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PET COMPUTER PROGRAMS FOR USE WITH THE 88-INCH CYCLOTRON

R.A. Gough and L. Chlosta

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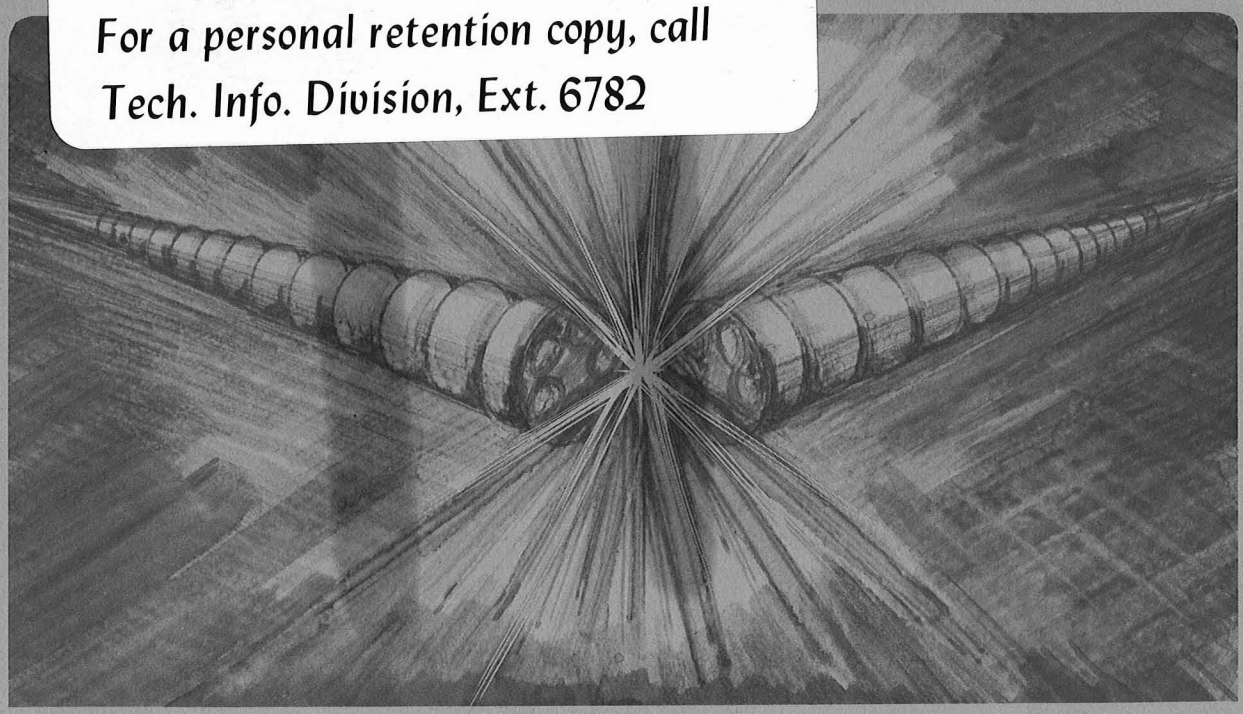

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PET Computer Programs for Use with the 88-Inch Cyclotron[1]

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PET COMPUTER PROGRAMS FOR USE WITH THE 88-INCH CYCLOTRON

ABSTRACT

This report describes in detail several offline programs written for the PET computer which provide an efficient data management system to assist with the operation of the 88-Inch Cyclotron. This function includes the capability to predict settings for all cyclotron and beam line parameters for all beams within the present operating domain of the facility. The establishment of a data base for operational records is also described from which various aspects of the operating history can be projected.

1. Introduction

Prior to 1969, the 88-Inch Cyclotron was used to accelerate beams of light ions with mass number $A \leqslant 4$. In the early 1970's, the demand for heavy ions grew, and by 1975 approximately 70 percent of all cyclotron operation has been devoted to the production of heavy ions. This trend is clearly seen in Fig. 1. The growing demand for heavier ions has generated improvements in the 88-Inch Cyclotron which have enhanced its versatility and productivity. However, it has also posed a considerable challenge to provide a rapid and accurate system of information storage and retrieval. The need to solve this problem has been heightened by the increasing number of non-resident scientists in the experimental program. This has resulted in a larger number of cyclotron users who were less familiar with the facility than the in-house groups. At present approximately 50 percent of the users do not keep an office at the cyclotron; 40 percent of these are from outside the Berkeley/LBL scientific community.

A variable energy cyclotron for light ions ($A \leqslant 4$) must provide a continuously variable range of energies for four particles: p,d, ^{3}He and ^{4}He. In contrast, the acceleration of heavy ions in the mass range $4 < A \leqslant 40$ can provide a continuously variable range of energies for well over 300 different stable ions with charge state $Q \leqslant 8$. For any one of these ions, and for any given final energy, approximately 50 cyclotron parameters must be specified to tune out an external beam (ref. 1) and another 11 beam line parameters must be specified in order to deliver the beam to the target. In calendar year 1979, 435 beam tune-outs were required to meet the needs of the experimental program. In calendar year 1980, this number was 409.

In response to these concerns, a series of computer programs has been written for the PET computer system in the cyclotron control room to serve as an off-line resource of information for both operations staff and for users. This combination of programs makes possible many of the routine calculations required in the day-to-day operation of the cyclotron and establishes a data base of operational records. Detailed descriptions of the programs MASTER, PRE, CYCREC and RECORDS, are given in order to provide documentation needed for use, maintenance and updating. Another series of programs STRAGGLE, SCATTER and STRIP, are used in calculations associated with the passage of beams through thin foils. They can be used to calculate the energy spread, multiple scattering, and the residual charge state distributions respectively. Their use is self-explanatory and so listings only will be provided in the appendix without further documentation.

2. Computer Hardware

Recent advances in microprocessor technology have made available several inexpensive small computers which are well suited to particle accelerator applications. The PET system at the 88-Inch Cyclotron, shown in Fig 2, cost less than $2500 (U.S. 1979). (This price includes interface to the existing Silent 700 ASR printer, but

not the printer itself.) It is programmed in BASIC. The PET model 2001 was purchased with 8K bytes of 8 bit RAM and 14K of ROM in which resides the BASIC operating system. An additional 24K of external memory is interfaced through an S100 bus (BETSI board) to the external memory port of the PET. An IEEE/488-RS232 link permits access to the TI Silent 700 ASR printer. The CBM 2040 dual floppy disk drive was added to the system later and has now become indispensible. The audio cassette drive can still be used to load programs from audio cassettes, but it is very slow. An auxiliary keyboard was added and operates in parallel with the main keyboard. One of the best additions to the PET system is the "Operators Tool Kit" which substantially increases the power of the PET editor and simplifies the writing and debugging of programs.

A limitation of this system is the present lack of information-transfer from the printer back to the PET; consequently when the printer is executing a carriage return the PET continues to transmit information over the RS232 link, so that the first few characters of the next line are often not printed. There are solutions to this difficulty when printing under program control, but they use up valuable memory. To produce a program listing, a good print-out can be obtained only by first transferring the program listing to the Silent 700 digital cassette and subsequently generating a hard copy on the internal readout mode of the printer. However, this is both inelegant and time-consuming. In two years of 24 hour, 7 day a week operation of the system (one year for the disk) there have been five failures, two of which crippled the entire system.

The cost of computational speed, memory, and the reliability and serviceability of computer hardware is improving all the time. The hardware described above is not optimal, but it shows the potential for inexpensive microprocessor-based systems in accelerator work. In the near future it may be advisable to transfer these programs to another computer such as the TM 990.

It should be noted that the programs discussed in this paper could equally well have been written on a midrange computer such as the Mod Comp IV 25. Our experience shows that for this approach to be attractive, the computer must be available and accessible at any time of day or night from a terminal located in the cyclotron control room. This capability does not presently exist at the 88-Inch Cyclotron.

3. Program MASTER

3.1 General Description

The object in writing the program MASTER was to provide simple and immediate access to necessary information about cyclotron settings, beams, and beam lines for both users and operators of the 88-Inch Cyclotron. This need has become more acute with the development of so many heavy ion beams and an expanding body of new users, many of whom are from outside LBL, and are less familiar with the cyclotron.

A prevailing philosophy in writing the program has been to make it possible for virtually anyone to use it with little or no instruction. Consequently, an interactive question and answer menu format has been adopted which guides the program user through the information required to perform the necessary calculations. There are several general features which have been incorporated into MASTER to simplify its use. In general input information is obtained by presenting a list of choices on the screen that requires the user merely to type in the number of his choice. Where possible the program will suggest the most reasonable choice.(eg. the lowest possible charge state or harmonic number). It is possible to override these suggestions, but the program will reject improper entries (e.g. Q > Z). Once a beam has been specified, the information is retained until the user requests that it be changed; thus, several calculations can performed without re-entering beam information. A final noteworthy feature is that the program automatically checks for disk errors each time information is read from the disk. So far, disk errors have been an infrequent occurrence.

There are currently six basic options from which users of the program may choose. They are displayed on the PET screen as follows:

TYPE NUMBER OF DESIRED PROGRAM

1. BRHO	2. FREQUENCY
3. PRE RUN	4. ENERGY
5. RESONANCE TABLE	6. CYCLOTRON SETTINGS

The calculations which are performed in each of these six parts of the program are all based upon the mass table which is shown in Table 1. This table includes the atomic masses of all stable isotopes from atomic number Z = 1 to 18. Certain long-lived isotopes (e.g. ^{14}C, ^{10}Be, and ^{36}Cl) are also included since they have been used to produce beams of interest in radioisotope dating (ref. 2). The mass of ^{40}Ca is also included in the table as are the molecular ions H_2, H_3, D_2, D_3, DH, DH_2, and D_2H. Finally, since krypton gas is sometimes used to support the arc of the ion source, and since it could be inadvertently accelerated under certain cyclotron conditions, the stable isotopes of krypton (A = 78, 80, 82, 83, 84, and 86) are included so that this information is available for calculation of cyclotron resonant frequencies. If the desired beam is not on the list shown in Table 1, the user may select number 44 ("other") to specify any beam and mass he wishes (see line 1810 of MASTER).

When the operation of the cyclotron was extended to higher main magnet fields (from K = 140 to K = 160) the earlier version of MASTER, called MSTR, required considerable expansion. MSTR is small enough to fit in the 32K PET memory and can be used without the disk. To accomodate the expansion to high K it was decided to split the program into two parts and to use the disk to overlay them. The two parts are known as MASTER and PRE. PRE is not a program in its own right, but rather a subprogram which is stored on the disk, and can be accessed only through MASTER. The calculations for options

1-5 above are performed by PRE; the calculations for option 6 (CYC. SETTINGS) are done by MASTER. When PRE is called into PET memory by MASTER, or vice versa, string variables are not retained and must be re-read. The values of the other variables are preserved. The variable TC is set equal to one to indicate that MASTER has been re-accessed from PRE (otherwise TC = 0). The programs operate in a continuous loop.

Listings of MASTER and of PRE are given in appendix A1 and A2 in this report along with an alphabetized explanation of the symbols used in the program.

3.2 Calculation of BRHO, FREQUENCY, and Beam ENERGY

The magnetic rigidity (BRHO), the frequency of the cyclotron RF system, and the beam energy are calculated when the user selects options 1, 2, and 4 respectively. The magnetic rigidity is a quantity associated with the mass (mc^2), kinetic energy (E), and charge state (Q) of a given beam which characterizes its rigidity when passing through a magnetic field. It can be shown that these quantities are related by the relativistic expression

$$\text{(1)} \qquad BRHO = \frac{1.3132653(E^2 + 2mc^2\ E)^{1/2}}{Q} \quad \text{kG-inch}$$

where mc^2, the ionic rest mass, is given by

$$mc^2 = 931.478 \times A - 0.51106 \times Q \quad \text{MeV}$$

In this expression, A is the atomic rest mass in amu, and E is given in MeV.

The frequency of the cyclotron RF system is given by

$$\text{(2)} \qquad F = 48.6160 \times H\ [1 - (1 + E/mc^2)^{-2}]^{1/2} \ \text{MHz}$$

where the harmonic number H is the ratio

$$\text{(3)} \qquad H = \frac{\text{frequency of the cyclotron RF system}}{\text{frequency of orbiting particle}}$$

The value for the proportionality constant in Eq. (2) (known locally as Cox's constant) was determined at the 88-Inch Cyclotron by experimental measurement (ref. 3). If the calculated frequency is > 16 MHz or < 5.6 MHz a warning message is issued that the calculated frequency is close to the limits of the RF system.

The beam energy is calculated in PRE in one of three ways: from BRHO, from the frequency of the cyclotron RF system, or from the magnetic energy analysis system provided in magnet M41 (ref. 4). To calculate the energy from BRHO or from the cyclotron frequency F it is necessary to rearrange Eqs. (1) and (2) above. Solving for E in MeV, we obtain

(4) $$E = [(mc)^2 + (Q \times BRHO/1.3132653)^2]^{1/2} - mc^2$$

(5) $$E = mc^2 [(1 - F/48.6160H)^{-1/2} - 1]$$

These calculations are performed in the program PRE on lines 4320 and 4200 respectively. It is often useful to calculate E from BRHO via Eq. (4) and then F via Eq. (2) to find the energy and frequency of a beam which has the same BRHO and a similar charge-to-mass ratio Q/A as another beam. This can be helpful since the tuning of both the cyclotron and the beam line for two such beams is virtually identical. The third method for calculating the kinetic energy of the beam requires the program user to input the resonant frequency in MHz of the M41 NMR probe. The magnetic rigidity of the beam is directly proportional to this frequency. The constant of proportionality can be measured using the $^{12}C(p,p)^{12}C$ resonance at 14.23 MeV (ref. 5) Using the most recent measurement of this constant (ref. 6), we have

(6) $$BRHO = 18.779756 \times \text{NMR frequency}.$$

Eq. (4) is then used to calculate the energy of the beam from BRHO.

The M41 magnetic analysis system is the most accurate and precise method available for energy measurements of 88-Inch Cyclotron beams. It is notable however, that the agreement between the nominal beam energies, as determined from the cyclotron frequency via Eq. (2) and the measured energies via Eqs. (6) and (4) is quite good. This agreement is generally a few parts in 10^3 except when the cyclotron is operating at high main magnet fields for $K \gtrsim 140$. For high field operation, the measured energy is typically lower than the nominal energy by about one percent.

3.3 Resonance Table

Another interesting facet of heavy ion cyclotron operation is that there are several ion species having nearly identical resonant conditions (e.g. $^{12}C^{3+}$, $^{16}O^{4+}$, $^{20}Ne^{5+}$), which can lead to the possibility of accelerating the wrong beam. This same situation is true for light ion operation, but only for deuterons, alphas, and molecular hydrogen; and the separation in frequency for these beams is typically more than 10 times the separation of the heavy ion resonances. It is sometimes advantageous to exploit this phenomenon. For example, it is possible to simplify the tuning of a weak beam such as $^{40}Ar^{8+}$ using $^{20}Ne^{4+}$ as an analog beam which can be produced with higher intensities by a PIG source. This is an established technique commonly used at many heavy ion cyclotron laboratories.

The frequency difference of two closely separated resonances on the same harmonic H can be calculated from:

$$(7) \quad \frac{\Delta F}{F} \equiv \frac{F_1 - F_0}{F_0} = \frac{(Q/A)_1 - (Q/A)_0}{(Q/A)_0} \equiv \frac{\Delta(Q/A)}{(Q/A)}$$

Equation (7) is obtained from differentiation of the cyclotron equation

$$(8) \quad F = \frac{HQB}{A}$$

with harmonic (H) and main magnet field (B) both held constant. Because of the large number of beams and energies run at the 88-Inch Cyclotron, Eq. (7), which requires look-up of the precise atomic masses, is quite laborious to use, and the possibility of neglecting to consider all possible ions which can have a value of $(HQ/A)_1 \cong (HQ/A)_0$ or of making calculational errors is increased when calculations are performed by hand.

Because a complete table of masses for all cyclotron beams is stored in the PET computer, it was a simple matter to provide the necessary code to search for all resonances having the same BRHO within a prescribed range of HQ/A. The computer will print a list of all such resonances in a resonance table. An example is given in Table 2 for a requested beam of 140 MeV $^{16}O^{4+}$. The beams considered by the search routine for inclusion in the resonance table must have $H \leqslant 3$, $Q \leqslant 10$, and $\Delta F \leqslant 50 kH_z$ for heavy or $\leqslant 100$ kHz for light ions. The values for DELTA F are given in Table 2 relative to the frequency of the requested beam (140 MeV $^{16}O^{4+}$ in this example). These values should be compared with the calculated resonance width printed at the top of the table to determine if two resonances can be resolved. The actual resonance width will depend on cyclotron tuning and, in particular, on the dee voltage, but it is possible to estimate resonance widths and determine how to scale them as follows. If the phase error $\Delta \sin \phi$ between the internally circulating beam and the cyclotron RF exceeds ± 1, then the beam will be out of phase and will not accelerate. So we may set

$$\Delta \sin \phi = \pi \, HN_T \, \frac{\Delta F}{F} = 1$$

to obtain the full width at half maximum (FWHM) of the internal beam where the number of turns $N_T = E/2QV_D$ and V_D is the dee voltage expressed in MV. The FWHM can therefore be expressed as

$$FWHM \;\alpha\; \frac{FQV_0}{HE}$$

This proportionality is found to hold approximately for external beams also, and comparison with experimental widths shows that at typical dee voltages of $V_D \sim 70KV$ a reasonable estimate of resonance widths is given by the relation

$$FWHM = \frac{14.3 \times FQ}{HE} \quad kHz$$

with F in MHz and E in MeV. This is calculated on line 3410 of PRE. It should be noted that a dee voltage of 70 kV is assumed by the program; proportionally narrower widths would be expected if lower dee voltages are used.

From the resonance table both the operator and the user can obtain valuable information which allows them to avoid unwanted beams or receive suggestions for tune up beams. Often the experimenter will use a tune up beam for calibration purposes. There is also a provision in the program for keying the resonance table to the precise cyclotron operating frequency so that a search for other resonances can be based on the exact values listed in the frequency column.

Obviously some discretion is required in using the information in the table. For example, referring to Table 2 in tuning up a 140 MeV $^{16}O^{4+}$ beam, little time should be wasted worrying about mistakenly tuning out a beam of $^{36}Ar^{9+}$. On the other hand, an operator tuning out $^{40}Ar^{10+}$ should be aware that there will be a substantial contamination of $^{36}Ar^{9+}$ (ref. 7) even though natural argon is used as a gas in the PIG source.

3.4 Beam Line Settings

In general, the required magnet currents for any given beam line are first calculated by a beam transport code (ref. 8) and then fine tuned by the experimenter until an acceptable beam spot is produced on the target. The fine tuning is necessary to optimize beam quality and to maximize the transmission from the first external beam stop to the target. Once this procedure has been completed for any given beam, the magnet currents required for any other beam can be easily scaled. In order to establish a data base for performing this scaling in the PET, it was first necessary to research a carefully tuned set of magnet currents that produced the best beam characteristics for each of the 19 sets of cave optics. These settings were scaled to equivalent values for a 104 MeV $^{16}O^{4+}$ beam which are shown in Table 3. The magnets numbered 1, 2, and 3 in the table are permanently assigned to the staging line quadrupole doublet elements QS1A and QS1B and to the main switching magnet MS respectively. The magnets numbered 10 and 11 are used exclusively by the program for the energy analyzing magnets M41/42 and for the high resolution area switching magnet M43. The remaining magnets numbered 4 through 9 are assigned according to the optics set listed in the column at the left of Table 3. All of the parameters in the table refer to magnet settings for 104 MeV $^{16}O^{4+}$. These parameters all represent magnet currents in amperes except for the parameters in magnet number 3, the main switching magnet, which are magnetic field values in kG (for reasons explained later below). The settings in Table 3 are loaded into a matrix IR (T,R) beginning at line 320 of PRE. With three exceptions discussed below, the current $CUR_{T,R}$, for optics set T and magnet R is then scaled according to the relation

$$(9)\ CUR_{T,R} = \frac{BRHO\ (\text{requested beam})}{BRHO\ (104\ MeV\ ^{16}O^{4+})} \times IR_{T,R}$$

The program as listed in Appendix A2 needs to be updated for two optics sets: cave 3B (biomed) and cave 4B (high resolution). This updating is accomplished by replacing the 104 MeV $^{16}O^{4+}$ parameters now in the IR matrix with a new set in lines 400 and 430 of PRE.

Due to saturation effects, two beam line magnets sometimes operate at sufficiently high fields to exhibit a non-linear field response to the applied current. These are the main switching magnet MS and the cave 0 bending magnet MB. For this reason the parameters to be scaled according to Eq. (9) for MS are the magnetic field values which are listed for each cave in Table 3. Converting magnetic fields to applied currents is accomplished empirically by fitting a polynomial function to the measured field vs current response curve. Details of this polynomial fit are given in Appendix A3. Below 10 KG (125 Amps) the response curve of the cave 0 bending magnet MB is approximately linear and applied currents can be scaled directly using Eq. (9). Beams delivered to cave 0 have a bending radius of 45 inches (1.143 m). The required fields in excess of 10 kG are calculated directly from BRHO (B_{MB} = BRHO/45) and subsequently converted to an applied current by a fourth order polynomial fit. As described in Appendix A3, this fit was made using experimental data from several beams requiring >125 Amps for delivery to cave 0. Use of the previously measured (ref. 9) field map instead of experimental data led to predicted magnet currents which, at the highest field settings are ~ 6 percent lower than experimentally observed values.

The third magnet for which the scaling law of Eq. (9) does not apply is the spin precession magnet in beamline 5A. In this case the required current is inversely proportional to the transit time through the magnet. The current is scaled in line 4390 of PRE according to the relation CUR = β x IR(16,7) / 0.11754912. The value of $\beta = v/c$ is determined via the relation $\beta = (\gamma^2-1)^{1/2}/\gamma$ where γ is the ratio of the total relativistic energy divided by the rest mass energy. The numerical constant in the denominator of the above expression is the value of β for 104 MeV $^{16}O^{4+}$.

The scaling of beam line parameters described above is performed when the PRE RUN option is selected. This option prints out a formatted pre-run preparation sheet which the cyclotron user is required to submit to the operations group 24 hours prior to their sceduled beam time. A variety of other information routinely required in setting up that run is also printed on this sheet both to serve as a check list and to provide a final communication between experimenter and the operations group. A resonance table also appears on the printout so that all concerned can reflect on problems or opportunities associated with nearby resonances (see section 3.3).

3.5 Cyclotron Settings

The objective in writing this part of the program MASTER was to produce a printout sheet for the operator with a reliable set of all the parameters required to tune out <u>any</u> beam that can be run at the 88-Inch Cyclotron. The intention here is not to predict the

fully optimized settings which result when a beam has been extensively run and developed. Fine tuning of certain parameters by the operators is expected. Rather, the settings provided by the program are intended to permit the operator to quickly establish approximate tuning of the cyclotron. It has been noted that final tuned values of all parameters including valley coils and voltages on the dee and deflectors are usually not very different from the predicted ones. Experience indicates that the initial objective has been satisfactorily achieved.

Several methods are employed to predict approximately 50 parameters that are required to tune the cyclotron. These methods include direct and precise calculations, as in the case of the frequency; using scaling laws as in the case of deflector voltages; and experience of many years of operation upon which we rely for the valley coil settings. The derivation of scaling laws and the systematic approach used in this section are discussed in detail in ref. 1. Table 4 shows a sample printout of cyclotron parameters for a 140 MeV $^{16}O^{4+}$ beam. The rest of this section describes in detail how the program MASTER determines the value for each parameter in order of appearance on the printout sheet.

3.51 Frequency

The frequency of the cyclotron RF system required for any particle and energy is calculated as discussed in section 3.2 using Eq. (2). As a further aid to the operator, the position of the RF panels required to establish a resonant condition is also given. The associated D.V.M. reading is determined empirically by a polynomial function of frequency, and the coefficients of this function are given in Appendix A3.

3.52 Dee Voltage

It is a prevailing philosophy at the 88-Inch Cyclotron to operate for heavy ions near the 75 kV upper operating limit of dee voltage in order to reduce the charge exchange losses during acceleration. Thus, in the majority of cases, a dee voltage of 70 kV is normally recommended (allowing for 5 kV of tuning). However there are certain beams, characterized by a low number of turns N_T, for which this dee voltage will create orbit centering problems. If we assume that acceleration always occurs at peak dee voltage we arrive at a simple expression for the turn number:

$$N_T = E/2QV_D, \tag{10}$$

where V_D is the dee voltage expressed in MV. If a dee voltage $V_D = 0.07$ (70 kV) leads to a value of $N_T<50$, the PET is programmed to reduce V_D to keep a constant turn pattern with $N_T = 50$. Such beams have a value for $E/Q \leqslant 7$ and since $E = KQ^2/A$ it is clear that they must also have a low value of KQ/A. Beams with a low value for Q/A can generally be produced in a PIG source with very high intensities, and therefore, charge exchange losses associated with the reduced dee voltage are not a problem. The choice of limiting turn number $N_T = 50$ is somewhat arbitrary but it is consistent with our experience with the limits

of the center region parameters and valley coils for orbit centering. An absolute lower limit of V_D = 20 kV is placed on dee voltages recommended by the PET. This is also somewhat arbitrary, and there has been little experience with such beams since they require $E/Q \leqslant 2$ (from Eq. 10). Figure 3 is a graphic representation of the dee voltages recommended by the PET.

3.53 Main Magnet

It is difficult to give an accurate prediction of the main magnet setting since the azimuthally averaged field experienced by the particle as a function of radius $\overline{B}(R)$ is determined by contributions of the main magnet as well as the 17 trim coils. A detailed calculation of these contributions is beyond the scope of the program MASTER and the capabilities of the computer, but a less sophisticated, empirical approach has proven satisfactory.

The program MASTER uses the correlation between the main magnet current (I_{MM}) and magnetic rigidity (BRHO) of the beam. Input data from approximately 35 beams were used with I_{MM} ranging from 322-2560 Amps to fit a seventh order polynomial. The magnetic rigidities for these beams were calculated from the run values of the cyclotron frequency using Eqs. (5) and (1). The data point (I_{MM}, BRHO) = (0,0) was also included in the fit. The field contribution per ampere of trim coil 17 current for beams of high BRHO, where trim coil 17 is typically used, is known both from calculation (ref. 10) and experiment (ref. 7) to be approximately 5 percent of the field contribution per ampere of current in the main magnet. Thus the expression used to calculate I_{MM}, the main magnet current, is of the form

$$(11) \qquad I_{MM} = \sum_{n=0}^{7} a_n(\mathrm{BRHO})^n - 0.05 \times I(\mathrm{T.C.}\ 17)$$

The coefficients a_n in the polynomial expansion are given in Appendix A3. Generally, the error in the predicted main magnet current settings is several parts in 10^3, but there are a small number of cases where the error is as high as 1.3 percent. The scatter associated with this error current is shown in Fig. 4. The program prints out the calculated main magnet current, and also recommends a range of currents ($\pm\ \Delta\ I_{MM}$) over which a search should be conducted to find a given resonance. This range is calculated by the formula

$$(12) \quad \Delta I_{MM} = \frac{I_{MM}}{100} + 5 \text{ Amps}$$

The recommended search zone is indicated on Fig. 4 as the area between the oblique lines.

At present, calculated magnet settings beyond about 2600 Amps should be regarded as suspect since they are calculated by extrapolation. As more data are available with high K operation of the cyclotron ($140 < K \leqslant 160$) a new set of fitting coefficients a_n

should be calculated which incorporates the new experimental data or new data from CYDE (ref. 10).

3.54 Trim Coil Settings

The most difficult part of choosing a set of cyclotron parameters is providing the operators with an appropriate set of 17 trim coil currents for any requested beam. As stated earlier, predicting trim coil currents from detailed field maps as is now done by the CYDE program on the CDC 6600 is beyond the capabilities of the PET computer. The approach adopted is to provide the PET with a data base of a finite number of sets of trim coil currents which can be used for the production of any beam which can be run at the 88-Inch Cyclotron, and then to program search algorithms into the PET so that the correct set can be selected for any requested beam. The procedures for establishing this data base are described in ref. 1, but further details are given in this section which are essential to understanding the MASTER program.

As explained in ref. 1 we can take advantage of the fact that a trim coil solution optimized for a particular beam will be satisfactory for another beam provided that the energy and the charge-to-mass ratios (E/A and Q/A) of the two beams are similar. For example, a beam of $^{10}B^{3+}$ with E/A = 6.4 MeV/amu and Q/A = 0.3 can be run from a trim coil solution calculated for a beam of $^{14}N^{4+}$ with E/A = 6.07 MeV/amu and Q/A = 0.286. Nevertheless, approximately 400 trim coil solutions are required to ensure that the correct radial field profile can be created for any beam within the operating domain of the cyclotron. The number of trim coil solutions can be kept to around 400 only by careful considerations which are most easily explained in terms of the resonance chart in Fig. 5. This is a log-log plot of particle frequency versus magnetic field. Beams with the same Q/A fall on straight lines of unit slope. This can be seen by taking the logarithm of cyclotron Eq. (8) which gives log B = log F_p - log Q/A where the particle frequency $F_p = F_{RF}/H$. A scale of E/A is provided at the top of the figure ($E/A \propto F_p^2$). Note that the position of each of the points on the chart can be uniquely determined by specifying both the energy per nucleon (E/A) and the charge-to-mass ratio (Q/A). A trim coil solution, calculated by CYDE, is required for each of these points. The spacing of the points, both in energy and charge-to-mass ratio, reflects the range of E/A and Q/A which can be run using the trim coil solution calcluated for each point.

3.541 Spacing Between Lines of Constant Q/A

We now focus on the limits to which a given trim coil solution can be "stretched." For beams with $Q/A \leq 0.5$, it is necessary to consider the spacing of the lines in Fig. 5 which have constant Q/A. The limits to which a trim coil solution can be stretched at constant main field is determined by relativistic requirements on the azimuthally averaged radial field profile $\overline{B}(R)/B(0)$. It can be shown (ref. 11) that for a trim coil solution calculated for ion (a) with $(Q/A)_a = \epsilon_a$ to be used for another ion (b) with $(Q/A)_b = \epsilon_b$ at the same cyclotron constant K (i.e. main magnet setting), the following inequality must hold:

$$(13) \quad \left| \frac{250H}{931V_D} K^2 \varepsilon_b (\varepsilon_b^2 - \varepsilon_a^2) \right| \leqslant 1$$

where the dee voltage V_D is now expressed in kV. This expression is the result of placing limits on the allowed phase slip of $\pm 30^o$. The K^2- dependence of this expression implies that the spacing between lines of consant Q/A must be closer at high main magnet fields. This is illustrated in Fig. 6A where values of ε_b are plotted as a function of K for two values of ε_a: $\varepsilon_a(1)$ = 0.43750 and $\varepsilon_a(2)$ = 0.41666. In this example, the line segment labelled $\varepsilon_b(1)$ represents the maximum Q/A to which trim coil solutions with Q/A = $\varepsilon_a(1)$ can be stretched. Similarly, the line segment $\varepsilon_b(2)$ represents the minimum Q/A to which trim coil solutions with Q/A = $\varepsilon_a(2)$ can be stretched. The shaded region above K ~ 147 represents values of Q/A which cannot be accessed from solutions on either $\varepsilon_a(1)$ or $\varepsilon_a(2)$. Thus, when the grid was expanded to include beams with K as high as 160 another series of points was added to Fig. 5 on the line with Q/A = 0.429.

The portion of the grid with 0.455 < Q/A < 0.5 has not been developed, since beams with this range of charge-to-mass ratios are not available with present PIG sources. With advanced ion sources such as EBIS (ref. 12,13) or ECR (ref. 13) sources, it will be necessary to expand the present grid further. Three lines of Q/A = 0.462, 0.467, and 0.471 are indicated as possible ions for the expansion. The size of the gap in the present grid is indicated by the cross-hatched region in Fig 6B. Several additional ions will be required to completely cover this gap.

3.542 Index Numbers

The numbers enclosed by boxes on Figs. 5 and 6 form part of an indexing system for the grid points on Fig. 5. These numbers identify each of the 27 lines of constant Q/A. For example, the recently added series of points on line 85 correspond to $^7Li^{3+}$ beams with Q/A = 0.429. These line numbers start at 10 for protons and end with line 200 for $^{16}O^{2+}$. The numbers increase monotonically with decreasing Q/A; however, the lines are not numbered consecutively in order to allow for other ions (with different Q/A) to be added to the grid at some future time. (For example, several lines will be needed between lines 30 and 40). To completely specify the index number of any point on Fig. 5, it is necessary to associate with the line number another number which describes a specific point on that line. To illustrate how this is done, consider, for example, the index number 10.09. This indicates a beam on line 10 (protons) which is the 9th beam on the line counting from the low energy end. Thus 10.09 is the index number for 30 MeV protons. This can be seen by referring to Fig. 5 or to Appendix A4c. The rationale for providing this compound indexing scheme is to retain the same index number associated with a particular trim coil solution even when new points are added to the grid. Thus, the index number 160.11 associated with 140 MeV $^{16}O^{4+}$ remained unchanged when the grid was expanded for beams

with K > 140, despite the addition of about 130 high K trim coil solutions. A complete tabulation of all the points on the grid system is given in Appendix A4c. Note that the solution number listed in Appendix A4c is a simple running index and is not permanently associated with a particular trim coil solution if new beams are added to the grid.

