the thick diamond. The width

Table 8.3

RATIO OF CHANNELLED TO RANDOM STOPPING POWER

E/A (MeV)	$\Delta E_C/\Delta E_R$ <110> Peak	Leading edge	E/A (MeV)	$\Delta E_C/\Delta E_R$ <111> Peak	Leading edge	E/A (MeV)	$\Delta E_C/\Delta E_R$ <100> Peak	Leading edge
Protons (thick crystal)								
2.53[illegible]	0.774	0.619	2.469	0.880	0.775	2.633	0.888	0.754
3.72[illegible]	0.791	0.642	3.649	0.880	0.775	3.749	0.880	0.761
4.771	0.793	0.642	4.715	0.879	0.760	4.797	0.879	0.741
5.756	0.801	0.641	5.722	0.883	0.760	5.801	0.873	0.728
6.787	0.799	0.620	6.758	0.882	0.757	6.830	0.882	0.723
7.810	0.820	0.635	7.786	0.884	0.760	7.843	0.883	0.729
8.831	0.818	0.636	8.809	0.885	0.749	8.863	0.876	0.715
9.847	0.817	0.628	9.827	0.887	0.727	9.876	0.883	0.718
10.857	0.831	0.634	10.837	0.891	0.722	10.881	0.881	0.711
11.862	0.837	0.640	11.844	0.897	0.723	11.890	0.890	0.693
Protons (thin crystal)								
3.922	0.695		3.897	0.881		3.939	0.77	
5.942	0.662		5.923	0.889		5.955	0.75	
7.950	0.637		7.935	0.894		7.961	0.71	
8.955	0.663		8.942	0.918		8.965	0.79	
9.961	0.674		9.948	0.911		9.970	0 90	
Alpha (thick crystal)								
2.533	0.782	0.635	2.467	0.86[illegible]	0.779	2.620	0.860	0.776
3.378	0.802	0.649	3.332	0.[illegible]89	0.803	3.442	0.872	0.766
4.176	0.795	0.647	4.141	0.879	0.787	4.237	0.873	0.770
^{7}Li (thick crystal)								
2.882	0.775	0.610	2.801	0.856	0.772	2.994	0.860	0.725

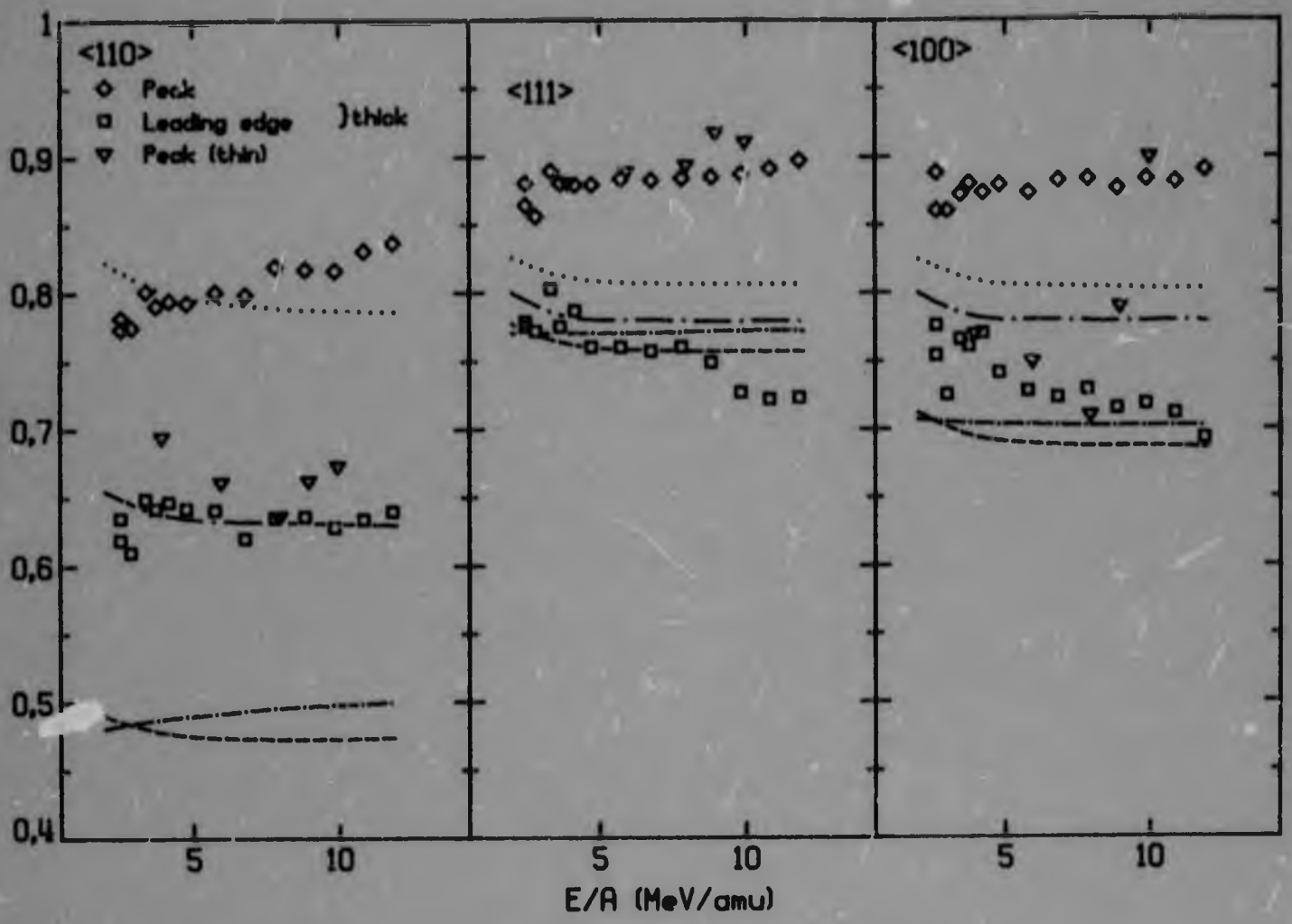


Figure 8.5: Ratio of channelled to random stopping powers. ••••• Dettmann; ----- modified Dettmann; -•-•- Esbensen and Golovchenko; —•—•— planar.

of the thin diamond <110> peak was consistent with that expected to be produced by resolution and straggling if the channelled ions see a somewhat reduced electron density. The <100> values are also close to the <100> thick target leading-edge values. The <111> values are close to the <111> thick target peak values. It is possible that this is due to mis-alignment of the crystal, as there was some difficulty in aligning the thin crystal. It is possible that some mosaic spread and strain was present in the diamond, because it is a Type IIa crystal.

The leading-edge values for <111> and <100> measured on the thicker target are apparently energy dependent, increasing to lower energies. In these channels the local electron density at the channel centre is higher, and thus straggling will be greater. Thus it is possible that the lower value at higher energies is due to the influence of straggling in the peaks leading to lower leading-edge values. The influence of straggling would be expected to be less at lower energies, where the effect of dechannelling would be greater. Thus the leading edge for these axes would give a better reflection of the least energy loss, at lower energies. This is consistent with the <100> peak values obtained for the thin diamond, which are comparable with the lower energy <100> leading-edge values of the thick diamond.

Thus, the least energy loss can be represented by the <110> thick target leading-edge values, and the <111> and <100> values at lower energy. Combining these with the thin target peak values leads to estimates of the ratio, m, of channelled to random ions of 0.64 ± 0.02 for <110> and $m_{100} = 0.77$, $m_{111} = 0.80$. These represent average values for all energies: from the theoretical results the energy variation is expected to be small.

The results can now be compared with the theoretical results also shown in Figure 8.5. It is immediately clear that there is a much more pronounced axial variation than that predicted by the Dettmann theory. The theory must, therefore, be modified to include the effect of channelling on the valence electron stopping, and this has been done by treating the valence electrons as a spatially periodic gas as described in Chapter 2. It can be seen that the results from this modified theory are very close to those of the theory of Esbensen and Golovchenko, and these may be considered together, as the approximations involved in the theories render this difference insignificant. This agreement is perhaps to be expected for the reasons given in Section 2.4.5: the equation (2.4.29) from the theory of Esbensen and Golovchenko can be regarded as a local density approximation obtained from equation (2.4.35) for the periodic electron gas. The theoretical values then follow the trend of the experimental values, but the reduction in stopping power and axial dependence are more pronounced than that observed in experiment.

It has been pointed out that the true least energy loss will only be experienced by hyperchannelled ions, that is, those trapped in one channel throughout their motion in the crystal [Ap 72]. It can be expected that these will be observed only in experiments using the thinnest crystals [Ap 72]; the least energy loss in thicker crystals will then be that of ions that have wandered from channel to channel along the most widely spaced plane intersecting the channel [Ei 72]. This widest planar channel is {111} (wide spacing) for the <110> axis and {110} for both <111> and <100> axes. Accordingly, this minimum planar energy loss was evaluated and is also shown in Figure 8.5, for the modified Dettmann theory. These values are more in accord with the experimental least energy loss values.

The slightly higher <111> experimental value is perhaps due to greater multiple scattering, or due to the possibilities in feeding into various planes. Thus the next widest plane intersecting the <111> axis is {112} and the <100> is {100}. The latter is wider than {112} and hence will have a lower energy loss.

Finally, some observations can be made about the theoretical approaches. Both the modified Dettmann theory and the Esbensen and Golovchenko theory give similar results. The former is, however, computationally more simple, that is, no numerical integration over electron densities is required, and fewer terms need to be summed (~10 compared with ~150) for convergence. The modified Dettmann theory also allows the solid-state structure of the target to be included both in the random and channelled energy loss calculations. This could be important in the examination of allotropic effects, if more accurate measurements become available. It should be noted that the use of realistic, that is, experimental X-ray scattering factors can be important in both theories. Thus, in the theory of Esbensen and Golovchenko, use of theoretical scattering factors calculated from spherically symmetric charge distributions (for example, those of Doyle and Turner [Do 68] as used by Esbensen and Golovchenko) lead, in the case of diamond, to energy losses 15 % higher in <100>, and lesser variation in the other axes. Such theoretical scattering factors are probably adequate for large G; for small G the scattering factors are sensitive to the valence electron distribution and more realistic values should be used.

8.5 CONCLUSION

The energy loss of channelled and random ions has been measured for

3 - 12 MeV protons, 12 - 18 MeV alpha particles and 24 MeV lithium ions for the <110>, <111> and <100> axes in thin diamond crystals. The dependence of the random stopping power on velocity and atomic number of the ions is in agreement with that expected from the Bethe-Bloch theory. The actual values measured agree within errors with the values recommended by Andersen and Ziegler [Ans 77]. The straggling of the random beam has also been investigated. At small energy losses it is in agreement with the Bohr value, and increases at larger values in qualitative agreement with the Tschalär theory. It is probable, however, that the results at larger energy losses are influenced by the crystal structure: an amorphous target would be more suitable for exploring this regime.

The leading edge of the channelled spectra for larger energy losses in the thicker diamond used has been interpreted as being characteristic of the least energy losses for the channelled ions. The values obtained indicate that the Dettmann theory is inadequate and should be modified to include the effect of channelling on the valence electron energy loss. The modified theory is then in agreement with the theory of Esbensen and Golovchenko. Both theories predict lower values than observed. It is probable that the observed values are those characteristic of non-hyperchannelled ions, and values for the widest planes intersecting the axes are more in accordance with the measured values.

Both the modified Dettmann theory and the theory of Esbensen and Golovchenko give similar results. However, the Dettmann theory is computationally simpler and is more amenable to the incorporation of solid-state bonding (that is, allotropic) effects in the random case. The use

of realistic X-ray scattering factors is important in both theories, if detailed comparison with experiment is to be made.

The results reported here are somewhat limited by the variation in target thickness and subsequent limitation on obtainable accuracy. It would be worthwhile to improve the uniformity of thin diamond crystals. In this regard, the crystals should be of Type Ia, with a low A-nitrogen concentration, and with little (or preferably no) B-nitrogen or platelets. These can be expected to be the best channelling diamonds. A more uniform crystal would enable more accurate measurements to be made, and also allow the investigation of allotropic effects.

CONCLUSION

Channelling measurements on natural diamond have been extended to include dechannelling, the effect of amorphous and impurity layers on the surface, and energy loss measurements. The increase in dechannelling in a series of Type Ia diamonds (which comprise the majority of natural diamonds) compared with the best crystals has been quantified and shown to be due to the presence of platelets on {100} planes.

The yield, as a function of depth, has been measured for the major axial directions at a variety of energies and temperatures. The variation of yield with temperature is rather small on account of the high Debye temperature of diamond and the scaling of the yield with $u_2^2 z$, that has been observed in silicon and germanium, has not been found in diamond. However, the yield as a function of depth has been found to scale with an energy dependent characteristic length, z_e, determined by electron multiple scattering. This has been interpreted as being the dominant dechannelling mechanism in good crystals. The scaled yield is very similar for the three major axes, indicating that the same mechanism is acting in all cases, and that small differences between the axes in the initial transverse energy distributions, and in the distribution of electrons in the channel are of relatively minor importance. Such differences that do exist are rapidly 'washed out' in the diffusion process in transverse phase space.

Theoretical calculations using the steady increase model fail to reproduce the experimental behaviour, but the diffusion model gives good results, if realistic electron scattering terms are used. The model employed used multi-string transverse energy distributions and included damping and absorption terms, although the effect of these is small. An analytical solution of the diffusion equation has been given for the Lindhard single-string initial distribution, and a constant $\frac{dE_\perp}{dz}$. This can give reasonable results for small depths, but fails at larger depths where the detailed variation of the diffusion function with transverse energy becomes important.

The numerical solutions have enabled the effect of various terms of the diffusion model to be examined and it was noted that the damping term can lead to an increase in the yield at large depths (while the yield is decreased at smaller depths) in contrast to a decrease at all depths noted with the steady increase model.