3.543 Energy Spacing of Points with Fixed Q/A

Stretching a trim coil solution with fixed Q/A to change the energy of an ion involves a change in the main magnet field. Thus in addition to the changing relativistic requirements on the radial field profile $\overline{B}(R)/B(0)$ we also introduce changes in this radial profile inadvertantly due to the radial dependence of saturation in the main field. For energies $E/A \gtrsim 10$ MeV/amu relativistic effects dominate. The limits of stretching imposed by purely relativistic considerations are calculable (ref. 11). In order for a trim coil solution calculated for a beam with energy E_0 to be used for the same ion with final energy E_1, the following inequality must hold

$$(14) \quad \left| \frac{250\ HE_1}{931\ AQV_D} \left[E_1 - E_o\ (E_o/E_1)^{1/2}\right] \right| < 1$$

where again V_D is the dee voltage expressed in kV. This formula is obtained by placing limits on the allowed phase slip of $\pm 30^o$ and is valid only when saturation effects can be ignored. Figure 7 shows the fractional energy stretching $(E_1 - E_o)/E_o$ predicted by the expression 14 as a function of E/A for protons, helium-3 and alphas/deuterons.

For most beams, however, energy stretching limits at constant Q/A must take into account the effects of saturation on the radial field profile $\overline{B}(R)/B(0)$. To estimate these effects, a series of CYDE calculations were run (ref. 11) at several values of K and E/A. The results of these calculations are summarized in Figs. 8A and 8B for H=1 and H=3 beams respectively. Considerable license is taken in producing the curves. For example, the interpolations necessarily ignore possible irregularities peculiar to individual trim coil solutions. Accordingly the spacing of grid points on each part of the grid is conservatively chosen using the curves in Figs. 7 and 8 only as a guideline. As indicated in Appendix A4c, each grid point has associated with it a number (DEA) = $(E_1-E_0)/E_0$ which gives the range of energies spanned by that trim coil solution. In over four years of cyclotron operation, this system of stretching trim coil solutions has proven very successful and reliable. It is useful to remember that small changes in magnetic field can be effected using trim coil 17 without disturbing the radial field profile established by the main magnet and other 16 trim coils. It is sometimes necessary to utilize trim coil 17 in this way in order to successfully employ a trim coil solution recommended by the PET.

3.544 Phase Slip Compensation-"Preferred Stretches"

Because of magnet saturation in the 88-Inch main magnet a small increase in the main field leads to a lowering of the $\overline{B}(R)/B(0)$ curve with R as indicated schematically by the dashed curve in Fig. 9, there is a resulting slip in phase between the frequency of the particle and the frequency of the cyclotron RF system. The field profile indicated by the dashed line in Fig. 9 is better matched to the isochronous requirements of a particle with slightly lower energy/amu, i.e. a particle having a reduced relativistic mass increase. Thus there are preferred directions for stretching a trim coil solution where some degree of phase slip compensation takes place. It is of interest to characterize these preferred directions both qualitatively and quantitatively.

To develop a qualitative insight into these preferred directions for stretching trim coil solutions, we can imagine that around each point in Fig. 5 we draw a zone of beams which can be run from the trim coil solution associated with that point. Since there are preferred directions, each zone can be approximated by an ellipse with the major axis making an angle ϕ with the horizontal. It can be shown that this angle is given by

$$\begin{aligned} \sin\phi &= s\,(2s^2 + t^2 - 2st)^{-1/2} \\ \text{(15)}\quad \text{where } s &= \log\,[1 - (E_1 - E_0)/2E_0]^{-1} \\ \text{and } t &= \log\,[1 - (\varepsilon_a - \varepsilon_b)/\varepsilon_a]^{-1} \end{aligned}$$

A simplified resonance chart is shown in Fig. 10 which indicates the directions of preferred stretching as determined from Eq. (15). At high fields, these preferred directions approach stretching at constant field because saturation effects completely dominate relativistic effects.

3.545 Figures of Merit

While the above considerations helped to provide physical insight, it became necessary to develop a more quantitative picture so MASTER could meet the needs of day to day operations. To do this, figures of merit F_S and F_R were established in the following way. First we note from Fig. 11 that a stretch from a grid point (.) to the requested beam (x) is equivalent to stretching along the line F_1 at constant B, followed by a stretch F_2 at constant Q/A. We then calculate F_1, which is the fraction of maximum stretch ε_b. F_1 is taken as positive in the direction of increasing Q/A. Then we calculate F_2 which is the fraction of maximum stretch E_1 along a line of constant Q/A. F_2 is taken as positive in the direction of increasing E/A. E_1 is determined from considerations described in section 3.542. That is, from the value of DEA = $(E_1 - E_0)/E_0$ stored for each grid point (see Appendix A4c) we obtain

$$E_1 = E_0\ (\ \mathrm{DEA} + 1).$$

To obtain the limiting value of ε_b (when stretching at constant magnetic field) the left side of the inequality expressed in relation (13) is set equal to 1. We then obtain the cubic equation:

$$\varepsilon_b^3 - \varepsilon_a^2 \varepsilon_b - \frac{931V_D}{250HK^2} = 0.$$

This equation is solved for ε_b using Cardan's formulae (ref. 14) with care taken to correctly eliminate extraneous roots having no physical significance. From the limiting values E_1 and ε_b, the fractions F_1 and F_2 are calculated

$$F_1 = \frac{(Q/A)_a - (Q/A)_x}{\varepsilon_a - \varepsilon_b}$$

$$F_2 = \frac{(E/A)_x \, (Q/A)_a^2 \, (A/Q)_x^2 - (E_o/A)_a}{(E_1/A)_a - (E_o/A)_a}$$

The quantities F_S and F_R are now calculated from Eq. (16)

$$(16) \qquad F_S = F_1 + F_2$$

$$F_R = (F_1^2 + F_2^2)^{1/2}$$

If a given stretch is exactly in a preferred direction, then $F_1 = -F_2$ and $F_S = 0$. If the requested beam is identical to the beam for which a grid point trim coil solution has been calculated, then $F_1 = F_2 = 0$ and $F_S = F_R = 0$ also. If $|F_S| > 1$, the trim coil solution for the grid point under consideration will not provide a field profile suitable for the requested beam. In general, the grid point with the smallest value of F_S gives the preferred trim coil solution for any given requested beam. It should be emphasized that the approximations inherent in Eqs. (13) and (14) are valid only for short stretches. The system of calculating F_S provides a quantitative figure of merit for the operator or the computer to evaluate the choice of trim coil solution.

3.546 Search Algorithm for Beams on the Grid (CS = 1)

For any requested beam, the program MASTER first determines which of three search algorithms to employ. The parameter CS is accordingly set equal to 1,2, or 3. The domain CS = 1 is for beams which lie on the grid depicted in Fig 5. The domain CS = 2 is defined as beams with $Q/A < 0.125$ for $K > 55$ and $Q/A < 0.167$ for for $K < 55$. These beams are found on the left (low energy) side of

Fig. 5 and will be discussed in the following section. The domain CS = 3 is characterized by beams of very low K and fall below the grid at the bottom of Fig. 5. Discussion of these beams follows in section 3.548.

Almost all beams of interest to the nuclear science program lie on the grid system and utilize the search algorithm associated with CS = 1. Because evaluation of the figures of merit F_S and F_R, for every point on the grid is very time consuming on the PET, the program begins by finding those "nearest-neighbor" points on the grid which bracket the requested beam. It establishes the grid line (Q/A = constant) which brackets the Q/A of the requested beam first on the left then on the right. Then it brackets the K of the requested beam by considering grid points which lie along the left and right bracketing Q/A = constant lines. In general, a requested beam is bracketed by four nearest-neighbor grid points for which figures of merit F_S and F_R are then calculated. The recommended solution is the one associated with the grid point having the smallest value of $|F_S|$ unless another point has a value of $F_R < 0.2$ (line 3310 of MASTER), in which case the recommended trim coil solution is the one associated with the smallest value of F_R. In this case the location on Fig. 5 of the requested beam is very close to a grid point and this proximity is thought to be the more reliable criterion. Once the index number of the recommended solution has been established using the data in Appendix A4c, the appropriate trim coil currents are read in from the disk (see Appendix A4d).

There are many special cases where it is not possible to find four grid points that bracket the requested beam using the above procedure. If Q/A for the requested beam equals Q/A for a grid line within ± 0.001, then a two-point bracketing procedure is adopted. If, in addition, it has a K value lower than the K of the lowest point on the line then adjacent Q/A grid lines are also considered and five bracketing points will be evaluated. Requested beams with K > 160 cannot be bracketed from above, and a special programming routine was developed to handle this case.

Figure 12 shows the results of several stretches using MASTER, which illustrate the cases cited above. Figure 12d represents an interesting case which has been the subject of further study. It has been experimentally verified that the trim coil solution calculated and optimized for a 427 MeV $^{16}O^{7+}$ beam will provide a satisfactory field shape for both 360 MeV $^{14}N^{6+}$ and 245 MeV $^{9}Be^{4+}$ beams. The phase slip compensation discussed in section 3.544 is illustrated in Fig. 13 where phase histories of several $^{9}Be^{4+}$ beams have been calculated by CYDE all using the trim coil settings for the 427 MeV $^{16}O^{7+}$ beam. From these CYDE calculations, the $^{9}Be^{4+}$ beam energy with the best phase-slip compensation is seen to be ~ 245 MeV. The PET results indicate this energy to be ~ 244 MeV in close agreement with the CYDE calculation.

3.547 Beams with Very Low Q/A (CS = 2)

It can be seen from Fig. 10 that for third harmonic beams (H = 3) with very low Q/A the preferred direction for stretching

trim coil solutions is in the direction of constant main field (i.e. constant BRHO). In fact, all H = 3 beams which lie to the left of the grid system in Fig. 5 can be run using a grid point beam with Q/A = 0.125 or 0.167. To examine these stretches in more detail, we evaluate the left hand side of the the inequality (relation 13) for the following three cases:

1. $\epsilon_a = 0.125$, K = 160, V_D = 70kV,

2. $\epsilon_a = 0.125$, K = 140, V_D = 70kV, and

3. $\epsilon_a = 0.167$, K = 55, V_D = 70kV.

The results are shown in Fig. 14. It can be seen that for no value of ϵ_b does the expression exceed unity, which implies that points on line 190 (Q/A = 0.167) for $K \leqslant 55$ and that points on line 200 (Q/A = 0.125) for $K \leqslant 160$ can be stretched to cover all H = 3 beams which lie to the left of these lines.

The trim coil solution recommended by MASTER for these low Q/A beams is the grid point on line 190 or line 200 having the closest value of BRHO to that of the requested beam. Line 190 is used for beams with $K \leqslant 55$ (BRHO $\leqslant$ 421 kG - in). MASTER will also use the same criterion in recommending beams with H > 3. While this has proven successful in isolated cases, a thorough evaluation of this recommendation has not been made. This procedure should be checked with the code CYDE. Another procedure for handling beams with H > 3 would be to calculate with CYDE a series of trim coil solutions for $^{14}N^{1+}$ beams (Q/A = 0.071). These could then be used to recommend the appropriate trim coil solution for H > 3 beams again using the "nearest-BRHO" criterion. Since demand for these beams is very low, these program improvements have had low priority and have not yet been pursued.

3.548 Beams with Very Low K (CS = 3)

Occasionally, beams are requested which lie below the grid system of Fig. 5. Associated with the lowest grid point on each Q/A line is a parameter LK which is the lowest value of K to which that trim coil solution can be stretched at fixed Q/A. The values of LK are determined from the equation

$$LK = \frac{E/A\ (1- DEA)}{(Q/A)^2}$$

where DEA = $(E_1 - E_0)/E_0$ gives the maximum allowed energy stretch at constant Q/A. (DEA values are tabulated in Appendix A4c.) The values of LK, shown in Table 5, represent the lowest values of K which can be accessed from the grid using the search algorithms described in section 3.546. If the first two search algorithms fail to produce a recommended trim coil solution, then the third search algorithm is initiated. Seven pre-selected grid points will be considered by the program. They have index numbers 10.01, 20.01, 30.01, 130.01, 160.01, 180.01, and 190.01 and are the lowest energy, lowest K points of the seven selected grid lines. The

program will choose one of these seven points having the closest E/A to that of the requested beam thus providing the closest matching of the relativistic requirements. The trim coil currents of the selected grid point are then multiplied by the ratio

$$\frac{\text{BRHO (requested beam)}}{\text{BRHO (grid point beam)}} .$$

The field profile requirements can be met by this simple scaling procedure because there is little or no radial dependence of the main field setting when operating at these low currents. Although this procedure has not been extensively evaluated, it has been demonstrated to work successfully for several beams.

3.55 Harmonic (Valley) Coil Settings

Two standard sets of valley coil settings are provided by the PET as shown in Table 6. Set 1 is recommended for ions with Q/A > 0.5 and set 2 is recommended for all heavy ion beams, deuterons and alphas.

These settings generally produce high extraction efficiency and good beam quality. Cyclotron operation with valley coil settings which significantly differ from these values can sometimes permit good extraction efficiency but often lead to poor transmission through the analyzing slit at AS41 due presumably to poor beam quality. It is generally always true that such valley coil settings can be tuned back to the values approximating those listed in Table 6 with no loss of external beam.

3.56 Center Region Parameters

There are 5 center region parameters. Two of these specify the radial (RAD) and azimuthal (AZI) location of the source relative to the magnetic center of the cyclotron. The third parameter (ROT) specifies the angle to which the source is rotated about its own axis. Parameters 4 and 5 represent two approximately orthogonal motions of the puller electrode (P N/S and P E/W). Since the east-west position of the puller is sometimes limited by voltage breakdown and since there is little interaction or coupling of this parameter to most other parameters, no attempt to predict P E/W is made by the program. Table 7 shows four sets of the remaining four center region parameters and the conditions under which each set should be used. These values are loaded into a matrix labelled CR at line 440 - 450 in MASTER.

3.57 Deflector Settings

There are 15 deflector parameters which must be specified: 12 positions and 3 voltages. In specifying the 12 deflector positions for any given beam, there are five sets from which to choose as shown in Table 8. The range of E/Q covered by each data set is also indicated. The voltages shown at the bottom of the table for each of the 5 data sets are those required to establish the voltage gradients necessary to extract a 65 MeV $^{4}He^{2+}$ beam. The voltages required for any other beam are obtained by multiplying the voltages in the table by

$$\frac{E/Q}{32.5}$$

The numbers in Table 8 are loaded into a matrix DDD in lines 460-520 of MASTER .

It should be noted that beams with E/Q > 70 (e.g. 140-160 MeV alphas) have not been extracted with the present deflector system. MASTER will nevertheless produce a scaled set of deflector voltages for position set number 5. In practice, extraction of these beams will probably not be possible until the new deflector system is installed and made operational.

4. Program RECORDS

In January 1979 a program for computer controlled storage and retrieval of the 88" Cyclotron Operations Records data on magnetic tape cassettes was implemented using a PET Computer. Data so stored pertained to beams run at the Cyclotron during two-month periods. Each record included the following 9 parameters: the date the run started, the energy, mass, ion, and charge state of the particle accelerated; the experimental area to which the beam was sent; the duration of the run (expressed in number of 8-hour operations shifts); the average beam intensity delivered on target; and the name of the experimenter. This program called RECORDS, was dimensioned to accomodate as many as 120 individual records for each reporting period.

4.1. Options

At the beginning of each period the PET is initialized with 120 blank records using dummy variables for each of the nine parameters included in every record. These initialization data are then recorded on cassette, and are reloaded into the PET prior to data entry.

After the initialized data tape has been reloaded, information is taken from the Cyclotron Operations Log and is entered into the PET, replacing the nine dummy parameters in memory. One program option permits examination of the most recent entry, while another permits correction of any record previously entered. In both cases, the records data are displayed on the PET screen, whereas a third option generates a hard-copy printout of all records entered during the current reporting period, converting the number of operating shifts to hours, and totaling them.

After the records data have been so entered, they are once again stored on tape, together with the remainder of the blank records which have not yet been updated. When more data are to be entered, the tape is once again loaded under program control, such that subsequent records entries will fall into proper chronological sequence. This provision was implemented so that the records could be maintained at random intervals during the reporting period. Thus, the operations staff can work with the program as the operating schedule permits.

At the end of the reporting period, the program can be used to generate a hard-copy printout of all beams run during the period, and the total number of operating hours. A sample printout is shown

in Table 9 for one month of operation (half of the total reporting period). In addition, a program option permits sorting the records data according to beam [energy (E), mass (A), element (Z), and charge state (Q)], particle (A, Z, and Q); isotope (A and Z); Z; cave; or experimenter. In this case the hard-copy printout includes only those records which satisfy the desired criteria. The number of operating hours involved in these runs is expressed both as a subtotal and as a percentage of the two-months total.

4.2. Search Routines

By the end of 1979, a sizeable data base had thus been created on magnetic tape, but the time and number of manual steps required to load data from cassettes prevented efficient use of these data. Upon the addition of a dual floppy disk drive to the PET system and subsequent transfer of data from cassette to diskette, it became practicable to make effective use of this data base.

The first program written using disk data access is called ANNUAL. It generated a hard-copy printout of all beams run at the 88" Cyclotron during the calendar year 1979. This proved to be more spectacular than useful, but the program was then expanded to provide an annual data sort by beam, particle, isotope, ion, cave, or experimenter such as described above. As the data base grew larger, a program was implemented which searched the data in reverse chronological order for a specific beam. An option in the program allows the result to be displayed on the PET screen, on a hard-copy printout or both, at the user's discretion.

Another use of the data base has been made by modifying the data sort program to search for and print out the subset of entries pertaining to beams which have been run using the increased field strength capability of the main magnet. Since the data base does not contain the main magnet current data, the search was done by solving for the cyclotron constant $K = AE/Q^2$ and then searching for those records where the value of K exceeded 140.

A further use of these data was to generate a list of runs by outside experimenters not associated with resident user groups. In order to accomplish this, the names of outside users have been flagged by an asterisk in the data base. When the data are printed, the asterisk is suppressed.

4.3. Calculation of Power Consumption

A considerably more ambitious program, still under development, will estimate the total power consumed during each run. It will use the information contained in the data base to calculate the power used by the main magnetic field (including trim coils and valley coils), the ion source, the RF system, and the beam line transport magnets for any given run.

The program first calculates the magnetic rigidity (BRHO) for each beam from equation (1) using approximate values for the mass. BRHO is then used to estimate the main magnet current (I_{MM}) using the expression

$$I_{MM} = \sum_{n=0}^{7} a_n \, (BRHO)^n .$$

This expression is similar to equation (11) but lacks the correction term for trim coil seventeen. Since the data base contains no information regarding trim coil currents, and since their calculation lies well beyond the scope of the program RECORDS (and indeed, beyond the capability of the PET computer), this correction is approximated in a simpler manner.

Engineering measurements were recently made on the main magnet power supply and on the main magnet booster power supply to determine the input power consumption of each supply at various current settings of the cyclotron main magnet. Two separate curves were then plotted of main magnet current vs. input power, one for beams requiring main magnet currents equal to or less than 2500 amps, the other for those beams requiring currents exceeding that value.

In order to estimate the trim coil input power consumption values, where their actual current settings were unavailable for use, the assumption was made that the trim coil values required for acceleration of various energy $^{16}O^{4+}$ beams could be considered typical. Power consumption values for the trim coils themselves were obtained from an engineering study made shortly after their construction and installation, and were scaled to the current settings used for these beams. These power values were then totalled for each of the above beams, with the sums added to the appropriate main magnet power curves. In the case of trim coil seventeen, its current contribution was de-rated by five percent when added to the greater of the two power curves, since this trim coil is generally used only for acceleration of those beams for which the cyclotron constant (K) is equal to or greater than 140 (i.e., booster on).

Two more curves were then plotted using the power value points thus obtained, and second order polynomial equations describing these curves were derived empirically using polynomial fits (see Appendix A3). The coefficients obtained are not included herein, since further studies are currently in progress in order to refine the equations, but this preliminary version is already in use to provide power cost estimates for various beams.

The ion source power supply consumption is usually one of two values, one for light ion operation (mass number A equal to or less than 4), the other for heavy ion acceleration. The same is also generally true for the harmonic (valley) coils, where the two values are determined by whether or not the charge-to-mass ratio exceeds 0.5 (e.g., protons). Since the data base contains sufficient information to calculate these values, these power consumption figures may be derived in a straightforward manner.

The portion of the program which will estimate power consumption figures for the RF system is currently being developed. This involves calculation of the RF frequency, using eq. (2), and calculation of dee voltage (see section 3.52). Curves for input power vs. frequency have been plotted for several dee voltage

values, and the final version of the program will probably involve scaling between these curves.

The third portion of the program dealing with the beam transport system will require power consumption data for the switching magnet, the bending magnet, and the M43 power supplies, as well as the power supplies used for the quadrupole magnets, and the beam analyzing magnet system. Each of the experimental areas to which beams can be delivered has its own unique set of beam transport elements, whose current requirements are generally proportional to the BRHO value of the beam. Two noteworthy exceptions are the switching magnet and the bending magnet, which operate in the saturation regions of the current/magnetic field curve. In these two cases, the field intensity requirements will be proportional to BRHO, with the currents subsequently obtained via polynominal fits to the measured I vs. B curves as discussed in section 3.4.

5. Program CYCREC

5.1. General Description

Another PET program for storing and analyzing operating records of the 88" Cyclotron was introduced in January 1980. This program, called CYCREC (for CYClotron RECords) calculates the amount of time that the operation of the Cyclotron is devoted to each of eight categories. These are Beam Development, Tuning, Optics, Beam on Target, Scheduled Maintenance, Unscheduled Maintenance, Experimenter's Problems, and Ion Source Preparation. A ninth category, Holiday/Shutdown, was added so that the total hours thus analyzed would ultimately equal the number of hours in the calendar year. To each of these categories is assigned a code number.

The concept of the program is essentially a straightforward one: each day a member of the Cyclotron operating crew loads the program into the PET, and enters data obtained from the Operations Log for the previous 24 hours, starting at midnight (0000 hours). The PET prompts the operator to enter the time, then the code number for the activity which began at that time. The program is demensioned such that as many as fifteen individual entries may be made per day, with the time of the last entry "2400" and code number "0", indicating "no further entries".

The data thus entered are then stored on cassette tape. At the end of the reporting period (also two months) the data tape is reloaded in the PET, which calculates the total number of hours devoted to each category, converts them into percentages of the total available operating time (hence excluding the "Holiday/Shutdown" category), and generates a hard-copy printout of the result.

A problem encountered in implementing this program arose from the PET's array limitation of 255 elements. In order to store two months data, an array exceeding 900 elements would be required. The technique ultimately used to circumvent this problem breaks the reporting period into blocks of six days, thus requiring a 90-element array. In practice, the total number of entries for each day is also stored on tape, requiring a 96-element array. Ideally,

all data blocks are sequentially written onto a single data tape covering the full two months.

Another problem which surfaced during the development of this program (as well as the previously described program, RECORDS) was an apparent inability of the PET to read input file data reliably from cassette tape. A short test program which read the tape data into the PET, one character at a time, showed that the data had been recorded correctly, yet tape read errors plagued both programs. The solution to this problem was found only upon receipt of a soft-ware bulletin from the manufacturer which described a subtle ommission from the PET operating system.

The cassette I/O buffer in the PET stores 192 characters, and transfers them as a single continuous serial data record, either to or from tape. When reading from tape, the cassette drive motor is energized while the record is being read, then stopped while the data are shifted into memory. However, the inertia of the cassette reel often causes the tape to advance the next file header beyond the read heads. The usual result of such a read error is termination of the program, frequently via a program crash. The omission in this case is the failure to provide an inter-record gap (IRG); the solution is to detect when 191 characters have been written into the buffer, then to turn on the cassette drive motor briefly so as to create an IRG. Use of this technique permits virtually error free data transfer to and from tape.

5.2. Options

Since the reporting period is broken into six-day blocks, the operation of the program differs considerably from that of RECORDS. Before the data tape is loaded, the operator enters the data block ID, and then selects the function to be performed from an options list. These dictate how the tape is to be used, and the PET prompts the operator accordingly.

In the case of the "Update Data" option, the program inquires if the data block has been initialized. if it has not, the user is instructed to insert an auxiliary data tape into the cassette deck so that a full block of dummy parameters may be recorded. This auxiliary tape is also used to record data which have been updated where less than six days have been entered in each block. In either case the program directs the operator to load this tape prior to any further data update. Actual data entry then proceeds as previously described. A feature of the program allows the calculation of the date for the next entry, which is displayed as a prompt.

The program option, "Examine Data", was provided so that the user could check the accuracy of the entries prior to committing them to tape. All data for the selected block are displayed on the PET screen in six vertical columns, together with the date to which the data pertain (here the dummy initialization data are suppressed). The fact that the screen is thus comfortably filled is one of the reasons that the six-by-sixteen array size was adopted. Should all six columns contain valid (as opposed to initialization) data, a program prompt advises the operator that the information should be stored on tape.

In the event that an erroneous entry is detected, either through use of the previously described option or from the operator's own knowledge, an option is included in the program which allows such entries to be corrected. The user is asked the date of the error, whereupon the program calculates the data block containing that entry. Should that be other than the block residing in PET memory (which would not be the case if the error were detected during data update, or data examination following an update), the operator is instructed to load the affected block into the PET. The data for the day in question are then displayed on the screen, whereupon data re-entry is required. If the current data block is the one thus affected, the usual methods concerning storage of data on tape are employed. Otherwise, the data block must be stored on a separate tape (e.g. the auxiliary data tape) for later retrieval.

A somewhat trivial option in the program, that of "Check Data", was included so that in the event of an interruption of the usual data entry sequence, the operator could ascertain the date of the most recent valid data update. In practice, the user terminates the current sequence by entering the time "2400" and the code "0". He then selects the "Check Data" option to determine the date of the interrupted entries. Following that, he selects the "Correct Data" option, using the date thus obtained. This option is usually exercised when the exigencies of Cyclotron Operation pre-emptorially redirect the user's efforts after the current date has scrolled off the PET screen.

At the end of the reporting period, when all data have been entered into the PET and stored on tape (usually involving more than one cassette), all data blocks can be consolidated onto one continuous tape). This program feature is the "Transfer Data" option. When this is selected, the PET instructs the operator to insert and load the tape containing the first valid data block. He is then directed to remove that tape and insert the object cassette into the tape deck, whereupon the data block is recorded. The program subsequently prompts the operator to remove the object tape without rewinding it, then to load the cassette containing the next data block. Once again, he is told to remove that cassette and to insert the object tape. Before this data block is recorded, however, the tape drive motor is energized for a half-second so as to create an "inter-block gap". That sequence is then repeated until the data for the full two months have been transferred to the object tape, which is then ready for storage.

The bimonthly report is generated immediately after the data transfer is performed. The data tape used for this program option is the object tape described above. In this manner the accuracy of the data transfer itself can be determined, and if necessary, errors may be corrected on the original data tape(s). Should this be necessary, the entire data transfer process must then be repeated so that the final object tape is free of errors.

The program option used to generate the bi-monthly report, "Analyze Data", begins by prompting the operator to insert the data tape into the cassette deck, to rewind it, and then to load the first data block. After generating an array of nine zero elements, the PET calculates the time (in minutes) devoted to the first

category entered. It does this by subtracting the first time entry from the second, and adding this quantity to the array element corresponding to the code number of the first activity entry. This process is then continued through the day's final time entry, which indicates the stop point (2400 Hours) of the next to last activity entry (the last activity entry is the code number for "no further entries"). The program then progresses to the next day covered by the first data block, summing the times thus calculated with those in the array obtained from the data for the first day. The remainder of the first data block is analyzed in this manner, and then program execution is halted to permit the operator to change cassettes, should this be necessary (this feature was retained, even though the object tape should by this time be correct. Indeed, entry errors occasionally remain undetected up to this point). Normally the operator is required to respond simply with a carriage return whereupon the cassette drive which had been halted under program control following the first data block load, resumes.

The data in the second block are then analyzed and added to the array elements obtained from the first data block; the remaining data blocks are subsequently treated in the same manner. After the tape read sequence has been completed, the array thus created consists of nine elements, each representing the two months total time devoted to the activity corresponding to its code number. At that time these totals are expressed in minutes; the program then converts them to hours, sums them, deducts the time for the ninth category ("Holiday/shutdown"), and calculates the percentage of this subtotal represented by the totals for each of the remaining categories. The program then generates a hard-copy printout of the results of these calculations. A sample printout is shown in Table 10.

5.3. Annual

Shortly after this program was implemented, a dual floppy disk drive was incorporated into the PET System. Since CYCREC, As finally adopted, was performing adequately, no plans were envisioned to utilize the disk as the primary data storage medium. Instead, an option was written into the program "Annual" so that a hard-copy printout could be generated yielding a twelve-month (six reporting periods) time summation of the nine categories, along with the percentages of the total available operating time. The data are read from the disk, thus sparing the user the time-consuming task of loading six complete object tapes. In keeping with the same philosophy, the data transferred to disk is not identical to that contained on the data tapes: at the end of each reporting period, when the object tape has been loaded into the PET and the hard-copy report generated, the information written onto the disk is simply the hourly totals for each of the nine categories. Thus, a maximum of 54 data entries are required per calendar year, as contrasted with the more than 5400 possible entries required by the tape formatting technique (that figure assumes 15 entries per day, 30 days per month, for a full year).

5.4 Development of CYCREC-2

While it is true, as stated earlier, that the current operational version of CYCREC performs "adequately", this must not be construed as being synonymous with "optimally". That the program was not changed to use disk data storage exclusively was primarily due to the authors' relative inexperience with the PET disk operating system (DOS). In particular, it was thought that the concept used to store and retrieve data in this program should remain unchanged, despite the data storage medium. Moreover, since the program RECORDS was not converted to rely on disk data storage exclusively -- indeed, such a conversion is unnecessary -- no consideration was given to the concept of re-writing the CYCREC program with such a goal in mind. After use of the current version of CYCREC for one full calendar year, all personnel involved agree that a serious effort should be made toward a change in the operation of the program. This would of course entail a revision of its basic philosophy. That such a change be suggested is not surprising: the essential nature of CYCREC is currently patterned after RECORDS, yet the only true similarity between them is the use of data storage techniques.

Therefore, a totally different program, designed to accomplish the same end, is under development. It will use the PET's disk data storage capability as a primary medium, with tape data storage as an alternate. The number of activity codes will be increased, so as to reduce the ambiguity which presently exists between some of them. The concept of a data array will be discarded, since only one day's data will be entered into the PET whereupon it will be analyzed, with simply the results of the analysis written onto the disk, together with the date. When data update is once again to be performed, the data residing on the disk will be read back into PET memory, to be summed with the results of the succeeding day's data. The date entry will be incremented, and rewritten onto the disk together with the new analysis data. In the event that the operator is interrrupted during the update procedure, the entries already made may be written directly onto the disk as a special data file, also including the date. When data entry is resumed, the disk will first be searched for such special files, and the data will be read back into the PET and displayed on the screen. The file will then be scratched from the disk immediately, while the operator is prompted to continue the update procedure.

One of the advantages inherent in this concept is that the data format on the disk will be totally compatible with that currently used in the applicable portion of the program "ANNUAL".

The major disadvantage of such a revision in the concept of the program will be that the data as entered via the PET keyboard, after having been analyzed and written onto the disk, will no longer be available for direct correction. In order to circumvent this problem, the "Examine Data" option will provide a hard-copy printout of each day's data, exactly as entered (in lieu of the six days' screen display). These printouts will be retained on file during the reporting period. Should a data entry error be detected subsequent to its having been incorporated into the data already

written onto the disk, the operator will thus still be able to apply a correction to the final summary table through application of the time-honored "Finagler's Constant" technique. (The actual methodology of such an application will be left as an exercise for the reader).

However, among the principal advantages to such a revision of the original program will be the reduction of the number of manual tape loads required, together with the attendant reduction in time consumed in merely preparing to manipulate the data. In addition, the process of updating data itself will be materially simplified by the removal of the fifteen entries-per-day restriction.

At this time, since the advantages of the planned program modification seem to overwhelmingly outweigh its disadvantages, its initial developmental steps have been undertaken, and it will hopefully be implemented early in 1981.

6. CONCLUSIONS

Before these programs could be written, a very high degree of organization was required, not only of the data but also of the decision making processes that are operative when the tasks are performed without the aid of a computer. This organization was, in itself, a very worthwhile exercise.

The primary objective in writing these programs was to provide an efficient data management system to facilitate access to information needed by those associated with the operation and use of the 88-Inch Cyclotron. The programs have received an enthusiastic level of operator acceptance and permit them to discharge their responsibilities with increased confidence and independence. Space requirements for storage of tabulated data (such as the many volumes of F-BRHO tables) have been substantially reduced.

The programs have been fully operational for over a year and seem to be performing satisfactorily. Further effort will be directed toward simplifying the use of the record keeping programs.

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Table 1:

Mass Table Used by the Program MASTER

Z	M	A	BEAM($)
1	1	1.00782522	PROTONS
1	2	2.0141022	DEUTERONS
2	3	3.0160297	HELIUM-3
2	4	4.0026033	ALPHAS
3	6	6.015123	LITHIUM-6
3	7	7.016005	LITHIUM-7
4	9	9.01218301	BERYLLIUM-9
4	10	10.0135352	BERYLLIUM-10
5	10	10.0129385	BORON-10
5	11	11.0093053	BORON-11
6	12	12	CARBON-12
6	13	13.0033551	CARBON-13
6	14	14.00324	CARBON-14
7	14	14.0030744	NITROGEN-14
7	15	15.000109	NITROGEN-15
8	16	15.994915	OXYGEN-16
8	17	16.999133	OXYGEN-17
8	18	17.99916	OXYGEN-18
9	19	18.998405	FLOURINE-19
10	20	19.9924405	NEON-20
10	21	20.993847	NEON-21
10	22	21.991385	NEON-22
11	23	22.98977	SODIUM-23
12	24	23.985044	MAGNESIUM-24
12	25	24.985839	MAGNESIUM-25
12	26	25.982594	MAGNESIUM-26
13	27	26.981541	ALUMINUM-27
14	28	27.976929	SILICON-28
14	29	28.976497	SILICON-29
14	30	29.973772	SILICON-30
15	31	30.973763	PHOSPHOROUS-31
16	32	31.972073	SULPHUR-32
16	33	32.971459	SULPHUR-33
16	34	33.96787	SULPHUR-34
16	36	35.967079	SULPHUR-36
17	35	34.9688536	CHLORINE-35
17	36	35.9683073	CHLORINE-36
17	37	36.965903	CHLORINE-37
18	36	35.967547	ARGON-36
18	38	37.962733	ARGON-38
18	40	39.962384	ARGON-40
20	40	39.962592	CALCIUM-40
1	2	2.0156504	H2
1	3	3.0234756	H3
2	4	4.0282044	D2
2	6	6.0423066	D3
3	3	3.0219274	DH
4	4	4.0297526	DH2
5	5	5.0360296	D2H
36	78	77.9204	KRYPTON-78
36	80	79.91638	KRYPTON-80
36	82	81.91348	KRYPTON-82
36	83	82.9141301	KRYPTON-83
36	84	83.911505	KRYPTON-84
36	86	85.9106161	KRYPTON-86

Table 2: Resonance Table for 140 MeV Oxygen-16 4 +
(Mass = 15.994915 AMU)
Approx Achievable Res Width = 2.7 KHZ FWHM

F		DELTA F		HARM	ENERGY		ION	CHG	ST
6.612314	MHZ	-6.289	KHZ	H = 1	35	MEV	Alphas	1	+
6.616539	MHZ	-2.065	KHZ	H = 1	105	MEV	Carbon-12	3	+
6.618603	MHZ	0	KHZ	H = 1	140	MEV	Oxygen-16	4	+
6.618994	MHZ	.391	KHZ	H = 1	175	MEV	Neon-20	5	+
6.620588	MHZ	1.985	KHZ	H = 1	210.1	MEV	Magnesium-24	6	+
6.621894	MHZ	3.291	KHZ	H = 1	245.1	MEV	Silicon-28	7	+
6.622211	MHZ	3.608	KHZ	H = 1	280.2	MEV	Sulphur-32	8	+
6.622483	MHZ	3.88	KHZ	H = 1	315.2	MEV	Sulphur-36	9	+
6.622261	MHZ	3.658	KHZ	H = 1	315.2	MEV	Chlorine-36	9	+
6.622398	MHZ	3.795	KHZ	H = 1	315.2	MEV	Argon-36	9	+
6.622652	MHZ	4.048	KHZ	H = 1	350.2	MEV	Argon-40	10	+
6.622618	MHZ	4.014	KHZ	H = 1	350.2	MEV	Calcium-40	10	+
6.571054	MHZ	-47.549	KHZ	H = 1	34.7	MEV	D2	1	+

Table 3:

Matrix of 19 Beam Line Settings for 104 MeV $^{16}O^{4+}$

Optics Set	QS1A (AMPS)	QS1B (AMPS)	MS (kG)	(AMPS)						M41/42	M43
	1	2	3	4	5	6	7	8	9	10	11
01 (HLC)	137.5	124.8	14.35	103.4	137.5	158.9	0.	0.	0.	0.	0.
02 (GHIORSO)	125.8	121.8	14.35	76.3	84.2	158.9	0.	0.	0.	0.	0.
1A D/S	167.	122.7	14.35	100.	108.	-7.4	0.	0.	0.	0.	0.
1B (MORETTO)	172.	129.	14.35	98.	114.	53.	0.	0.	0.	0.	0.
1B (RUBY)	162.9	120.9	14.35	131.7	181.2	53.	0.	0.	0.	0.	0.
2 (RAMA)	161.	137.	9.73	140.	102.	49	48.	-150.	-179.	0.	0.
2 (Sc.Cham)	167.	148.	9.73	143.	109.	13.4	16.4	93.	95.	0.	0.
3B (Bio Med)	141.	125.	4.708	101.	89.	188.	0.	0.	0.	0.	0.
4A (Hi Res)	116.	97.	4.708	71.	81.	80.	72.	-77.	-91.	916.	-116.
4A (Hi Trans)	140.7	99.3	4.708	88.9	82	-63	-66	-106.7	-109.4	921.	-121.
4B (Hi Res)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4B (Hi Trans)	139.8	111.5	4.85	101.7	100.	71.5	66.6	-68.4	-76.9	916.	228.8
4C (Hi Res)	116.	97.	4.708	71.	81.	62.	59.	-66.	-75.	916.	650.
4C (Hi Trans)	140.	110.	4.835	101.	102.	-58.	-45.	62.3	68.6	919.	671.
5A (Muller)	141.	122.	4.835	52.	68.	0.	0.	0.	0.	0.	0.
5A (Str.Cham)	138.8	117.	4.835	41.1	37.	0.	0.	0.	0.	0.	0.
5B (E. Det)	131.	109.	0.	3.4	0.	0.	0.	0.	0.	0.	0.
5B (Yano)	121.	90.3	0.	57.1	43.3	0.	0.	0.	0.	0.	0.
5B (Par Tgt)	125.4	92.5	0.	21.3	23.	678.5	166.6	0.	0.	0.	0.

Table 4:

Cyclotron Settings for 140 MeV $^{16}O^{4+}$

Frequency = 6.6186 MHz (Res panels - D.V.M. = 24.04*)
Dee volts = 70 kV*
Main magnet current = 2419 Amps* (2390 - 2448)

Recommended trim coil solution

Trim Coil Settings

Coil	Amps
1	32
2	-345
3	0
4	0
5	0
6	0
7	0
8	-142
9	-147
10	-393
11	-578
12	-478
13	-907
14	-1754
15	-1599
16	-2261
17	2400

Index #	Soln #	FR	FS
160.11	286	0	0

Valley Coils*

Coil	1	2	3	4	5
Angle (DEG)	90	310	--	--	120
Amps	200	100	---	--	50

Center Region

RAD = 385
AZI = 20
ROT = 15
P N/S = 30*
P E/W = *

Deflector Positions	Deflector Volts*
1) 39.4	
2) .21	Entrance = 52.7 kV
3) 40.364	
4) .254	
5) 40.476	
6) .261	Middle = 62.4 kV
7) 42.921	
8) .496	
9) 43.57	
10) 1.25	Exit = 0 kV
11) 48.49	
12) 1.93	

*Optimize as required

Table 5:

List of the lowest values of K to which the lowest energy beam on each Q/A = constant line can be stretched. NC is the solution number of that lowest energy beam.

I	QA(I)	NC(I)	LK(I)
1	1	1	1.68
2	.6667	30	2.622
3	.5	73	4.4
4	.471	106	500
5	.467	111	500
6	.462	121	500
7	.455	131	113.129
8	.444	144	135.805
9	.438	150	51.604
10	.429	166	127.537
11	.417	172	28.768
12	.4	190	91.063
13	.385	201	130.477
14	.375	207	63.716
15	.357	221	109.356
16	.35	231	152.31
17	.333	233	6.013
18	.313	253	115.988
19	.286	261	41.381
20	.25	276	6
21	.2222	294	105.46
22	.214	302	59.93
23	.2	318	111.463
24	.188	329	2.654
25	.167	345	4.303
26	.143	363	152.581
27	.125	365	39.579

Table 6: Valley Coil Settings

Valley Coil Number	SET 1 [Q/A > 0.5] ANGLE	SET 1 [Q/A > 0.5] Amps	SET 2 [Q/A ⩽ 0.5] ANGLE	SET 2 [Q/A ⩽ 0.5] Amps
1	90^0	90	90^0	200
2	---	---	310^0	100
3	---	---	---	---
4	---	---	---	---
5	360^0	8	120^0	50

Table 7: Center Region Parameters

	SET 1 H > 1	SET 2 H=1 E/Q < 32.5	SET 3 H=1 32.5⩽E/Q < 50	SET 4 H=1 E/Q ⩾50
RAD	520	445	385	320
AZI	19	22	20	24
ROT	15	15	15	15
P N/S	55	40	30	15

Table 8: Deflector Settings

	Set 1	Set 2	Set 3	Set 4	Set 5
	$\frac{E}{Q} < 10$	$10 \leqslant \frac{E}{Q} < 32.5$	$32.5 \leqslant \frac{E}{Q} < 47.5$	$47.5 \leqslant \frac{E}{Q} < 62.5$	$\frac{E}{Q} \geqslant 62.5$
1	39.4	39.4	39.4	39.4	39.4
2	.4	.34	.21	.21	.202
3	40.36	40.36	40.364	40.36	40.327
4	.42	.34	.21	.21	.202
5	40.4	40.42	40.476	40.48	40.359
6	.496	.401	.261	.224	.307
7	42.731	42.92	42.921	42.83	43.03
8	.7	.577	.496	.53	.485
9	43.57	43.57	43.57	43.57	44.008
10	1.25	1.25	1.25	1.25	.798
11	48.49	48.49	48.49	48.49	48.975
12	1.93	1.749	.93	1.93	1.237
ENT (kV)	97.5	81.	49.	46.94	40.95
MID (kV)	97.5	76.	58.	50.55	42.761
EXIT (kV)	0	0	0	0.	12.536

Table 9:

BEAMS SUMMARY FOR MARCH 1979

	DATE	ENERGY		MASS	ION	CHG		CAVE	HRS	AVG AMT	EXPERIMENTER
1	03/01/79	100	MEV	15	N	+	4	02	15	3	NITSCHKE
2	03/01/79	25	MEV	1	H	+	1	5B	2	25	YANO
3	03/01/79	95	MEV	15	N	+	4	02	18	2.8	NITSCHKE
4	03/02/79	111	MEV	18	O	+	4	02	22	2.1	HOFFMAN
5	03/03/79	185	MEV	40	AR	+	8	1A	7	.003	DIAMOND
6	03/04/79	170	MEV	40	AR	+	7	1A	9	.021	DIAMOND
7	03/04/79	185	MEV	40	AR	+	8	1A	39	.005	DIAMOND
8	03/06/79	11	MEV	1	H	+	1	3B	2	1	CLEMENSON
9	03/06/79	65	MEV	4	HE	+	2	VT	8	2	BEAM DEV
10	03/07/79	116	MEV	18	O	+	4	02	27	2.2	HOFFMAN
11	03/08/79	11	MEV	1	H	+	1	3B	3	1	CLEMENSON
12	03/08/79	25	MEV	1	H	+	1	5B	2	25	YANO
13	03/08/79	216	MEV	16	O	+	5	4A	28	.075	HUIZENGA
14	03/09/79	315	MEV	16	O	+	6	4A	4	.005	HUIZENGA
15	03/10/79	75	MEV	16	O	+	3	4A	8	.025	HUIZENGA
16	03/11/79	175	MEV	16	O	+	5	4A	8	.1	HUIZENGA
17	03/11/79	65	MEV	4	HE	+	2	2	44	.8	SHOTTER
18	03/13/79	65	MEV	4	HE	+	2	2	28	.5	SHOTTER
19	03/15/79	175	MEV	20	NE	+	5	1B	14	.0002	WOZNIAK
20	03/15/79	170	MEV	40	AR	+	7	1B	4	.0007	WOZNIAK
21	03/16/79	11	MEV	1	H	+	1	3B	3	1	CLEMENSON
22	03/16/79	25	MEV	1	H	+	1	5B	2	25	YANO
23	03/16/79	187	MEV	12	C	+	4	3B	14	.0002	HOLLEY
24	03/17/79	41.5	MEV	3	HE	+	2	2R	10	2.5	CERNY
25	03/17/79	110	MEV	14	N	+	4	2R	14	2.3	CERNY
26	03/18/79	140	MEV	16	O	+	4	2R	6	.5	CERNY
27	03/18/79	122	MEV	18	O	+	4	02	8	1.9	HOGAN
28	03/18/79	75	MEV	18	O	+	4	02	4	1.5	HOGAN
29	03/18/79	111	MEV	18	O	+	4	02	4	2.6	HOGAN
30	03/19/79	111	MEV	18	O	+	4	02	8	2.2	HOFFMAN
31	03/19/79	116	MEV	18	O	+	4	02	16	2.4	HOFFMAN
32	03/20/79	120	MEV	18	O	+	4	02	8	1.8	HOFFMAN
33	03/20/79	88	MEV	12	C	+	3	02	24	2.3	HOFFMAN
34	03/21/79	35	MEV	4	HE	+	1	VT	8	.5	RYCKEWAERT
35	03/22/79	140	MEV	3	HE	+	2	4C	8	<.0001	GRUHN
36	03/22/79	175	MEV	20	NE	+	5	2R	32	1.4	MOLTZ
37	03/23/79	160	MEV	12	C	+	4	2R	7	2	MOLTZ
38	03/23/79	160	MEV	14	N	+	4	2R	14	1.75	MOLTZ
39	03/24/79	200	MEV	14	N	+	5	2R	20	1.1	MOLTZ
40	03/25/79	104	MEV	12	C	+	3	2R	16	1.2	MOLTZ
41	03/26/79	78	MEV	12	C	+	3	2R	8	1	MOLTZ
42	03/26/79	25	MEV	1	H	+	1	5B	3	25	YANO
43	03/26/79	166.8	MEV	84	KR	+	10	3P	13	<.0001	ROCKWELL
44	03/27/79	40	MEV	18	O	+	3	02	5	.15	ALEKLETTE
45	03/27/79	50	MEV	18	O	+	3	02	3	.1	ALEKLETTE
46	03/27/79	87	MEV	18	O	+	4	02	4	.6	HOGAN
47	03/27/79	122	MEV	18	O	+	4	02	4	1.8	HOGAN
48	03/28/79	99	MEV	18	O	+	4	02	4	2	HOGAN
49	03/28/79	25	MEV	1	H	+	1	5B	4	25	YANO
50	03/28/79	116	MEV	18	O	+	4	02	16	1.2	HOFFMAN
51	03/29/79	116	MEV	18	O	+	4	02	16	1.2	GHIORSO
52	03/30/79	140	MEV	3	HE	+	2	4C	24	<.0001	DE VRIES
53	03/31/79	80	MEV	3	HE	+	2	2	8	.1	SHOTTER
					TOTAL HOURS				630		

BEAM INTENSITIES EXPRESSED IN MICROAMPERES

Table 10:

TIME ACCOUNTING FOR MAY-JUNE 1980

	TOTAL HOURS	PERCENT
BEAM DEVELOPMENT.....	61.47	5.54
TUNING.....	88.73	8
OPTICS.....	70.47	6.36
ON TARGET.....	511.58	46.17
SCHEDULED MAINTENANCE.....	120	10.83
UNSCHEDULED MAINTENANCE.....	170.88	15.42
WAITING FOR EXPERIMENTER.....	26.8	2.41
OTHER (BEAM OFF).....	58.03	5.23
SUBTOTAL	1108 HOURS	
HOLIDAY/SHUTDOWN.....	356	
TOTAL	1464 HOURS	
TOTAL EXPERIMENTAL TIME.....	756 HOURS	68.17 %

FIGURE CAPTIONS

1. Particle distribution history of the 88-Inch Cyclotron from 1968 to 1980, (XBL 809-1999A).

2. Schematic of the PET computer system, (XBL812-2127).

3. Recommended dee voltage as a function of E/Q, (XBL 812-2128).

4. Error distribution in prediction of main coil current, (XBL 812-2129).

5. Resonance chart showing all beams for which paramenters are stored in the PET, (XBL 811-62).

6. K-depencence in "stretching" trim coil solutions at constant magnetic field for two regimes of Q/A, (XBL 812-2130).

7. Energy "stretching" limits for light ion trim coil solutions, (XBL 812-2131).

8. Energy "stretching" limits for heavy ion trim coil solutions.
   a) First harmonic, (XBL 812-2132).
   b) Second harmonic, (XBL 812-2133).

9. Schematic illustration of radial field profile matching, (XBL 812-2134).

10. Resonance chart indicating "preferred" directions of trim coil solution "stretching" which result from phase slip compensation, (XBL 812-2135).

11. Vector representation of solution "stretching", (XBL 812-2136).

12. Summary of recommended trim coil solutions for selected beams.

13. Phase history calculations using CYDE illustrating phase-slip compensation, (XBL 789-1782).

14. Illustration of trim coil solution "stretching" at constant magnetic field for low values of Q/A, (XBL 812-2137).

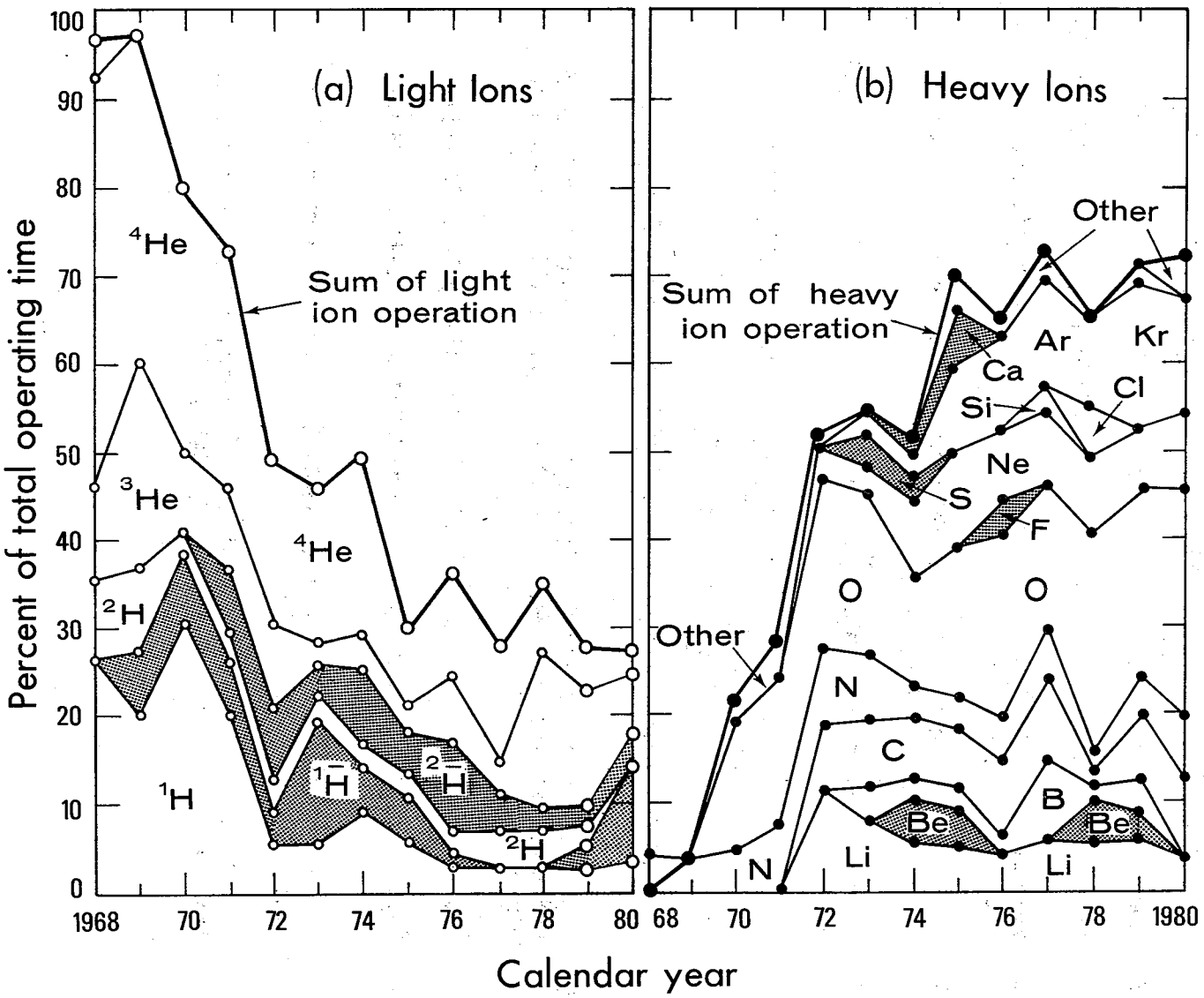


Figure 1

XBL 809-1999A

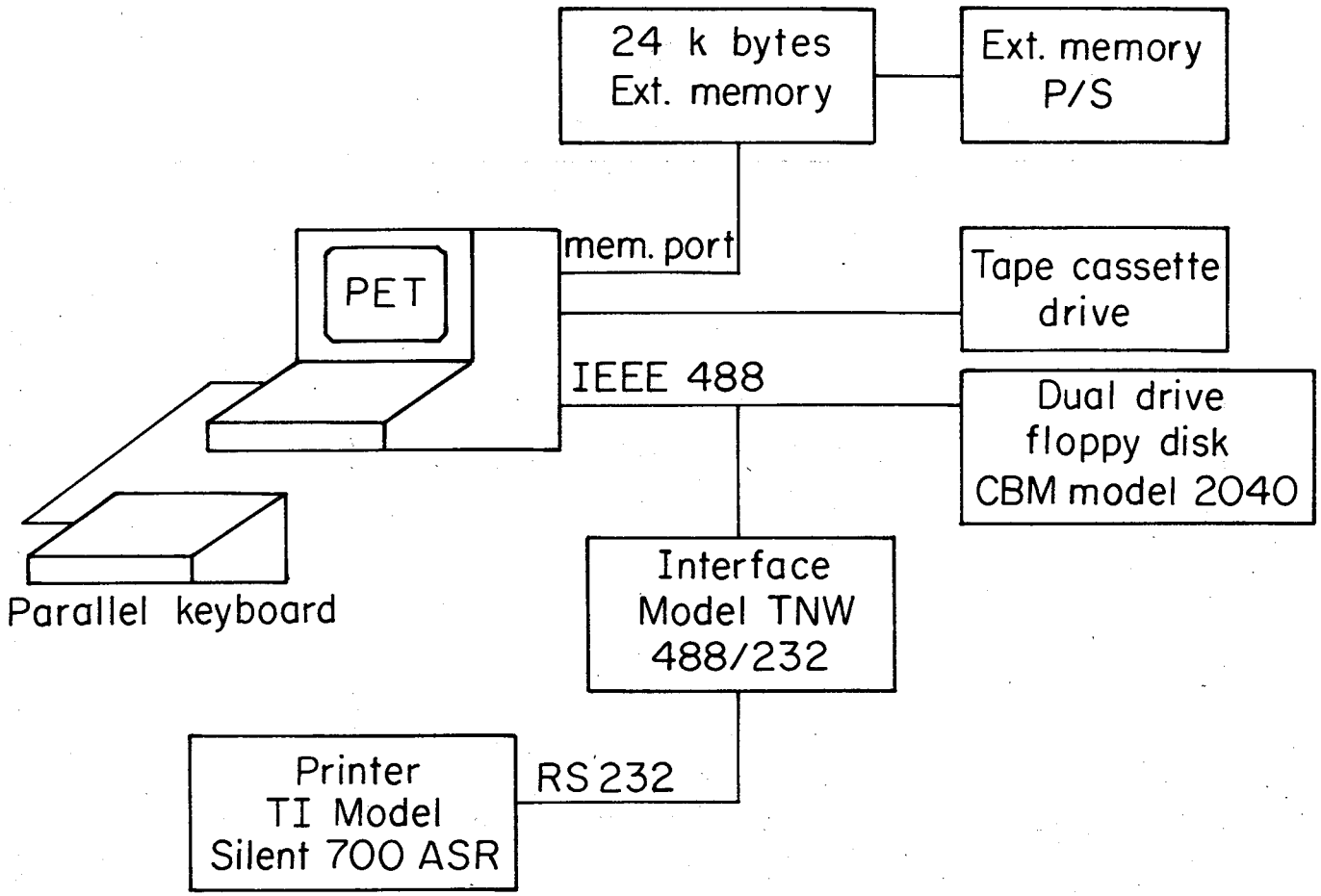


Figure 2

XBL 812-2127

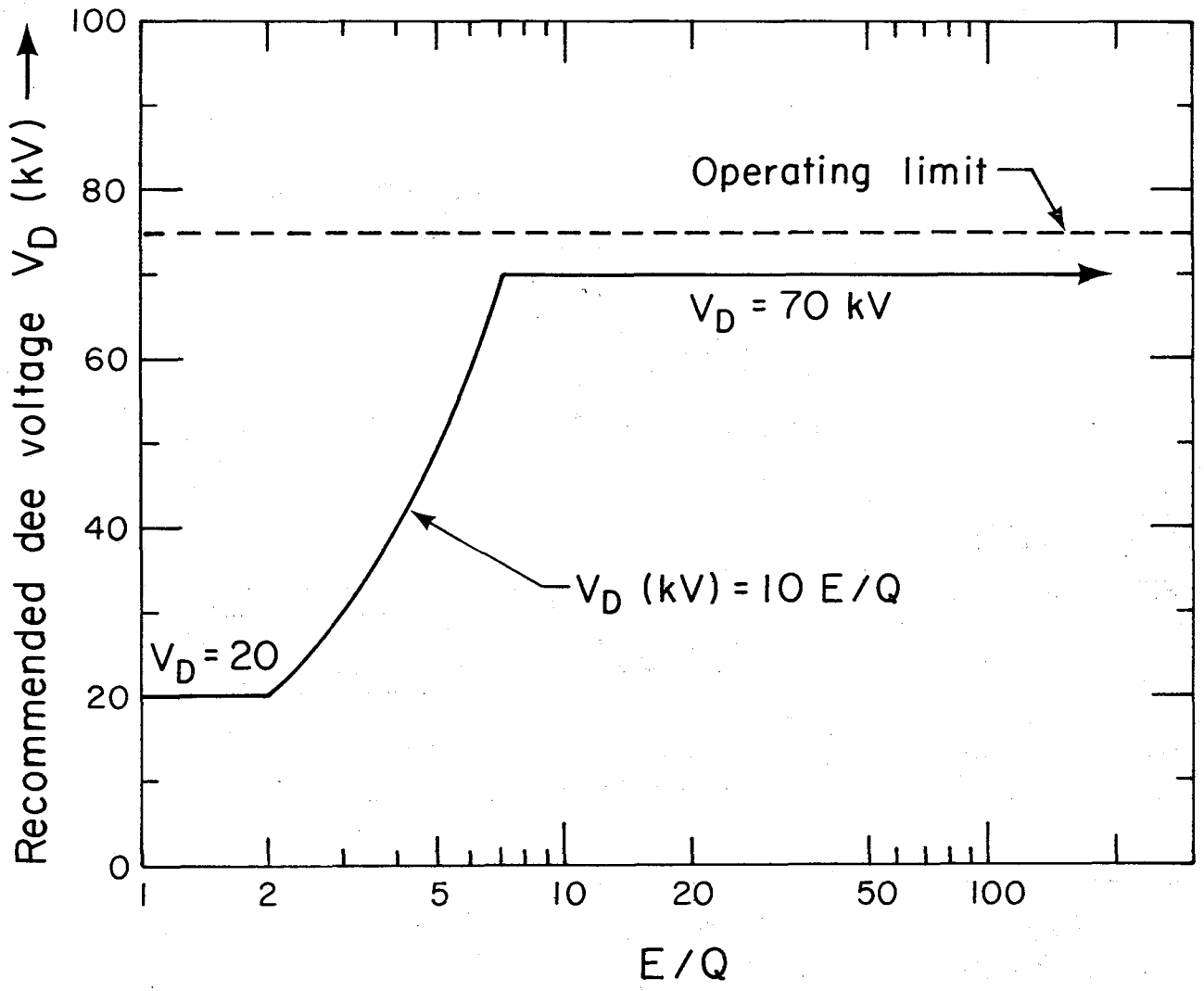


Figure 3

XBL 812-2128

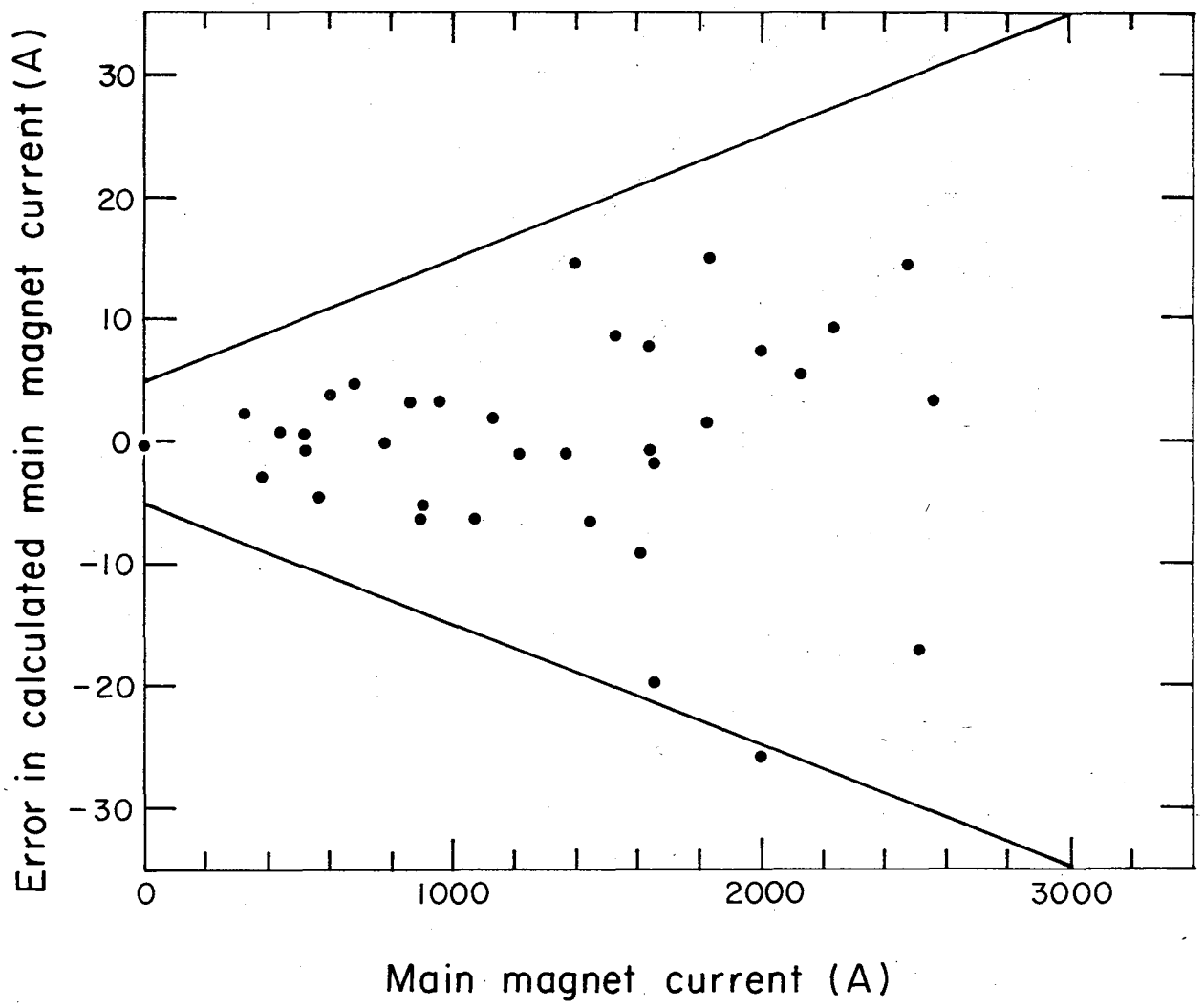


Figure 4

XBL 812-2129

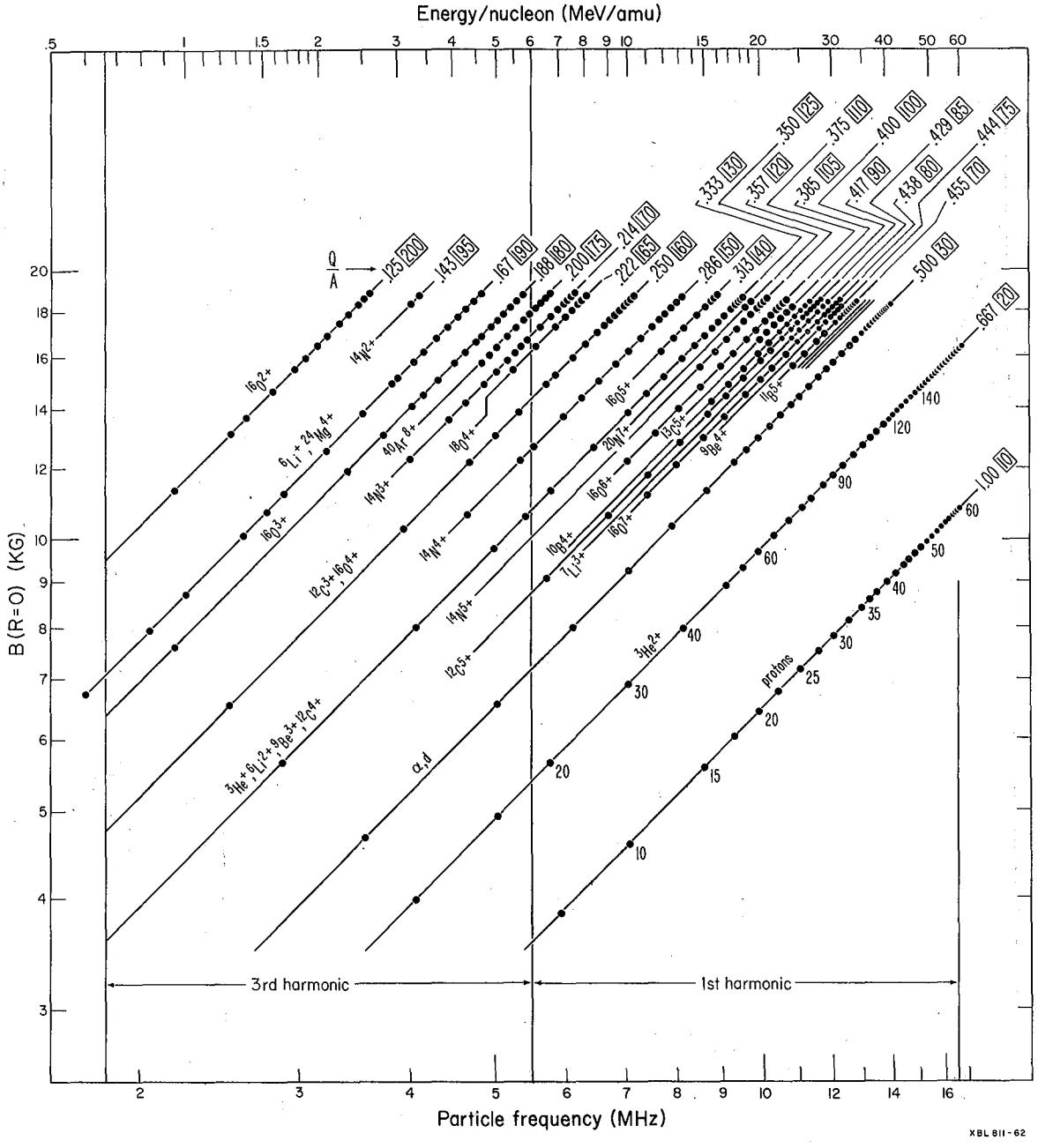
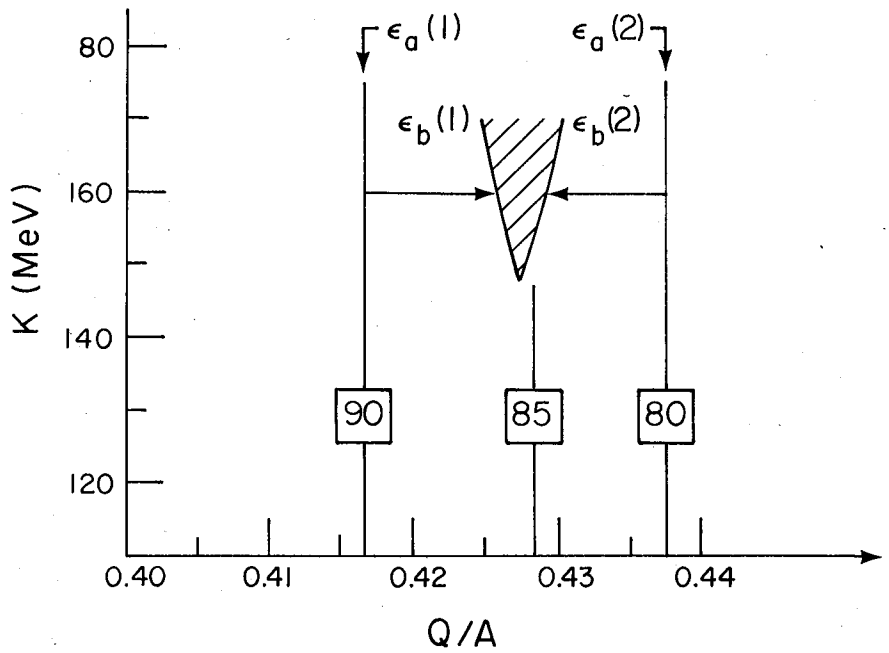