The effect of amorphous surface layers on the minimum yield at the surface has been studied in <110>. Layers of carbon, aluminium and gold were evaporated onto a polished diamond surface, and a wide range of thicknesses was obtained by removing the layers sequentially using argon ion milling. The effect could then be studied down to relatively small increases in the yield. The use of gold, aluminium and carbon layers allowed a wide range of reduced thickness, τ, to be covered, from τ = 0.2 to 140.

The results were, in general, in good agreement with calculations based on Thomas-Fermi multiple-scattering theory, but small deviations

could be due to deviations of the true ion-atom interaction potential from the statistical Thomas-Fermi potential. It is probable that high precision measurements could be used to distinguish between different potentials. The increase in yield is due predominantly to the tail of the multiple-scattering distribution and thus this type of measurements is complementary to direct measurement of the distribution which gives greatest weight to the maximum of the distribution at small angles.

A scaling law for the yield as a function of τ, derived for power law scattering, has been demonstrated to hold approximately for the range of τ used in the experiment and has been used to correct the aluminium thickness for a small oxygen contribution.

The use of small layer thicknesses has enabled comparisons to be made with Lindhard's estimates of the effect on the yield of contamination layers. While his expression, derived from Rutherford scattering, gives reasonable results for low Z layers, deviations occur at high Z. Using an approximation to the Thomas Fermi single scattering cross-section, an alternative expression has been derived, which gives good results up to $\Delta\chi = 0.1$.

Calculations of the yield as a function of depth in a crystal overlaid with an amorphous layer have been made using the diffusion model. Results are in good agreement with experiment, lending further weight to the validity of the diffusion model.

The dechannelling produced by defects has been studied in a group

of strong Type Ia diamonds. It has been shown that the dechannelling probability is proportional to the infrared absorption at 1370 cm^{-1}, which is in turn proportional to the area per unit volume of platelets on {100} planes. The dechannelling probability is also proportional to the concentration of B-aggregates of nitrogen. The dechannelling in a diamond with only B-features is found to be similar to, but smaller than, that in diamonds with similar B concentration, but with platelets, and is probably due to dislocation loops found in these diamonds.

A model for the dechannelling cross-section of a platelet has been given, combining the effect of a stacking fault and a dislocation loop. The dechannelling cross-section of a stacking fault has been evaluated taking into account the distribution of transverse energies, and has been found to be about 4 to 5 times larger than simple approaches based on the minimum yield. An expression for the dechannelling cross-section of a dislocation loop has been obtained by combining the approaches of Kudo and Quéré. This expression approximates the radial dependence of Quéré and the energy dependence of Kudo. Estimates of the area per unit volume of platelets obtained with this model are in accord with estimates obtained from electron micrograph counts. If it is assumed that the B-aggregates and platelets are associated, the loop contribution can be estimated from the results for the B-only diamond, and a similar value for the platelet area per unit volume can be obtained. The concentration of B-nitrogen is such that it is consistent with platelets having the Lang structure. Some consequences of this model and the suggested sequence of growth and decay of platelets are pointed out.

The energy loss of protons, alpha particles and lithium ions in

thin diamond crystals has been measured. The random energy losses are in agreement with those tabulated by Andersen and Ziegler, but the errors are such that it cannot be determined if any differences are due to the allotropic form of carbon used. The straggling in the random beam is in accord with the theory of Bohr for small energy losses in the crystal, and increases in qualitative agreement with the theory of Tschalär for larger energy losses. It is possible that the width of the spectrum at larger energy losses is effected to some extent by feeding into channels, and close comparison has not been made.

The channelled ion energy loss has also been measured, and values for the ratio, m, of channelled to random stopping for 'best channelled' ions are $m = 0.64 \pm 0.02$ for <110>, $m \leq 0.8$ for <111> and $m \leq 0.75$ for <100>. No dependence of m on the atomic number of the incident ion was observed.

Comparison has been made with the theories of Dettmann and of Esbensen and Golovchenko. It has been shown that the effect of channelling on the valence electron contribution to stopping should be taken into account in the theory of Dettmann. An expression for the energy loss in a periodic electron gas has been derived by using a sum rule. When combined with the core contribution of Dettmann, results close to those of Esbensen and Golovchenko are obtained. The theoretical results calculated at the channel centre are rather lower than the experimental results, but calculations for the principal plane passing through the axis are in closer accord with the experimental results. This indicates that effects of hyperchannelling are not seen.

The use of diamond as a target in channelling experiments is not without difficulties, but these can be overcome with care in the selection, characterisation and preparation of crystals. Selection from a large suite of crystals allows perfect crystals, at least by channelling standards, to be obtained and differences between the channelling in these and in less perfect crystals may be explained quantitatively in terms of known defects. Channelling experiments may be performed on diamond with the same confidence as on other laboratory-grown, crystals.

APPENDIX 1

CHANSPEC

A FORTRAN computer program, CHANSPEC, was written for the off-line analysis of channelling spectra on the Nuclear Physics Research Unit's Interdata (Perkin-Elmer) 7/32 computer. This programme accepted input spectra from cards or magnetic tape and performed operations on the data defined by a sequence of command cards ('card' is used here loosely as a term for any suitable sequence of records and thus input or commands could be on cards, disc file or read from a terminal):

i) READ

Spectra can be read in, and a number of random spectra averaged.

ii) FIT

The surface edge of the spectra could be 'deconvoluted' and the surface peak extracted from the channelling spectra. The yield could then be extrapolated to the surface. This was performed by fitting a suitable function to the edge, using least-square methods. The surface peak was fitted with a gaussian,

$$h \exp \left[\frac{-(x - x_0)^2}{2\sigma^2} \right],$$

and the underlying edge with a quadratic step (that is, $n(x) = a + b(x - x_0) + c(x - x_0)^2$, where n is the number of

counts and x the analyser channel or energy and a, b, c are fitting parameters, with n = 0 for $x > x_0$, where x_0 corresponds with the surface) convoluted with a gaussian. This yields for the fitting function

$$_1(u) = E_1 + E_2 + E_3 + P \; ; \qquad u = x - x_0$$

where $$E_1 = (a + bu + cu^2)\ \mathrm{cerf}\left(\frac{u}{\sigma}\right)$$

$$E_2 = \frac{(b + 2cu)\sigma}{\sqrt{2\pi}}\ e^{-\frac{u^2}{2\sigma^2}}$$

$$E_3 = c \int_u^{\infty} v\ \frac{1}{\sqrt{2\pi}\ \sigma}\ e^{-\frac{v^2}{2\sigma^2}}\ dv$$

$$P = \frac{h}{\sqrt{2\pi}\ \sigma}\ e^{-\frac{u^2}{2\sigma^2}}$$

Here, cerf(x) is the complementary error function. The coefficient c is usually small and thus E_3 may be neglected. E_2 may also often be neglected.

The gaussian peak term, P, was not used in fits to random spectra. After fitting, the unconvoluted edge was used to replace the convoluted experimental points.

iii) DEPTH

A conversion from an energy scale to a depth scale could be performed using the method of Zaidins [Za 74] and his parameterisation of the stopping-power and range, with values suitable for diamond. The program allowed a lower channelled energy loss (a constant fraction of random energy loss) to be used if required. This is discussed in Chapter 5.

iv) NORM

Spectra could be normalised to random.

v) SMOOTH

Statistical fluctuations in the data could be smoothed using a least squares cubic spline smoothing technique [Rei 67]. A parameter to define the amount of smoothing was calculated by the program, but could be over-ridden. The former was generally adequate.

vi) DAMAGE

This command allowed extraction of radiation damage profiles [Der 78] or the analysis of dechannelling probability using the single scattering model (Chapter 7), depending on the version of the program.

Processed data could be printed (PRINT) or plotted on the line printer (PLOT) at any stage, or analysis could be re-started at the as-read-in stage without a re-read (RESTART). Additional commands allowed a

sequence of commands to be stored, and thus a series of spectra could be analysed using one command.

The program was designed to have a flexible structure that could easily be expanded to accommodate extra commands. A central core called independent subroutines to perform each command. The sequence of commands could be arbitrary within the confines of compatibility (for example, FIT could not be performed after DEPTH). The flexibility provided by the program was a great aid in the analysis of spectra, and the program was found to be more useful than a simpler program with a fixed purpose.

A listing of the program follows.

```
C----- CHANSPEC - A PROG TO ANALYSE CHANNEL TAG SPECTRA -----
C  VERSION 1 : 14/6/78
C  LAST UPDATE 27/6/78   -- V 2.1 --
C
C     EXTERNAL SUBPROGRAMS REQUIRED:
C        LGETSTR(UNIT,S,...)=RETURNS S, TRUE IF UNIT ASSIGNED
C        OPFILE(FILENAME,'ST'/'UN',...) = OPENS FILE ON UNIT
C        *SPECREC (.DAT, HEADER, ISPF =RETURNS ISPF VALUES OF HEADER ON TAG STACK
C        DINGUS - DEMUIT CALLED AS SUBROUTINE
C
      LOGICAL HEADER,ADD/OK,DATLIST,ETEND,OPLG,OPLG,OPLG,PIDST,HDRDED
     1,MAGAT,PP
      DOUBLE PRECISION HEADY1,HEADY2,DATE,TIME,TARGID
      REAL HDER,INDEX
      COMMON
     1/DATA1/ HEADER(256),WTB,ISPF
     2/HDRDAT/ SPEC(2,4096),TARGE,ISPOE,CDET(1024),BANDDR(1024),HDRD
     3/HEADER/ HEADY1,HEADY2,DATE,TIME,
     4/CHANTAG/ CHAN(2),IPAGE1,IPAGE2,PAGE1,PAGE2,PAGE3,
     5/DIRECT/ MASTER,LINES,HEADR,HWRITE,ETEND,ETEMP,ITYPE,PP
     6/PLANE/ HEADAT$,HEADAL,DATLST,ETEND,OPLG,OPLG,OPLG,PIDST,HDRDED
     7/DATE/ ID,DAY,TIME,DAY$,DMY$,CHAN
     8/TRACE/ LOOKE,ETM,IDT,G,IMPLOT,IHDRD
     9/ CHA*4 / HDRD,IDD)
C
      DIMENSION INDEX(2),COMMAND(8),
     1,IDUMP(2),IPAGE(2),IPAGE2(2),PAGE1(2),PAGE2(2)
C
      DATA  COMMAND/
     1/ 'STAN','DET ','END ','READ','PAGE','INFO','TIME',
     2  'SAVE','PLOT','SPEC','FIT ','HELP','DEPT',
     3  'PEEK','ADAT','DATA','DUMP',2*'    ',10*' '/
      DATA  IDD/ HDRD /, 1,2,3,4,5,6,7,8,9,10,7 *
      DATA IPAGE1,PAGE2,PAGE3,/4H    ,4H  /
      DATA TARGET4 /'HEAT','CHAN'  'CHAN'/
C
      ITYPE = 0
      PP = TIME
      CALL OPFILE( 1,1,' ',ERR )
      READ ( MASTER,IOSTAT=IOS ) HDER
      IF ( IOS.NE.0 ) GO TO 1
      CALL LGETSTR( 1,DAT,LEN )
      WRITE( 6,1000 )
1000  FORMAT( ' CHANSPEC V2.1 ( 5/PP ) 00' )
      LINES = 2
      CALL HEADAT
C
C  --GEOM COMMAND CARD
C
 10   CALL GETCOM ( 6,10,8,IER )
      READ(CARD,HDRD,ERR=9999)CARD,IPAGE1,IPAGE2,PAGE1,PAGE2
9000  FORMAT ( 1A4,2A4,2I10 )
      IF ( CARD( 1 ) .EQ. '*   ' ) GO TO 100
      CALL LGETSTR ( 6 )
      IF ( LEN .EQ. 0 ) WRITE( MASTER,10 ) CARD
      IF ( LEN .NE. 0 )
     +WRITE( MASTER,6100 ) CARD,IPAGE1,IPAGE2,PAGE1,PAGE2
6100  FORMAT( ' ',1A4,' ','1',' ',3A4,' ',2A4,' ',2A4 )
      WRITE ( MASTER,6000 )
C
C  SECOND CASE
      CALL WHICH( CARD(1),COMMAND,IJUMP )
      IF(IJUMP .LE. 7) GO TO (200,300,9999,400,500,600,700,800) , IJUMP
      CALL JUMPY (IJUMP)

      GO TO 10
C
C -- ENSURE STANDARD SEQUENCE
C
 200  ETEND = .FALSE.
      IF ( HDER .EQ. 0 ) GO TO 220
 210  DO 215 I = 1,1024
      IF ( ERROR ) GO TO 10
      IPAGE1 = IPAGE (I)
      IPAGE2 = IPAGE (I)
      PAGE1 = PAGE (I)
      PAGE2 = PAGE (I)
      J = ICOUNT ( I )
      CALL JUMPY ( J )
 215  CONTINUE
      HDER = HDER - 1024
      GO TO 210
 220  WRITE( MASTER,6400 )
6400  FORMAT ( ' ',10X,'I',' STANDARD HDR DET' )
      CALL FINISH
      GO TO 10
C
C -- STORE STANDARD SEQUENCE
C
 300  CONTINUE
      HDER = 1
310   HDER = HDER+1
      CALL GETCOM ( 6,10,8,ERR )
      READ ( 9000,ERR=9999 ) CARD,IPAGE1,IPAGE2,
     1 IPAGE1(1),PAGE1(1),PAGE2(1)
      IF ( HDER .EQ. 0 ) WRITE( MASTER,6300 ) CARD
      IF ( HDER .NE. 0 )
     +WRITE( MASTER,6200 ) HDER,IPAGE1,IPAGE2,PAGE1,PAGE2
6200  FORMAT( ' ',1A4,' ',3A4,' ',2A4,' ',2A4 )
      CALL WHICH( CARD(1),COMMAND,IJUMP )
      IF ( IJUMP .EQ. 1 ) GO TO 310
      IF ( IJUMP .LE. 8 ) GO TO 9000
      CALL JUMPY (IJUMP)
      LINES = LINES+HDER+1
      WRITE( MASTER,6400 )
6000  FORMAT( ' ',10X' ' )
      GO TO 10
C
C -- CHANGE A VALUE
C
400   CALL LGETSTR( 2 )
      WRITE ( MASTER,6300 ) CARD,PAGE1
6300  FORMAT( ' ',3A4,' ',2A4,' ',2A4 )
      CALL GETVAL
      GO TO 10
100   CALL LGETSTR ( ATAPE,MASTER )
      IF ( MASTER .EQ. 0 ) CALL OPFILE ( 'DTAPE01',1 )
      GO TO 10
500   PAUSE
      GO TO 10
700   CALL WHICH( CARD(2),IMODE,2,ITYPE )
      IF ( ITYPE .LT. 1 ) GO TO 500
      GO TO 10
600   IF ( CARD(2) .EQ. 'PEAK' ) GO TO 610
      IF ( CARD(2) .EQ. 'PIN ' ) GO TO 620
      GO TO 9998
```

```
      SUBROUTINE SETIN ( DATE,TIME,THERE )
      WRITE ( 6,6100 ) DATE,TIME
 6100 FORMAT( ' ',23A1,'(14.4A1.2A1.A2/' '.12A1'+'/ )
      LINES = LIPS(1)
      LINELS = LINES
      RETURN
      ENTRY WRENDI
      NL = 0
 10   WRITE( 6,6200 ) NL,DATE,TIME
 6200 FORMAT( 1H1,T16,23A1,2X,A2,2X,A4,T116,'PAGE ',I4 /
     1 ' ',T116,'(CONTINUED)' / ' ',T116,'----------' / )
      LINES = 3
      LINELS = 3
      RETURN
      ENTRY WRLINE
      IF ( LINES .GE. LINELS ) RETURN
      WRITE( 6,6300 )
 6300 FORMAT( ' ' )
      LINES = LINES + 1
      LINELS = LINES
      RETURN
      ENTRY LINESKY
      IF ( LINES .GT. 60 ) LINES = 9999 LINES.GT.
      NL = 0
      IF ( (LINES-54)*(60-L) .GE. 0 ) GO TO 20
      LINES = LINES+L
      LINELS = -1
      RETURN
      END
C
      BLOCK DATA
      LOGICAL HEADTO,HEDVAL,DOTLST,DTEND,DPLG,DPLG,DPLG,FIRST,HEWPED
      COMMON
     1/CONTRO/ SPEED(3,1024),IHEAD,IOPEC,EDCT(1024),DAMDOS(1024),HEAD
     1/PELTL/ POSTRP,LINES,HEAD,DWRITE,ATAPE,RTEAP1,ITYPE,PB
     1/PLOG1/ HEDATA,HEDVAL,DATLST,DTEND,DPLG,DPLG,DPLG,FIRST,HEWPED
     1/VOLUME/ ES,ESLTAE,ESLTAS,ES,ESP,ANS,LCHAN
     1/ERROR/ LERAE,ERAE,ISPLG,ISPLST,ISERAE
C
      DATA HEDATA,HEDVAL,DATLST,DTEND,DPLG,DPLG,DPLG,FIRST,HEWPED
     1 /  TRUE.,.F. FALSE.,TRUE.,.FALSE. /
C
      DATA  ES,DELTAE,DELTAS,ES ,ESP,ANS,LCHAN
     1 /   1 0.0 ERA.0 1.1 ES.0 PTAES.ISS 0.ERA  /
C
      DATA LINES,ERAE,ISPLST,HEAD,ISERAE / 0 1 0 /
      DATA HEDAE,HWRITE,ATAPE,RTEAP1 / 0,0,1,0 /
      END
C
C
      SUBROUTINE  JUMP ( LJUMP )
      GO TO ( 2,3,999,5,6,7,8, 998, 999, 600, 7000, 800, 900,
     1          1000, 1100, 1200, 1300, 1 ), LJUMP
C
 400  CALL SETTAE
      RETURN
 500  CALL TAPLET
      RETURN
 600  CALL IPOOTO
      RETURN
 700  CALL ATAPES
      RETURN
 800  CALL RANDIV
      RETURN
 900  CALL DECALE
      RETURN
1000  CALL ^C107
      RETURN
1100  CALL READIN ( 0 )
      RETURN
1200  CALL CHANGE
      RETURN
1300  CONTINUE
      CALL FINIS
      END
C
      SUBROUTINE SETTAE
      LOGICAL HEADTO,HEDVAL,DOTLST,DTEND,DPLG,DPLG,DPLG,FIRST,HEWPED
      COMMON
     1/CONTRO/ HEADTO(1024),HTE,ISP
     1/VOLUME/ SPEED(3,1024),IHEAD,ISPEC,EDCT(1024),DAMDOS(1024),HEAD
     1/HEADER/ HEADER(10),HEADE,HEADTE(3),HEADTP(3),DATE,TIME
     1/(CADDIR/ CADDC(3),IPOOPL,IPOOPO,PEOOPL,PEOOPO,POOOPL,POOOPO
     1/POSTRP/ POSTRP,LINES,HEAD,DWRITE,ATAPE,RTEAP1,ITYPE,PB
     1/PLOG1/ HEDATA,HEDVAL,DATLST,DTEND,DPLG,DPLG,DPLG,FIRST,HEWPED
     1/VOLUME/ ES,ESLTAE,ESLTAS,ES,ESP,ANS,LCHAN
     1/ ERROR / HERR(2048)
      DIMENSION TAPLET(1),LCHAN(4)
      EQUIVALENCE ( ES,TAPLET )
      DATA LCHAN /'0   ','00  ','000 ','0000'/
C
      IF ( CADDC(3) .EQ. 'A   ' ) GO TO 100
      IF ( IPOOPL .NE. 0 ) GO TO 1
      CALL REPEAT ( 4,10,0,HERR )
      PRINT 10,HEAD,10,0,HERR,0,0,0
```

```
      SUBROUTINE  SETUP
      IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER*4 I4
      LOGICAL*1 L1(4)
      EQUIVALENCE (I4,L1(1))
      I4 = 0
      L1(1) = 1
      IF ( I4 .EQ. 1 ) GO TO 10
      CALL LIB$ERASE_PAGE ( 1, 1 )
      WRITE( 6,1000)
10    CONTINUE
      CALL LIB$ERASE_PAGE ( 1, 1 )
      WRITE( 6,1010)
1000  FORMAT(1H0)
      RETURN
C
C     ENTRY FOR INPUT
C
      ENTRY INPUT
      CONTINUE
      IF ( IFIX( A ) .EQ. 0 ) IF1 = 1
      IF ( IFIX( A ) .EQ. 1 ) GO TO 20
      IF ( IFIX( A ) .EQ. 2 ) GO TO 30
      IF1 = IFIX( A )
      GO TO 40
20    CONTINUE
      IF1 = 1
      GO TO 40
30    CONTINUE
      IF1 = 2
40    CONTINUE
      RETURN
C
C     ENTRY FOR OUTPUT
C
      ENTRY OUTPUT
      IF ( IFIX( A ) .EQ. 0 ) IF2 = 1
      IF ( IFIX( A ) .EQ. 1 ) GO TO 50
      IF ( IFIX( A ) .EQ. 2 ) GO TO 60
      IF2 = IFIX( A )
      GO TO 70
50    CONTINUE
      IF2 = 1
      GO TO 70
60    CONTINUE
      IF2 = 2
70    CONTINUE
      RETURN
2000  FORMAT(1X,'*** WARNING: FILE EXPECTED TO BE TAG',I3,2X,
     1  'BUT FOUND',/)
2010  FORMAT(1X,'*** ERROR: TAG',I5,' NOT FOUND',/)
2020  FORMAT(1X,'*** ERROR: TAG',I5,
     1  ' CHANNEL',I3,' LOST',/)
2030  FORMAT(1X,'*** ERROR: CONFIGURATION ERROR.CHANNEL',I3,
     1  ' CONFIG ARE (',I1,',',I6,',',I6,')',/)
2040  FORMAT(1X,'*** WARNING OF CONFIGURATION ERRORS IS',I3)
2050  FORMAT(1X,'*** ERROR: SPECTRUM LENGTH=0')
      END
C
C
C     SUBROUTINE  DECALE
C
      SUBROUTINE DECALE
      LOGICAL*4 NEGATA,NEGVAL,SATLAT,ETAT,SPLE,SPLE,SPLE,FIRST,NEGNEG
      DOUBLE PRECISION* NEGATA,VALNEG
      COMMON
     1/DATA/ NEGATA(1024),NTE,IDP
     1/SPECT/ SPECT(1024),IMAGE,IMPRE,ERCT(1024),BANDE(1024),NEGA
     1/NEGATA/ NEGATA(1024),NEGATA,NEGATA(1),NEGATA(1),DATE,TIME
     1/CHANNEL/ CHANNEL(1),PSAMP,PSAMP,PSAMP,PSAMP,PSAMP,PSAMP,PSAMP,
     1/SPECTLY/ MASTER,LINES,NEGATA,NEGATA,NEGATA,NEGATA,TYPE,PS
     1/LABEL/ NEGATA,NEGATA,SATLAT,ETAT,SPLE,SPLE,SPLE,FIRST,NEGNEG
     1/CHANNEL/ ES,SPLE,SPLE,SPLE,SPLE,SPLE,SPLE,SPLE,SPLE,SPLE,
     1/CONFIG/ LIGNE,ETAT,SPLE,SATLAT,SATLAT
     0/ SCRACH / NEGATA(1024)
C
      DATA ETA / 0.01745329 /, DEG / 0.001 /
      IF ( NEGATA .NE. NEGATA ) SPLE = RETURN
      SATLAT= FALSE
C
      IF ( SATLAT .LT. 1.0E-10 ) SATLAT = 10.
      IF ( SATLAT .LT. 1.0E-10 ) SATLAT = PSAMP4
      DELTA = 0.
      DELTAT = 0.
      IF ( SATLAT .NE. 0. ) DELTAT = PSAMP4
      SPECT = 0.
      NEGATA = DELTAT*0.5
      DEPTH = 0.0
      I0 = I-1+NEGATA
      I = 0
      IMAGE = 0
C
      CALL SCRIT ( NEGATA.DELTAT,0.01,NEGATA )
      CALL SCRIT ( 0.1*NEGATA,NEGATA*DELTAT,0.01,NEGATA )
      IF ( IDP .GT. 0.0 ) GO TO 99
      NEGATA = 0.5/DELTAT*0.5
      NEGATA = 0.0
      VALUE = 0.0
      NEGATA = 0.0
      DO 10 I = 0,NEGATA
      IF ( NEGATA(NEGATA) .LT. 1.0E-10 ) GO TO 10
      NEGATA = NEGATA+1
      VALUE = VALUE+SPECT( I )
10    CONTINUE
      NEGATA = 1 / NEGATA
      DO 20 I = 0,NEGATA
      SPECT( I ) = SPECT( SPECT(NEGATA).PLOT(NEGATA) )
      SPECT(0.1) = VALUE*PLOT(NEGATA)
      DEPTH = DEPTH+0.5
      NEGATA = NEGATA-1
      IF ( SPECT(NEGATA-NEGATA) .LT. 1.0E-10 ) GO TO 20
      IF ( NEGATA .LT. (1+NEGATA-1) ) GO TO 10
20    CONTINUE
      NEGATA = NEGATA+1
      DEPTH = DEPTH-0.5
      CALL LINE(I, DEPTH+1 )
      WRITE( 6,400 ) DEPTH, VALUE,DELTAT
400   FORMAT( 1X,'CHANNEL',I5,' DEPTH (MILS) FROM DEPTH =',
     1 F7.1,'  CHANNEL CONTENTS =',F10.1,'  AVG OF CHANNEL CONTENTS IS',F10.1,
     2 /,1X,'DEPTH STEP SIZE =',F10.1,' MILS')
      IF ( IMAGE .EQ. 0 ) IF ( SATLAT .GT. 1.0E-10 ) GO TO 30
410   FORMAT( 1X,'DEPTH REGULAR WIDTH IS',F6.3,' RECORDS' )
      NEGATA = 0
      IF ( IMAGE .EQ. 0 ) NEGATA = 0.001
      NEGATA( I0 ) = NEGATA( I0+1 )
      NEGATA( I1 ) = NEGATA( I0+1 )
      I0 = I0
      I = 0
      DO 40 I=1,I0+1
40    SPECT( I ) = NEGATA( I )
      SPLE = TRUE
      NEGATA = DELTAT
      I = I0+1
      GO TO 1
      RETURN
C
99    CALL LINE(I, 2 )
      WRITE( 6,100 ) IDP
100   FORMAT( 1X,'*** ERROR: DEPTH=',F10.3 )
      RETURN
      END
```

```
      SUBROUTINE SCRITICIN,Z,XOUT,YOUT,IER)
C---- CALCULATES XOUT FOR GIVEN ZIN
      IF ( IER .NE. 0 ) RETURN
      ITER=0
      LZ=1=0
      Z0=ABS(Z(1))
      Z1=0.0
      IF ( Z1 .LE. 0.0 ) GO TO 100
      ZO=Z1=ZIN=1/ABS(Z1N)
   10 CONTINUE
      IF ( ZOUT .LT. 0.0 ) GO TO 110
   11 Z=ABS(ZOUT)
      ITER=ITER+1
      IF ( ITER .GT. 20 ) GO TO 120
      IF ( ABS(Z-Z1) .LT. .0001 ) RETURN
      Z0=Z1=ZOUT=1/Z=Z1/ABS(Z0UT)
      GO TO 10
  100 IER=1
      RETURN
  110 LZ0=-LZ0=1
      ZOUT=1.E=04
      IF ( LZ0.LT.0 ) GO TO 11
      IER=2
      RETURN
  120 IER=3
      RETURN
      END

C
      FUNCTION DGAUSS ( X )
      DATA A,0 /7 1000,-1 0143 /
      DGAUSS = (DEXP(-X**2/2))
      RETURN
      END
      FUNCTION DGAUS ( X )
      DATA C,0 / 0 69830,-0 9 /
      DGAUS = (DEXP(-X**2/2))
      RETURN
      END

C
C
      SUBROUTINE REPLOT
      REAL LINE(10),YMAX(101),ALINE(3)
      DOUBLE PRECISION XSAVE1,XSAVE2,EXNO1,EXNO2,TID,TIME,DATE
      LOGICAL MODATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,MSAVED
      COMMON
     1/DATA1/ XDATA(1024),NTS,ISP
     2/NEWREP/ SPEC(2,1024),IWORK,ISPEC,EPCT(1024),SAVDOR(1024),NPAR
     3/HEADNG/ HEAD(10),HEADY1(3),HEADY2(3),DATE,TIME
     4/CADDIW/ CADD(3),IPADR1,IPADR2,PADR1,PADR2,PADR3,PADR4
     5/PCTL/ PRSTEP,LINES,NDEAD,RWRITE,RTAPE,RTEMP1,LTYPE,FB
     6/PLMSG/ MODATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,MSAVED
     7/VALUES/ EB,DELTAE,DELTAZ,ZE,SBR,AMG,LCHAN