Figure 5

XBL811-62

A



B

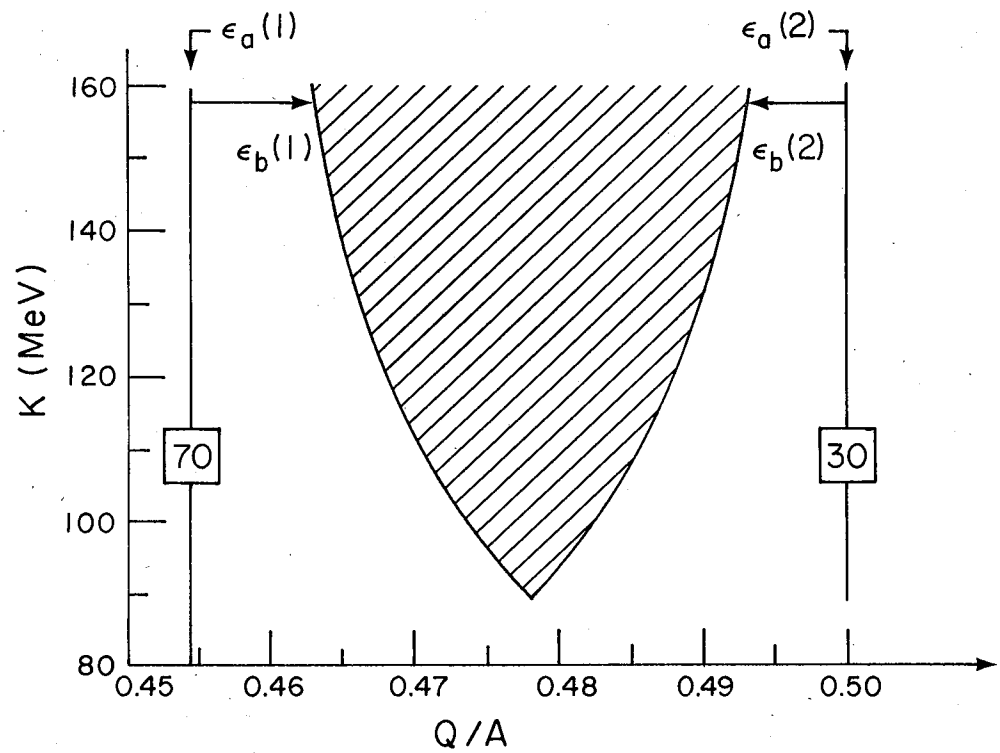


Figure 6

XBL 812-2130

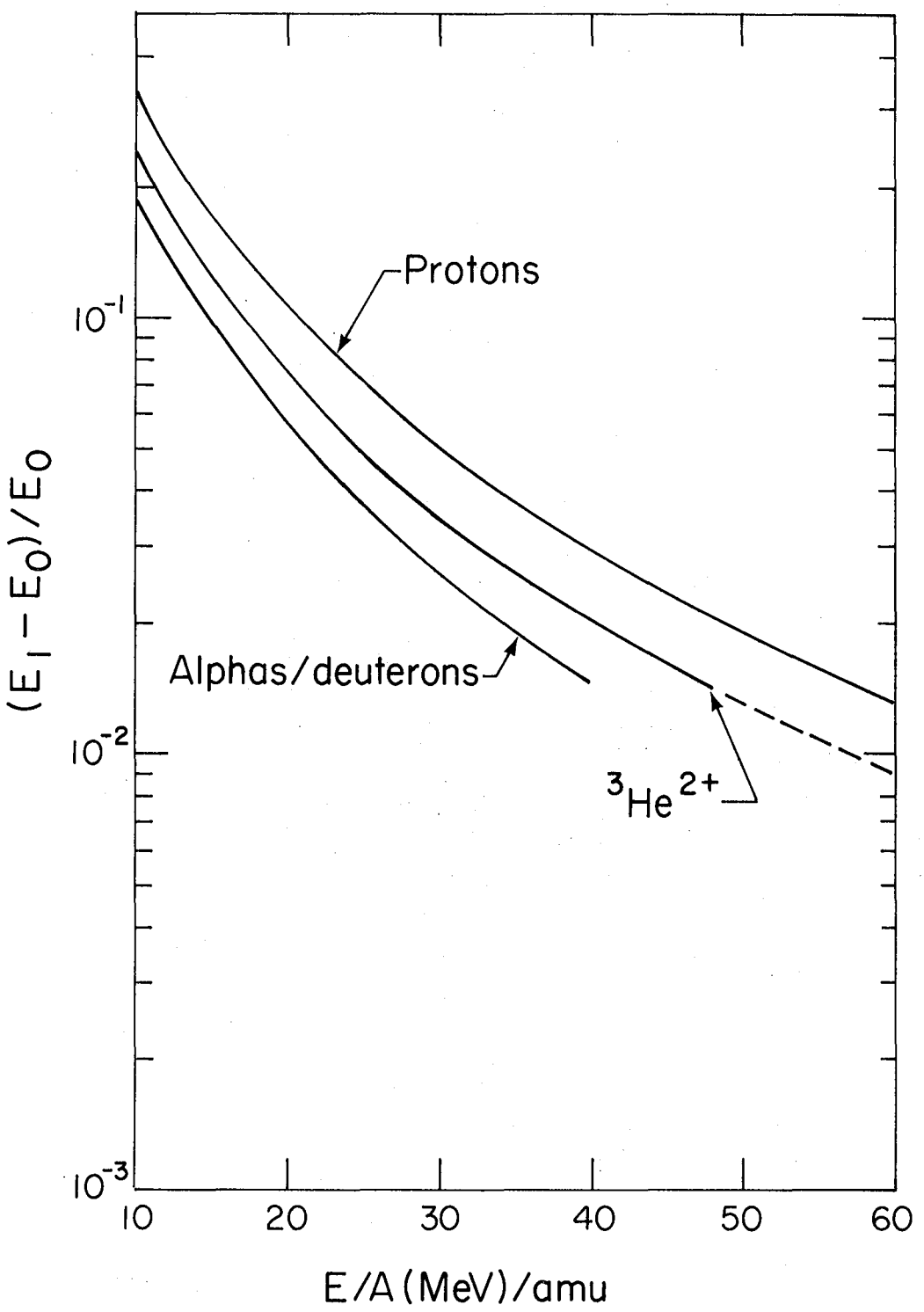


Figure 7

XBL 812-2131

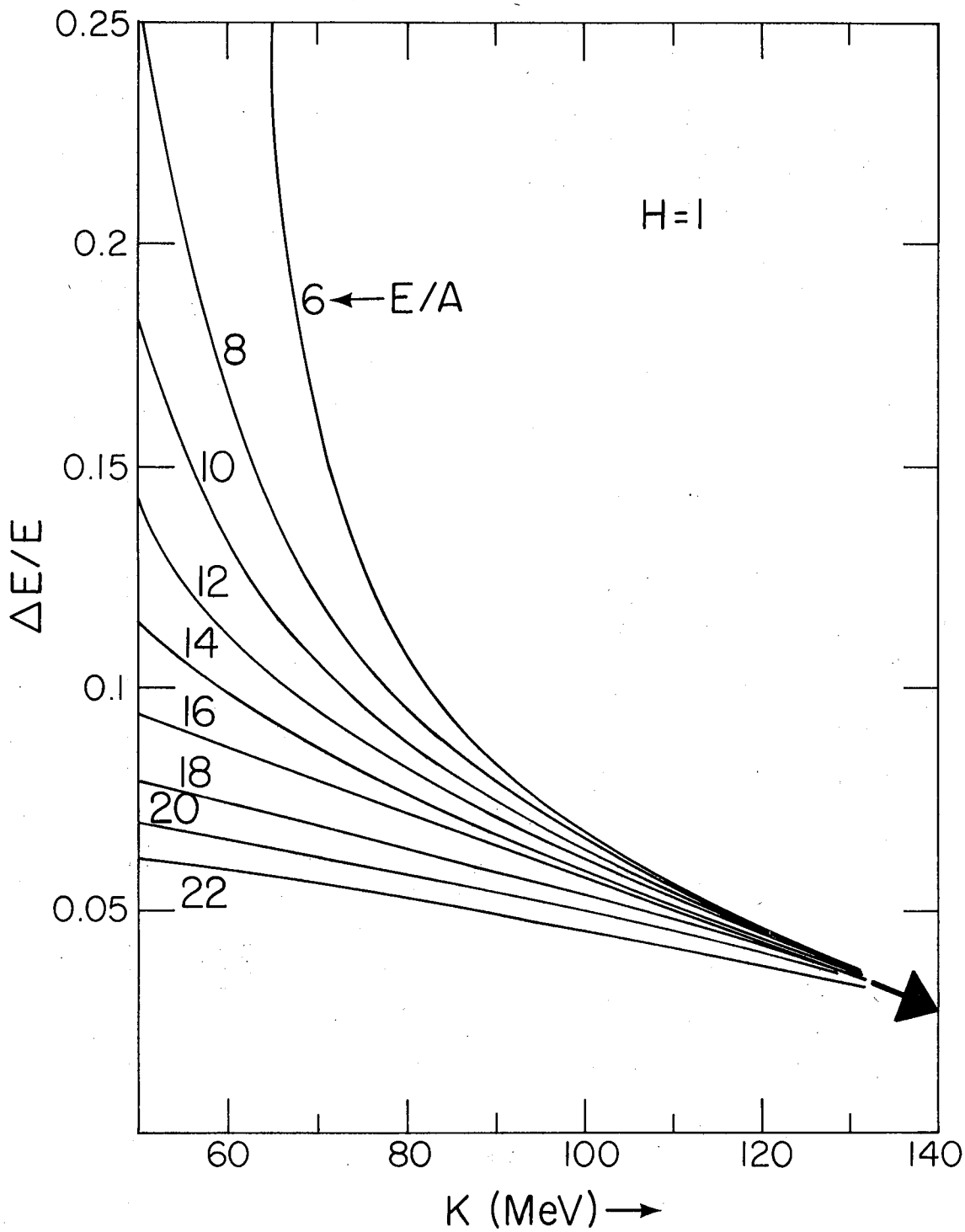


Figure 8a

XBL 812-2132

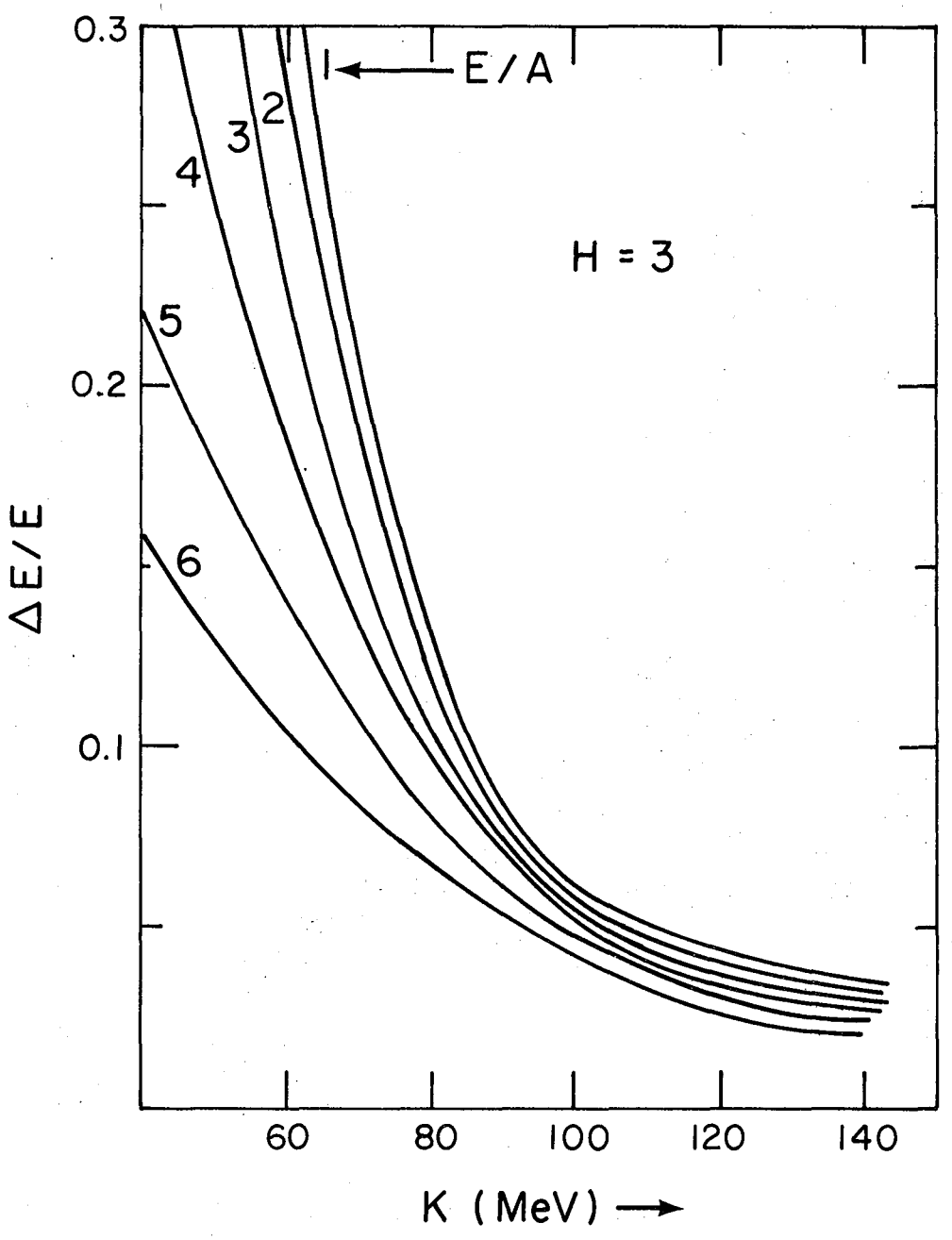


Figure 8b

XBL 812-2133

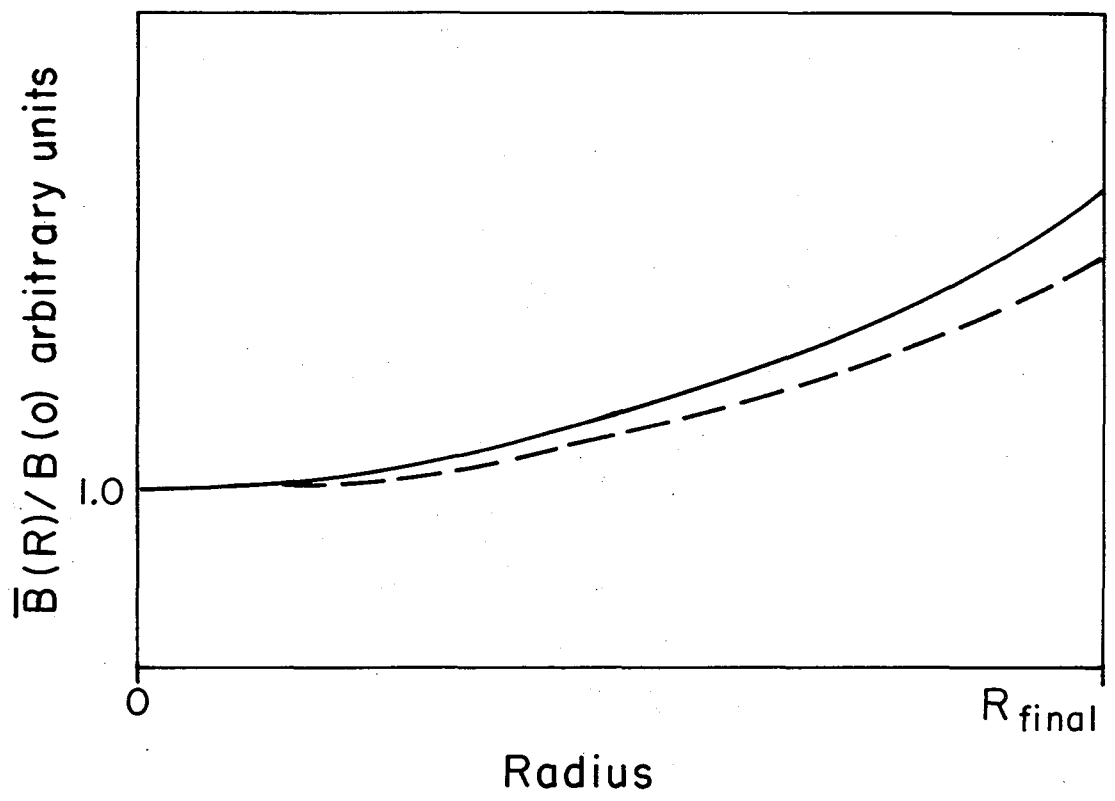


Figure 9

XBL 812-2134

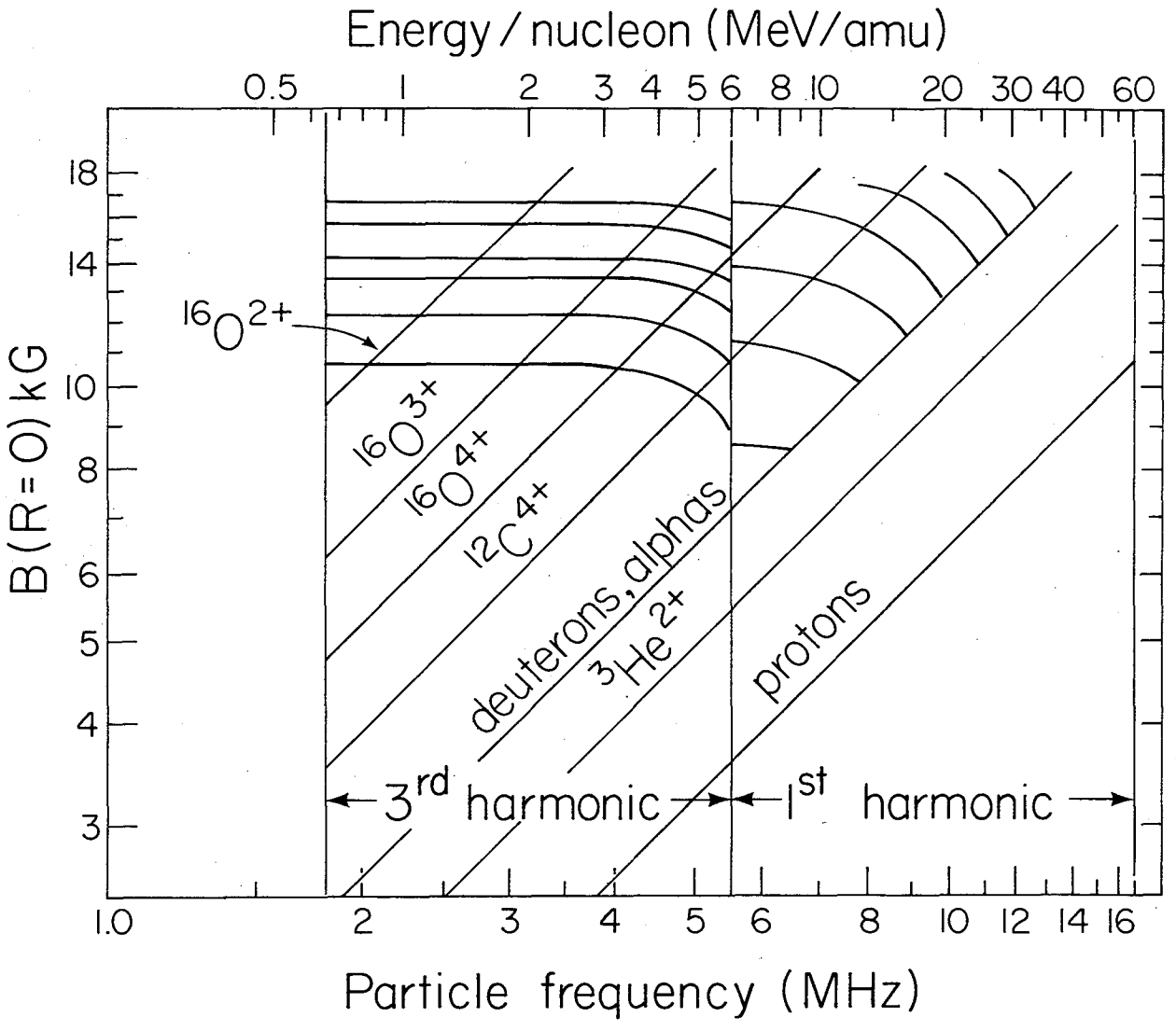


Figure 10

XBL 812-2135

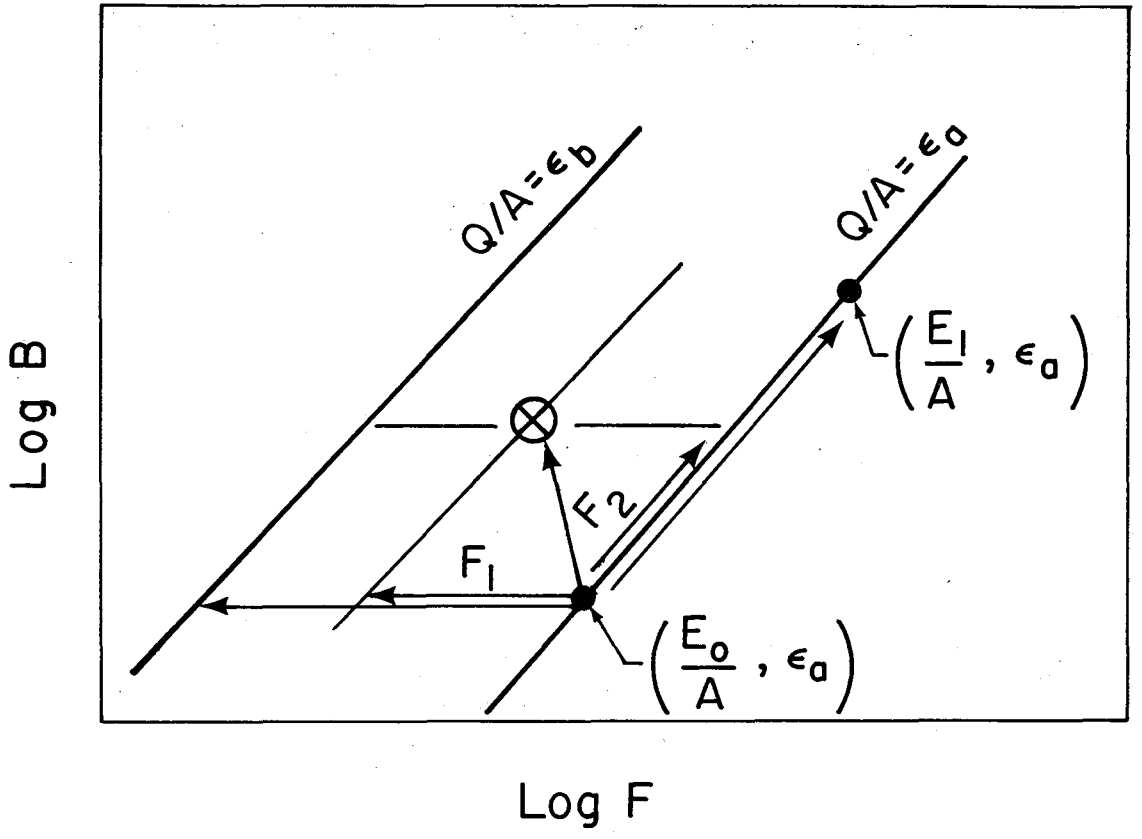
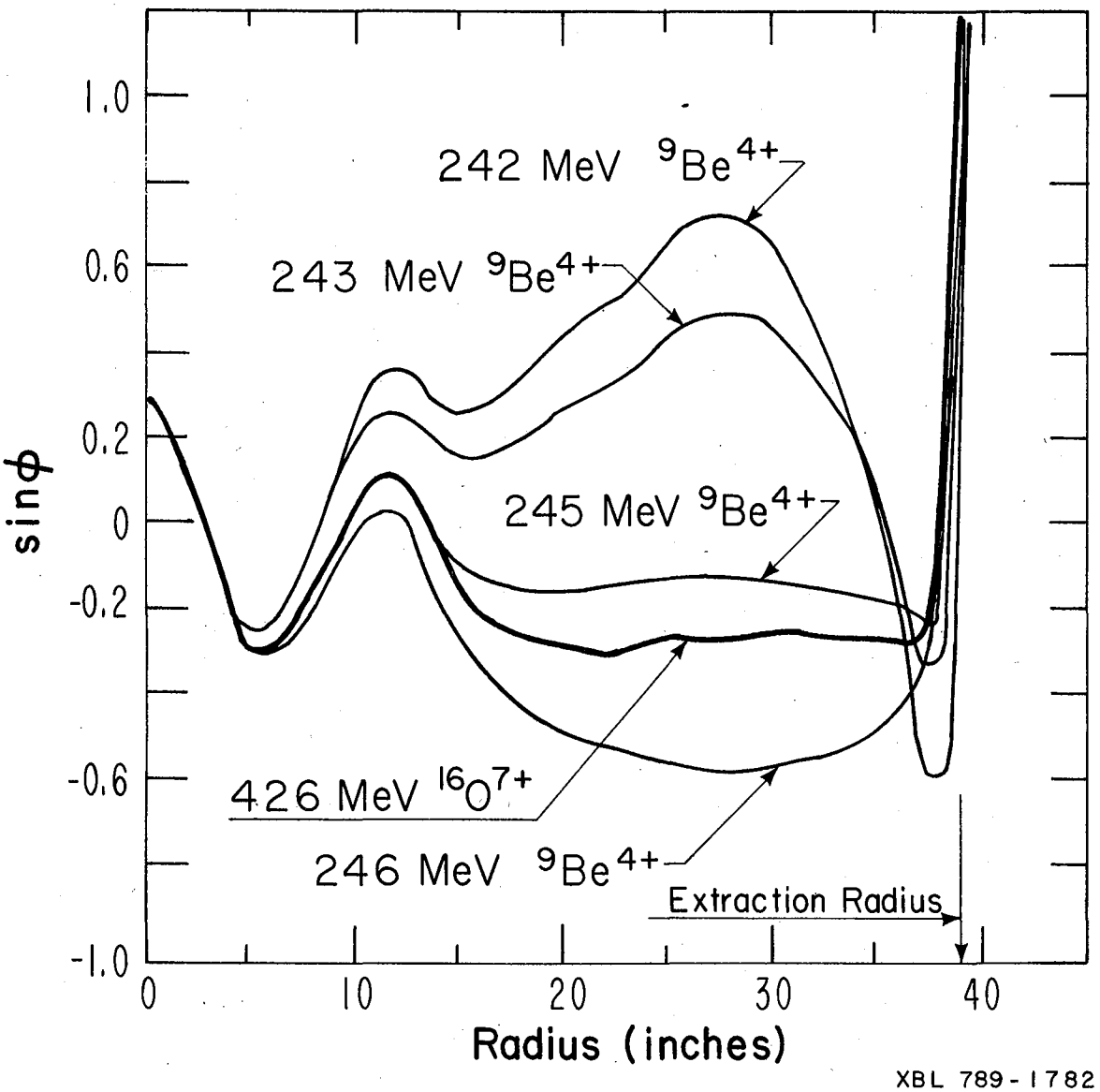


Figure 11

XBL 812-2136

Figure 12

	BEAM	INDEX NO.	SOLUTION NO.	FR	FS
A.	182 MeV $^{22}Ne^{5+}$	165.07	300	0.239	0.097
		160.16	291	0.872	-0.798
B.	111 MeV $^{13}C^{3+}$	165.07	300	0.358	0.32
		160.16	291	0.75	-0.587
C.	168 MeV $^{40}Ar^{7+}$	190.14	358	0.736	-0.171
		180.10	338	1.406	0.726
D.	245 MeV $^{9}Be^{4+}$	75.01	144	0.524	-0.473
		80.10	159	0.831	0.227
		70.03	133	1.758	0.349
	244 MeV $^{9}Be^{4+}$	75.01	144	0.657	-0.607
		80.10	159	0.918	0.084
		70.03	133	1.64	0.197
	360 MeV $^{14}N^{6+}$	85.02	167	0.095	0.043
E.	41 MeV protons	10.15	15	0.915	-0.916
		10.14	14	0.862	0.862


1.0
0.6
0.2
0
-0.2
-0.6
-1.0
sinφ
242 MeV $^{9}Be^{4+}$
243 MeV $^{9}Be^{4+}$
245 MeV $^{9}Be^{4+}$
426 MeV $^{16}O^{7+}$
246 MeV $^{9}Be^{4+}$
Extraction Radius
0
10
20
30
40
Radius (inches)