     8/CCDES/ LCODE,AVAL,ISPLG,ISPLOT,IXSAVE
     9/ SCRACH / WORK(3190)

C
C     UPDATED 1/31/78 -- PLOT NEG VALS
C
      IF ( MODATA .OR. NEWVAL ) RETURN
      DATLST = .FALSE.
      IF ( IPADR1 .EQ. 0 ) IPADR1 = 1
      IF ( IPADR2 .EQ. 0 ) IPADR2 = DIGN( ISPEC.IPADR1+49 )
      NL = IPADR2 - IPADR1
      IF ( NL .LT. 2 ) GO TO 99
C     ------------------------------------------------------
      NL = NL + 2 + ( IABS( IYPLOT ) - IYPLOT ) / 2
      IB = IXSAV
      IF ( SPLG ) IB = 2-IXSAV
      CALL XLINE
      CALL LINSCT( NL )
      WRITE( MWRITE,200 )
  200 FORMAT( ' ' )
      WRITE ( MWRITE,300 ) XD,ZD,XE,HEADY1(IXSAV),HEADY2(IXSAV)
  300 FORMAT( T31,3A2,/,'    ',3A2 )
      IF ( SPLG ) WRITE(MWRITE,301) XB,ZB,YB,HEADY1(IB),HEADY2(IB)
      IF ( IYPLOT .GE. -1 ) WRITE( MWRITE,302 ) X11,Y11,Z11,EXNO1,04
      IF ( IYPLOT .GE. -2 ) WRITE( MWRITE,303 ) X22,Y22,Z22,EXNO2,04
      IYPLOT = IABS( IYPLOT )
      WRITE ( MWRITE,310 ) HEADX,HEADY1(IXSAV),HEADY2(IXSAV)
  310 FORMAT(/,T7,4A,T34,2A2 / )
      ICHN = 1
      IF ( HEADX .EQ. 'CHAN' .AND. ITYPE .NE. 0 ) ICHN = 0
      YMIN = 0.0
      YMAX = 0.0
      DO 10 I = IPADR1,IPADR2
      YMAX = AMAX1 ( YMAX,SPEC(IXSAV,I),SPEC(ID,I) )
      YMIN = AMIN1 ( YMIN,SPEC(IXSAV,I),SPEC(ID,I) )
      IF ( IYPLOT .LE. 0 ) GO TO 10
      YMIN = AMIN1( YMIN,EXTRA(I,1) )
      YMAX = AMAX1( YMAX,EXTRA(I,1) )
      IF ( IYPLOT .EQ. 1 ) GO TO 10
      YMIN = AMIN1( YMIN,EXTRA(I,2) )
      YMAX = AMAX1( YMAX,EXTRA(I,2) )
   10 CONTINUE
      LLMIN = -100
      LLMAX = -100
      IF ( YMAX .EQ. 0.0 ) GO TO 14
      ALMAX = ALOG10( YMAX ) - 0.17609913
      IF ( ALMAX .LT. 0.0 ) ALMAX = ALMAX-1.0
      LLMAX = ALM
      IF ( YMIN .EQ. 0.0 ) GO TO 15
   14 ALMIN = ALOG10( -YMIN ) - 0.17609912
      IF ( ALMIN .LT. 0.0 ) ALMIN = ALMIN-1.0
      LLMIN = ALMIN
   15 CONTINUE
      LLEXP = MAX0( LLMIN,LLMAX )
      IF ( LLEXP .NE. -100 ) GO TO 16
      YMAX = 1.0
      LLEXP = -1
   16 YDIV = 10.0**LLEXP
      ISCP = YMAX/YDIV + .99
      ISCN = YMIN/YDIV - .99
      ISCALE = ISCP-ISCN
      ISJUMP = 1
      ISM = 1
      IF ( ISCALE .LE. 10 ) GO TO 19
      ISJUMP = 2
      ISM = MOD( -ISCN,2 ) + 1
   19 CONTINUE
      ISCP1 = ISCP+1
      ISTEP = ISCALE+ISM/100
      IS = -ISCN/ISTEP + 1
      IF ( YMIN .EQ. 0.0 ) GO TO 17
      IF ( IS .NE. 0 ) GO TO 23
   17 ISCN = ISCN-1
      ISCP = ISCP+1
   23 ISTEP = -(ISCN+ISCP)
      WRITE( MWRITE,220 ) ISCN,ISCP,LLEXP
      DO 30 I = IPADR1,IPADR2
      II = ( SPEC( IXSAV ) - YAVMIN ) /YSTEP + 1.0
      ID = ( SPEC( ID,I ) -YAVMIN ) /YSTEP + 1.0
      IF( IYPLOT GE 1 ) IY2=(EXTRA(I,1)-YAVMIN)/YSTEP+1.0
      IF( IYPLOT GE 2 ) IY3=(EXTRA(I,2)-YAVMIN)/YSTEP+1.0
      IC = I-ICHN
      CD = FLOAT( IC )*DSTEP
      DATA LINE,YAX,AL,DE /1H1,' ',1H-,1H0,1H+,' ',1H.,1H*,1H/,
      DATA XX,XX,XL,YLINE,X11,X22 / 1H*,1H*,' ',1H.,1H*,1H/ /
      I = I
      IF ( MODE(IC,10) .EQ. 0 ) I = 2
      LINE(I) = XLINE(I)
      LINE(IM) = XLINE(I)
      IF ( I .NE. IPADR1 .AND. I .NE. IPADR2 ) GO TO 31
      DO 32 II=1,100
   32 LINE( II ) = YLINE
      DO 33 II=IXSAV,IXSAV
      II = ( YDIV+YSTEP ) /DFLOAT( II-1 ) + 1.0
   33 LINE ( II ) = ALINE( 3 )
      IF ( I .EQ. IPADR1 ) I = 2
   31 CONTINUE
      IF ( IYPLOT .GE. 0 ) LINE( IX2 ) = XX2
      IF ( IYPLOT .GE. 1 ) LINE( IX1 ) = X11
      LINE(II) = XX
      LINE(IS) = XX
      IF ( J .EQ. 1 ) WRITE( MWRITE,230 ) LINE
      IF ( J .EQ. 2 ) WRITE( MWRITE,240 ) CD,LINE
      IF ( I .NE. IPADR2 ) GO TO 30
      DO 35 II=1,100
   35 LINE( II ) = XL
      GO TO 36
   34 CONTINUE
      IF ( IYPLOT .GE. 1 ) LINE( IX1 ) = XL
      IF ( IYPLOT .GE. 2 ) LINE( IX2 ) = XL
      LINE(II) = XL
      LINE(IS) = XL
   36 CONTINUE
      WRITE( MWRITE,250 ) IXSAV,IXSAV,LLEXP
      CALL XLINE
      IYPLOT = 0
      RETURN
   99 CALL LINSCT( 2 )
      WRITE( MWRITE,270 )
  270 FORMAT ( ' ',5('*'),' YOU HAVE PLOT LIMITS')
      IYPLOT = 0
      RETURN
  210 FORMAT( T12,I2,T13,I2,' *10**',I2 )
  220 FORMAT ( T15,101A1 )
  230 FORMAT ( T5,97A1,T12,101A1 )
      END

C
C
      SUBROUTINE MEAN
      LOGICAL MODATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,MSAVED
      DOUBLE PRECISION DATE,TIME,TADJID,HEADY1,HEADY2
      COMMON
     1/DATA1/ XDATA(1024),NTS,ISP
     2/NEWREP/ SPEC(2,1024),IWORK,ISPEC,EPCT(1024),SAVDOR(1024),NPAR
     3/HEADNG/ HEAD(10),HEADX,HEADY1(3),HEADY2(3),DATE,TIME
     4/CADDIW/ CADD(3),IPADR1,IPADR2,PADR1,PADR2,PADR3,PADR4
     5/PCTL/ PRSTEP,LINES,NDEAD,RWRITE,RTAPE,RTEMP1,LTYPE,FB
     6/PLMSG/ MODATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,MSAVED
     7/VALUES/ EB,DELTAE,DELTAZ,ZE,SBR,AMG,LCHAN
     8/CCDES/ LCODE,AVAL,ISPLG,IXSAV,IXSAV
     9/ SCRACH / WORK(3190)

C     ------------------------------------------------------
      IF ( MODATA .OR. NEWVAL ) RETURN
      IPADR1 = PADR1 = 1
      IF ( IPADR2 .GT. 0 .AND. IPADR2 .NE. IXSAV ) RETURN
      ICHN = 1
      IF ( HEADX .EQ. 'CHAN' .AND. ITYPE .NE. 0 ) ICHN = 0
      CALL DATIM( DATE,TIME,TADJID )
      IF ( IPADR1 .EQ. 0 ) IPADR1 = 1
      IF ( IPADR2 .EQ. 0 ) IPADR2 = 1+NPC
      NL = IPADR2-IPADR1+2
      CALL XLINE
      CALL LINSCT( NL )
      WRITE( MWRITE,280 ) HEADX,HEADY1(IXSAV)
     1  ,HEADY2(IXSAV)
  280 FORMAT( /T7,4A,T34,2A2/ )
      DO 10 I = IPADR1,IPADR2,10
      K = (I-ICHN)*NPERSTEP
      J = MIN0 ( I+9,IPADR2 )
      WRITE( MWRITE,310 ) I,(SPEC(IXSAV,K),K=I,J)
  310 FORMAT ( T5,I7 1X,10(1X,G10 4) )
   10 CONTINUE
      CALL XLINE
      DATLST = .FALSE.
      RETURN
      END

C
C
      SUBROUTINE DAMDIV
      LOGICAL MODATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,MSAVED
      LOGICAL ANOT
      DOUBLE PRECISION HEADY1,HEADY2
      COMMON
     1/DATA1/ XDATA(1024),NTS,ISP
     2/NEWREP/ SPEC(2,1024),IWORK,ISPEC,EPCT(1024),SAVDOR(1024),NPAR
     3/HEADNG/ HEAD(10),HEADX,HEADY1(3),HEADY2(3),DATE,TIME
     4/CADDIW/ CADD(3),IPADR1,IPADR2,PADR1,PADR2,PADR3,PADR4
     5/PCTL/ PRSTEP,LINES,NDEAD,RWRITE,RTAPE,RTEMP1,LTYPE,FB
     6/PLMSG/ MODATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,MSAVED
     7/VALUES/ EB,DELTAE,DELTAZ,ZE,SBR,AMG,LCHAN
     8/CCDES/ LCODE,AVAL,ISPLG,IXSAV,IXSAV
     9/ SCRACH / WORK(3190)

C     ------------------------------------------------------
      DATA RNOT / .TRUE. /
      IF ( MODATA .OR. .NEWVAL ) RETURN
      IF ( PADR1 .LT. 1 ) PADR1=1 0
      IF ( PADR2 .GT. 1 ) PADR2 = PADR1+PADR2
      IF ( SPLG ) GO TO 10
      IF ( RNOT ) GO TO 30
      IF ( LCODE .NE. LPCODE ) GO TO 91
      I1 = 1
      I2 = 1
      DO 10 I = 1,ISPEC
      SPEC(I,I) = SPEC(I,I)+SAMDOR(I)*PADR1
      SPEC(IXSAV,I) = SPEC(IXSAV,I)+SAMDOR(I)*PADR1
   10 CONTINUE
      CALL LINSCT( 2 )
      WRITE( MWRITE,600 ) NPAR
  600 FORMAT( ' ',' SPECTRUM NORMALISED TO RANDOM WITH MEAN OF'
     1 ,T3,' RANDOMS' )
      HEADY1( ID ) = ' YIELD '
      HEADY1( IXSAV ) = ' YIELD '
      DATLST = .FALSE.
```

```
      HOPTMZ2 =  TRUE.
      RETURN
99    CONTINUE
      IF (  .NOT.FIRST  ) GO TO 98
      LRECOV = LCONV
      FIRST = .FALSE.
      WRAT = .FALSE.
      NRAN = 0
      DO 10 I = 1,IPSEC
10    RANDOM (I) = I.0
98    IF ( LCONV  .OR.  LRCONV ) GO TO 98
      ANRAN = FLOAT(NPRAN)
      DO 70 I = 1,IPSEC
      RAN = PARA(1+NPEC(1)NORE,I)
      IF ( RANDOM(I)  .EQ.  0.0 ) GO TO 30
      RINV = 1.0/RANDOM(I)
      RANDOM(I) = ( RANRAN*(RINV+RINV)/(ANRAN+1.0 )
      IF ( RANDOM(I)  .NE.  0.0 ) RANDOM(I) = 1.0/RANDOM(I)
30    CONTINUE
      NRAN = NRAN+1
      CALL LINEIT( 2 )
      WRITE( NWRITE,410 ) NRAN
410   FORMAT ( '0',7X,'RANDOM',I3,' STORED' )
      RETURN
95    WRITE( NWRITE,200 )
200   FORMAT ( '0',20('*'),' NO RANDOM AVAILABLE' )
      GO TO 99
97    CALL LINEIT( 2 )
      WRITE( NW,170,210 )
210   FORMAT ( '0',20('*'),' RANDOM HISTORY ERASED' )
98    NRANDS = 0
      RETURN
      END
C
C
      SUBROUTINE SMOOTH
      LOGICAL NEWDATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,NSMOOTH
      DOUBLE PRECISION WSAVY1,WSAVY2
C
      COMMON
     1/DATA1/ NDATA(1024),NTG,ISP
     2/NEWSP/ SPEC(3,1024),INDEX,ISPEC,EPCT(1024),RANDOM(10*4),NRAN
     3/WSAVE/ NSAVE(2),NSAVE,WSAVY1(2),WSAVY2(2),DATE,TIME
     4/CASEID/ CASE(3),IPARM1,IPARM2,PARM1,PARM2,PARM3,PARM4
     5/PRCTL/ PRNTOP,LINCT,NREAD,NWRITE,NTAPE,NTEMP1,ITYPE,PB
     6/PLAG1/ NDATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,NSMOOTH
     7/*BLANK*/ EB,DELTAE,DELTAZ,ZB,IBB,ANG,LCHAN
     8/CONST/ LCONV,RVAL,IRPLG,IMPLOT
     9/ SCRATCH / WORK(2390)
     +/POINT/ NC(6),MARK(6),WERE(6),MARKINT,MB
      DIMENSION Y( NY ), SY ( NY ), SRY ( NY ), R ( 6,MB )
C
      INITIALISE
C
      PI = 4.*ATAN(1.0)
      C1 = 1./6.
      R(1,1) = 0.0
      R(1,2) = 0.0
      R(1,NY) = 0.0
      R(1,NY+1) = 0.0
      R(2,1) = 0.0
      R(2,2) = 0.0
      R(2,NY) = 0.0
      R(2,NY+1) = 0.0
      P = 0.0
      Q = 0.0
      N = 0.0
      P2 = -1
      P = Y(2)-Y(1)
      R(1,1)=SY(1)+SY(1)
      R(1,2)=(Y(2)-SY(2)
      DO 15 I=3,NY
      Q = P
      P = Y(I)-Y(I-1)
      SRY(I) = P-Q
      R(1,I)=SY(I)+SY(I)
      R(2,I)=-3.0*(R(1,I)+R(1,I-1))
      R(3,I)=R(1,I)+3.0*(R(1,I-1))
15    CONTINUE
C
C     ITERATIVE SOLUTION
C
      DO 20 I=3,NY
      R(2,I-1) = P*R(4,I-1)
      R(4,I-2) = Q*R(4,I-2)
      R(4,I) = 1.0/(P*R(3,I)+C1*(3.0-P*R(2,I-1)-Q*R(4,I-2))
      R(7,I) = 3*(Y(I)-Y(I-1)-R(7,I-1)*R(6,I-2)*R(7,I-2)
      P = P*R(2,I)+C1*(2.0-R*R(3,I-1)
      Q = R
      R = R(1,I)*P
20    CONTINUE
C
      NP2 = NY+2
      DO 45 I=3,NY
      J = NP2-I
      R(7,J) = R(4,J)*R(7,J)-R(5,J)*R(7,J+1)-R(6,J)*R(7,J+2)
45    CONTINUE
C
      Q = 0.0
      S = 0.0
      DO 50 I=3,NY
      R = R
      R = R(7,I+1)-R(7,I)
      RRR = R-Q
      R(6,I)=RRR*R(1,I-1)
      Q = R+R(5,I)*RRR
50    CONTINUE
C
      R=R*R(1,NY)
      R(5,NY+1) = 0
      Q = R-Q*2
      Q = Q+Q
      P2 = P2*2
      IF (P2  GE  1.0E-06  .P2  LE. 0) GO TO 70
      P = 0.0
      R = R(5,3)-R(6,3)
      DO 60 I=3,NY
      Q = R
      R = R(5,I+1)-R(6,I)
      Q = R-Q-R(5,I-1)*R(6,I-1)-R(6,I-2)*R(6,I-3)
      P = P+Q*R(4,I)*Q
      R(4,I) = Q
60    CONTINUE
      R = R-P*P
      IF (R  .LE. 0.0) GO TO 70
      P = P*(P2-P2)/((SQRT(R/P2)+P)*P2)
      GO TO 10
C
70    NM1 = NY-1
      DO 80 I=1,NM1
      SRY(I) = Y(I)-R*R(6,I+1)
80    CONTINUE
      SRY(NY) = Y(NY)-P*R(5,NY+1)
      RETURN
      END
C
C
      SUBROUTINE PSMOOTH(A,F,X,IFLAG)
      DOUBLE PRECISION WSAVY1,WSAVY2,DATE,TIME,TRANID,A,F,X
     1 ,C,NAA,WERE
      LOGICAL DPLAG
      DIMENSION A(6),R(6),DATA(30),CHRVER(30),ERASE(80),PSAA(30),
     1          DEV(120),CHANK(30)
      LOGICAL NDATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,NSMOOTH
     1,PASAA,PB
      EQUIVA
     1/DATA1/ NDATA(1024),NTG,ISP
     2/NEWSP/ SPEC(3,1024),INDEX,ISPEC,EPCT(1024),RANDOM(10*4),NRAN
     3/WSAVE/ WSAV(20),WSAVR,WSAVY1(2),WSAVY2(2),DATE,TIME
     4/CASEID/ CASE(3),IPARM1,IPARM2,PARM1,PARM2,PARM3,PARM4
     5/PRCTL/ PRNTOP,LINCT,NREAD,NWRITE,NTAPE,NTEMP1,ITYPE,PB
     6/PLAG1/ NDATA,NEWVAL,DATLST,STEND,DPLG,SPLG,RPLG,FIRST,NSMOOTH
     7/*BLANK*/ EB,DELTAE,DELTAZ,ZB,IBB,ANG,LCHAN
     8/CONST/ LCONV,RVAL,IRPLG,IMPLOT
     9/ SCRATCH / WORK(2390)
     +/POINT/ NC(6),MARK(6),WERE(6),MARKINT,MB
      GO TO (10,40,30,40),IFLAG
10    CONTINUE
      IF ( IPARM1  .EQ.  0 ) IPARM1 = SMP*FB/DELTAE + .5
      IF ( IPARM2  .EQ.  0 ) IPARM2 = SMP*FB/DELTAE + .5
      IPARM3 = PARM3*.1
      NPAR = PARM2 + .5
      CALL WLINE
      CALL LINEIT( 2 )
      WRITE( NWRITE,2000 )
      IB = I-IBBDE
      START=FLOAT(IPARM1)
      NPOINT=(IPARM2-IPARM1+1
      DO 100 I=1,NPOINT
      IE = I+IPARM1-1
      CHANK (  ) = IE
      DATA( ) = SPEC( INDEX, IE )
100   CONTINUE
      IE = 10**(FB/DELTAE
      X(2) = IE
      IF ((IPARM2-IB-1)*(IE-IPARM1-1B)  .LE.  0 ) GO TO 900
      IE = IE-IPARM1+1
      X( 3 )  = (DATA(IE-4) + DATA(IE-3) + DATA(IE-2))/3
      X( 4 ) = (DATA(1) + DATA(2) + DATA(3))/3 **( 3 )
      X( 4 ) = X( 4 ) / ( IB-2 )
      X( 1 ) = 1
      X( 5 ) = AMAX1( DATA(IE-1),DATA(IE),DATA(IE+1))
      X( 6 ) = 0
      GO 1 1 =  1
      GO 2 2 =  2
      GO 3 3 = 10
      GO 4 4 = 1
      GO 5 5 = 30
      GO 6 6 =  5
      ILCT = 0
      IF (  .NOT.DPLAG ) ILCT = 2
      IP ( ( IRPLG-1.0( IRPLG-2)  NE  0 ) GO TO 110
      GO 7 7 = 0.0050
      GO 8 8 = 0.0100
      GO 9 9 = 10.
```

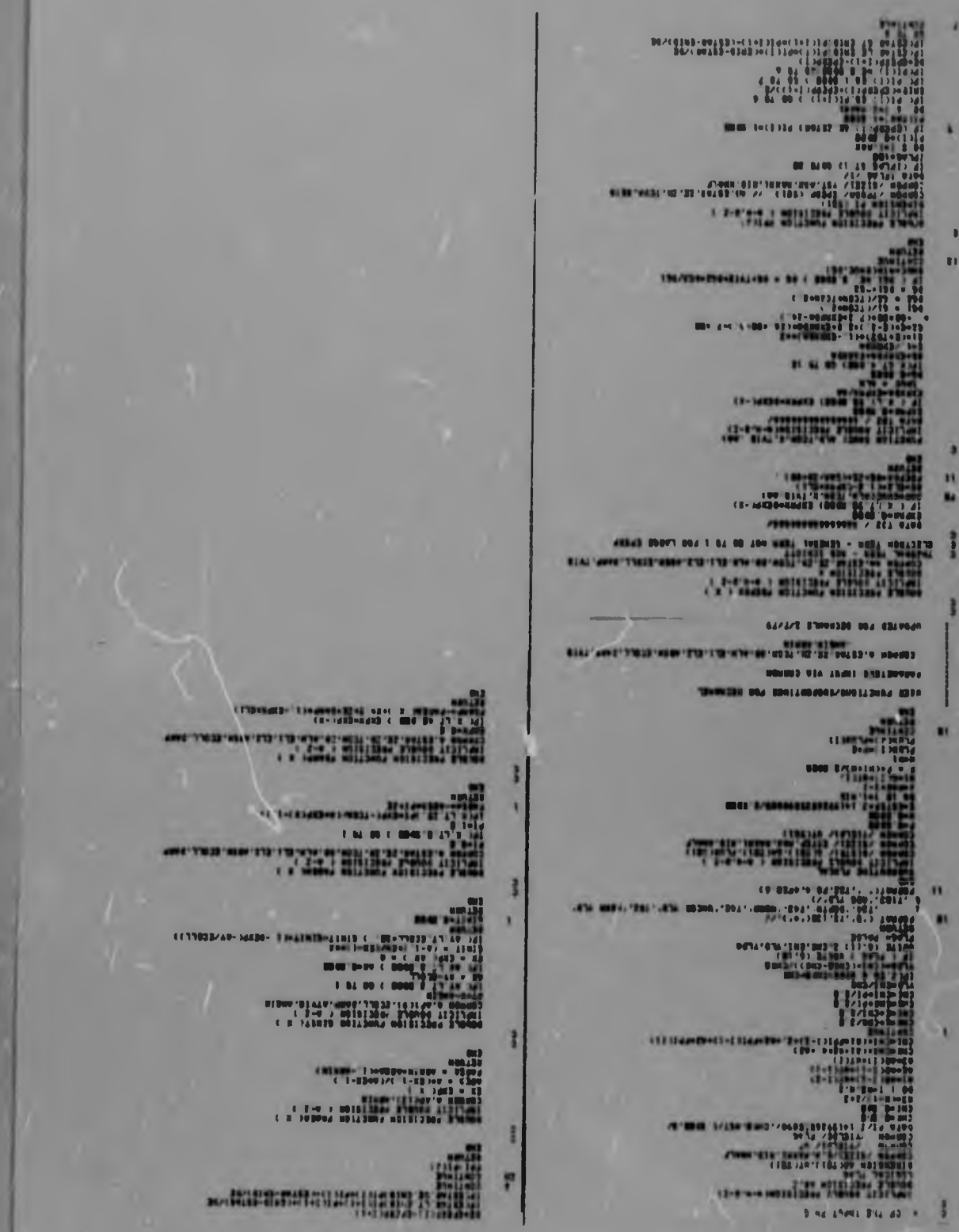
```
      ILET = 7
      RETURN
      CALL LINECTL ( )
      WRITE( NWRITE,6000 )
 6000 FORMAT( '0***** RANGE ERROR' )
      NERROR = TRUE.
      RETURN
   70 CONTINUE
   90 CONTINUE
C     CALL CH( 99
      P=0.0000
      YLIM=SPMAX(1.00/(.01/ST.0)
      DO 400 I=1,NPOINT
      CALL FCURVE(X(I),0.0,DTON.EDGE(I),PEAK(I)
      CURVE(I)=EDGE(I)+PEAK(I)
      DEV(I)=0.0
      IF ( DATA(I).LT.YLIM ) GO TO 400
      DEV(I)=(CURVE(I)-DATA(I))/AMAX1(CURVE(I).0.1)
      P=P+DEV(CURVE(I))+DEV(I)
  400 CONTINUE
      IF (IPLAG.NE.7) RETURN
      IE = NC + 1 + 7
      IEP10 = IE-NC)+3
      DO 220 I = 1.IEP10
  210 SPEC( IE.I ) = SPEC( IEORE.I )
      IEP10 = IEREE + 1
      DO 221 I = IEP10.IE
      DATA( I ) = 0.
      I = 1
      C = I-NC 0 )
  221 SPEC( IE.I ) = X(I) - X(4)*C + X(6)*C*C
      IE = IE-1
      DO 222 I = IE.IEPEC
  222 SPEC( IE.I ) = 0.0
      ADAPTIV( ID ) = ADAPTIV( IWORE )
      ADAPTIV( ID ) = ADAPTIV( IWORE )
      DELTAE = 500*RE/( IE-1 )
      IWORE = ID
C     PRINT OUT RESULTS
      PPEE=P/(.NPOINT-NPAE)
      IF ( IPAGE) 223, , ) GO TO 240
      CALL LINECTL( NPAGE+6 )
      WRITE ( 6.2100 ) (COMMON(I).DATA(I).CURVE(I).DEV(I).EDGE(I).
     1                  PEAK(I).I=1.NPOINT)
  240 CONTINUE
      CALL LINECTL( 10 )
      DO 241 I = 1.6
  241 WORK( I ) = SNGL( WERK(I)/(X(I)+(.0-20))+100.
      WRITE( NWRITE.2200 ) P.PPEE.(X(I).WERK(I).I=1.6)
      WRK6=WERK(1.6)*(1.0-ACEN
      WPEAK=W(2)-6*WAT+1.0
      IRI=1
      DO 280 I=1.NPEAK
  280 IF ( CLPHI(I).LT.CURVE(IRIN) ) IRIN=I
      CALL LINECTL (8+3*(I)
      WRITE ( 6.2300 ) IPEA.CURVE(IRIN).X(3)
      IF ( PIDT ) GO TO 290
      IF ((IPPLS.EQ.1).OR.(.NOT.RNFLAG)) GO TO 315
      CHISP=W(3)/WRK6
      DCHISQ=WDE(SP=W(4)/W(I)-WPAK/WERE)
      CHAN=W(2)-(IRIN-(PAPE)-1)
      ZLIRIN=CURVE(IRIN-1)/(X(3)+CHAN+WRK+CHAN*CHAN+WRK)
      WRITE(6.2310) CHISP.CHISQ.DCHISQ

  315 CONTINUE
      WRITE(6.2320)
      CP(.NLINE
      DATA XX6.XX2.PX7.XX4.HRAND.RNFLAG/6*0.0. FALSE./
C ----IF SAMPLE SPECTRUM AVAIL. CALC RANDOM LEVEL FROM MEAN OF SPECTRA
      IF ( IAPLS.LT.1  OR.  IAPLS.LT.2 ) RETURN
      XX6=XX6+X(6)
      XX5=XX5+X(5)
      XX4=XX4+X(4)
      XX3=XX3+X(3)
      XX2=XX2+X(2)
      XX1=XX1+X(1)
      HRAND=XX6/XX5
      SPP2=XX2/XX5
      SPP7=XX7/XX5
      SPP4=XX4/XX5
      RNFLAG= TRUE.
      RETURN
  350 XX1 = 0.
      XX2 = 0.
      XX4 = 0.
      XX6 = 0.
      XX5 = 0
      GO TO 315
 2000 FORMAT( '0',.TO.'FIT TO EDGE/SURFACE PEAK ( SAUERIAN )')
 2100 FORMAT('0',.T4.'CHAN',T44.'DATA',T54.'FIT',T64.'EDGE',T74.'EDGE'.
     1 T84.'PEAK'/(T31.3(F5.1,4X),3PF6.2,T74.8PF6.1,T84.F5.1))
 2200 FORMAT('0',.TO.'BEST FIT PARAMETERS.CHI SQ = '.1PE9.2,
     +       '   REDUCED CHI SQ='.8PF6.2./.
     +       T44.'PEAK WIDTH =  '.8PF6.2.2X.'+/- '.F5.2.' E'.
     +     /T44.'PEAK POSITION = '.F6.1.2X.'+/- '.F5.2.' E'.
     +     /T44.'SURFACE COUNTS= '.F6.1.2X.'+/- '.F5.1.' E'.
     +     /T44.'EDGE SLOPE =  '.F6.2.2X.'+/- '.F5.3.' E'.
     +     /T44.'PEAK HEIGHT =  '.F6.1.2X.'+/- '.F5.1.' E'.
     +     /T44.'CHANNAFIC TERM= '.F6.2.2X.'+/- '.F5.3.' E'/)
 2201 FORMAT(40(/'0'),/,T40,'=',T84,'=',/,
     1       T40,'=',T55,'PEAK AREA =  ',F6.1,' CTS',T84,'=',/,
     2       T40,'=',T55,'MINIMUM COUNT= ',F6.1,' CTS',T84,'=',/,
     4       T40,'=',T55,'SURFACE COUNT= ',F6.1,' CTS',T84,'=',/,
     3       T40,'=',T55,'SURFACE WIDTH= ',8PF6.2,' E',T84,'=',/,
     5       T40,'=',T55,'MINIMUM YIELD= ',F6.3,' E',T84,'=',/,
     6       T40,'=',T55,'RECOVERY RATE= ',1PE9.2,'  /E0',T84,'=')
 2320 FORMAT(        T40,'=',T84,'=',/,T40,40('='))
      END
      SUBROUTINE PEAKVO(C.S.ACEN.FEDGE.FPEAK)
C     GAUSS)%=
      DOUBLE PRECISION X
      DIMENSION X(6)
      DATA SQT2PI /2.5066283/
      ACEN = CBTSPE
      C1=C-ACEN
      T=C1/X(1)
      TSQRT=T/2
      EDGE=X(2)+X(3)*C1+X(4)*C1*C1
      PEAK = EXP( -X(6 )/SQT2P
      FEDGE=EDGE*(ERFC(T)+(2.**(3)*C1-X(4))*X(1)*PEAK
      FPEAK=X(5)*PEAK/X(1)
      RETURN
      END
```