XBL 789-1782

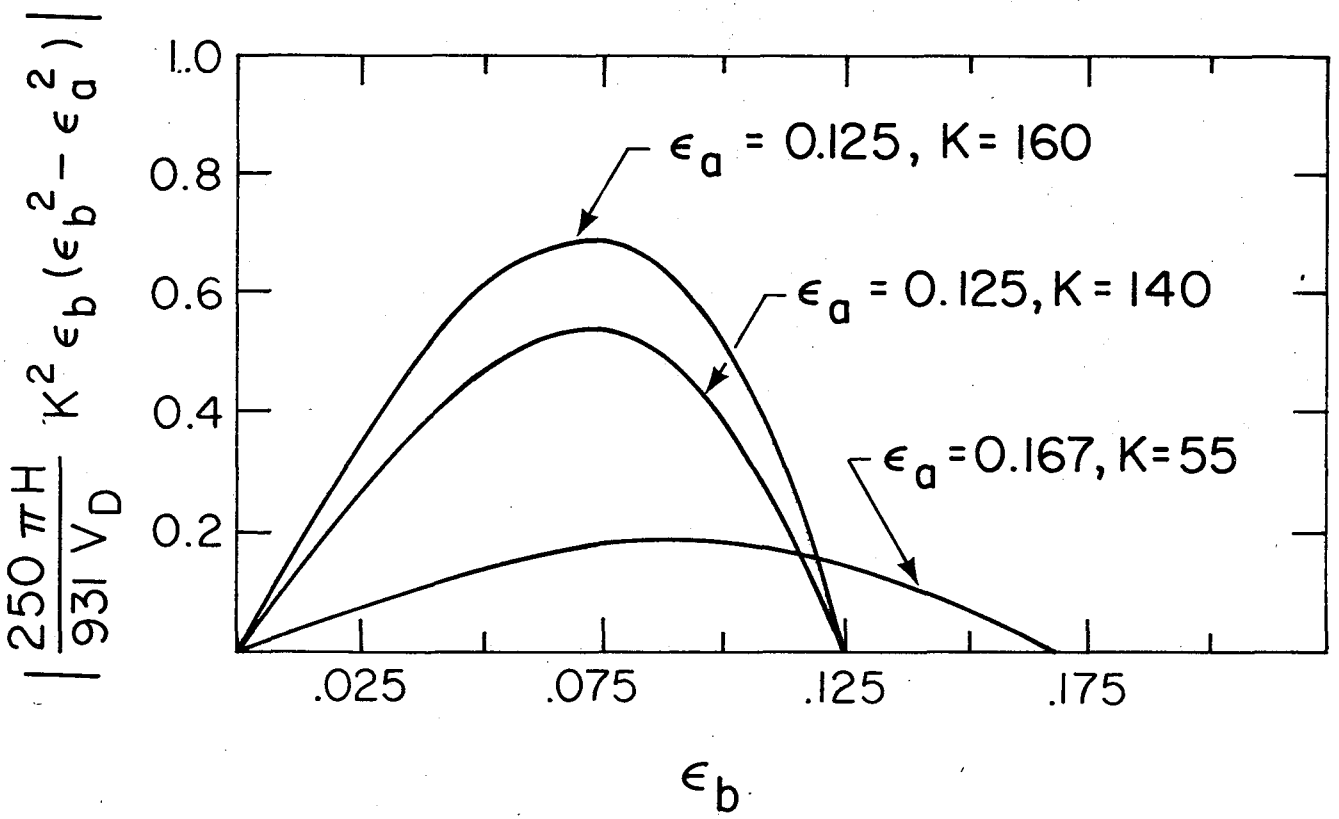


Figure 14

XBL812-2137

APPENDIX A.1.a.: Listing of Program MASTER

```
1 REM 08/27/80
2 REM THIS IS THE PROGRAM 'MASTER'
3 REM
100 PRINT"":PRINT"READING DATA"
104 REM
105 REM TC=1 IMPLIES PROGRAM HAS BEEN CALLED BY 'PRE'
106 REM
110 IF TC=1 THEN 150
114 REM
115 REM ASSIGN CONSTANTS
116 REM
120 VM=931.478:ME=.511006:ZZ=1.3132653:YZ=48.616
124 REM
125 REM ASSIGN 104 MEV OXYGEN-16 AS DEFAULT BEAM
126 REM
130 L=16:E=104:Q=4:H=1:M=16:LS=16:HS=1:F=5.71476888
134 REM
135 REM LOAD BEAMS LIST
136 REM
140 IF TC<>1 THEN DIM BEAM$(56):OPEN 15,8,15
150 FOR I=1TO55:READ BEAM$(I):NEXT I
160 DATA "PROTONS",DEUTERONS,HELIUM-3,ALPHAS,LITHIUM-6,LITHIUM-7,BERYLLIUM-9
170 DATA BERYLLIUM-10,BORON-10,BORON-11,CARBON-12,CARBON-13,CARBON-14
180 DATA NITROGEN-14,NITROGEN-15,OXYGEN-16,OXYGEN-17,OXYGEN-18,FLOURINE-19
190 DATA NEON-20,NEON-21,NEON-22,SODIUM-23,MAGNESIUM-24,MAGNESIUM-25
200 DATA MAGNESIUM-26,ALUMINUM-27,SILICON-28,SILICON-29,SILICON-30
210 DATA PHOSPHORUS-31,SULPHUR-32,SULPHUR-33,SULPHUR-34,SULPHUR-36
220 DATA CHLORINE-35,CHLORINE-36,CHLORINE-37,ARGON-36,ARGON-38,ARGON-40
230 DATA CALCIUM-40,H2,H3,D2,D3,DH,DH2,D2H,KRYPTON-78,KRYPTON-80,KRYPTON-82
240 DATA KRYPTON-83,KRYPTON-84,KRYPTON-86
250 IF TC=1 THEN 1470
260 DIM Z(56),A(56),BR(4),N(4),IN(2),LK(28),NC(28),DN(4),TR(17),RB(7)
270 DIM QA(28),EA(378),DEA(378),FR(4),FS(4),DX$(6),CR(4,4),DDD(5,15)
280 FOR I=1TO7:READ RB(I):NEXT I
290 DATA 150.795,155.757,179.402,219.611,253.562,292.722,263.464
294 REM
295 REM LOAD MASS TABLE
296 REM
300 FORI=1TO55:READ Z(I),A(I):NEXT I
310 DATA 1,1.00782522,1,2.0141022,2,3.0160297,2,4.0026033,3,6.015123,3,7.016005
320 DATA 4,9.012183,4,10.0135352,5,10.0129385,5,11.0093053,6,12.0,6,13.0033551
330 DATA 6,14.00324,7,14.0030744,7,15.000109,8,15.9949150,8,16.999133,8
340 DATA 17.99916,9,18.998405,10,19.9924405,10,20.993847,10,21.991385,11
350 DATA 22.98977,12,23.985044,12,24.985839,12,25.982594,13,26.981541
360 DATA 14,27.976929,14,28.976497,14,29.973772,15,30.973763,16,31.972073
370 DATA 16,32.971459,16,33.96727,16,35.967079,17,34.9688536,17,35.9683073,17
380 DATA 36.965903,18,35.967547,18,37.962733
390 DATA 18,39.962384,20,39.962592,1,2.0156504
400 DATA 1,3.0234756,2,4.0282044,2,6.0423066,3,3.0219274
410 DATA 4,4.0297526,5,5.0360296
420 DATA 36,77.9204,36,79.91638,36,81.91348
430 DATA 36,82.91413,36,83.911505,36,85.910616
434 REM
435 REM LOAD CENTER REGION PARAMETERS
436 REM
440 FOR RN=1TO4:FOR PN=1TO4:READ CR(RN,PN):NEXT PN:NEXT RN
450 DATA 520,19,15,55,445,22,15,40,385,20,15,30,320,24,15,15
```

```
454 REM ____________________________
455 REM LOAD DEFLECTOR PARAMETERS
456 REM
460 FOR RA=1TO5:FOR PA=1TO15:READ DDD(RA,PA):NEXT PA:NEXT RA
470 DATA 39.4,.4,40.36,.42,40.4,.496,42.731,.7,43.57,1.25,48.49,1.93,97.5
480 DATA 97.5,0,39.4,.34,40.36,.36,40.42,.401,42.92,.577,43.57,1.25,48.49,1.749
490 DATA 81,76,0,39.4,.21,40.364,.254,40.476,.261,42.921,.496,43.57,1.25
500 DATA 48.49,1.93,49.56,0,39.4,.21,40.36,.213,40.48,.224,42.83,.53,43.57
510 DATA 1.25,48.49,1.93,46.94,50.55,0,39.4,.202,40.327,.237,40.359,.307,43.03
520 DATA .485,44.008,.798,48.975,1.237,40.95,42.761,12.536
524 REM ____________________________
525 REM LOAD INFORMATION ON 27 O/A GRID LINES
526 REM
530 FOR I=0 TO28:READ OA(I),NC(I),LK(I):NEXT I
540 DATA 2,0,500
550 DATA 1,1,1.68,.6667,30,2.622,.5,73,4.4,.471,106,500,.467,111,500,.462,121
560 DATA 500,.455,131,113.129,.444,144,135.805,.438,150,51.604,.429,166
570 DATA 127.537,.417,172,28.768,.4,190,91.063,.385,201,130.477,.375,207
580 DATA 63.716,.357,221,109.356,.35,231,152.31,.333,233,6.013,.313,253
590 DATA 115.988,.286,261,41.381,.25,276,6,.2222,294,105.46,.214,302,59.93
600 DATA .2,318,111.463,.188,329,2.654,.167,345,4.303,.143,363,152.581,.125
610 DATA 365,39.579,0,378,500
614 REM ____________________________________________
615 REM LOAD INFORMATION ON 377 GRID POINTS
616 REM NEGATIVE ENTRIES INDICATE START OF GRID LINE ENDING IN '5'
617 REM
620 FOR I=0TO378:READ EA(I),DEA(I):IF DEA(I)=0 THEN DEA(I)=.00001
630 IF EA(I)=0 THENEA(I)=1
640 NEXT I
650 DATA 0,0
660 DATA 7,.76,10,.324,15,.175,17.5,.136,20,.106,22.5,.086,25,.071,27.5,.059
670 DATA 30,.05,32.5,.043,35,.037,36,.035,38,.032,40,.029,42,.026,44,.025
680 DATA 45,.023,47,.021,49,.02,50,.019,51.5,.018,53,.017,54,.016,55,.016
690 DATA 56,.015,57,.014,58,.014,59,.0136,60,.013
700 DATA 3.33,.65,5,.33,6.67,.45,10,.24,13.3,.15,16.7,.103,18.3,.087,20,.075
710 DATA 21.6,.064,23.3,.055,25,.05,26.7,.042,28.3,.038,30,.034,31.7,.031
720 DATA 33.3,.028,35,.025,36.7,.023,37.7,.022,39,.02,40,.02,41,.019,42.3,.018
730 DATA 43.3,.017,44.3,.016,45.7,.015,46.7,.014,47.7,.014,48.7,.013,49.3,.013
740 DATA 50,.0126,51,.012,52,.012,52.7,.011,53.3,.011,54.3,.01,55.3,.01,56,.01
750 DATA 56.7,.01,57.7,.0094,58.7,.0091,59.3,.009,60,.009
760 DATA 2.5,.56,5,.3,7.5,.33,10,.19,12.5,.13,15,.096,17.5,.073,18.75,.064
770 DATA 20,.056,21.25,.05,22.5,.045,23.75,.04,25,.037,26.25,.033,27.5,.0306
780 DATA 28.75,.028,30,.026,31.25,.024,32.5,.0222,33.75,.022,35,.018
790 DATA 35.75,.0156,36.5,.0132,37,.0116,37.5,.01,38,.008,38.5,.0068
800 DATA 38.75,.006,39,.0052,39.25,.0044,39.5,.0036,39.75,.0032,40,.003
810 DATA 1,0,0,0,0,0,0,0,31,.022
820 DATA 1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,30.5,.022
830 DATA 1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,29.8,.022
840 DATA 24.27,.035,25.9,.031,27.45,.028,28.9,.025,30,.0188,30.9,.015
850 DATA 31.4,.0136,31.8,.0118,32.3,.01,32.7,.0083,33.1,.0069,33.4,.0058
860 DATA 33.6,.0048
870 DATA -27.6,.03,28.9,.025,29.7,.022,30.6,.018,31.1,.015,31.7,.013
880 DATA 11.25,.12,13.125,.092,15,.075,16.875,.063,18.75,.053,20.31,.046
890 DATA 21.875,.04,23.43,.034,25,.03,26.79,.0283,27.8,.022,28.75,.0188
900 DATA 29.4,.0162,30,.0136,30.6,.011,31,.00943
910 DATA -24.3,.036,25.7,.03,26.8,.025,27.9,.021,28.6,.018,29.3,.014
920 DATA 6.67,.25,9.17,.182,11.25,.107,13.33,.083,15.41,.066,17.08,.056
930 DATA 18.75,.048,20.4,.041,21.67,.036,22.9,.032,24.33,.03
```

```
940 DATA 25,.024,25.63,.021,26.3,.018,26.8,.015,27.25,.013,27.7,.011,28.125
950 DATA .0094
960 DATA 15.5,.06,17,.051,18.5,.044,20,.038,21.25,.033,22.4,.03,23.5,.0215
970 DATA 24.25,.018,25,.014,25.5,.0115,26,.009
980 DATA -20,.033,20.8,.03,21.5,.025,22.3,.021,23.1,.017,23.7,.014
990 DATA 10,.104,11.56,.083,13.3,.066,14.69,.055,16.25,.046,17.5,.04
1000 DATA 18.75,.033,19.69,.03,20.6,.022,21.25,.018,21.9,.0146,22.2,.0128
1010 DATA 22.5,.011,22.8,.0094
1020 DATA 14.64,.048,15.7,.041,16.79,.035,17.86,.03,18.6,.0235,19.3,.019
1030 DATA 19.6,.0168,20,.0146,20.4,.012,20.7,.01
1040 DATA -19,.018,19.6,.014
1050 DATA 1.667,.6,3.33,.5,5,.19,5.83,.125,6.67,.25,8.33,.104,10,.075,11,.064
1060 DATA 12.11,.054,13.33,.0445,14.23,.038,15,.033,15.58,.03
1070 DATA 16.25,.023,16.6,.02,17.25,.016,17.5,.014,17.8,.012,18.1,.0095
1080 DATA 18.3,.008
1090 DATA 11.88,.0435,12.81,.037,13.63,.028,14.4,.024,15,.019,15.3,.0166
1100 DATA 15.6,.014,15.9,.0114
1110 DATA 4.29,.211,5.71,.09,6.07,.13,7.14,.085,7.86,.072,8.57,.06,9.28,.051
1120 DATA 10,.043,10.71,.035,11.42,.03,11.8,.026,12.1,.023,12.5,.019,12.9,.016
1130 DATA 13.1,.014
1140 DATA 1.25,.7,3.125,.34,4.375,.125,5,.08,5.625,.055,6.5,.062,6.875,.056
1150 DATA 7.5,.045,8.125,.036,8.5,.033,8.75,.03,9.06,.026,9.4,.022,9.7,.018
1160 DATA 9.8,.016,10,.014,10.2,.012,10.3,.01
1170 DATA -5.5,.055,6.22,.042,6.89,.03,7.22,.025,7.5,.02,7.72,.017,7.92,.0138
1180 DATA 8.06,.0115
1190 DATA 3.21,.145,3.92,.081,4.28,.06,4.714,.045,5,.037,5.36,.032,5.54,.028
1200 DATA 5.71,.025,5.93,.022,6.43,.03,6.7,.025,6.93,.0213,7.1,.0176,7.3,.0151
1210 DATA 7.43,.0126,7.57,.01
1220 DATA -4.625,.036,4.8,.033,5,.03,5.35,.027,5.6,.025,5.8,.02,6,.022,6.2,.018
1230 DATA 6.4,.014,6.5,.012,6.6,.01
1240 DATA .938,.9,2.34,.175,2.81,.107,3.25,.076,3.44,.056,3.75,.045,4.06,.036
1250 DATA 4.31,.031,4.56,.028,4.69,.026,4.92,.024,5.125,.023,5.31,.022,5.5,.021
1260 DATA 5.69,.02,5.81,.02
1270 DATA .6,.8,.833,.7,1,.6,1.35,.48,1.5,.44,1.66,.31,2.05,.16,2.5,.076
1280 DATA 2.933,.045,3,.045,3.25,.038,3.46,.034,3.667,.03,3.89,.028
1290 DATA 4.1,.027,4.25,.026,4.41,.025,4.58,.025
1300 DATA -3.21,.028,3.36,.028
1310 DATA .937,.34,1.25,.126,1.38,.088,1.56,.06,1.75,.047,1.875,.041
1320 DATA 1.968,.038,2.06,.035,2.19,.033,2.31,.031,2.44,.03,2.5,.029,2.56,.028
1330 DATA 100,100
1340 PRINT""
1350 PRINT" "
1354 REM ____________________________________
1355 REM OFFER THE USER SIX BASIC OPTIONS
1356 REM
1360 PRINT"TYPE NUMBER OF DESIRED PROGRAM:":PRINT"
1370 PRINT"1. BRHO          2. FREQUENCY"
1380 PRINT"3. PRE RUN       4. ENERGY"
1390 PRINT"5. RES. TABLE    6. CYC. SETTINGS"
1400 INPUT FL
1410 DN(1)=0:DN(2)=0
1420 IF FL<=5 AND FL>=1 AND INT(FL)=FL THEN 1450
1430 IF FL=6 THEN 1470
1440 PRINT"IMPROPER ENTRY, TRY AGAIN:":GOTO 1350
1444 REM ____________________________________________________________
1445 REM CALL IN PROGRAM 'PRE' FOR ALL OPTIONS EXCEPT 'CYC. SETTINGS'
1446 REM
1450 TP=1:PRINT"":PRINT"I AM PROCESSING YOUR REQUEST, PLEASE"
1460 PRINT"BE PATIENT.":LOAD ":PRE",8
1470 PRINT"
```

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1480 PRINT"CONNECT PET TO PRINTER,THEN TYPE ANY KEY"
1490 GET A$:IF A$="" THEN 1490
1500 A$=""
1510 PRINT"  "
1514 REM ____________________________________________________________
1515 REM DETERMINE IF PREVIOUSLY SELECTED BEAM IS DESIRED FOR NEXT CALCULATION
1516 REM
1520 PRINT"ENERGY (MEV) =",E
1530 PRINT"ELEMENT      =   ",BEAM$(L)
1540 PRINT"MASS (AMU) =   ",M:PRINT"CHARGE STATE = ",Q
1550 PRINT"HARMONIC =     ",H:PRINT"
1560 INPUT"IS THIS THE RIGHT BEAM (Y/N)";G$
1570 PRINT"  "
1580 IF LEFT$(G$,1)="Y" THEN 2230
1584 REM ____________________
1585 REM OFFER THE USER BEAM MENU
1586 REM
1590 PRINT"":PRINT"WHICH BEAM...?":PRINT" "
1600 PRINT" 1 PROTON            2 DEUTERONS"
1610 PRINT" 3 HELIUM-3          4 ALPHAS"
1620 PRINT" 5 LITHIUM-6         6 LITHIUM-7"
1630 PRINT" 7 BERYLLIUM-9       8 BERYLLIUM-10"
1640 PRINT" 9 BORON-10         10 BORON-11"
1650 PRINT"11 CARBON-12        12 CARBON-13"
1660 PRINT"13 CARBON-14        14 NITROGEN-14"
1670 PRINT"15 NITROGEN-15      16 OXYGEN-16"
1680 PRINT"17 OXYGEN-17        18 OXYGEN-18"
1690 PRINT"19 FLUORINE-19      20 NEON-20"
1700 PRINT"21 NEON-21          22 NEON-22"
1710 PRINT"23 SODIUM-23        24 MAGNESIUM-24"
1720 PRINT"25 MAGNESIUM-25     26 MAGNESIUM-26"
1730 PRINT"27 ALUMINUM-27      28 SILICON-28"
1740 PRINT"29 SILICON-29       30 SILICON-30"
1750 PRINT"31 PHOSPHOROUS-31   32 SULFUR-32"
1760 PRINT"33 SULFUR-33        34 SULFUR-34"
1770 PRINT"35 SULFUR-36        36 CHLORINE-35"
1780 PRINT"37 CHLORINE-36      38 CHLORINE-37"
1790 PRINT"39 ARGON-36         40 ARGON-38"
1800 PRINT"41 ARGON-40         42 CALCIUM-40"
1810 PRINT"43 MOLECULAR IONS   44 OTHER"
1820 INPUT L:LS=L
1830 IF L<=44 AND L>=1 AND INT(L)=L THEN 1850
1840 PRINT"IMPROPER ENTRY, TRY AGAIN...":GOTO 1590
1850 IF L<>43 THEN 1900
1860 PRINT"WHICH MOLECULAR ION...":PRINT""
1870 PRINT"1 H2 +          2 H3 +":PRINT"3 D2 +          4 D3 +"
1880 PRINT"5 DH +          6 DH2 +":PRINT"7 D2H +"
1890 INPUT L:L=L+42:GOTO1940
1900 IF L<>44 THEN 1940
1910 L=56:INPUT"ATOMIC NUMBER Z=";Z(L)
1920 INPUT "MASS (AMU) =";A(L)
1930 INPUT "ELEMENT NAME =";BEAM$(L)
1940 M=INT(A(L)+.5):PRINT"
1950 INPUT"ENERGY (MEV)      ";E
1960 Q=1:IF LS<3 OR LS=43 THEN 2120
1970 Q=INT((A(L)*E/141)^.5)+1
1980 QT=INT((A(L)*E/161)^.5)+1
1990 IF Q>Z(L) THEN 2020
2000 PRINT"LOWEST CHARGE STATE (K=140) =",Q
2010 INPUT"OK (Y/N)";G$:IF LEFT$(G$,1)="Y" THEN 2120
```

```
2020 IF QT>Z(L) THEN 2090
2030 Q=QT
2040 PRINT"LOWEST CHARGE STATE (K=160) =",Q
2050 INPUT"OK (Y/N)";G$:IF LEFT$(G$,1)="Y" THEN 2120
2060 INPUT"CHARGE STATE     ";Q
2070 IF Q>Z(L) THEN 1840
2080 GOTO 2120
2090 Q=Z(L)
2100 PRINT"LOWEST CHARGE STATE =",Q
2110 INPUT"OK (Y/N)";G$:IF LEFT$(G$,1)="N" THEN 2060
2120 H=1
2130 F=H*YZ*(1-(1+E/(A(L)*VM-Q*ME))^-2)^.5
2140 IF F>5.5ANDF<16.5THEN2170
2150 H=H+2:IF H>15THEN2200
2160 GOTO 2130
2170 PRINT"LOWEST HARMONIC =",H
2180 INPUT"OK (Y/N)";G$
2190 IF LEFT$(G$,1)="Y" THEN 2220
2200 INPUT "HARMONIC NO. ";H
2204 REM ____________________________________________
2205 REM BEGIN CALCULATING CYCLOTRON SETTINGS
2206 REM
2210 F=H*YZ*(1-(1+E/(A(L)*VM-Q*ME))^-2)^.5:FS=F
2220 HS=H
2230 IF F>16.5THENPRINT")_)_ FREQUENCY TOO HIGH )_)_":GOTO 2260
2240 IF F>5.6ANDF<16.1 THEN 2260
2250 PRINT"&&& CAUTION &&& FREQUENCY NEAR LIMIT OF                    RF SYSTEM"
2260 F=H*YZ*(1-(1+E/(A(L)*VM-Q*ME))^-2)^.5:FS=F
2270 PRINT" ":PRINT E;"MEV ";BEAM$(L);" ";Q;"+";      HARM =";H
2280 PRINT" ":PRINT"FREQUENCY = ";
2290 F=H*YZ*(1-(1+E/(A(L)*VM-Q*ME))^-2)^.5
2300 PRINT F;" MHZ"
2310 BRHO=ZZ*(E*E+2*(A(L)*VM-Q*ME)*E)^.5/Q
2320 X=E/M:Y=Q/M:SA=1
2330 KX=X*Y^-2
2340 PRINT"":PRINT"SEARCHING FOR CYC. SETTINGS"
2344 REM ____________________________________________________________
2345 REM DETERMINE IF REQUESTED BEAM FALLS TO THE LEFT OF THE GRID
2346 REM (SEARCH ALGORITHM NO. 2)
2347 REM
2350 IF Y<.125 AND KX>=55 THEN 2750
2360 IF Y<.166 AND KX<55 THEN 2670
2364 REM ____________________________________________
2365 REM INITIATE SEARCH ALGORITHM NO. 1
2366 REM 2370-2440 BRACKET REQUESTED BEAM FROM THE LEFT
2367 REM
2370 I=28:T10=21:BR(1)=27:I10=20:DOA=.001
2380 IF RR=1 THEN DOA=-.001
2390 I=I-1
2400 IF SGN(EA(NC(I)))=SGN(EA(NC(I+1)))THEN T10=T10-1:GOTO 2420
2410 T10=T10-.5
2420 IF OA(I)-DOA>=Y THEN 2450
2430 IF KX>=LK(I) THEN BR(1)=I:I10=T10
2440 GOTO 2390
2444 REM ____________________________________________
2445 REM 2450-2510 BRACKET REQUESTED BEAM FROM THE RIGHT
2446 REM
2450 I=0:T20=0:BR(2)=1:I20=1
2460 I=I+1
2470 IF SGN(EA(NC(I)))=SGN(EA(NC(I-1))) THEN T20=T20+1:GOTO 2490
2480 T20=T20+.5
```

```
2490 IF QA(I)+DQA<=Y THEN 2520
2500 IF KX>=LK(I) THEN BR(2)=I:I20=T20
2510 GOTO 2460
2514 REM ____________________________________________________
2515 REM 2520-2650 BRACKET REQUESTED BEAM FROM ABOVE AND BELOW
2516 REM ____________ CALCULATE FIGURES OF MERIT FR & FS ____
2517 REM
2520 I=1
2530 J=NC(BR(I))-1
2540 J=J+1
2550 DN(I)=(J-NC(BR(I)))*(J-NC(BR(I)+1))
2560 IF J=NC(BR(I)+1) THEN 2600
2570 K=ABS(EA(J))*QA(BR(I))^-2
2580 N(I)=J:IN(I)=J-NC(BR(I))+1
2590 IF KX>K THEN 2540
2600 GOSUB 4350
2610 IF DN(I)=0 THEN 2630
2620 I=I+2:N(I)=N(I-2)-1:BR(I)=BR(I-2):GOSUB 4350
2630 IF BR(1)<>BR(2) AND (I=1 OR I=3) THEN I=2:GOTO 2530
2640 RR=0
2650 IF BR(1)=BR(2) AND N(1)=NC(BR(1)) THEN RR=1
2660 GOTO 2830
2664 REM ____________________________________________
2665 REM DETERMINE INDEX NO. FOR SEARCH ALGORITHM NO. 2
2666 REM
2670 FOR J=345TO349
2680 K=ABS(EA(J))*(QA(25))^-2
2690 IFKX>K THENNEXTJ
2700 IF J>349 THEN J=349
2710 W=EA(J-1)*(QA(25))^-2
2720 IF(K-KX)< ABS(KX-W)THEN 2740
2730 DX$(1)=STR$(190+.01*(J-345)):GOTO3020
2740 DX$(1)=STR$(190+.01*(J-344)):GOTO 3020
2750 FOR J=365TO377
2760 K=ABS(EA(J))*(QA(27))^-2
2770 IFKX>K THENNEXTJ
2780 IF J>377 THEN J=377
2790 W=EA(J-1)*(QA(27))^-2
2800 IF(K-KX)< ABS(KX-W)THEN 2820
2810 DX$(1)=STR$(200+.01*(J-365)):GOTO3020
2820 DX$(1)=STR$(200+.01*(J-364)):GOTO 3020
2824 REM ____________________________
2825 REM PRINT OUT INDEX NUMBERS ON SCREEN
2826 REM
2830 IF RR=1 THEN 2860
2840 PRINT" ":PRINT"INDEX #'S ARE...":PRINT""
2850 PRINT"INDEX #";TAB(10);"SOLN #";TAB(20);"FR";TAB(29);"FS":PRINT""
2860 DX$(1)=STR$(10*I10+.01*IN(1)):DX$(2)=STR$(10*I20+.01*IN(2))
2870 IF RR=1 THEN DX$(6)=DX$(1):IF BR(1)=1 OR BR(2)= 27 THEN RR=1:GOTO 2370
2880 DX$(3)=STR$(10*I10+.01*(IN(1)-1)):DX$(4)=STR$(10*I20+.01*(IN(2)-1))
2890 FOR I=1TO6:IF LEFT$(RIGHT$(DX$(I),2),1)="." THEN DX$(I)=DX$(I)+"0"
2900 NEXT I
2910 FORJ=1TO4:FR(J)=.001*INT(1000*FR(J)):FS(J)=.001*INT(1000*FS(J)):NEXTJ
2920 IF ABS(FS(1))>1 THEN 2950
2930 PRINT DX$(1);TAB(10);N(1);TAB(18);FR(1);TAB(27);FS(1)
2940 IF RR=1 THEN RR=1:GOTO 2370
2950 IF DN(1)=0 OR ABS(FS(3))>1 THEN 2970
2960 PRINT DX$(3);TAB(10);N(3);TAB(18);FR(3);TAB(27);FS(3)
2970 IF BR(1)=BR(2) THEN 3020
2980 IF ABS(FS(2))>1 THEN 3000
2990 PRINT DX$(2);TAB(10);N(2);TAB(18);FR(2);TAB(27);FS(2)
3000 IF DN(2)=0 OR ABS(FS(4))>1 THEN 3020
3010 PRINT DX$(4);TAB(10);N(4);TAB(18);FR(4);TAB(27);FS(4)
```

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3014 REM ____________________________________________
3015 REM BEGIN HARD COPY PRINTOUT OF CYCLOTRON SETTINGS
3016 REM
3020 OPEN 4,4,1:CMD 4
3030 IF LEFT$(RIGHT$(DX$(1),2),1)="." THEN DX$(1)=DX$(1)+"0"
3040 PRINT#4,"CYCLOTRON SETTINGS FOR";E;" MEV ";BEAM$(L);Q;"+"
3050 PRINT#4," "
3054 REM ____________________________________
3055 REM CALCULATE DVM SETTING FOR RESONATOR PANELS
3056 REM
3060 DV=3454.45588-2588.12*F+788.200521*F^2-127.762457*F^3+12.0524011*F^4
3070 DV=DV-.665679489*F^5+.0200027251*F^6-2.52851401E-4*F^7
3080 PRINT#4,"FREQUENCY=";INT(1E4*F)/1E4;" MHZ    ";
3090 PRINT#4,"( RES PANELS - D.V.M.=";INT(DV*100)/100;"* )"
3094 REM ____________________
3095 REM CALCULATE DEE VOLTAGE
3096 REM
3100 DV=.07
3110 NT=E/(2*Q*DV)
3120 IF NT>=50 THEN 3150
3130 DV=E/(100*Q)
3140 IF DV<.02 THEN DV=.02
3150 DC=1000*DV
3160 GOSUB 4520
3170 PRINT#4,"DEE VOLTS=";DC;"* KV":B=BRHO
3174 REM ____________________________
3175 REM CALCULATE MAIN MAGNET CURRENT
3176 REM
3180 MN=-3.36763141E-16*B^7+9.188321E-13*B^6-9.624233E-10*B^5+5.18654E-7*B^4
3190 MN=-1.51574E-4*B^3+.02260*B^2+1.0070*B+.0267+MN
3200 IF Y>=.125 AND KX>=55 OR Y>=.166 THEN 3240
3210 DX$(5)=DX$(1):CS=2
3214 REM_____________________________________________
3215 REM FETCH TRIM COIL VALUES FROM DISK VIA ALGORITHM NO. 2
3216 REM
3220 GOSUB 4600
3230 GOTO 3650
3234 REM ____________________________________
3235 REM DETERMINE WHICH TRIM COIL SOLUTION TO RECOMMEND
3236 REM
3240 SV=FR(1)
3250 IF DN(1)=0 THEN 3270
3260 IF FR(3)<SV THEN SV=FR(3)
3270 IF BR(1)=BR(2) THEN 3310
3280 IF FR(2)<SV THEN SV=FR(2)
3290 IF DN(2)=0 THEN 3310
3300 IF FR(4)<SV THEN SV=FR(4)
3310 IF SV>=.2 THEN 3370
3320 IF SV=FR(1) THEN I=1:GOTO 3490
3330 IF DN(1)=0 THEN 3350
3340 IF SV=FR(3) THEN I=3:GOTO 3490
3350 IF SV=FR(2) THEN I=2:GOTO 3490
3360 I=4:GOTO 3490
3370 SS=ABS(FS(1))
3380 IF DN(1)=0 THEN 3400
3390 IF ABS(FS(3))<SS THEN SS=ABS(FS(3))
3400 IF BR(1)=BR(2) THEN 3440
3410 IF ABS(FS(2))<SS THEN SS=ABS(FS(2))
3420 IF DN(2)=0 THEN 3440
3430 IF ABS(FS(4))<SS THEN SS=ABS(FS(4))
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3440 IF SS=ABS(FS(1)) THEN I=1:GOTO 3490
3450 IF DN(1)=0 THEN 3470
3460 IF SS=ABS(FS(3)) THEN I=3:GOTO 3490
3470 IF SS=ABS(FS(2)) THEN I=2:GOTO 3490
3480 I=4
3490 IS=I
3494 REM ____________________________________________
3495 REM DETERMINE IF SEARCH ALGORITHM NO. 3 IS REQUIRED
3496 REM
3500 IF BRHO<400 AND ABS(FS(IS))>1 GOTO 3540
3510 DX$(5)=DX$(I):CS=1
3514 REM ____________________________________________________
3515 REM FETCH TRIM COIL VALUES FROM DISK VIA SEARCH ALGORITHM NO. 1
3516 REM
3520 GOSUB 4600
3530 GOTO 3650
3534 REM ____________________________
3535 REM INITIATE SEARCH ALGORITHM NO. 3
3536 REM
3540 CS=3
3550 IF E/M>=31/6 THEN DX$(5)=" 10.01":J=1:GOSUB 4600
3560 IF E/M>=35/12 AND E/M<31/6 THEN DX$(5)=" 20.01":J=2:GOSUB 4600
3570 IF E/M>=25/12 AND E/M<35/12 THEN DX(5)$=" 30.01":J=3:GOSUB 4600
3580 IF E/M>=35/24 AND E/M<25/12 THEN DX$(5)=" 130.01":J=4:GOSUB 4600
3590 IF E/M>=139/120 AND E/M<35/24 THEN DX$(5)=" 160.01":J=5:GOSUB 4600
3600 IF E/M>=5/6 AND E/M<139/120 THEN DX$(5)" 180.01":J=6:GOSUB 4600
3610 IF E/M<5/6 THEN DX(5)$=" 190.01":J=7:GOSUB 4600
3620 FOR I=1TO17
3630 TR(I)=INT(TR(I)*BRHO/RB(J)+.5)
3640 NEXT I
3644 REM ____________________________________________________________
3645 REM CORRECT MAIN MAGNET CALCULATION FOR TRIM COIL 17 CONTRIBUTION
3646 REM CALCULATE RECOMMENDED RANGE FOR MAIN MAGNET CURRENT SEARCH
3647 REM
3650 MM=MM-.05*TR(17):MD=.01*MM+5
3660 PRINT#4,"MAIN MAGNET CURRENT=";INT(MM);"* AMPS    (";INT(MM-MD);" -";
3670 PRINT#4,INT(MM+MD);" )"
3680 GOSUB 4520
3690 PRINT#4," "
3694 REM ____________________________________________________
3695 REM PRINT OUT RECOMMENDED TRIM COIL VALUES AND INDEX NUMBERS
3696 REM
3700 PRINT#4,"    RECOMMENDED TRIM COIL SOLUTION"
3710 IF DX$(6)=" 10.01" OR DX$(6)=" 200.01" THEN 3740
3720 IFRP=1THENPRINT#4,"    (INDEX #";DX$(6);" MAY BE PREFERABLE TO SOLUTION";
3730 IF RP=1 THEN PRINT#4," GIVEN BELOW; CHECK PET SCREEN.)"
3740 PRINT#4," "
3750 PRINT#4," TRIM COIL SETTINGS"
3760 GOSUB 4520
3770 PRINT#4,"     COIL/AMPS";
3780 IF CS=1 THEN PRINT#4,"            INDEX #    SOLN #       FR          FS"
3790 IF CS>1 THEN PRINT#4," "
3800 GOSUB 4520
3810 PRINT#4,"-----------------------------------------------------------------"
3820 GOSUB 4520
3830 IF CS=2 THEN PRINT#4,TAB(30);"USE INDEX #";DX$(1)
3840 I=IS
3850 IFCS=1THEN PRINT#4,TAB(25);DX$(I);"      ";N(I);"      ";FR(I);"      ";FS(I)
3860 GOSUB 4520
3870 IF L=1ANDE<7THENPRINT#4,TAB(32);"SEE LOG BOOK 6/8/76 DWL"
3880 IF CS=3 THEN PRINT#4,TAB(25);"USE SCALED SOLUTION, INDEX # ";DX$(5)
3890 GOSUB 4740
```

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3894 REM ------------------------------------
3895 REM PRINT OUT VALLEY COIL PARAMETERS
3896 REM
3900 PRINT#4," ":PRINT#4," "
3910 PRINT#4,TAB(16);"VALLEY COILS◆":RP=0
3920 GOSUB 4520
3930 PRINT#4,TAB(16);"-------------"
3940 PRINT#4,"    COIL #                 1        2        3        4        5"
3950 PRINT#4,"    ------------------------------------------------------------"
3960 IF Q/M >=.5 THEN 4000
3970 PRINT#4,"      ANGLE(DEG)          90      310        -        -      120"
3980 PRINT#4,"      AMPS               200      100        -        -       50"
3990 GO TO 4020
4000 PRINT#4,"      ANGLE(DEG)          90        -        -        -      360"
4010 PRINT#4,"      AMPS                90        -        -        -        8"
4020 PRINT#4," ":PRINT#4," "
4024 REM ------------------------------------
4025 REM SELECT AND PRINT OUT CENTER REGION PARAMETERS
4026 REM
4030 IF H>1 THEN RN=1:GOTO 4070
4040 IF E/Q=<32.5 THEN RN=2:GOTO 4070
4050 IF E/Q=<50 THEN RN=3:GOTO 4070
4060 RN=4
4070 PRINT#4,TAB(16);"CENTER REGION"
4080 PRINT#4,"                          -------------"
4090 PRINT#4,"      RAD=";CR(RN,1):PRINT#4,"      AZI=";CR(RN,2)
4100 PRINT#4,"      ROT=";CR(RN,3):PRINT#4,"      P N/S=";CR(RN,4);"◆"
4110 PRINT#4,"      P E/W= ◆":PRINT#4," ":PRINT#4,"
4114 REM ------------------------------------
4115 REM SELECT AND PRINT OUT DEFLECTOR SETTINGS
4116 REM
4120 IF E/Q=<10 THEN RA=1:GOTO 4170
4130 IF E/Q=<32.5 THEN RA=2:GOTO4170
4140 IF E/Q=<47.5 THEN RA=3:GOTO4170
4150 IF E/Q=<62.5 THEN RA=4:GOTO4170
4160 RA=5
4170 FOR I=13TO15:DDD(QA,I)=DDD(RA,I)◆E/(Q◆32.5):NEXT I
4180 GOSUB 4520
4190 PRINT#4,"DEFLECTOR POSITIONS              DEFLECTOR VOLTS◆"
4200 GOSUB 4520
4210 PRINT#4,"-------------------              ---------------"
4220 PRINT#4,"      1) ";DDD(RA,1)
4230 PRINT#4,"      2) ";DDD(RA,2);"                          ENTRANCE=";
4240 PRINT#4,INT(DDD(QA,13)◆10)/10;" KV"
4250 PRINT#4,"      3) ";DDD(RA,3):PRINT#4,"      4) ";DDD(RA,4)
4260 PRINT#4,"      5) ";DDD(RA,5)
4270 PRINT#4,"      6) ";DDD(RA,6);"                          MIDDLE=";
4280 PRINT#4,INT(DDD(QA,14)◆10)/10;" KV"
4290 PRINT#4,"      7) ";DDD(RA,7):PRINT#4,"      8) ";DDD(RA,8)
4300 PRINT#4,"      9) ";DDD(RA,9)
4310 PRINT#4,"     10) ";DDD(RA,10);"                          EXIT=";
4320 PRINT#4,INT(DDD(QA,15)◆10)/10;" KV"
4330 PRINT#4,"     11) ";DDD(RA,11):PRINT#4,"     12) ";DDD(RA,12)
4340 PRINT#4," ":PRINT#4," ":PRINT#4,"◆ OPTIMIZE AS REQUIRED":CLOSE 4:GOTO1350
4344 REM ------------------------------------
4345 REM SUBROUTINE TO CALCULATE FIGURES OF MERIT FR & FS
4346 REM
4350 C2=35.5616◆(QA(BR(I)))^4/(EA(N(I)))^2/H
4360 SRD=C2^2-.037037◆(QA(BR(I)))^6
4370 D=QA(BR(I))-Y
4380 IF SRD>0 THEN 4450
4390 CPHI=5.1962◆C2/(QA(BR(I)))^3
4400 PHI=ATN((1-CPHI^2)^.5/CPHI)
4410 IF D>0 THEN PHI=PHI-4◆
```

```
4420 EPB=1.155*(QA(BR(I)))*COS(PHI/3)
4430 IF D>0 THEN EPB=-EPB
4440 GOTO 4470
4450 SPD=SPD^.5
4460 EPB=(C2+SPD)^.333+(C2-SPD)^.333
4470 F1=-D/(EPB-QA(BR(I)))
4480 IF D>0 THEN F1=-F1
4490 F2=(KX*(QA(BR(I)))^2-ABS(EA(N(I))))/DEA(N(I))/ABS(EA(N(I)))
4500 FR(I)=(F1^2+F2^2)^.5:FS(I)=F1+F2
4510 RETURN
4514 REM ____________________________________________
4515 REM SUBROUTINE TO DELAY PROGRAM EXECUTION
4516 REM
4520 FOR V=1TO 500:NEXT V
4530 RETURN
4534 REM ____________________________________________
4535 REM SUBROUTINE TO FETCH TRIM COIL VALUES FROM DISK
4536 REM
4540 INPUT#15,EN$,EM$,ET$,ES$
4550 IF EN$="00" THEN RETURN
4560 CLOSE 4
4570 PRINT"ERROR ON DISK"
4580 PRINT EM$,EN$,ET$,ES$
4590 CLOSE 2:END
4600 PRINT"":PRINT"READING TRIM COILS FROM DISK":PRINT#15,"I1"
4610 SDX=DX:TS=SN:DX=VAL(DX$(5)):LN=INT(DX):LN$=STR$(LN):SN=INT(100*(DX-LN)+.5)
4620 D$="1: LINE"+LN$
4630 OPEN 2,8,2,D$+",S,R"
4640 GOSUB 4540
4650 FORJ=1TOSN:FOR I=1TO17
4660 INPUT#2,TR(I)
4670 RS=ST
4680 GOSUB 4540
4690 IF S=64 THEN CLOSE 2:END
4700 IF RS<>0 THEN PRINT"BAD DISK STATUS IS";RS:CLOSE 2: END
4710 NEXT I:NEXT J
4720 CLOSE 2
4730 RETURN
4734 REM ____________________________________________
4735 REM SUBROUTINE TO CHECK FOR T. C. SOLUTIONS WHICH HAVE NOT BEEN
4736 REM CALCULATED VIA CYDE
4737 REM
4740 FOR I=1TO17
4750 IF TR(I)<>0 THEN 4800
4760 NEXT I
4770 PRINT#4," THIS SOLUTION HAS NOT YET"
4780 PRINT#4,"      BEEN CALCULATED. CONSULT"
4790 PRINT#4,"      BEAM DEVELOPMENT GROUP.":RETURN
4794 REM ____________________________________________
4795 REM SUBROUTINE TO PRINT OUT TRIM COILS 1 THRU 9
4796 REM
4800 FOR I=1TO9
4810 GOSUB 4520
4820 PRINT#4,TAB(6);I;" ";TR(I)
4830 NEXT I
4834 REM ____________________________________________
4835 REM SUBROUTINE TO PRINT OUT TRIM COILS 10 THRU 17
4836 REM
4840 FOR I=10TO17
4850 GOSUB 4520
4860 PRINT#4,TAB(5);I;" ";TR(I)
4870 NEXT I
4880 RETURN
4890 END
```

APPENDIX A.1.b.: Symbols Used in MASTER

A (56)	•	Precise values for atomic masses (^{12}C = 12.000000)
	•	The mass of all stable or quasi-stable (e.g. ^{14}C) nuclides with $1 \leqslant Z \leqslant 18$ are read in from lines 300-390
	•	Other masses stored are ^{40}Ca (line 390), molecular ions H2, H3, D2, D3, DH, DH2, DZ2 (lines 390-410), and all stable isotopes of Krypton, often used as arc support gas.
	•	Any other mass can be read in from the keyboard (see lines 1810, 1920).
A $	•	Dummy variable used to delay program execution pending keyboard entry (see lines 1490, 1500).
B	•	Abbreviation for BRHO when used in long fromulae (e.g. line 3180, 3190).
Beam $ (56)	•	Identifies ionic species. Note that ALPHAS is an identifier of Helium -4 and is used for charge states of both 2+ and (inappropriately) 1+ (see lines 150-240).
BR (4)	•	The values of BR vary from 1 to 27 and represent the number of the Q/A = constant line on which each of the 4 braketing trim coil solutions lie. (In general BR(1) = B(3) and BR(2) = BR(4)).
	•	BR = 27 implies Q/A = 0.125. BR = 1 implies Q/A = 1.
	•	BR values are defined on lines 2370, 2430, 2500 and 2620.
BRHO	•	Magnetic rigidity calculated on line 2310 in KG-in.
CPHI	•	COSϕ (ref. 14,p.92).
	•	CPHI is a quantity used in solving a cubic equation for ε_b (see ref. 1, eqn. 15).
	•	Its value is determined in line 4390.

CR(4,4)	•	Matrix of center region paramenters in which four parameters (RAD, AZI, ROT, PN/S) are stored for each of four operating domains.
	•	see lines 440, 450.
CS	•	Assumes the values 1, 2 or 3 according to which alogrithm is adopted in determining the trim coil solution to recommend.
C2	•	A quantity used in solving a cubic equation for ϵ_b (see CPHI).
	•	C2 = C/2 in ref. 14.
D	•	D = Q/A (bracketing line) -Q/A (requested beam).
	•	See line 4370.
D$	•	Identifies file name when reading trim coil solutions from disk.
	•	See lines 4620, 4630.
DC	•	Dee voltage in kilovolts (line 3150).
DDD (5, 15)	•	Matrix of 15 dee voltage parameters (12 pos^n, +3 voltages) for each of 5 different operating domains.
	•	See lines 460-520.
DEA (378)	•	$\pm \frac{\Delta E/A}{E/A} = \frac{E_1 - E_o}{E_o}$; see lines 620-1330.
	•	For each beam on the grid, DEA represents the max. energy deviation at constant Q/A for which the trim coil solution is estimated to apply with no loss of beam intensity.
	•	e.g. from Appendix A4c, we see that a trim coil solution for 10 MeV protons will cover from 6.76 - 13.24 MeV with no predicted loss of intensity.
DN(4)	•	DN = 0 if lowest or highest point on a Q/A = constant line is being considered, otherwise DN $\neq$ 0.
	•	See line 2550
DQA	•	DQA = ±0.001 (see lines 2370, 2380).

	•	Defines "width" of a Q/A line. e.g. the line no.27 has Q/A = 0.125 ± 0.001. Any Q/A within this window is treated as being co-linear with the grid lne.
DV	•	Used in line 3060, 3070 to calculate the DVM setting for RF resonance panels.
	•	Used in line 3100-3140 to calculate dee voltage in millions of volts.
DX	•	Index number e.g. 190.05 (see line 4610).
DX $	•	String representation of index number.
E	•	Total kinetic energy of ion in MeV.
EA(378)	•	Kinetic energy per nucleon for each beam on the grid (MeV/amu)
	•	See lines 620-1330; negative entries signify the lowest energy entry on a line whose index number ends in "5".
EM $	•	Disk-status variable for error messages. See CBM disk manual, pp. 31-35.
EN $	•	See EM $.
EPB	•	EPB = ε_b is that value of Q/A which represents the max. deviation from the Q/A of the grid point under consideration to which its trim coil solution can be stretched at constant BRHO without loss of beam.
	•	See ref. 1 (eqn. 15).
ES $	•	See EM $
ET $	•	See EM $
F	•	RF frequency
FL	•	Flag which determines which of the 6 user options has been selected: BRHO, FREQUENCY, PRE RUN, RESONANCE TABLE or CYC. SETTINGS.
FR (4)	•	For each of the 4 bracketing grid points, FR and FS are two figures of merit which determine how far the requested beam is "stretched" from a grid point.
	•	See line 4500 of MASTER and section 3.545 of text.

FS (4)	•	See FR (4). FS = 1.0 implies max stretch. FS < 1 must be satisfied if T.C. solution is acceptable.
F1	•	F1 is a quantity which represents the fraction of max. stretch (at const BRHO) between the Q/A of the grid point and the Q/A of the requested beam.
	•	See section 3.545 of text and line 4470 of MASTER
F2	•	F2 is a quantity which represents the fraction of max. stretch at const. Q/A.
	•	See section 3.545 of text and line 4490 of MASTER.
G$	•	Used to input "yes/no" answers from keyboard.
H	•	Harmonic number.
HS	•	Saves the harmonic number so H can be varied in search loops and subsequently retrieved via H = HS.
I	•	General purpose indexing variable.
IN(2)	•	Gives the number of the grid point along each of the 2 bracketing Q/A lines.
	•	IN (2) = 1 corresponds to the lowest energy point on the line which brackets on the right. IN (1) = 1 corresponds to the lowest energy point on the line which brackets on the left.
IS	•	Used from lines 3490 - 3840 to save the value of the index number I.
	•	It specifies which of the four bracketing grid points is currently under consideration.
I1Q	•	I1Q is equal to $1/10^{th}$ of the Q/A line no. which brackets the requested beam on the left.
I2Q	•	Same as I1Q, except with reference to Q/A line which brackets on the right.
J	•	General purpose indexing variable
	•	In lines 2540 and following, it is used to index the solution number.
K	•	Specifies the K-value of grid points
	•	$K \alpha (BRHO)^2$

	•	See line 2680: $K = (E/A)/(Q/A)^2 = EA/Q^2$
KX	•	Specifies the K-value of the requested beam
L	•	Identifies the requested ion species (see line 1820).
LK(28)	•	The lowest value of K which can be run from the lowest E/A point on each Q/A line $LK = \frac{EA(1-DEA)}{(QA)^2}$
LN	•	Defined on line 4610 to be the integer part of the index number ≡ Q/A line number.
LN$	•	String representation of LN
LS	•	Saves the value of L (ion species) to permit a search loop on L and subsequent retrieval via L = LS.
M	•	Mass (amu) rounded to nearest integer.
MD	•	Estimated error on prediction of main magnet field to give search range (MM ± MD).
	•	Calc in line 3650.
ME	•	Electron rest mass = 0.51106 MeV (line 120).
MM	•	Calculated Main magnet current (line 3190)
MN	•	Used in line 3180 and 3190 in the calculation of MM.
N (4)	•	N(I) is the solution number of the four bracketing grid points (I = 1, 4).
NC(28)	•	The solution number of the lowest E/A point on each line.
NT	•	Number of turns (see line 3110).
PA	•	Indexes the 15 deflector parameters for each of 5 operating domains (line 460).
PHI	•	PHI ≡ ϕ; see CPHI.
PN	•	Used in line 440 to index the four center region parameters for each of four operating domains (parameter number)

Q	•	Charge state.
QA(28)	•	Charge to mass ratio Q/A for the grid lines.
QT	•	Used in lines 1980, 2020, 2030 to ensure that $Q \leqslant Z$.
RA	•	Used in line 460 to index the five operating domains for deflector settings.
RB(7)	•	BRHO of the lowest E/A points on seven selected Q/A lines which extend to low field values.
	•	It is used for BRHO scaling which is important for requested beams with BRHO < 400 kG - in when other search alogorithms fail to produce a trim coil solution.
	•	See line 280, 290.
RN	•	Used in line 440 to index the four sets of center region parameters (regime no.).
RP	•	RP = 1 signifies requested beam has a) Q/A = 1 or b) $Q/A \leqslant 0.125$ or c) has a Q/A which lies directly on a grid line AND an $E/A \leqslant$ lowest E/A on that grid line.
	•	Otherwise RP = 0
	•	See lines 2870, 2940
	•	Its purpose is to tell the program that the requested point cannot be bracketed in the normal way.
RR	•	RR = 1 signifies that the requested beam lies a) directly on a grid line and b) on or below the lowest E/A on that grid line.
	•	See line 2650
	•	It is case c) for RP = 1.
RS	•	Used in line 4670, 4700 to designate a disk error.
S	•	Used in lines 4630, 4690 to determine when a complete file has been read from disk.
	•	See file error 64 on p. 35 of CBM disk operating manual
SA	•	SA = 1 line 2320; used nowhere else in MASTER.

	•	Seems to serve no purpose (vestigial variable?).
SDX	•	Used in line 4610 SDX = DX (used nowhere else in MASTER).
SN	•	Calculated on line 4610.
	•	Determines the decimal part of the index number and converts it to an integer.
	•	It is the number along a given Q/A line of the index point (numbering from low E/A to high E/A.
	•	Used to select correct T.C. soln from disk.
SRD	•	A quantity used in solving the cubic eqn. (see CPHI). SRD ≡ surd meaning square root.
SS	•	Used in lines 3370 and following to determine which of bracketing points has smallest FS.
SV	•	Used in lines 3240 and following to determine which of bracketing points has smallest FR.
TC	•	TC = 1 implies MASTER has been re-accessed from PRE.
	•	Otherwise TC = 0.
TR(17)	•	Trim coil currents in amps (loaded from disk).
TS	•	TS = SN; See SN and line 4610
T1Q	•	T1Q is a temporary index which equal 1/10th of the integer part of the index number.
	•	Used for line which brackets from left.
	•	Similar to I1Q.
T2Q	•	Same as T1Q except for line which brackets from the right.
	•	Similar to I2Q.
V	•	Used in line 4520 to cause a pause in the execution of the program, usually to allow time for the silent 700 to complete a carriage return.
VM	•	VM = 931.478 = MeV/amu (line 120).
W	•	Used in 2710, 2720 as an alternate variable to K.

X	•	E/A of requested beam.
Y	•	Q/A of requested beam.
YZ	•	"Cox's constant" = 48.616 (line 120).
Z (56)	•	Atomic number (Z) of the beam (lines 300-430).
ZZ	•	Proportionality constant in calculating BRHO for units of kG-inch.
	•	ZZ = 1.3132653 (line 120).

APPENDIX A.2.a.: Listing of Subprogram PRE

```
1 REM 08/27/80
2 REM THIS IS THE PROGRAM 'PRE'
3 REM
100 PRINT"":PRINT"READING DATA"
110 FOR I=1TO55:READ BEAM$(I):NEXT I
120 DATA PROTONS,DEUTERONS,HELIUM-3,ALPHAS,LITHIUM-6,LITHIUM-7,BERYLLIUM-9
130 DATA BERYLLIUM-10,BORON-10,BORON-11,CARBON-12,CARBON-13,CARBON-14
140 DATA NITROGEN-14,NITROGEN-15,OXYGEN-16,OXYGEN-17,OXYGEN-18,FLOURINE-19
150 DATA NEON-20,NEON-21,NEON-22,SODIUM-23,MAGNESIUM-24,MAGNESIUM-25
160 DATA MAGNESIUM-26,ALUMINUM-27,SILICON-28,SILICON-29,SILICON-30
170 DATA PHOSPHOROUS-31,SULPHUR-32,SULPHUR-33,SULPHUR-34,SULPHUR-36
180 DATA CHLORINE-35,CHLORINE-36,CHLORINE-37,ARGON-36,ARGON-38,ARGON-40
190 DATA CALCIUM-40,H2,H3,D2,D3,DH,DH2,D2H,KRYPTON-78,KRYPTON-80,KRYPTON-82
200 DATA KRYPTON-83,KRYPTON-84,KRYPTON-86
210 IF PP<>1 THEN DIM CV$(19)
220 FOR C=1TO19:READCV$(C):NEXT C
230 DATA "01 (HLC)","02 (GHIORSO)","1A (D/S)","1B (MORETTO)","1B (RUBY)"
240 DATA "2 (RAMA)","2 (SCAT CHAMBER)","3B (BIO MED)","4A (HI RESOLUTION)"
250 DATA "4A (HI XMISSION)","4B (HI RESOLUTION)","4B (HI XMISSION)"
260 DATA "4C (HI RESOLUTION)","4C (HI XMISSION)"
270 DATA "5A (MULLER)","5A (STREAMER CHAM.)","5B (E-DET)","5B (YANO)"
280 DATA "5B (PARITY TGT.)"
290 IF PP=1 THEN 590
300 PP=1
304 REM
305 REM LOAD MATRIX OF MAGNET CURRENTS FOR 19 SETS OF BEAM LINE OPTICS
306 REM USING 104 MEV OXYGEN-16 4+ AS STANDARD BEAM
307 REM
310 DIM IR(19,11),MAG$(11),SL$(6),TV$(6)
320 FOR T=1TO19:FOR R=1TO11:READ IR(T,R):NEXT R: NEXT T
330 DATA 137.5,124.8,14.35,103.4,137.5,158.9,0,0,0,0,0
340 DATA 125.8,121.8,14.35,76.3,84.2,158.9,0,0,0,0,0
350 DATA 167,122.7,14.35,100,108,-7.4,0,0,0,0,0
360 DATA 172,129,14.35,98,114,53,0,0,0,0,0
370 DATA 162.9,120.9,14.35,131.7,181.2,53.0,0,0,0,0,0
380 DATA 161,137,9.73,140,102,49,48,-150,-179,0,0
390 DATA 167,148,9.73,143,109,13.4,16.4,93,95,0,0
400 DATA 141,125,4.708,101,89,188,0,0,0,0,0
410 DATA 116,97,4.708,71,81,80,72,-77,-91,916,-116
420 DATA 140.7,99.3,4.708,88.9,82,-63,-66,-106.7,-109.4,921,-121
430 DATA 0,0,0,0,0,0,0,0,0,0,0
440 DATA 139.8,111.5,4.85,101.7,100,71.5,66.6,-68.4,-76.9,916,228.8
450 DATA 116,97,4.708,71,81,62,59,-66,-75,916,650
460 DATA 140,110,4.835,101,102,-58,-45,62.3,68.6,919,671
470 DATA 141,122,4.835,52,68,0,0,0,0,0,0
480 DATA 138.8,117,4.835,41.1,37,0,0,0,0,0,0
490 DATA 131,109,0,3.4,0,0,0,0,0,0,0
500 DATA 121,90.3,0,57.1,43.3,0,0,0,0,0,0
510 DATA 125.4,92.5,0,21.3,23,678.5,166.6,0,0,0,0
520 PRINT"":GOTO 590
530 PRINT" "
534 REM
535 REM OFFER THE USER SIX BASIC OPTIONS
536 REM
540 PRINT"TYPE NUMBER OF DESIRED PROGRAM:":PRINT"  "
550 PRINT"1. BRHO          2. FREQUENCY"
560 PRINT"3. PRE RUN       4. ENERGY"
570 PRINT"5. RES. TABLE    6. CYC. SETTINGS"
```

```
580 INPUT FL
590 ON FL GOTO 650,720,1710,4090,3310
600 IF FL<>6 THEN 630
610 TC=1:PRINT"":PRINT"I AM PROCESSING YOUR REQUEST, PLEASE"
614 REM ____________________________________
615 REM CALL PROGRAM 'MASTER' FOR CYC. SETTINGS
616 REM
620 PRINT"BE PATIENT.":LOAD ":MASTER",8
630 PRINT"IMPROPER ENTRY, TRY AGAIN:"
640 GOTO 530
650 GOSUB 720
654 REM ____________________________
655 REM CALCULATE AND PRINT OUT BRHO
656 REM
660 BRHO=ZZ*(E*E+2*(A(L)*VM-Q*ME)*E)^.5/Q
670 IF FL=3 GOTO 1760
680 IFFL=5THENGOTO3350
690 PRINT" ":PRINT"BRHO=";BRHO;"KG-IN":PRINT"
700 IF FL=4 GOTO 4310
710 GOTO 530
714 REM ____________________________
715 REM SUBROUTINE TO SELECT DESIRED BEAM
716 REM
720 PRINT"  "
730 IF FL=4 THEN 750
734 REM ____________________________________________________
735 REM ASCERTAIN IF PREVIOUSLY SELECTED BEAM IS DESIRED FOR NEXT CALCULATION
736 REM
740 PRINT"ENERGY (MEV) =",E
750 PRINT"ELEMENT      =    ",BEAM$(L)
760 PRINT"MASS (AMU) =    ",M:PRINT"CHARGE STATE = ",Q
770 PRINT"HARMONIC =     ",H:PRINT"
780 INPUT"IS THIS THE RIGHT BEAM (Y/N)";G$
790 PRINT""
800 IF LEFT$(G$,1)="Y" AND FL=2 THEN 1510
810 IF LEFT$(G$,1)="Y" THEN 1560
814 REM ____________________________
815 REM OFFER BEAM MENU TO THE USER
816 REM
820 PRINT"":PRINT"WHICH BEAM...?":PRINT" "
830 PRINT" 1 PROTON            2 DEUTERONS"
840 PRINT" 3 HELIUM-3          4 ALPHAS"
850 PRINT" 5 LITHIUM-6         6 LITHIUM-7"
860 PRINT" 7 BERYLLIUM-9       8 BERYLLIUM-10"
870 PRINT" 9 BORON-10         10 BORON-11"
880 PRINT"11 CARBON-12        12 CARBON-13"
890 PRINT"13 CARBON-14        14 NITROGEN-14"
900 PRINT"15 NITROGEN-15      16 OXYGEN-16"
910 PRINT"17 OXYGEN-17        18 OXYGEN-18"
920 PRINT"19 FLUORINE-19      20 NEON-20"
930 PRINT"21 NEON-21          22 NEON-22"
940 PRINT"23 SODIUM-23        24 MAGNESIUM-24"
950 PRINT"25 MAGNESIUM-25     26 MAGNESIUM-26"
960 PRINT"27 ALUMINUM-27      28 SILICON-28"
970 PRINT"29 SILICON-29       30 SILICON-30"
980 PRINT"31 PHOSPHOROUS-31   32 SULFUR-32"
990 PRINT"33 SULFUR-33        34 SULFUR-34"
1000 PRINT"35 SULFUR-36        36 CHLORINE-35"
1010 PRINT"37 CHLORINE-36      38 CHLORINE-37"
1020 PRINT"39 ARGON-36         40 ARGON-38"
1030 PRINT"41 ARGON-40         42 CALCIUM-40"
1040 PRINT"43 MOLECULAR IONS 44 OTHER"
1050 INPUT L:LS=L
```

```
1060 IF L<=44 THEN 1080
1070 PRINT"IMPROPER ENTRY, TRY AGAIN...":GOTO820
1080 IF L<>43 THEN 1130
1090 PRINT"WHICH MOLECULAR ION...":PRINT""
1100 PRINT"1 H2 +          2 H3 +":PRINT"3 D2 +          4 D3 +"
1110 PRINT"5 DH +          6 DH2 +":PRINT"7 D2H +"
1120 INPUT L:L=L+42:LS=L:GOTO1170
1130 IF L<>44 THEN 1170
1140 L=56:LS=L:INPUT"ATOMIC NUMBER Z=";Z(L)
1150 INPUT"MASS (AMU) =";A(L)
1160 INPUT"ELEMENT =";BEAM$(L)
1170 AA=A(L)+.5
1180 M=INT(AA):PRINT"
1190 IF FL=4 THEN GOTO 1310
1200 INPUT"ENERGY (MEV)      ";E
1210 Q=1:IF L<3 OR L>=43 AND L<=49 THEN 1370
1220 Q=INT((A(L)*E/141)^.5)+1
1230 QT=INT((A(L)*E/161)^.5)+1
1240 IF Q>Z(L) THEN 1270
1250 PRINT"LOWEST CHARGE STATE (K=140) =",Q
1260 INPUT"OK (Y/N)";G$:IF LEFT$(G$,1)="Y" THEN 1380
1270 IF QT>Z(L) THEN 1340
1280 Q=QT
1290 PRINT"LOWEST CHARGE STATE (K=160) =",Q
1300 INPUT"OK (Y/N)";G$:IF LEFT$(G$,1)="Y" THEN 1380
1310 INPUT"CHARGE STATE     ";Q
1320 IF Q>Z(L) THEN 1070
1330 GOTO 1370
1340 Q=Z(L)
1350 PRINT"LOWEST CHARGE STATE =",Q
1360 INPUT"OK (Y/N)";G$:IFLEFT$(G$,1)="N" THEN 1310
1370 IFFL=4THEN1470
1380 H=1
1390 F=H*YZ*(1-(1+E/(A(L)*VM-Q*ME))^-2)^.5
1400 IF F>5.5ANDF<16.5THEN1430
1410 H=H+2:IF H>15THEN1470
1420 GOTO1390
1430 IF FL=1 THEN1490
1440 PRINT"LOWEST HARMONIC =",H
1450 INPUT"OK (Y/N)";G$
1460 IF LEFT$(G$,1)="Y" THEN 1490
1470 INPUT "HARMONIC NO. ";H
1480 F=H*YZ*(1-(1+E/(A(L)*VM-Q*ME))^-2)^.5:FS=F
1490 HS=H
1500 IFFL=4THEN1560
1510 IF F>16.5THENPRINT")_)_ FREQUENCY TOO HIGH )_)_":GOTO1560
1520 IF F>5.6ANDF<16.1 THEN1560
1530 PRINT"&&& CAUTION &&& FREQUENCY NEAR LIMIT OF                    RF SYSTEM"
1540 GOTO 1560
1550 RETURN
1560 IFFL<>5THEN1630
1570 PRINT"DO YOU WISH TO SPECIFY THE"
1580 INPUT"  RF FREQUENCY (Y/N)";G$
1590 IF LEFT$(G$,1)="N" THEN 1630
1600 PRINT"RF FREQUENCY (MHZ) =";
1610 INPUT F:FS=F
1620 E=(A(L)*VM-Q*ME)*((1/(1-(F/(H*YZ))^2))^.5-1):GOTO1640
```