APPENDIX 2

LISTING OF DECHANNELLING PROGRAM

```
      PROGRAM DECHANNEL

C     PROGRAM TO CALCULATE DECHANNELED YIELD
C     CALCULATED BY DIFFUSION APPROXIMATION

C           VER*100 = 5    20/7/79

C     RUN TO CERN PLUS 11/77
C     TIME.GE.0.LIGHT PEN TO PRINTOUT 121875
C      = 4.5   INCLUDES DAMP.485082  RUN FROM = 5.2

C
C
C
C     THE DECHANNELED YIELD IS CALCULATED BY INTEGRATION OF THE
C     TRANSVERSE ENERGY DISTRIBUTION CALCULATED BY NUMERICAL
C     SOLUTION OF THE DIFFUSION EQUATION DN/DT=1/2(D/DE(AD*DN/DE))
C     THE EQUATION IS TRANSFORMED INTO -1.1 FROM (0.INFINITY)
C     BY THE SUBSTITUTION E=TAN(PI*(Y)/2 )0 GOODS TO PROVIDE FIXED
C     BOUNDARY CONDITIONS E=0. SOLUTION IS FOUND BY THE CRANK-NICHOLSON
C     METHOD.

      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      REAL*4 HEAD(13),PHEAD(13),BLANK
      LOGICAL *1 FLAG,EXPAND,FLUX
      DIMENSION AC(51),X(51),DX(51),DY(51),DA(51),DA1(51)
     1          ,DPSI(51),WORK(51),DF(51),DF1(51),DF2(51),DF3(51)
     2          ,DF4(51),DF5(51),PSI(51),PSI1(51)
      COMMON /PSIDAT/ DF1,DF2,DF3
      COMMON /DIFFUS/ DEPSI(51),DAMPING
      COMMON /FLAGS/ FLAG,EXPAND,FLUX
      COMMON /STEP/ ISTEP,MAX,ESTEP,HSTEP
      COMMON /DIFFUN/ DF1,DF2,DF3
      COMMON /DIFFUS/ DEPSI(51),DAMPING
      COMMON /FLAGS/ FLAG  /PARA
      DATA BLANK /'    '/
      READ (5,1000) HEAD
      READ ( 5,1000 ) PHEAD,FLUX
      READ ( 5,*) ISTEP,ESTEP
      IF(ESTEP.LT.1.0-10)ESTEP=0.5
      NPARA=0
      DO 5 I=1,20
      PARA(I)=0.0000
      DO 10 I=1,13
      READ 15,1000) PHEAD(I),PARA(I)
      IF ( PHEAD(I) .EQ.BLANK ) GO TO 20
      NPARA=NPARA+1
10    CONTINUE
15    CONTINUE
      NSTEP=1.0000/STEP + 2000
      NSTEP=NSTEP+1
      PI=4.0000*ATAN(1.0000)
      PI2=4.0000/(PI**2)
      PI=4.0000/PI
      IPASS=0
      WRITE (6,4000) HEAD
      CALL DATIME( DATE,TIME,TASKID )
      WRITE( 6,4000 ) DATE,TIME
4000  FORMAT( '0  T30. Plus Ch '/,80(' '),' of ',A8 )
      WRITE (6,4100) (PHEAD(I),PARA(I),I=1,NPARA)
      WRITE (6,4001) ISTEP,MAX,ESTEP
      NMAX = ( MAX-1 ) / 8
      NIO = NMAX+1

C     CALCULATE ARRAYS CONTAINING TRIG FNS.TRANSFORMATIONS
C     AND INPUT FUNCTIONS

      CALL DISCRT

C     CALCULATE DIFF FNS FOR EQUATION
C     DEN/DT=-DF1*DEN/DY2+DF2*DN/DY

      CALL DIFFUN

C     WRITE OUT DESIRED TABLES

      DO 99 I = 1,10
      READ (5,200) HAD,XFLAG,ELI,ELS
      IF ( HAD(1) .EQ.  ' ' ) GO TO 26
      IF ( HAD(1) .EQ.  'DF1' )
      CALL TABLE(DF1,ZFAR,ELI,ELS,XFLAG,'DIFFUSION FUNCTION 1')
      IF ( HAD(1) .EQ.  'DF2' )
      CALL TABLE(DF2,ZFAR,ELI,ELS,XFLAG,'DIFFUSION FUNCTION 2')
      IF ( HAD(1) .EQ.  'DF3' )
      CALL TABLE(DF3,ZFAR,ELI,ELS,XFLAG,'DIFFUSION FUNCTION 3')
      IF ( HAD(1) .EQ.  'ENER' )
      CALL TABLE (EPSP,ZFAR,ELI,ELS,XFLAG,'TRANSVERSE ENERGY   ')
      IF ( HAD(1) .EQ.  'AREA' )
      CALL TABLE (AREA,ZFAR,ELI,ELS,XFLAG,'ACCESSIBLE AREA     ')
      IF ( HAD(1) .EQ.  'DEDX' )
      CALL TABLE(DEPSP,ZFAR,ELI,ELS,XFLAG,'RATE OF T.E. CHANGE ')
99    CONTINUE
26    CALL TABLE(DA,ZFAR,ELI,ELS,XFLAG,'T.E. DISTRIBUTION   ')
      IF ( FLUX ) CALL FLUCAL
      IF ( FLUX )
      CALL TABLE ( FLX,ZFAR,ELI,ELS,XFLAG,'FLUX DISTRIBUTION   ')
      ALL YIELD (DA,ZFAR)

C     READ IN STEP VARIABLES,CALCULATE ARRAYS FOR
C     CRANK-NICHOLSON SOLUTION AND ESTIMATE
C     INITIAL FUNCTION ERROR

11    READ (5,203,END=12) ZSTEP,DSTEP,IOUT(1),IOUT(2)
      IF (DSTEP) 12,13,13.12
12    CONTINUE
      WRITE ( 6,6100 ) ZSTEP,HSTEP
      TFLAG= TRUE
      CALL STEPCO(A,B,DI,E,ZSTEP)

C     CALCULATE NO. OF STEPS REQUIRED

      I=0
      J=0
      IF ( IOUT(1) .LT. IOUT(2) ) J=1
      I3R4 = 3-J
      IR=IOUT(I3R4)
      IL=IOUT(J)
300   I=I+IR
      X=DF1(I,IL)
      IF ( X ) 300,310,300
310   L=L+1
      NTOT=NSTEP/IR+NSTEP/IL-NSTEP/LCM
      IPASS(1)=0
      IPASS(2)=0
```

```
      SUBROUTINE STEPCO (A,B,BI,C,ZSTEP)
C
C     *  THIS SUBROUTINE CALCULATES THE ABOVE FOR THE C-N STEPS
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DOUBLE PRECISION A,B,BI,C,ZSTEP
      DIMENSION AC(50),BC(50),CC(50),BI(50),DP1(50),DP2(50),DP3(50)
      COMMON /SIZE1/ Y,TEP,MAX,HAND1,RED,HHALF  /DIFFUN/ DP1,DP2,DP3
      C1=2*TEP/3.
      C2=2*TEP/3.*ZSTEP**2
      C3=2*TEP/3.*ZSTEP
      C4=2*TEP/3.
      DO 200 I=1,MAX
      DP1(I)=0
      DP2(I)=0
      DP3(I)=0
      AC(1)=B1
      BC(1)=1.0+2.*B+B1-B2
      CC(1)=1.0-2.*B+B1+B2
      DO 300 I=2,MAX-1
      AC(I)=-B
      BC(I)=1.+2.*B
      CC(I)=-B
  300 CONTINUE
      AC(MAX)=B1-B2
      BC(MAX)=1.+2.*B+B1-B2
      CC(MAX)=-B1-B2
      RETURN
      END
      SUBROUTINE STEP ( A,B,B1,C,NSTEP )
C
C     *  THIS SUBROUTINE CALCULATES THE DISTRIBUTION PN AT A DEPTH
C     *  NSTEP=ZSTEP FROM THE INPUT PN 0
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DOUBLE PRECISION A,B,B1,C
      DIMENSION G(150),AC(50),BC(50),BI(50),CC(50),DC(50),PC(50)
      COMMON /SIZE1/ ZSTEP,MAX,HAND1,RED,HHALF
      DO 400 I=1,MAX,2
      G(I)=0.0
      G(I+1)=0.0
      DO 300 I=1,MAX
      AC(I)=-B
      BC(I)=1.+2.*B
      CC(I)=-B
  300 CONTINUE
      AC(1)=0
      BC(1)=1.+B1-B2
      CC(1)=-B1+B2
      AC(MAX)=-B1+B2
      BC(MAX)=1.+B1-B2
      CC(MAX)=0
      DO 400 I=1,NSTEP
      ACE=AC(1)-CC(1)*AC(I-1)
      DC(1)=AC(1)/BCE
      DO 500 I=2,MAX-1
      DC(I)=CC(I)/(BC(I)-AC(I)*DC(I-1))
      PC(1)=(PC(1)+CC(1)*PC(I-1))/BCE
  400 CONTINUE
      DO 450 I=1,MAX-1
      K=MAX-I
      G(K)=PC(K)-DC(K)*G(K+1)
  450 CONTINUE
      RETURN
      END
      SUBROUTINE TABLE(A0,Z,ELIN1,ELINC,ISKP,MEAN)
C
C     *  THIS SUBROUTINE PRINTS OUT TABLES FROM INPUT ARRAYS
C     *  OVER A SPECIFIED INTERVAL ELIN1 TO ELINC AT A SPACING
C     *  ISKP WITH HEADING MEAN.  DEFAULT VALS ARE ELIN1=0.
C     *  ELINC=1, ISKP=1 FOR INPUT OF THESE VARIABLES IF 0
C
      IMPLICIT DOUBLE PRECISION ( A-H,O-Z )
      DOUBLE PRECISION A0,Z,ELIN1,ELINC
      REAL MEAN(5)
      LOGICAL PLAG
      DIMENSION A0(50),Z(50)
      COMMON /SIZE1/ ZSTEP,MAX,HAND1,RED,HHALF
      COMMON /YIELD1/ PLAG
      PLAG=.TRUE.
      ISKP=ISKP
      IF (ISKP EQ 0) ISKP=1
      NLO=IDINT((ELIN1+1.0)/ZSTEP+.5)+1
      NUP=IDINT((ELINC+1.0)/ZSTEP+.5)+1
      IF (NUP GT (MAX+1)/2) NUP=MAX
      INUT=1+(NUP-NLO)/ISKP
      WRITE (6,33) MEAN,Z
      DO 10 I=NLO,NUP,INUT
      K=ZSTEP*(I-1)-1.0
      J=I+ISKP-1
      IF (J GT NUP) J=NUP
   10 WRITE (6,31) K,(A0(K),K=I,J,ISKP)
      PLAG=.TRUE.
      RETURN
   31 FORMAT(' ',F5.1,6(2X,1P1E10.3))
   33 FORMAT('1',T52,8HZ =,//T6,'Y',T25,'DEPTH=',F10.4,//)
      END
      SUBROUTINE YIELD (A0,Z)
C
C     *  THIS SUBROUTINE CALCULATES THE YIELD AND NORMALIZATION
```



REFERENCES

Abe 72a F Abel, G Amsel, M Bruneaux and C Cohen, Phys Lett A42, 165 (1972).

Abe 72b F Abel, G Amsel, M Bruneaux and C Cohen, Rad Eff 12, 35 (1972).

Abr 70 M Abramowitz and I A Stegun, Handbook of Mathematical Functions (U S National Bureau of Standards, 1970).

Ad 62 S L Adler, Phys Rev 126, 413 (1962).

Ag 78 M K Agrawal and D K Sood, Nucl Instr Meth 149, 425 (1978).

Ah 75 M Ahlberg, G Johansson and K Malmqvist, Nucl Instr Meth 131, 377 (1975).

And 67 J U Andersen, Matt Fys Medd Dan Vid Selsk No 7, 36 (1967).

And 70 J U Andersen and L C Feldman, Phys Rev B1, 2063 (1970).

And 71 J U Andersen, O Andreasen, J A Davies and E Uggerhøj, Rad Eff 7, 25 (1971).

And 72 J U Andersen and E Laegsgård, Rad Eff 12, 3 (1972).

Ans 77 H H Andersen and J F Ziegler, Hydrogen Stopping Powers and Ranges in all Elements (Pergamon Press, New York, 1977).

Ap 67 B R Appleton, C Erginsoy and W M Gibson, Phys Rev 161, 330 (1967).

Ap 68 B R Appleton, L C Feldman and W L Brown, Intl. Conf. on Solid State Research with Accelerators (1967) (Brookhaven National Laboratories 1968) p45.

Ap 72 B R Appleton, J H Barrett, T S Noggle and C D Moak, Rad Eff 13, 171 (1972).

Aw 65 T Awaya, J Phys Soc Jap 20, 669 (1965).

Ba 68 J H Barrett, Phys Rev 166, 219 (1968).

Ba 71 J H Barrett, Phys Rev B3, 1527 (1971).

Ba 73 J H Barrett, Phys Rev Lett 31, 1542 (1973).

Bed 72 F Bernhard, P Krygel, R Manns and S Schwabe, Rad Eff 13, 249 (1972).

Beh 73 R Behrisch and B M U Scherzer, Thin Solid Films 19, 247 (1973).

Beh 76 R Behrisch and J Roth, Ion Beam Surface Layer Analysis, Ed: O Meyer, G Linker and F Käppeler (Plenum Press, New York, 1976).

Bel 72 V V Beloshitsky, M A Kumakhov and V A Muralev, Rad Eff 13, 9 (1972).

Bel 73 V V Beloshitsky, M A Kumakhov and V A Muralev, Rad Eff 20, 95 (1973).

Bel 78 V V Beloshitsky and M A Kumakhov, Rad Eff 35, 209 (1978).

Ben 49 R S Bender, F C Shoemaker, S G Kauffmann and G M B Bouricius, Phys Rev 76, 273 (1949).

Ber 65 R Berman (Ed), Physical Properties of Diamond (Clarendon Press, Oxford, 1965).

Bet 30 H A Bethe, Ann der Phys 5, 325 (1930).

Bj 72 K Björkqvist, B Cartling and B Domeij, Rad Eff 12, 267 (1972).

Bl 33a F Bloch, Ann der Phys 16, 285 (1933).

Bl 33b F Bloch, Zeit Phys 81, 363 (1933).

Bod 72 E Bonderup, H Esbensen, J U Andersen and H E Schiøtt, Rad Eff 12, 261 (1972).

Bøg 64 E Bøgh, J A Davies and K O Nielsen, Phys Lett 12, 129 (1964).

Bøg 67 E Bøgh, Can J Phys 46, 653 (1967).

Bøg 72 E Bøgh, Rad Eff 12, 13 (1972).

Bøg 73 E Bøgh, in Channelling, Ed: D V Morgan (J Wiley, London, 1973) p435.

Boh 15 N Bohr, Phil Mag 25, 10 (1915).

Boh 48 N Bohr, Mat Fys Medd Dan Vid Selsk No 8, 18 (1948).

Bol 65 D Bollen, Wireless World 71, 381 (1965).

Bon 69 F Bonsignori and A Desalvo, Lett Nuovo Cim 1, 589 (1969).

Bon 70 F Bonsignori and A Desalvo, J Phys Chem Sol 31, 2191 (1970).

Bot 78 A Bontemps and J Fontenille, Phys Rev B18, 6302 (1978).

Br 70 W Brandt and J Reinheimer, Phys Rev B2, 3104 (1970).

Br 77 W Brandt, Ann Israel Phys Soc 1, 441 (1977).

Bun 79 A F Burenkov and F F Komarov, Phys Lett A69, 439 (1979).

Bur 78a E A Burgemeister, Physica 93B, 164 (1978).

Bur 79 E A Burgemeister and M Seal, Nature 279, 785 (1979).

Bus 78 L A Bursill, J C Barry and F R W Hudson, Phil Mag A37, 789 (1978).

Cam 71 S U Campisano, F Grasso and E Rimini, Rad Eff 9, 153 (1971).

Cam 73 S U Campisano, G Foti, F Grasso and E Rimini, Phys Rev B8, 1811 (1973).

Cam 78 S U Campisano, G Foti, E Rimini and S T Picraux, Nucl Instr Meth 149, 371 (1978).

Cat 58 S Caticha-Ellis and W Cochran, Acta Cryst 11, 245 (1958).

Chr 77 R M Chrenko, R E Tuft and H M Strong, Nature 270, 141 (1977).

Chu 72 W K Chu and D Powers, Phys Lett A40, 23 (1972).

Cla 56 C D Clark, R W Ditchburn and H B Dyer, Proc Roy Soc Lond A234, 363 (1956).

Cle 74 E Clementi and C Roetti, At Dat and Nucl Dat Tables 14, 117 (1974).

Clr 70 G J Clark, D V Morgan and J M Poate, Atomic Collision Phenomena in Solids, Ed: D W Palmer, M W Thompson, P D Townsend (North-Holland, Amsterdam, 1970) p388.

Cu 52 J F H Custers, Physica 18, 489 (1952).

Dad 69 L A Davidson, J F Gibbons, R L Der, T M Kavanagh and J M Khan, Appl Phys Lett 14, 295 (1969).

Dad 71 L A Davidson, S Chou, J F Gibbons and W S Johnson, Rad Eff 7, 35 (1971).

Das 72 J A Davies, L M Howe, D A Marsden and J L Whitton, Rad Eff 12, 247 (1972).

Das 73 J A Davies, in Channelling, Ed: D V Morgan (J Wiley, London, 1973) p392.

Dat 67 S Datz, C Erginsoy, G Leibfried and H O Lutz, Ann Rev Nucl Sci 17, 129 (1967).

Dav 70 G Davies, Nature 228, 758 (1970).

Dav 73 G Davies and I Summersgill, Diamond Research (Industrial Diamond Information Centre, London, 1973) p6.

Dav 76 G Davies, J Phys C9, L537 (1976).

Dav 77 G Davies, Chem and Phys of Carbon 13, 1 (1977).

Dav 79 G Davies, in The Properties of Diamond, Ed: J E Field (Academic Press, London, 1979) p165.

Dea 64 G Dearnaley, IEEE Trans Nucl Sci 11, 249 (1964).

Del 70 G Delsarte, J C Jousset, J Mory and Y Quéré, Atomic Collision Phenomena in Solids, Ed: D W Palmer, M W Thompson, P D Townsend (North-Holland, Amsterdam, 1970) p501.

Dem 72 G Della Mea, A V Drigo, S Lo Russo, P Mazzoldi and G G Bentini, Rad Eff 13, 115 (1972).

Der 78 T E Derry, PhD Thesis, University of the Witwatersrand (1978).

Des 77 A Desalvo and R Rosa, J Phys C10, 1595 (1977).

Det 74 K Dettmann and M T Robinson, Phys Rev B10, 1 (1974).

Det 75 K Dettmann, Zeit Phys A272, 227 (1975).

Do 68 P A Doyle and P S Turner, Acta Cryst A24, 390 (1968).

Dy 65 H B Dyer, F A Raal, L du Preez and J H N Loubser, Phil Mag 11, 763 (1965).

Ei 72 F H Eisen, G J Clark, J Bøttiger and J M Poate, Rad Eff 13, 93 (1972).

Ei 73 F H Eisen, in Channelling, Ed: D V Morgan (J Wiley, London, 1973) p415.

Ell 67 C Ellegaard and N O Lassen, Matt Fys Medd Dan Vid Selsk 35, 16 (1967).

Els 78 J A Ellison, S T Chui and W M Gibson, Phys Rev B18, 5963 (1978).

Elt 60 R J Elliott, Proc Phys Soc 76, 737 (1960).

Er 65 C Erginsoy, Phys Rev Lett 15, 360 (1965).

Er 68 C Erginsoy, Intl Conf on Solid State Research with Accelerators (1967) (Brookhaven National Laboratories, 1968) p 30.

Es 78 H Esbensen and J A Golovchenko, Nucl Phys A298, 382 (1978).

Eva 62a — T Evans and C Phaal, Proc Fifth Biennial Conf on Carbon (Penn State Univ, 1962) p147.

Eva 62b — T Evans and C Phaal, Proc Roy Soc Lor A270, 538 (1962).

Eva 64 — T Evans and P F James, Proc Roy Soc Lond A277, 260 (1964).

Eva 73 — T Evans, Diamond Research (Industrial Diamond Information Centre, London, 1973) p2.

Eva 75 — T Evans and P Rainey, Proc Roy Soc Lond A344, 111 (1975).

Eva 78 — T Evans, Diamond Research (Industrial Diamond Information Centre, London, 1978) p17.

Evn 78 — S Evans, Diamond Conference Abstracts, 1978 (Unpublished).

Fa 60 — D S Falk, Phys Rev 118, 105 (1960).

Fel 68 — L C Feldman, B R Appleton and W L Brown, Intl Conf on Solid State Research with Accelerators (1967) (Brookhaven National Laboratories, 1968) p58.

Fel 70 — L C Feldman and J W Rodgers, J Appl Phys 41, 3776 (1970).

Fer 40 — E Fermi, Phys Rev 57, 445 (1940).

Fes 73 — H W Fesq, D M Bibby, J P F Sellschop and J I W Watterson, J Radioanal Chem 17, 195 (1973).

Fes 75 — H W Fesq, D M Bibby, C S Erasmus, E J D Kable and J P F Sellschop, Phys Chem Earth 9, 817 (1975).

Fie 79 — J E Field (Ed), The Properties of Diamond (Academic Press, London, 1979).

Fir 58 — O B Firsov, Sov Phys JETP 6, 534 (1958).

Fon 72 — A Fontell, E Arminen and E Liminen, Rad Eff 12, 255 (1972).

Fot 71 — G Foti, F Grasso, R Quatrocchi and E Rimini, Phys Rev B3, 2169 (1971).

Fot 77 — G Foti, J W Mayer and E Rimini, in Ion Beam Handbook for Material Analysis, Ed: J W Mayer and E Rimini (Academic Press, New York, 1977) p42.

Fr 56 — F C Frank, Proc Roy Soc Lond A237, 168 (1956).

Fr 64 — F C Frank, Proc Phys Soc 84, 745 (1964).

Fr 65 — F C Frank and A R Lang, in Physical Properties of Diamond, Ed: R Berman (Clarendon Press, Oxford, 1965) p69.

Fr 67 F C Frank, B R Lawn, A R Lang and E M Wilks, Proc Roy Soc Lond A301, 239 (1967).

Fu 71a F Fujimoto, K Komaki and H Nakayama, Phys Stat Sol (a) 5, 725 (1971).

Fu 71b F Fujimoto, K Komaki, H Nakayama and M Ishii, Phys Stat Sol (a) 6, 623 (1971).

Fu 72 F Fujimoto, K Komaki, H Nakayama and M Ishii, Rad Eff 13, 43 (1972).