```
1624 REM ____________________________________
1625 REM CALCULATE AND PRINT OUT FREQUENCY
1626 REM
1630 F=H+YZ+(1-(1+E/(A(L)+VM-Q+ME))^-2)^.5:FS=F
1640 ON FL GOTO 1650,1660,1650,4160,1650
1650 PRINT" ":PRINT E;" MEV ";BEAM$(L);Q;"+":GOTO 660
1660 PRINT" ":PRINT E;"MEV ";BEAM$(L);" Q=";Q;"+";"  HARM =";H
1670 PRINT" ":PRINT"FREQUENCY = ";
1680 F=H+YZ+(1-(1+E/(A(L)+VM-Q+ME))^-2)^.5
1690 PRINT F,"MHZ"
1700 PRINT"  ":GOTO 530
1710 J=0:FOR I=1TO6:SL$(I)="":TV$(I)="":NEXT I
1720 PR.NT"":PRINT"CONNECT PET TO PRINTER,THEN TYPE ANY KEY"
1730 GETS$:IF S$="" THEN 1730
1740 S$=""
1744 REM ____________________________________
1745 REM BEGIN PRE-RUN - SELECT CAVE AND OPTICS
1746 REM
1750 GOSUB 720
1760 PRINT"":PRINT"TYPE CAVE SELECTION...":PRINT"
1770 FOR C=1TO8:PRINT TAB(1);C;TAB(5);"CAVE";TAB(10);CV$(C):NEXT C
1780 PRINT"  9  CAVE 4A"
1790 PRINT" 10  CAVE 4B"
1800 PRINT" 11  CAVE 4C"
1810 FOR C=12TO16:PRINTC;TAB(5);"CAVE";TAB(10);CV$(C+3):NEXT C
1820 INPUT T
1830 IF T>11 THEN T=T+3:GOTO 1930
1840 IF T<9 THEN 1930
1850 PRINT" ":PRINT"PLEASE INDICATE (TYPE "1" OR "2"):":PRINT"
1860 PRINT"1) HIGH RESOLUTION                    2) HIGH TRANSMISSION"
1870 INPUT HI
1880 IF T=9 AND HI=2 OR T=10 AND HI=1 THEN T=T+1:GOTO 1910
1890 IF T=10 AND HI=2 OR T=11 AND HI=1 THEN T=T+2:GOTO 1930
1900 IF T=11 AND HI=2 THEN T=14
1910 IF T=11 THEN PRINT"":PRINT"OPTICS FOR CAVE 4B (HI RES.) HAVE NOT"
1920 IF T=11 THEN PRINT"YET BEEN DEVELOPED":GOTO 530
1930 F$="N"
1934 REM ____________________________________
1935 REM INQUIRE IF CAVE 3 STRIPPER FOIL IS TO BE USED
1936 REM
1940 IF Q=Z(L) GOTO 2010
1950 PRINT"
1960 IF T>8 AND T<15 THEN INPUT "IS CAVE 3 STRIPPERFOIL TO BE USED (Y/N)";F$
1970 PRINT" "
1980 IF LEFT$(F$,1)="Y" THEN INPUT "FINAL CHARGE STATE";QR
1990 IF QR<=Z(L) GOTO 2010
2000 PRINT" ":PRINT"FINAL CHARGE STATE MAY NOT EXCEED Z.":GOTO 1970
2004 REM ____________________________________
2005 REM ASSIGN MAGNET DESCRIPTORS, SLITS, AND TV INFORMATION
2006 REM (ACCORDING TO CAVE AND OPTICS REQUESTED)
2007 REM
2010 IF T>10 THEN TT=T-10:GOTO 2030
2020 ON T GOTO 2040,2040,2060,2080,2080,2120,2120,2160,2180,2180
2030 ON TT GOTO 2260,2260,2340,2340,2420,2420,2460,2470,2470
2040 MAG$(4)="QVOA":MAG$(5)="QVOB":MAG$(6)="  MB":TV$(1)="OZV11":TV$(2)="OZ01"
2050 TV$(3)="OZ02":GOTO 2490
2060 MAG$(4)="Q1A1A":MAG$(5)="Q1A1B":MAG$(6)="  M11":TV$(1)="OZV11"
2070 TV$(2)="OZV12":TV$(3)="OZ1A1":SL$(3)=" ASV1X..... MILS":GOTO 2490
2080 MAG$(4)="Q1B1A":MAG$(5)="Q1B1B":MAG$(6)="  M11":TV$(1)="OZV11"
2090 TV$(2)="OZV12":TV$(3)="OZ1B2":SL$(3)=" ASV1X ..... MILS"
```

```
2100 IF T=4 THEN 2490
2110 TV$(3)="QZ1B1":GOTO 2490
2120 MAG$(4)="QV2A":MAG$(5)="QV2B":MAG$(6)="Q21A":MAG$(7)="Q21B":MAG$(8)="Q22A"
2130 MAG$(9)="Q22B":TV$(1)="QZV2":TV$(2)="QZ21":TV$(3)="QZ22"
2140 SL$(3)=" ASV2X ...... MILS":IF T=6 THEN2490
2150 TV$(4)="S.C.":TV$(5)="S.G.":GOTO 2490
2160 MAG$(4)="Q31A":MAG$(5)="Q31B":MAG$(6)=" M32":TV$(1)="QZV3":TV$(2)="QZ3B1"
2170 GOTO 2490
2180 MAG$(4)="Q31A":MAG$(5)="Q31B":MAG$(6)="Q4A1A":MAG$(7)="Q4A1B"
2190 MAG$(8)="Q4A2A":MAG$(9)="Q4A2B":MAG$(10)=" M41":MAG$(11)=" M43"
2200 TV$(1)="QZV3":TV$(2)="PHV3":TV$(3)="QZ3A1":TV$(4)="QZ41":TV$(5)="QZ42"
2210 TV$(6)="S.C.":SL$(3)=" AS3A1 ..... MILS"
2220 SL$(4)=" AS3A2 - OUT (MIN. D.V.M.)":SL$(5)=" AS41 ..... MILS"
2230 IF T=9 THEN 2490
2240 SL$(3)=" AS3A1 - OUT (MIN. D.V.M.)":SL$(4)=" AS3A2 ..... MILS"
2250 TV$(3)="QZ3A2":GOTO 2490
2260 MAG$(4)="Q31A":MAG$(5)="Q31B":MAG$(6)="Q4B1A":MAG$(7)="Q4B1B"
2270 MAG$(8)="Q4B2A":MAG$(9)="Q4B2B":MAG$(10)=" M41":MAG$(11)=" M43"
2280 TV$(1)="QZV3":TV$(2)="QZ3A1":TV$(3)="QZ41":TV$(4)="QZ42":TV$(5)="FIL PIS"
2290 TV$(6)="SCALE":SL$(3)=" AS3A1 ..... MILS"
2300 SL$(4)=" AS3A2 - OUT (MIN. D.V.M.)":SL$(5)=" AS41 ..... MILS"
2310 IF T=11 GOTO2490
2320 TV$(2)="QZ3A2":SL$(3)=" AS3A1 - OUT (MIN. D.V.M.)"
2330 SL$(4)=" AS3A2 ..... MILS":GOTO 2490
2340 MAG$(4)="Q31A":MAG$(5)="Q31B":MAG$(6)="Q4C1A":MAG$(7)="Q4C1B"
2350 MAG$(8)="Q4C2A":MAG$(9)="Q4C2B":MAG$(10)=" M41":MAG$(11)=" M43"
2360 TV$(1)="QZV3":TV$(2)="PHV3":TV$(3)="QZ3A1":TV$(4)="QZ41":TV$(5)="QZ42"
2370 TV$(6)="S.C.":SL$(3)="AS3A1 ..... MILS"
2380 SL$(4)=" AS3A2 - OUT (MIN. D.V.M.)":SL$(5)=" AS41 ..... MILS"
2390 IF T=13 GOTO2490
2400 TV$(3)="QZ3A2":SL$(3)=" AS3A1 - OUT (MIN. D.V.M.)"
2410 SL$(4)=" AS3A2 ..... MILS": GOTO 2490
2420 MAG$(4)="Q5A1A":MAG$(5)="Q5A1B":TV$(1)="QZV5A":TV$(2)="QZ5A1"
2430 SL$(3)="ASV5A ..... MILS"
2440 IF T=14 THEN TV$(3)="IR CAM."
2450 GO TO 2490
2460 MAG$(4)="MC1R":GOTO 2490
2470 MAG$(4)="Q5B1A":MAG$(5)="Q5B1B":TV$(1)="QZ5B1":IF T=16 THEN 2490
2480 MAG$(6)="MB5B1":MAG$(7)="SOL."
2484 REM ____________________________
2485 REM INITIATE PRE-RUN SHEET PRINTOUT
2486 REM
2490 PRINT" ":OPEN 4,4,1:CMD 4
2500 PRINT#4,"RUN DATE ........ TIME ...... :EXPT'R ...........";
2510 PRINT#4,"REQ INT ..........":PRINT#4,"
2520 PRINT#4,"   ";E;" MEV  ";BEAM$(L);"    ";Q;" +    ";"CAVE ";CV$(T);
2530 PRINT#4,"   SUGGESTED CYC REF........."
2540 PRINT#4,"..............................................................";
2550 PRINT#4,"......................":PRINT#4," "
2560 GOSUB 4350
2570 PRINT#4,"MAG";
2580 PRINT#4,"       AMPS";TAB(26);"SLITS":PRINT#4," "
2590 MAG$(1)="QS1A":MAG$(2)="QS1B":MAG$(3)="MS "
2600 SL$(1)="     X COLL  POS..... WID....."
2610 SL$(2)="     Y COLL   TOP..... BOT....."
```

```
2614 REM ____________________________________________________
2615 REM SCALE AND PRINT OUT MAGNET CURRENTS AND NMR FREQUENCY
2616 REM
2620 FOR J=1TO11:SS=SGN((-1)^J)
2630 IF LEFT$(F$,1)="Y" AND J=6 THEN GOSUB 4410
2640 CUR=(BRHO/578.932988)*IR(T,J)
2650 IF T>2 OR J<6 OR CUR<125 THEN 2680
2660 BMB=BRHO/45
2670 CUR=3180.9-1007.2*BMB+121.65*BMB^2-6.4319*BMB^3+.1279811*BMB^4
2680 IF T=6 AND J>7 THEN CUR=2*Q*CUR/Z(L)
2690 IF J<>3 OR T>16 THEN 2720
2700 CUR=-25.69+31.91*CUR-4.5607*CUR^2+.6071*CUR^3-.03871*CUR^4+.0009859*CUR^5
2710 IF (T=15 OR T=16) AND J=3 THEN CUR=-CUR
2720 IF T=19 AND J=7 THEN GOSUB 4370
2730 CUR=.1*(INT(10*CUR+.5))
2740 IF CUR=0 AND J<>3 THEN 2840
2750 IF SS>0 THEN 2810
2760 IF LEFT$(F$,1)="Y" AND J=5 THEN 2780
2770 PRINT#4," ";MAG$(J);"     ";CUR;TAB(16);SL$((J+1)/2):GOTO 2840
2780 PRINT#4," ";MAG$(J);"     ";CUR;"       ";Q;"+          ";SL$(3)
2790 GOSUB 4350
2800 PRINT#4,"-------------------------":GOTO 2870
2810 IF LEFT$(F$,1)="Y" AND J=6 THEN 2830
2820 PRINT#4,MAG$(J);"     ";CUR:GOTO 2840
2830 PRINT#4,MAG$(J);"     ";CUR;"       ";QR;"+"
2840 IF T<>6 OR J<7 THEN 2870
2850 IF ABS(CUR)<286 THEN 2870
2860 PRINT#4,"QUAD CURRENT TOO HI FOR P/S!!!!!"
2870 NEXT J
2880 IF T<9 OR T>14 THEN 2910
2890 NMR=BRHO/18.779756
2900 PRINT#4,"      M41 NMR =";NMR;"    MHZ"
2910 PRINT#4,"":PRINT#4,"":PRINT#4,"TV CAMERAS";TAB(20);"SPECIAL INSTRUCTIONS"
2920 PRINT#4," ":X=0
2924 REM ____________________________
2925 REM PRINT OUT SPECIAL MESSAGES
2926 REM
2930 FOR X=1TO6
2940 GOSUB 4350
2950 IF TV$(X)="" THEN 3230
2960 IF T=18 AND X=3 THEN 3230
2970 IF X>2 AND (T<9 OR T>14) THEN 3210
2980 IF X=1 AND (T<8 OR T>14) THEN 3210
2990 IF X=2 AND (T=8 OR T>16) THEN 3210
3000 IF X=2 AND T>10 AND T<15 THEN 3210
3010 IF(X=3 OR X=4) AND LEFT$(F$,1)="N" THEN 3210
3020 IF X=5 AND T<>9 AND T<>10 AND T<>13 AND T<>14 THEN 3210
3030 PRINT#4,TV$(X),".......";
3040 IF X=1 AND T>8 THEN PRINT#4,TAB(10);"DEGAUSS M32"
3050 IF X=1 AND T=8 THEN PRINT#4,TAB(10);"DISCONNECT M32 DEGAUSSING P/S"
3060 IF X=2 THEN PRINT#4,TAB(10);"CONNECT MC P.S. BEHIND RACK A10"
3070 IF X=3 THEN PRINT#4,TAB(10);"USE STRIPPER FOIL";
3080 IF T=9 OR T=11 OR T=13 THEN 3100
3090 IF X=3 THEN PRINT#4," CLOSEST TO QZ3A2":GOTO 3220
3100 IF X=3 THEN PRINT#4," CLOSEST TO QZ3A1"
3110 IF X=4 THEN PRINT#4,TAB(10);"STRIPPER FOIL NEAREST";
3120 IF T=9 OR T=11 OR T=13 THEN 3140
3130 IF X=4 THEN PRINT#4," QZ3A1 MUST BE OUT":GOTO 3220
3140 IF X=4 THEN PRINT#4," QZ3A2 MUST BE OUT":GOTO 3220
3150 IF X=5 THEN PRINT#4,TAB(10);"NOTE POLARITY OF ALL Q4A QUADS"
3160 IF X=6 THEN PRINT#4,TAB(10);"NOTE LOCATION OF TV AT";
3170 IF T=9 OR T=11 OR T=13 THEN 3190
```

```
3180 IF X=6 THEN PRINT#4," QZ3A2, NOT QZ3A1":GOTO 3220
3190 IF X=6 THEN PRINT#4," QZ3A1, NOT QZ3A2"
3200 GOTO 3220
3210 PRINT#4,TV$(X),"........"
3220 NEXT X
3230 IF T=15 OR T=16 OR T=18 THEN PRINT#4,TAB(30);"CONNECT MC P.S. BEHIND"
3240 IF T=15 OR T=16 OR T=18 THEN PRINT#4,TAB(34);"RACK A10 AND IN CAVE 5"
3250 IF E/Q=<65 THEN 3270
3260 PRINT#4,TAB(30);"USE T.C. 14 UNBALANCE"
3270 IFL=5ORL=6ORL=7ORL=9ORL=10ORL=18ORL=22ORL=24ORL=25ORL=26ORL=12 THEN 3290
3280 GOTO 3300
3290 PRINT#4,TAB(30);"USE NITROGEN FOR AUX. ARC SUPPORT GAS""
3300 FOR J=1TO5:PRINT#4,"":NEXT J:CLOSE 4:GOTO 3350
3310 PRINT"":PRINT"CONNECT PET TO PRINTER,THEN TYPE ANY KEY"
3320 GETS$:IF S$=""THEN 3320
3330 S$=""
3340 GOSUB720
3344 REM ____________________________________
3345 REM BEGIN CALCULATION OF RESONANCE TABLE
3346 REM ____________________________________
3350 PRINT"":PRINT"TYPE 'T' TO TERMINATE THE RES. TABLE AT ANY TIME."
3360 OPEN 4,4,1
3370 QS=Q:ES=E
3380 IF LEFT$(F$,1)="Y" THEN BRHO=TBRHO
3390 R=H*Q/A(L):PRINT#4,"          RESONANCE TABLE FOR";
3400 PRINT#4,E;" MEV ";BEAM$(L);Q;"+      (MASS=";A(L);" AMU)"
3404 REM ____________________________________
3405 REM CALCULATE AND PRINT OUT RESONANCE WIDTH
3406 REM (3410-3420)_________________________
3407 REM
3410 FWHM=.1*INT(10000*F*Q/(70*H*E))
3420 PRINT#4,"            APPROX ACHIEVABLE RES WIDTH=";FWHM;" KHZ FWHM"
3430 PRINT#4,"":PRINT#4,"          F                DELTA F      HARM          ENERGY";
3440 PRINT#4,"           ION            CHG ST":PRINT#4,"  "
3450 L=0
3460 L=L+1:H=1
3470 Q=0
3480 Q=Q+1
3490 IF A(L)=0 THEN 4050
3500 U=1-(H*Q/A(L))/R
3510 GET T$
3520 IF T$="T" THEN CLOSE 4:T$=" ":L=LS:Q=QS:F=FS:E=ES:H=HS:GOTO 530
3530 IF ABS(U)>.02 THEN 3990
3540 GOTO4310
3550 F=H*YZ*(1-(1+E/(A(L)*VM-Q*ME))^-2)^.5
3560 DZ=F-FS:DF=ABS(DZ):DZ=.001*INT(1000000*DZ):E=.1*(INT(10*E+.5))
3570 F=.000001*(INT(1000000*F+.5)):IF DF<.00001THENDZ=0
3580 DD=.05:IF (M/QS)<2.1 THEN DD=.1
3590 IF L>42ANDL<50ANDQ>1THEN3990
3600 IFDF>DDTHEN3990
3610 IF F<10 THEN PRINT#4," ";
3620 F=(INT(1000000*F))/1000000
3630 FM=F
3640 PRINT#4,F;
3650 IF F=INT(F) THEN PRINT#4,"          MHZ";:GOTO 3730
3660 F=10*F:IF F=INT(F) THEN PRINT#4,"        MHZ";:GOTO 3730
3670 F=10*F:IF F=INT(F) THEN PRINT#4,"       MHZ";:GOTO 3730
3680 F=10*F:IF F=INT(F) THEN PRINT#4,"      MHZ";:GOTO 3730
3690 F=10*F:IF F=INT(F) THEN PRINT#4,"     MHZ";:GOTO 3730
3700 F=10*F:IF F=INT(F) THEN PRINT#4,"    MHZ";:GOTO 3730
3710 F=10*F:IF F=INT(F) THEN PRINT#4,"   MHZ";:GOTO 3730
3720 PRINT#4," MHZ";
```

```
3730 F=FM
3740 PRINT#4," ";
3750 IF ABS(DZ)<100 THEN PRINT#4," ";
3760 IF ABS(DZ)<10 THEN PRINT#4," ";
3770 IF DZ=0 THEN 3790
3780 IF ABS(DZ)<1 THEN PRINT#4," ";
3790 PRINT#4,DZ;
3800 DZ=(INT(1000*DZ))/1000
3810 DZM=DZ
3820 IF DZ=INT(DZ) THEN PRINT#4,"     KHZ   ";:GOTO 3870
3830 DZ=10*DZ:IF DZ=INT(DZ) THEN PRINT#4,"   KHZ   ";:GOTO 3870
3840 DZ=10*DZ:IF DZ=INT(DZ) THEN PRINT#4,"  KHZ   ";:GOTO 3870
3850 DZ=10*DZ:IF DZ=INT(DZ) THEN PRINT#4," KHZ   ";:GOTO 3870
3860 PRINT#4," KHZ   ";
3870 DZ=DZM
3880 PRINT#4,"H=";H;"     ";
3890 IF E<100 THEN PRINT#4," ";
3900 IF E<10 THEN PRINT#4," ";
3910 PRINT#4,E;
3920 IF E=INT(E) THEN PRINT#4,"  ";
3930 PRINT#4," MEV     ";
3940 PRINT#4,BEAM$(L);
3950 FOR I=1TO12:IF LEN(BEAM$(L))<(15-I)THEN PRINT#4," ";
3960 NEXT I
3970 IF Q<10 THEN PRINT#4," ";
3980 PRINT#4," ";Q;"+"
3984 REM ____________________________________________
3985 REM PLACE LIMITS ON H AND Q FOR RESONANCE TABLE
3986 REM
3990 H=H+2:IFH>3 THEN4020
4000 IFQ>10THEN4040
4010 GOTO3500
4020 H=1:IFQ>10THEN4040
4030 IF Q<Z(L) THEN 3480
4040 IF L=42 THEN PRINT#4,""
4050 IF L<56 THEN 3460
4060 CLOSE4
4070 L=LS:Q=QS:F=FS:E=ES:H=HS
4080 GOTO530
4084 REM_____________________________
4085 REM BEGIN CALCULATION OF BEAM ENERGY
4086 REM
4090 PRINT"":PRINT"BEAM ENERGY TO BE CALCULATED FROM:":PRINT"
4100 PRINT"  1 CYCLOTRON RF FREQUENCY"
4110 PRINT"  2 M41 NMR FREQUENCY"
4120 PRINT"  3 BRHO":PRINT"
4130 PRINT"TYPE 1, 2, OR 3..."
4140 INPUT J
4150 GOSUB 720
4160 ON J GOTO 4170,4220,4260
4170 PRINT"ENTER RF FREQUENCY IN MHZ":PRINT"
4180 INPUT F
4190 PRINT"  ":PRINT"ENERGY (MEV)=";
4200 E=(A(L)*VM-Q*MF)*((1/(1-(F/(H*YZ))^2))^.5-1)
4210 PRINTE:GOTO 530
4220 PRINT"TYPE NMR FREQUENCY IN MHZ":PRINT"
4230 INPUT NMR:PRINT"
4240 BRHO=18.779756*NMR
4250 GOTO 690
4260 PRINT"BRHO=";TAB(7);BRHO," KG-IN":PRINT""
4270 INPUT "DO YOU WISH TO SPECIFY A NEW BRHO (Y/N)";G$
```

```
4280 IF LEFT$(G$,1)="N" THEN 4310
4290 PRINT"TYPE BRHO IN KG-IN":PRINT" "
4300 INPUT BRHO
4310 A=A(L)
4320 E=((A+VM-Q+ME)^2+(Q+BRHO/ZZ)^2)^.5-(A+VM-Q+ME)
4330 IF FL=5ORFL=3THEN3550
4340 PRINT"ENERGY (MEV) =";E:PRINT" ":GOTO 530
4344 REM ____________________________________
4345 REM SUBROUTINE TO DELAY PROGRAM EXECUTION
4346 REM
4350 FOR I=1TO1000:NEXT I
4360 RETURN
4364 REM ____________________________________________________________
4365 REM SUBROUTINE TO CALCULATE BETA AND GAMMA, AND TO SCALE CURRENT IN SPIN
4366 REM PRECESSION MAGNET
4367 REM
4370 GAMMA=(E+A(L)+VM)/(A(L)+VM)
4380 BETA=SQR((GAMMA^2-1)/GAMMA^2)
4390 CUP=BETA+IR(16,7)/.11754912
4400 RETURN
4410 TBRHO=BRHO
4414 REM ____________________________
4415 REM SUBROUTINE TO CALCULATE BRHO
4416 REM
4420 BRHO=ZZ+(E+E+2+(A(L)+VM-QR+ME)+E)^.5/QR
4430 RETURN
4440 END
```

APPENDIX A.2.b.: Symbols Used in PRE

A(56)	•	Precise values for atomic masses as read in by Master.
AA	•	Used in line 1170 to convert precise mass A into nearest integer mass M.
BEAM $	•	Identifies ionic species. Note that ALPHAS is an identifier for helium-4 both in a 2+ charge state and (inappropriately) a 1+ charge state.
BETA	•	$\beta = v/c$ = velocity of ion/speed of light
BMB	•	BMB = magnetic field in kilo Gauss in the bending magnet MB. Assumes ρ = 45" for bending to cave 0 (line 2660) in calculation of currents > 125 Amps.
BRHO	•	Magnetic rigidity in kG - in.
C	•	Used in lines 1770 and 1810 to enumerate 19 sets of cave optics.
CUR	•	Current in amps in magnet under consideration.
	•	In the case of magnets which operate in a non-linear region (e.g. MS, MB) CUR is temporarily equal to the magnetic field and later converted (using polynomial functions) to a current in amps (e.g. lines 2670, 2700).
CV $	•	Identifies the cave or target area including the choice of optics solutions where appropriate e.g. hi transmission vs. hi resolution.
	•	19 sets of beam line optics are identified in lines 220-280.
DD	•	DD = .05 or 0.1 MHz for heavy and light ions respecively.
	•	DD is used to place a limit on the range of frequencies included in the resonance table.
	•	See line 3580.
DF	•	DF = Absolute value of DZ (see DZ).

DZ	•	Defined in line 3560 to be the difference in MHz between the frequency of the test ion minus the frequency of the requested ion in generating the resonance table.
DZM	•	Used in lines 3810 and 3870 to save and subsequently retrieve the value of DZ to permit formatting manipulations (3830-3850) of DZ.
E	•	Kinetic energy of ion in MeV.
ES	•	A Variable used to save and subsequently retrieve the value of E while E is used in various search loops.
F	•	RF frequency.
F $	•	Used in 1930, 1960 to input "yes/no" answers from keyboard.
FL	•	Flag which specifies which of the 6 user options has been selected: BRHO, FREQUENCY, PRE-RUN, ENERGY, RES. TABLE, CYC. SETTINGS.
FM	•	Used in 3630 and 3730 to save and subsequently retrieve the value of F to permit manipulation on F for formatting purposes.
FS	•	A variable used to save and subsequently retrieve the value of F while F is used in various search loops.
FWHM	•	Calculated in line 3410 as the full width at half max. of the beam resonance.
G $	•	Used to input "yes/no" answers from keyboard.
GAMMA	•	$\gamma = \frac{\text{total relativistic energy}}{\text{rest mass energy}}$ (line 4370)
	•	Used only in the calculation of $\beta = v/c$
H	•	harmonic number.
HI	•	Used to determine whether high-resolution (HI = 1) or high transmission (HI = 2) beam optics is desired in caves 4A, B, C.
	•	See lines 1850-1870.

HS	•	Used to save and subsequently retrieve the value of H while H is used in various search loops.
I	•	General purpose indexing variable.
IR(19, 11)	•	This matrix stores currents for up to 11 beam line magnets and 19 different beam line optics
	•	See lines 320-510 and Table 3.
	•	For I (T, J) J ≠ 3, currents stored are those required for a 104 MeV $^{16}O^{4+}$ beam.
	•	For I (T,3), the values stored do NOT represent currents, but rather magnetic field values in KG in the switching magnet.
	•	Parameters stored in this matrix were scaled from magnet settings associated with a previous run having high transmission and/or good beam quality.
J	•	General purpose indexing variable
	•	In the loop from 2620-2870, J is used to index the various magnets along the beam line.
L	•	Identifies the requested ion species (line 1050).
LS	•	Saves and subsequently retrieves the value of L while L is being used in various search loops.
M	•	Mass (amu) rounded to nearest integer.
MAG $ (11)	•	Used to assign magnet name or labels up to a max. of 11 magnets per beam line, e. g. "QS1A".
ME	•	Electron rest mass = 0.511006
NMR	•	Frequency in MHz from the NMR probe used to measure the magnetic field of the analyzing magnet (M41).
PP	•	Used in lines 210, 290 and 300 to avoid redimensioning arrays, re-loading data, and re-asking the user the same question on the screen.
	•	Its use is necessary because of the overlay between MASTER AND PRE.
Q	•	Charge state.

QR	•	Used in line 1980 to input final charge stae of ion after it emerges from a stripper foil in cave 3.
QS	•	Used to save and subsequently retrieve the value of Q while Q is used in various search loops.
QT	•	Calculated in line 1230 as the lowest charge state possible for K = 160 ± 1.
R	•	Defined in line 3390 as the ratio of H Q/A for the requested ion.
	•	Also used in IR matrix to index the magnet number.
S $	•	Dummy variable used in line 1730 to delay program execution pending keyboard entry.
SL $ (6)	•	Used to encode descriptors of slits (e.g. "ASV5A") and information related to slit widths etc.
SS	•	Defined in line 2620 as ± 1 to assist in formatting tasks
T	•	Used to index the 19 beam line optics cases selected at line 1820. (T is for target).
T $	•	Used in lines 3350, 3510, 2520 to terminate resonance table without crashing the program.
TBRHO	•	Used to save and retrieve BRHO
TC	•	TC is set = 1 at line 610 to indicate when MASTER has been re-accessed from PRE.
TT	•	Used in lines 2010 and 2030 to split up a branch statement which would otherwise be too long.
	•	TT = T-10
TV $ (6)	•	Used to identify objects which require that TV cameras be set up.
U	•	Defined in line 3500 and used in line 3530 to provide a quick elimination of candidates for the resonance table without having to go through the more time-consuming part of the program from line 3540 to 3980.
VM	•	VM = 931.478 MeV/amu from MASTER line 120.

X	•	Indexing Variable.
YZ	•	"Cox's constant" = 48.6160 from MASTER line 120.
Z (56)	•	Atomic number (Z) of the beam (lines 300-430 of MASTER).
ZZ	•	Proportionality constant in calculating BRHO in KG-in.
	•	ZZ = 1.3132653 from MASTER line 120.

APPENDIX A.3: Polynomial Fits

Many times throughout these programs, polynomial fitting routines have been used for empirical calculations or estimates of one quantity in terms of another. The functional form is thus

$$y = \sum_{n=0}^{N} a_n x^n$$

Examples where this has been used are summarized in Table 1 below:

Table 1

Application	y	x
Resonance panels	DVM setting	frequency
Main magnet	current	BRHO
Switching Magnet (MS)	current	magnetic field
Bending Magnet (MB)	current	magnetic field

Table 2 summarizes the coefficients a_n for each of these applications and the line number in the program where they are used (MASTER or PRE).

Table 2

n	a_n			
	Resonance panels (lines 3060-3070)	Main magnet Current (lines 3180-3190)	MS Current (line 2700 PRE)	MB Current (line 2670 PRE)
0	$+3.45445588 \times 10^{3}$	$+2.67 \times 10^{-2}$	-2.569×10^{1}	3.1809×10^{3}
1	-2.58812×10^{3}	$+1.0070$	$+3.191 \times 10^{1}$	-1.0072×10^{3}
2	$+7.88200521 \times 10^{2}$	$+2.260 \times 10^{-2}$	-4.5607	$+1.2165 \times 10^{2}$
3	$-1.27762457 \times 10^{2}$	-1.51574×10^{-4}	$+6.071 \times 10^{-1}$	-6.4319
4	$+1.20524011 \times 10^{1}$	$+5.18654 \times 10^{-7}$	-3.871×10^{-2}	1.279811×10^{-1}
5	$-6.65679489 \times 10^{-1}$	$-9.624233 \times 10^{-10}$	$+9.859 \times 10^{-4}$	
6	$+2.00027251 \times 10^{-2}$	$+9.188321 \times 10^{-13}$		
7	$-2.52851401 \times 10^{-4}$	$-3.36763141 \times 10^{-16}$		

Table 3 summarizes experimental data used to fit the I vs. B curve of the bending magnet MB. It is used for currents I > 125 amps where a bending radius RHO = 45 inches is assumed. (Below this current a linear approximation is used.)

Table 3

DATE	BEAM		BRHO (kG-inch)	B (kG)	I (Amps)
11/9/78	60 MeV	$^{4}He^{2+}$	440.912	9.798	120
11/10/78	40 MeV	$^{18}O^{3+}$	507.257	11.272	138
2/27/79	95 MeV	$^{15}N^{4+}$	535.807	11.907	149
3/27/79	87 MeV	$^{18}O^{4+}$	561.456	12.477	161
2/8/79	50 MeV	$^{18}O^{3+}$	567.215	12.605	162.5
3/28/79	99 MeV	$^{18}O^{4+}$	599.034	13.312	175
11/5/78	111 MeV	$^{18}O^{4+}$	634.413	14.098	192
3/7/79	116 MeV	$^{18}O^{4+}$	648.593	14.413	200.1
3/18/79	122 MeV	$^{18}O^{4+}$	665.215	14.783	210
11/19/78	105 MeV	$^{12}C^{3+}$	672.211	14.938	212

Table 4 lists the input data used to fit the main magnet current to BRHO and the predicted currents calculated using the coefficients listed in Table 2. The error current, I(RUN) - I(CALC), is plotted against main magnet current in Fig. 4 of the main text.

Table 4: Main Magnet Fitting Data

BRHO (kG-inch)	I(RUN) (Amps)	I(CALC) (Amps)	I(RUN)-I(CALC) (Amps)
0	0	0.03	-0.03
189.03	444	443.1	0.9
221.39	520	519.5	0.5
228.47	535	536.0	-1.0
257.05	606	602.2	3.8
288.99	681	676.5	4.5
363.72	861	857.4	3.7
386.16	910	915.4	-5.4
407.59	977	973.2	3.8
572.18	1638	1630.4	7.6
600.88	1830	1828.8	1.2
331.74	778	778.2	-0.2
381.61	897	903.4	-6.4
402.33	962	958.8	3.2
440.86	1063	1069.5	-6.5
459.22	1129	1127.3	1.7
541.19	1450	1456.6	-6.6
574.78	1646	1646.7	-0.7
598.96	1829	1814.2	14.8
626.05	2014	2040.0	-26.0
139.12	322	319.9	2.1
170.93	396	399.3	-3.3
241.27	561	565.7	-4.7
577.01	1659	1661.0	-2.0
620.34	1996	1988.6	7.4
486.62	1221	1222.1	-1.1
525.68	1399	1382.1	16.9
522.58	1367	1368.0	-1.0
577.15	1641	1661.9	-20.9
552.44	1524	1515.5	8.5
569.58	1605	1614.3	-9.3
634.48	2125	2119.8	5.2
665.60	2474	2459.5	14.5
671.50	2515.5	2532.7	-17.2
643.90	2224	2214.9	9.1
673.4	2560	2556.9	3.1

APPENDIX A.4: Trim Coil Programs and Use

Below are listed four programs which can be used to manipulate the trim coil solutions which are stored on disk. They are called WRITE, LWRITE, READ and LREAD.

Program WRITE will permit the user to copy onto disk a trim coil solution for any given beam. Each trim coil solution is thus stored with its own file name. Because of a limit on the number of file names the PET can put on one disk, it is necessary to have several disks to store all of the trim coil solutions using this program. However, it is possible using WRITE to change or correct the trim coil currents for one particular beam.

Program LWRITE will read trim coil solutions from the disk generated with WRITE and concatenate all the trim coil solutions having constant Q/A onto a new disk. All trim coil solutions lying on the same line (of constant Q/A) are now stored under one file name, and all trim coil solutions are stored on one disk.

Programs READ and LREAD perform the analogous functions to WRITE and LWRITE. Program READ is used at line 4535 of MASTER to fetch individual trim coil solutions from the disk files created by LWRITE. Program LREAD is useful in generating lists of trim coil solutions such as can be found in Appendix A4d.

A.4.a.: Listing of WRITE, LWRITE