Ge 74 D S Gemmell, Rev Mod Phys 46, 129 (1974).

Gi 73 W M Gibson and M Maruyama, in Channelling, Ed: D V Morgan (J Wiley, London, 1973) p349.

Gol 71 H Goldstein, Classical Mechanics (Addison-Wesley, Reading, Mass., 1971).

Gom 56 P Gombás, Handbuch der Physik 36, 109 (Springer, Berlin, 1956).

Got 59 S Göttlicher and E Wölfel, Zeit Electrochem 63, 891 (1959).

Got 75a G Götz, K D Klinge and U Finger, Atomic Collisions in Solids, Ed: S Datz, B R Appleton and C D Moak (Plenum Press, New York, 1975) p693.

Got 75b G Götz, K Hehl, F Schwabe and E Glaser, Rad Eff 25, 27 (1975).

Gr 73 F Grasso, in Channelling, Ed: D V Morgan (J Wiley, London, 1973) p181.

Gra 65 I S Gradshteyn and I M Ryzhik, Table of Integrals, Series and Products (Academic Press, New York, 1965).

Ha 77 P L Hanley, I Kiflawi and A R Lang, Phil Trans Roy Soc Lond A284, 329 (1977).

Ho 53 L van Hove, Phys Rev 89, 1189 (1953).

Hu 76 P R W Hudson and P P Phakey, Phys Stat Sol (a) 36, 627 (1976).

Hu 77a P R W Hudson and I S T Tsong, J Mat Sci 12, 2389 (1977).

Hu 77b P R W Hudson and P P Phakey, Nature 269, 227 (1977).

Jac 76 D P Jackson, Nucl Instr Meth 132, 603 (1976).

Jak 62 J D Jackson, Classical Electrodynamics (J Wiley and Sons, New York, 1962).

Jam 75 F James and M Roos, Comp Phys Comm 10, 343 (1975).

Jar 77 O N Jarvis, A C Sherwood, C Whitehead and M W Lucas, Phys Rev B16, 3880 (1977).

Jar 78 O N Jarvis, A C Sherwood, C Whitehead and M W Lucas, J Phys C11, 2923 (1978).

Jas 52 H L Jackson, A I Galonsky, F J Eppling, R W Hill, E Goldberg and J R Cameron, Phys Rev 89, 65 (1952).

Je 32 H Jensen, Zeit Phys 77, 722 (1932).

Jo 74 D L Johnson, Phys Rev B9, 4475 (1974).

Ka 59 W Kaiser and W L Bond, Phys Rev 115, 857 (1959).

Kea 66 D T Keating and G H Vineyard, Acta Cryst 9, 895 (1966).

Kem 65 P J Kemmey and P T Wedepohl, in Physical Properties of Diamond, Ed: R Berman (Clarendon Press, Oxford, 1965) p325.

Ki 72 M Kitagawa and Y H Ohtsuki, Phys Rev B5, 3418 (1972).

Ki 73 M Kitagawa and Y H Ohtsuki, Phys Rev B8, 3117 (1973).

Ki 76 M Kitagawa, Phys Lett A58, 487 (1976).

Kok 76 K Komaki, Ion Beam Surface Layer Analysis, Ed: O Meyer, G Linker and F Käppeler (Plenum Press, New York, 1976) Vol 2, p517.

Kom 74 F F Komarov and M A Kumakhov, Rad Eff 22, 1 (1974).

Kub 73 Y Kubota and Y H Ohtsuki, Phys Lett 43A, 521 (1973).

Kud 76a H Kudo, J Phys Soc Jap 40, 1645 (1976).

Kud 76b H Kudo and M Mannami, Phys Lett A58, 323 (1976).

Kud 78 H Kudo, Phys Rev B18, 5995 (1978).

Kum 75 M A Kumakhov, Sov Phys Usp 18, 203 (1975).

Lal 78 R A Langley and D K Brice, Phys Rev B18, 4673 (1978).

Lan 64 A R Lang, Proc Phys Soc 84, 871 (1964).

Lan 77 A R Lang, J Cryst Growth 42, 625 (1977).

Lan 79 A R Lang, in The Properties of Diamond, Ed: J E Field (Academic Press, London, 1979) p425.

Lau 51 R A Laubenstein, M J W Laubenstein, L J Koester and R C Mobley, Phys Rev 84, 12 (1951).

Lax 55 M Lax and E Burnstein, Phys Rev 97, 39 (1955).

Le 63 G Lehmann and G Leibfried, J Appl Phys 34, 2831 (1963).

Lig 64 E C Lightowlers and P J Dean, Diamond Research (Industrial Diamond Information Centre, London) 1964, p21.

Lig 76 E C Lightowlers and A T Collins J Phys D9, 951 976).

Lin 53 J Lindhard and M Scharff, Matt Fys Medd Dan Vid Selsk 15 , 27 (1953).

Lin 54 J Lindhard, Matt Fys Medd Dan Vid Selsk 8, 28 (1954).

Lin 63 J Lindhard, M Scharff and H E Schiøtt, Matt Fys Medd Dan Vid Selsk 14, 33 (1963).

Lin 64a J Lindhard, Phys Lett 12, 126 (1964).

Lin 64b J Lindhard and A Winther, Matt Fys Medd Dan Vid Selsk 4, 34 (1964).

Lin 65 J Lindhard, Matt Fys Medd Dan Vid Selsk 4, 34 (1965).

J Lindhard, V Nielsen and M Scharff, Matt Fys Medd Dan Vid Selsk 10, 36 (1968).

Lo 65 K Lonsdale, in Physical Properties of Diamond, Ed: R Berman (Clarendon Press, Oxford, 1965) p12.

Lug 73 E Lugujjo and J W Mayer, Phys Rev B7, 1782 (1973).

Lun 68 M Luntz and R H Bartram, Phys Rev 175, 468 (1968).

Mai 78 A Mainwood, F P Larkins and A M Stoneham, Sol St Electonics 21, 1431 (1978).

Man 68 J B Marion and F C Young, Nuclear Reaction Analysis (North-Holland, Amsterdam, 1968).

Mar 75 A D Marwick and P Sigmund, Nucl Instr Meth 126, 317 (1975).

Mas 73 M Matsunami and N Itoh, Phys Lett A43, 435 (1973).

Mas 75 M Matsunami, J Phys Soc Jap 38, 848 (1975).

Mat 76 E Matteson, E K L Chau and D Powers, Phys Rev A14, 169 (1976).

Mel 75 J D Melvin and T A Tombrello, Rad Eff 26, 113 (1975).

Mer 73 K L Merkle, P P Pronko, D S Gemmell, R C Mikkelson and J R Wrobel, Phys Rev B8, 1002 (1973).

Mey 71 L Meyer, Phys Stat Sol 44, 253 (1971).

Mog 70 D V Morgan and D van Vliet in Atomic Collision Phenomena in Solids, Ed: D W Palmer, M W Thompson, P D Townsend (North-Holland, Amsterdam, 1970) p 476.

Mog 73a D V Morgan, in Channeling, Ed: D V Morgan (J Wiley, London, 1973) p 79.

Mog 73b D V Morgan (Ed), Charneling (J Wiley, London, 1973).

Mol 47 G Molière, Z Naturforschung 2a, 133 (1947).

Mor 71 K Morita and N Itoh, J Phys Soc Jap 30, 1430 (1971)

Moy 72 J Mory and Y Quéré, Rad Eff 13, 59 (1972).

Ne 63 R S Nelson and M W Thompson, Phil Mag 8, 1677 (1963).

Om 77 T Omura, M Kitagawa and Y H Ohtsuki, Phys Stat Sol (b) 79, 321 (1977).

Ped 75 M J Pedersen, J U Andersen, D J Elliott and E Laegsgård, Atomic Collisions in Solids, Ed: S Datz, B R Appleton and C D Moak, (Plenum Press, New York, 1975) p863.

Pet 23 F Peter, Zeit Phys 15, 358 (1923).

Pic 69 S T Picraux, J A Davies, L Eriksson, N G E Johansson and J W Mayer, Phys Rev 180, 873 (1969).

Pic 76 S T Picraux, Ion Beam Surface Layer Analysis, Ed: O Meyer, G. Linker and F Käppeler, (Plenum Press, New York, 1976) p527.

Pic 78 S T Picraux, E Rimini, G Foti and S U Campisano, Phys Rev B18, 2078 (1978).

Pin 53 D Pines, Phys Rev 92, 626 (1953).

Pin 63 D Pines, Elementary Excitations in Solids (W A Benjamin, New York, 1963).

Qu 68 Y Quéré, Phys Stat Sol 30, 713 (1968).

Qu 76 Y Quéré, Rad Eff 28, 253 (1976).

Qu 78 Y Quéré, Rad Eff 38, 131 (1978).

Ra 40 C V Raman and P Nilakantan, Proc Ind Acad Sci A11, 389 (1940).

Rei 67 C H Reinsch, Num Math 10, 177 (1967).

Res 69 F G Resmini, A D Bacher, D J Clark, E A McClatchie and R de Swiniarski, Nucl Instr Meth 74, 261 (1969).

Ric 67 R D Richtmeyer and K W Morton, Difference Methods for Initial-Value Problems (J Wiley, New York, 1967).

Rim 72 E Rimini, E Lugujjo and J W Mayer, Phys Rev B6, 718 (1972).

Rob 63a M T Robinson and O S Oen, Appl Phys Lett 2, 30 (1963).

Rob 63b M T Robinson and O S Oen, Phys Rev 132, 2385 (1963).

Ros 77 V I Roslyakov, A S Rudnev, E I Sirotinin, A F Tulinov and V A Khodyrev, Phys Stat Sol a43, 59 (1977).

Rud 74 A S Rudnev, K S Shyshkin, E I Sirotinin and A F Tulinov, Rad Eff 22, 29 (1974).

Run 71 W A Runciman and T Carter, Sol St Comm 9, 315 (1971).

Sc 75 H E Schiøtt, E Bonderup, J U Andersen and H Esbensen, Atomic Collisions in Solids, Ed: S Datz, B R Appleton and C D Moak, (Plenum Press, New York, 1975) p843.

Sea 58 M Seal, Proc Roy Soc Lond A248, 379 (1958).

Sea 66 M Seal, Phil Mag 13, 645 (1966).

Sel 73 J P F Sellschop and W M Gibson, Diamond Research (Industrial Diamond Information Centre, London) 1973, p32.

Sel 75a J P F Sellschop, Diamond Research (Industrial Diamond Information Centre, London) 1975, p35.

Sel 75b J P F Sellschop, R J Keddy, D W Mingay, M J Renan and D G Schuster, Int J Appl Rad Isotopes 26, 640 (1975).

Sel 77 J P F Sellschop, M J Renan, R J Keddy, D W Mingay and D M Bibby, Intl J App Rad Isot 28, 277 (1977).

Sel 78 J P F Sellschop, H J Annegarn, R J Keddy, C C P Madiba and M J Renan, Nucl Instr Meth 149, 321 (1978).

Si 74 P Sigmund and K B Winterbon, Nucl Instr Meth 119, 541 (1974).

Si 76 P Sigmund, Ann Israel Phys Soc 1, 69 (1976).

Sob 68 E V Sobolev, V I Lisoivan and S V Lenskaya, Sov Phys Dokl 12, 665 (1968)

Sob 72 E V Sobolev and V I Lisoivan, Sov Phys Dokl 17, 425 (1972).

Sof 61 S D Softky, Phys Rev 123, 1685 (1961).

Sta 12 J Stark. Phys Zeit 13, 973 (1912).

Ste 57 E J [illegible]glass, Phys Rev 108, 1 (1957).

Sto 78 A M Stoneham, Diamond Conference Abstracts 1978 (Unpublished).

Su 54 G B B M Sutherland, D E Blackwell and W G Simeral, Nature 174, 901 (1954).

Th 73 M W Thompson in Channeling, Ed: D V Morgan (J Wiley, London, 1973) p1.

Ts 68 C TschalÄr, Nucl Instr Meth 61, 141 (1968).

Tu 76 W C Turkenburg, W Soszka, F W Saris, H H Kersten and B G Colenbrander, Nucl Instr Meth 132, 587 (1976).

Va 76 J W Vandersande, Phys Rev B13, 4560 (1976).

Va 78 J W Vandersande, Diamond Conference Abstracts 1978 (Unpublished).

Va 80 J W Vandersande, J Phys C13, 759 (1980).

Vi 62 A C Victor, J Chem Phys 36, 1903 (1962).

Vl 71 D van Vliet, Rad Eff 10, 137 (1971).

Wag 78 A G Wagh and J S Williams, Phys Lett A65, 175 (1978).

Wat 71 G D Watkins, R P Messmer, C Weigel, D Peak and J W Corbett, Phys Rev Lett 27, 1573 (1971).

Wei 73 C Weigel, D Peak, J W Corbett, G D Watkins and R P Messmer, Phys Rev B8, 2906 (1973).

Wes 70 J E Westmoreland, J W Mayer, F H Eisen and B Welch, Rad Eff 6, 161 (1970).

Wil 59 E M Wilks and J Wilks, Phil Mag 4, 158 (1959).

Wil 65 E M Wilks and J Wilks, in Physical Properties of Diamond, Ed: R Berman (Clarendon Press, Oxford, 1965) p221.

Wil 79 J Wilks and E M Wilks, in The Properties of Diamond, Ed: J E Field (Academic Press, London, 1979) p351.

Win 70 K B Winterbon, P Sigmund and J B Sanders, Matt Fys Medd Dan Vid Selsk 14, 36 (1970).

Wis 63 N Wiser, Phys Rev 129, 62 (1963).

Wo 73 G S Woods, Diamond Research (Industrial Diamond Information Centre, London) 1973, p25.

Wo 76 G S Woods, Phil Mag 34, 993 (1976).

Za 74 C S Zaidins, Nucl Instr Meth 120, 125 (1974).

Zi 72 J F Ziegler and R L Crowder, Appl Phys Lett 20, 178 (1972).