```
 5 REM WRITE 07/29/80
 10 PRINT"INITIALIZING DISK"
 15 DIM TR(17)
 20 OPEN 15,8,15
 30 PRINT#15,"I1"
 40 GOSUB 1000
 50 CR$=CHR$(13)
 60 PRINT"WRITE TEST FILE"
 70 INPUT "NAME OF FILE";P$
 71 INPUT "IS THE FILE TO CONTAIN ALL 0'S?(Y/N)";Z$
 72 PL$="@1: "+P$
 80 OPEN 2,8,2,PL$+",S,W"
 90 GOSUB 1000
 100 FOR I=1TO17
 107 IF LEFT$(Z$,1)="Y" THEN TR(I)=0:GOTO 130
 110 PRINT"":PRINT"AMPS FOR TRIM COIL #";I
 120 INPUT TR(I)
 130 PRINT#2,STR$(TR(I))CR$;
 140 NEXTI
 145 PRINT#2,"END"
 150 CLOSE 2
 160 GOTO 40
 1000 INPUT#15,EN$,EM$,ET$,ES$
 1010 IF EN$="00" THEN RETURN
 1020 PRINT"ERROR ON DISK"
 1030 PRINT EM$,ET$,ES$
 1040 CLOSE 2
 1050 END
READY.
```

```
5 REM LWRITE 08/27/80
10 PRINT"INITIALIZING DISK"
15 DIM TR(50,17)
20 OPEN 15,8,15
30 PRINT#15,"I1"
41 PRINT" ":PRINT"THE FUNCTION OF THIS PROGRAM IS TO COPY INDIVIDUAL FILES";
42 PRINT" CONTAINING TRIM COIL   SOLUTIONS ON A GIVEN LINE ONTO ONE FILE";
43 PRINT" WHICH HOLDS ALL THE SOLUTIONS FOR THE   ENTIRE LINE. IF YOU WISH";
44 PRINT" TO CORRECT AN  INDIVIDUAL SOLUTION,DO SO WITH PROGRAM  'WRITE' AND";
45 PRINT" THEN USE THIS PROGRAM,      'LWRITE', TO INCORPORATE THE CHANGE";
46 PRINT" INTO THE MASTER FILE."
48 GOSUB 1000
50 CR$=CHR$(13)
60 PRINT""
69 PS=P
70 INPUT "LINE NUMBER (10,20,ETC.) TO BE REWRITTEN";P
71 IF PS=P THEN 105
72 PRINT" "
74 INPUT "HOW MANY SOLUTIONS ON THIS LINE";NS
75 PRINT" ":PRINT"I'M REWRITING, PLEASE BE PATIENT."
76 FOR J=1 TO NS
78 HJ=.01*J:SN=P+HJ
79 SN$=STR$(SN)
80 IF LEFT$(RIGHT$(SN$,2),1)="." THEN SN$=SN$+"0"
81 F$="0:"+SN$
82 OPEN 2,8,2,F$+",S,R"
84 GOSUB 1000
86 FOR I=1 TO 17
88 INPUT#2,TR(J,I)
90 RS=ST
92 GOSUB 1000
94 IF S=64 THEN CLOSE 2:END
96 IF RS<>0 THEN PRINT"BAD DISK STATUS IS";RS:CLOSE 2:END
100 NEXT I
102 CLOSE 2
104 NEXT J
105 PRINT"PUT IN DISK TO BE USED, THEN TYPE ANY   KEY."
106 GET W$:IF W$="" THEN 106
107 W$=""
108 PRINT#15,"I1"
109 GOSUB 1000
110 P$=STR$(P):PL$="@1: LINE"+P$
115 OPEN 2,8,2,PL$+",S,W"
120 GOSUB 1000
122 FOR J=1TONS
124 FOR I=1TO17
126 PRINT#2,STR$(TR(J,I))CR$;
130 NEXT I
140 NEXT J
147 PRINT#2,"END"
150 CLOSE 2
155 PRINT"":PRINT"LINE";P;"HAS NOW BEEN REWRITTEN."
160 GOTO 48
1000 INPUT#15,EN$,EM$,ET$,ES$
1010 IF EN$="00" THEN RETURN
1020 PRINT"ERROR ON DISK"
1030 PRINT EM$,ET$,ES$
1040 CLOSE 2
1050 END
READY.
```

A.4.b.: Listing of READ, LREAD

```
5 REM READ 07/29/80
10 PRINT"INITIALIZE DISK"
15 DIM TR(18),A$(18)
20 OPEN 15,8,15
30 PRINT#15,"I1"
100 PRINT"READ TEST FILE":GOTO 110
105 PRINT" ":PRINT"READ TEST FILE"
110 INPUT "WHICH FILE";P$
120 PL$="1: "+P$
130 OPEN 2,8,2,PL$+",S,R"
140 GOSUB 1000
150 I=1
155 PRINT" "
160 INPUT#2,TR(I)
170 RS=ST
180 GOSUB 1000
185 IF INT(I/10)=0 THEN PRINT" ";
190 PRINTI;"    ";TR(I)
200 IF S=64 THEN 300
210 IF RS<>0 THEN 400
220 I=I+1
230 IF I<18 THEN 160
240 CLOSE 2
250 GOTO 105
300 CLOSE 2
310 END
400 PRINT"BAD DISK STATUS IS",RS
410 CLOSE 2
420 END
1000 INPUT#15,EN$,EM$,ET$,ES$
1010 IF EN$="00" THEN RETURN
1020 PRINT"ERROR ON DISK"
1030 PRINT EM$,EN$,ET$,ES$
1040 CLOSE 2
1050 END
READY.
```

```
5 REM LREAD 08/27/80
10 PRINT"INITIALIZING DISK"
15 DIM TR(50,17)
20 OPEN 15,8,15
30 PRINT#15,"I1"
100 PRINT"READ TEST FILE":GOTO 110
105 PRINT" ":PRINT"READ TEST FILE"
107 PS=P:SS=SN
110 INPUT "WHICH FILE";P
111 L=INT(P)
113 L$=STR$(L)
115 SN=INT(100*(P-L)+.5)
117 IF INT(PS)=INT(P)AND SN<=SS THEN 185
120 PL$="1: LINE"+L$
130 OPEN 2,8,2,PL$+",S,R"
140 GOSUB 1000
142 PRINT" ":PRINT"READING FROM DISK"
145 FOR J=1TOSN
150 FOR I=1TO17
160 INPUT#2,TR(J,I)
170 RS=ST
180 GOSUB 1000
181 NEXT I
182 NEXT J
184 CLOSE 2
185 PRINT" ":PRINT"TRIM COILS, INDEX #";P:PRINT" "
187 FOR I=1TO17
188 IF INT(I/10)=0 THEN PRINT" ";
190 PRINTI;"    ";TR(SN,I)
200 IF S=64 THEN 300
210 IF RS<>0 THEN 400
220 NEXT I
250 GOTO 105
300 CLOSE 2
310 END
400 PRINT"BAD DISK STATUS IS",RS
410 CLOSE 2
420 END
1000 INPUT#15,EN$,EM$,ET$,ES$
1010 IF EN$="00" THEN RETURN
1020 PRINT"ERROR ON DISK"
1030 PRINT EM$,EN$,ET$,ES$
1040 CLOSE 2
1050 END
READY.
```

APPENDIX A.4.c.: Index of Grid Trim Coil Solutions

The quantities listed in the following table are those required to select a trim coil solution for any first or third harmonic beam. A negative entry for E/A signifies the start of a constant Q/A line with a line number ending in 5 (e.g., index number 105.01, Q/A = .385, E/A = -20).

Protons

N	DX	QA	EA	DEA = $(E_1-E_0)/E_0$
SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
1	10.01	1	7	.76
2	10.02	1	10	.324
3	10.03	1	15	.175
4	10.04	1	17.5	.136
5	10.05	1	20	.106
6	10.06	1	22.5	.086
7	10.07	1	25	.071
8	10.08	1	27.5	.059
9	10.09	1	30	.05
10	10.1	1	32.5	.043
11	10.11	1	35	.037
12	10.12	1	36	.035
13	10.13	1	38	.032
14	10.14	1	40	.029
15	10.15	1	42	.026
16	10.16	1	44	.025
17	10.17	1	45	.023
18	10.18	1	47	.021
19	10.19	1	49	.02
20	10.2	1	50	.019
21	10.21	1	51.5	.018
22	10.22	1	53	.017
23	10.23	1	54	.016
24	10.24	1	55	.016
25	10.25	1	56	.015
26	10.26	1	57	.014
27	10.27	1	58	.014
28	10.28	1	59	.0136
29	10.29	1	60	.013

$^{3}He^{2+}$

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
30	20.01	.6667	3.33	.65
31	20.02	.6667	5	.33
32	20.03	.6667	6.67	.45
33	20.04	.6667	10	.24
34	20.05	.6667	13.3	.15
35	20.06	.6667	16.7	.103
36	20.07	.6667	18.3	.087
37	20.08	.6667	20	.075
38	20.09	.6667	21.6	.064
39	20.1	.6667	23.3	.055
40	20.11	.6667	25	.05
41	20.12	.6667	26.7	.042
42	20.13	.6667	28.3	.038
43	20.14	.6667	30	.034
44	20.15	.6667	31.7	.031
45	20.16	.6667	33.3	.028
46	20.17	.6667	35	.025
47	20.18	.6667	36.7	.023
48	20.19	.6667	37.7	.022
49	20.2	.6667	39	.02
50	20.21	.6667	40	.02
51	20.22	.6667	41	.019
52	20.23	.6667	42.3	.018
53	20.24	.6667	43.3	.017
54	20.25	.6667	44.3	.016
55	20.26	.6667	45.7	.015
56	20.27	.6667	46.7	.014
57	20.28	.6667	47.7	.014
58	20.29	.6667	48.7	.013
59	20.3	.6667	49.3	.013
60	20.31	.6667	50	.0126
61	20.32	.6667	51	.012
62	20.33	.6667	52	.012
63	20.34	.6667	52.7	.011
64	20.35	.6667	53.3	.011
65	20.36	.6667	54.3	.01
66	20.37	.6667	55.3	.01
67	20.38	.6667	56	.01
68	20.39	.6667	56.7	.01
69	20.4	.6667	57.7	.0094
70	20.41	.6667	58.7	.0091
71	20.42	.6667	59.3	.009
72	20.43	.6667	60	.009

alphas, deuterons, $^{6}Li^{3+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
73	30.01	.5	2.5	.56
74	30.02	.5	5	.3
75	30.03	.5	7.5	.33
76	30.04	.5	10	.19
77	30.05	.5	12.5	.13
78	30.06	.5	15	.096
79	30.07	.5	17.5	.073
80	30.08	.5	18.75	.064
81	30.09	.5	20	.056
82	30.1	.5	21.25	.05
83	30.11	.5	22.5	.045
84	30.12	.5	23.75	.04
85	30.13	.5	25	.037
86	30.14	.5	26.25	.033
87	30.15	.5	27.5	.0306
88	30.16	.5	28.75	.028
89	30.17	.5	30	.026
90	30.18	.5	31.25	.024
91	30.19	.5	32.5	.0222
92	30.2	.5	33.75	.022
93	30.21	.5	35	.018
94	30.22	.5	35.75	.0156
95	30.23	.5	36.5	.0132
96	30.24	.5	37	.0116
97	30.25	.5	37.5	.01
98	30.26	.5	38	.008
99	30.27	.5	38.5	.0068
100	30.28	.5	38.75	.006
101	30.29	.5	39	.0052
102	30.3	.5	39.25	.0044
103	30.31	.5	39.5	.0036
104	30.32	.5	39.75	.0032
105	30.33	.5	40	.003

$^{17}O^{8+}$ (dummy data)

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
106	40.01	.471	1	.00001
107	40.02	.471	1	.00001
108	40.03	.471	1	.00001
109	40.04	.471	1	.00001
110	40.05	.471	31	.022

$^{15}N^{7+}$ (dummy data)

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
111	50.01	.467	1	.00001
112	50.02	.467	1	.00001
113	50.03	.467	1	.00001
114	50.04	.467	1	.00001
115	50.05	.467	1	.00001
116	50.06	.467	1	.00001
117	50.07	.467	1	.00001
118	50.08	.467	1	.00001
119	50.09	.467	1	.00001
120	50.1	.467	30.5	.022

$^{13}C^{6+}$ (dummy data)

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
121	60.01	.462	1	.00001
122	60.02	.462	1	.00001
123	60.03	.462	1	.00001
124	60.04	.462	1	.00001
125	60.05	.462	1	.00001
126	60.06	.462	1	.00001
127	60.07	.462	1	.00001
128	60.08	.462	1	.00001
129	60.09	.462	1	.00001
130	60.1	.462	29.8	.022

$^{11}B^{5+}$

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
131	70.01	.455	24.27	.035
132	70.02	.455	25.9	.031
133	70.03	.455	27.45	.028
134	70.04	.455	28.9	.025
135	70.05	.455	30	.0188
136	70.06	.455	30.9	.015
137	70.07	.455	31.4	.0136
138	70.08	.455	31.8	.0118
139	70.09	.455	32.3	.01
140	70.1	.455	32.7	.0083
141	70.11	.455	33.1	.0069
142	70.12	.455	33.4	.0058
143	70.13	.455	33.6	.0048

$^{9}Be^{4+}$, $^{18}O^{8+}$

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
144	75.01	.444	-27.6	.03
145	75.02	.444	28.9	.025
146	75.03	.444	29.7	.022
147	75.04	.444	30.6	.018
148	75.05	.444	31.1	.015
149	75.06	.444	31.7	.013

$^{16}O^{7+}$

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
150	80.01	.438	11.25	.12
151	80.02	.438	13.125	.092
152	80.03	.438	15	.075
153	80.04	.438	16.875	.063
154	80.05	.438	18.75	.053
155	80.06	.438	20.31	.046
156	80.07	.438	21.875	.04
157	80.08	.438	23.43	.034
158	80.09	.438	25	.03
159	80.1	.438	26.79	.0283
160	80.11	.438	27.8	.022
161	80.12	.438	28.75	.0188
162	80.13	.438	29.4	.0162
163	80.14	.438	30	.0136
164	80.15	.438	30.6	.011
165	80.16	.438	31	.00943

$^{7}Li^{3+}$, $^{14}N^{6+}$

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
166	85.01	.429	-24.3	.036
167	85.02	.429	25.7	.03
168	85.03	.429	26.8	.025
169	85.04	.429	27.9	.021
170	85.05	.429	28.6	.018
171	85.06	.429	29.3	.014

$^{12}C^{5+}$

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
172	90.01	.417	6.67	.25
173	90.02	.417	9.17	.182
174	90.03	.417	11.25	.107
175	90.04	.417	13.33	.083
176	90.05	.417	15.41	.066
177	90.06	.417	17.08	.056
178	90.07	.417	18.75	.048
179	90.08	.417	20.4	.041
180	90.09	.417	21.67	.036
181	90.1	.417	22.9	.032
182	90.11	.417	24.33	.03
183	90.12	.417	25	.024
184	90.13	.417	25.63	.021
185	90.14	.417	26.3	.018
186	90.15	.417	26.8	.015
187	90.16	.417	27.25	.013
188	90.17	.417	27.7	.011
189	90.18	.417	28.125	.0094

$^{10}B^{4+}$, $^{20}Ne^{8+}$,...

190	100.01	.4	15.5	.06
191	100.02	.4	17	.051
192	100.03	.4	18.5	.044
193	100.04	.4	20	.038
194	100.05	.4	21.25	.033
195	100.06	.4	22.4	.03
196	100.07	.4	23.5	.0215
197	100.08	.4	24.25	.018
198	100.09	.4	25	.014
199	100.1	.4	25.5	.0115
200	100.11	.4	26	.009

$^{13}C^{5+}$

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
201	105.01	.385	-20	.033
202	105.02	.385	20.8	.03
203	105.03	.385	21.5	.025
204	105.04	.385	22.3	.021
205	105.05	.385	23.1	.017
206	105.06	.385	23.7	.014

$^{16}O^{6+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
207	110.01	.375	10	.104
208	110.02	.375	11.56	.083
209	110.03	.375	13.3	.066
210	110.04	.375	14.69	.055
211	110.05	.375	16.25	.046
212	110.06	.375	17.5	.04
213	110.07	.375	18.75	.033
214	110.08	.375	19.69	.03
215	110.09	.375	20.6	.022
216	110.1	.375	21.25	.018
217	110.11	.375	21.9	.0146
218	110.12	.375	22.2	.0128
219	110.13	.375	22.5	.011
220	110.14	.375	22.8	.0094

$^{14}N^{5+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
221	120.01	.357	14.64	.048
222	120.02	.357	15.7	.041
223	120.03	.357	16.79	.035
224	120.04	.357	17.86	.03
225	120.05	.357	18.6	.0235
226	120.06	.357	19.3	.019
227	120.07	.357	19.6	.0168
228	120.08	.357	20	.0146
229	120.09	.357	20.4	.012
230	120.1	.357	20.7	.01

$^{20}Ne^{7+}$

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
231	125.01	.35	-19	.018
232	125.02	.35	19.6	.014

$^{6}Li^{2+}$, $^{9}Be^{3+}$, $^{12}C^{4+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
233	130.01	.333	1.667	.6
234	130.02	.333	3.33	.5
235	130.03	.333	5	.19
236	130.04	.333	5.83	.125
237	130.05	.333	6.67	.25
238	130.06	.333	8.33	.104
239	130.07	.333	10	.075
240	130.08	.333	11	.064
241	130.09	.333	12.11	.054
242	130.1	.333	13.33	.0445
243	130.11	.333	14.23	.038
244	130.12	.333	15	.033
245	130.13	.333	15.58	.03
246	130.14	.333	16.25	.023
247	130.15	.333	16.6	.02
248	130.16	.333	17.25	.016
249	130.17	.333	17.5	.014
250	130.18	.333	17.8	.012
251	130.19	.333	18.1	.0095
252	130.2	.333	18.3	.008

$^{16}O^{5+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
253	140.01	.313	11.88	.0435
254	140.02	.313	12.81	.037
255	140.03	.313	13.63	.028
256	140.04	.313	14.4	.024
257	140.05	.313	15	.019
258	140.06	.313	15.3	.0166
259	140.07	.313	15.6	.014
260	140.08	.313	15.9	.0114

$^{7}Li^{2+}$, $^{14}N^{4+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
261	150.01	.286	4.29	.211
262	150.02	.286	5.71	.09
263	150.03	.286	6.07	.13
264	150.04	.286	7.14	.085
265	150.05	.286	7.86	.072
266	150.06	.286	8.57	.06
267	150.07	.286	9.28	.051
268	150.08	.286	10	.043
269	150.09	.286	10.71	.035
270	150.1	.286	11.42	.03
271	150.11	.286	11.8	.026
272	150.12	.286	12.1	.023
273	150.13	.286	12.5	.019
274	150.14	.286	12.9	.016
275	150.15	.286	13.1	.014

$^{12}C^{3+}$, $^{16}O^{4+}$, $^{20}Ne^{5+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
276	160.01	.25	1.25	.7
277	160.02	.25	3.125	.34
278	160.03	.25	4.375	.125
279	160.04	.25	5	.08
280	160.05	.25	5.625	.055
281	160.06	.25	6.5	.062
282	160.07	.25	6.875	.056
283	160.08	.25	7.5	.045
284	160.09	.25	8.125	.036
285	160.1	.25	8.5	.033
286	160.11	.25	8.75	.03
287	160.12	.25	9.06	.026
288	160.13	.25	9.4	.022
289	160.14	.25	9.7	.018
290	160.15	.25	9.8	.016
291	160.16	.25	10	.014
292	160.17	.25	10.2	.012
293	160.18	.25	10.3	.01

$^{9}Be^{2+}$, $^{18}O^{4+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
294	165.01	.2222	-5.5	.055
295	165.02	.2222	6.22	.042
296	165.03	.2222	6.89	.03
297	165.04	.2222	7.22	.025
298	165.05	.2222	7.5	.02
299	165.06	.2222	7.72	.017
300	165.07	.2222	7.92	.0138
301	165.08	.2222	8.06	.0115

$^{14}N^{3+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
302	170.01	.214	3.21	.145
303	170.02	.214	3.92	.081
304	170.03	.214	4.28	.06
305	170.04	.214	4.714	.045
306	170.05	.214	5	.037
307	170.06	.214	5.36	.032
308	170.07	.214	5.54	.028
309	170.08	.214	5.71	.025
310	170.09	.214	5.93	.022
311	170.1	.214	6.43	.03
312	170.11	.214	6.7	.025
313	170.12	.214	6.93	.0213
314	170.13	.214	7.1	.0176
315	170.14	.214	7.3	.0151
316	170.15	.214	7.43	.0126
317	170.16	.214	7.57	.01

$^{10}B^{2+}$, $^{15}N^{3+}$, $^{20}Ne^{4+}$, $^{40}Ar^{8+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
318	175.01	.2	-4.625	.036
319	175.02	.2	4.8	.033
320	175.03	.2	5	.03
321	175.04	.2	5.35	.027
322	175.05	.2	5.6	.025
323	175.06	.2	5.8	.02
324	175.07	.2	6	.022
325	175.08	.2	6.2	.018
326	175.09	.2	6.4	.014
327	175.1	.2	6.5	.012
328	175.11	.2	6.6	.01

$^{16}O^{3+}$, $^{32}S^{6+}$

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
329	180.01	.188	.938	.9
330	180.02	.188	2.34	.175
331	180.03	.188	2.81	.107
332	180.04	.188	3.25	.076
333	180.05	.188	3.44	.056
334	180.06	.188	3.75	.045
335	180.07	.188	4.06	.036
336	180.08	.188	4.31	.031
337	180.09	.188	4.56	.028
338	180.1	.188	4.69	.026
339	180.11	.188	4.92	.024
340	180.12	.188	5.125	.023
341	180.13	.188	5.31	.022
342	180.14	.188	5.5	.021
343	180.15	.188	5.69	.02
344	180.16	.188	5.81	.02

$^{6}Li^{1+}$, $^{12}C^{2+}$, $^{18}O^{3+}$, $^{24}Mg^{4+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
345	190.01	.167	.6	.8
346	190.02	.167	.833	.7
347	190.03	.167	1	.6
348	190.04	.167	1.35	.48
349	190.05	.167	1.5	.44
350	190.06	.167	1.66	.31
351	190.07	.167	2.05	.16
352	190.08	.167	2.5	.076
353	190.09	.167	2.933	.045
354	190.1	.167	3	.045
355	190.11	.167	3.25	.038
356	190.12	.167	3.46	.034
357	190.13	.167	3.667	.03
358	190.14	.167	3.89	.028
359	190.15	.167	4.1	.027
360	190.16	.167	4.25	.026
361	190.17	.167	4.41	.025
362	190.18	.167	4.58	.025

$^{7}Li^{1+}$, $^{14}N^{2+}$, $^{28}Si^{4+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
363	195.01	.143	-3.21	.028
364	195.02	.143	3.36	.028

$^{16}O^{2+}$, $^{32}S^{4+}$, $^{40}Ar^{5+}$,...

SOLN#	INDEX#	Q/A	E/A	ENERGY RANGE/ENERGY
365	200.01	.125	.937	.34
366	200.02	.125	1.25	.126
367	200.03	.125	1.38	.088
368	200.04	.125	1.56	.06
369	200.05	.125	1.75	.047
370	200.06	.125	1.875	.041
371	200.07	.125	1.968	.038
372	200.08	.125	2.06	.035
373	200.09	.125	2.19	.033
374	200.1	.125	2.31	.031
375	200.11	.125	2.44	.03
376	200.12	.125	2.5	.029
377	200.13	.125	2.56	.028

APPENDIX A.4.d.: List of 377 Trim Coil Solutions on the Grid

Protons

	10.01	10.02	10.03	10.04	10.05	10.06	10.07
1	0	-750	-500	0	-305	0	-126
2	0	27	-41	0	-232	0	-374
3	0	-164	-163	0	-128	0	-131
4	0	0	-48	0	-91	0	-99
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	-32
7	0	0	0	0	0	0	0
8	0	40	28	0	0	0	0
9	0	0	0	0	0	0	0
10	0	79	90	0	106	0	80
11	0	0	0	0	0	0	0
12	0	289	220	0	205	0	221
13	0	0	0	0	0	0	0
14	0	-161	356	0	450	0	458
15	0	205	-643	0	-811	0	-916
16	0	-800	0	0	0	0	0
17	0	0	0	0	0	0	0

	10.08	10.09	10.10	10.11	10.12	10.13	10.14
1	0	-512	0	-549	0	0	-364
2	0	-208	0	-185	0	0	-365
3	0	-298	0	-347	0	0	-250
4	0	0	0	0	0	0	-42
5	0	0	0	0	0	0	0
6	0	-58	0	-71	0	0	-95
7	0	0	0	0	0	0	0
8	0	0	0	-36	0	0	-53
9	0	0	0	0	0	0	0
10	0	41	0	38	0	0	0
11	0	0	0	0	0	0	0
12	0	235	0	185	0	0	189
13	0	0	0	0	0	0	0
14	0	443	0	492	0	0	296
15	0	-1020	0	-1186	0	0	-1038
16	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0

	10.15	10.16	10.17	10.18	10.19	10.20	10.21
1	0	0	-339	0	0	-313	0
2	0	0	-397	0	0	-426	0
3	0	0	-264	0	0	-278	0
4	0	0	-54	0	0	-64	0
5	0	0	0	0	0	0	0
6	0	0	-114	0	0	-136	0
7	0	0	0	0	0	0	0
8	0	0	-80	0	0	-106	0
9	0	0	0	0	0	0	0
10	0	0	-25	0	0	-59	0
11	0	0	0	0	0	0	0
12	0	0	128	0	0	68	0
13	0	0	0	0	0	0	0
14	0	0	305	0	0	299	0
15	0	0	-1210	0	0	-1387	0
16	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0

	10.22	10.23	10.24	10.25	10.26	10.27	10.28
1	0	0	-360	0	0	0	0
2	0	-426	-480	0	0	0	0
3	0	-310	-314	0	0	0	0
4	0	-71	-80	0	0	0	0
5	0	0	0	0	0	0	0
6	0	-158	-159	0	0	0	0
7	0	0	0	0	0	0	0
8	0	-136	-148	0	0	0	0
9	0	0	0	0	0	0	0
10	0	-102	-100	0	0	0	0
11	0	0	0	0	0	0	0
12	0	-156	0	0	0	0	0
13	0	0	0	0	0	0	0
14	0	528	245	0	0	0	0
15	0	-1552	-1479	0	0	0	0
16	0	0	270	0	0	0	0
17	0	0	-353	0	0	0	0

	10.29
1	-361
2	-480
3	-314
4	-79
5	0
6	-159
7	0
8	-179
9	0
10	-156
11	0
12	-90
13	0
14	269
15	-1554
16	337
17	-250

$^{3}He^{2+}$

	20.01	20.02	20.03	20.04	20.05	20.06	20.07
1	-750	-750	-750	-750	-548	-365	0
2	28	0	0	0	-204	-357	0
3	-102	-145	-191	-232	-196	-198	0
4	0	0	0	-28	-71	-79	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	-21	0
7	0	0	0	0	0	0	0
8	57	59	57	52	41	38	0
9	0	0	0	0	0	0	0
10	79	100	116	135	145	139	0
11	0	0	0	0	0	0	0
12	165	193	216	240	244	244	0
13	0	0	0	0	0	0	0
14	129	218	262	400	470	487	0
15	113	0	0	-340	-457	-543	0
16	-397	-317	-377	0	0	0	0
17	0	0	0	0	0	0	0

	20.08	20.09	20.10	20.11	20.12	20.13	20.14
1	-477	0	-412	0	-322	0	-213
2	-256	0	-321	0	-373	0	-464
3	-351	0	-365	0	-329	0	-308
4	0	0	0	0	0	0	-24
5	0	0	0	0	0	0	0
6	0	0	-26	0	-62	0	-71
7	0	0	0	0	0	0	0
8	0	0	0	0	0	0	-28
9	0	0	0	0	0	0	0
10	146	0	117	0	67	0	28
11	0	0	0	0	0	0	0
12	275	0	258	0	244	0	152
13	0	0	0	0	0	0	0
14	645	0	637	0	424	0	422
15	-1336	0	-1535	0	-1472	0	-1774
16	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0

	20.15	20.16	20.17	20.18	20.19	20.20	20.21
1	0	-190	0	-240	0	0	-210
2	0	-472	0	-516	0	0	-531
3	0	-324	0	-402	0	0	-417
4	0	-25	0	-61	0	0	-66
5	0	0	0	0	0	0	0
6	0	-87	0	-118	0	0	-136
7	0	0	0	0	0	0	0
8	0	-54	0	-87	0	0	-124
9	0	0	0	0	0	0	0
10	0	-28	0	-91	0	0	-180
11	0	0	0	0	0	0	0
12	0	57	0	-147	0	0	-340
13	0	0	0	0	0	0	0
14	0	317	0	419	0	0	173
15	0	-2000	0	-2000	0	0	-2000
16	0	0	0	-388	0	0	-950
17	0	0	0	0	0	0	0

	20.22	20.23	20.24	20.25	20.26	20.27	20.28
1	0	0	-168	0	0	-157	0
2	0	0	-530	0	0	-530	0
3	0	0	-432	0	0	-462	0
4	0	0	-66	0	0	-71	0
5	0	0	0	0	0	0	0
6	0	0	-149	0	0	-174	0
7	0	0	0	0	0	0	0
8	0	0	-162	0	0	-213	0
9	0	0	0	0	0	0	0
10	0	0	-288	0	0	-439	0
11	0	0	0	0	0	0	0
12	0	0	-598	0	0	-884	0
13	0	0	0	0	0	0	0
14	0	0	-155	0	0	-676	0
15	0	0	-2000	0	0	-2000	0
16	0	0	-1586	0	0	-2000	0
17	0	0	0	0	0	0	0

	20.29	20.30	20.31	20.32	20.33	20.34	20.35
1	0	0	-193	0	0	0	-153
2	0	0	-676	0	0	0	-750
3	0	0	-292	0	0	0	-236
4	0	0	-107	0	0	0	-171
5	0	0	0	0	0	0	0
6	0	0	-261	0	0	0	-232
7	0	0	0	0	0	0	-228
8	0	0	-290	0	0	0	-176
9	0	0	0	0	0	0	-326
10	0	0	-580	0	0	0	-394
11	0	0	0	0	0	0	-490
12	0	0	-1263	0	0	0	-1140
13	0	0	0	0	0	0	-59
14	0	0	-1221	0	0	0	-2000
15	0	0	-2000	0	0	0	-2000
16	0	0	-2500	0	0	0	-2500
17	0	0	0	0	0	0	0

	20.36	20.37	20.38	20.39	20.40	20.41	20.42
1	0	0	0	-201	0	0	0
2	0	0	0	-593	0	0	0
3	0	0	0	-320	0	0	0
4	0	0	0	-224	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	-303	0	0	0
7	0	0	0	-314	0	0	0
8	0	0	0	-240	0	0	0
9	0	0	0	-437	0	0	0
10	0	0	0	-471	0	0	0
11	0	0	0	-775	0	0	0
12	0	0	0	-788	0	0	0
13	0	0	0	-845	0	0	0
14	0	0	0	-2000	0	0	0
15	0	0	0	-2000	0	0	0
16	0	0	0	-2500	0	0	0
17	0	0	0	0	0	0	0

	20.43
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0

Alpha, deuteron, $^{6}Li^{3+}$,...

	30.01	30.02	30.03	30.04	30.05	30.06	30.07
1	-750	-750	-560	-296	-470	-417	-346
2	0	0	-166	-404	-249	-290	-333
3	-120	-226	-226	-189	-383	-406	-418
4	0	0	-35	-71	42	37	28
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
8	65	71	72	68	64	54	33
9	0	0	0	0	0	0	0
10	96	140	165	176	167	156	118
11	0	0	0	0	0	0	0
12	191	262	291	298	376	327	249
13	0	0	0	0	0	0	0
14	204	312	469	509	640	678	645
15	0	20	-396	-504	-1330	-1658	-2000
16	-300	-456	0	0	0	0	0
17	0	0	0	0	0	0	0

	30.08	30.09	30.10	30.11	30.12	30.13	30.14
1	0	-310	0	-144	0	-100	0
2	0	-335	0	-440	0	-413	0
3	0	-432	0	-348	0	-356	0
4	0	27	0	26	0	35	0
5	0	0	0	0	0	0	0
6	0	0	0	-39	0	-31	0
7	0	0	0	0	0	0	0
8	0	0	0	0	0	-39	0
9	0	0	0	0	0	0	0
10	0	64	0	-40	0	-150	0
11	0	0	0	0	0	0	0
12	0	179	0	-36	0	-354	0
13	0	0	0	0	0	0	0
14	0	284	0	90	0	-303	0
15	0	-2000	0	-2000	0	-2000	0
16	0	0	0	-724	0	-1527	0
17	0	0	0	0	0	0	0

	30.15	30.16	30.17	30.18	30.19	30.20	30.21
1	-79	0	-364	0	-240	0	0
2	-384	0	-440	0	-244	0	0
3	-375	0	-193	0	-408	0	0
4	48	0	-54	0	40	0	0
5	0	0	81	0	0	0	0
6	-46	0	-79	0	-177	0	0
7	0	0	-52	0	0	0	0
8	-92	0	-94	0	-317	0	0
9	0	0	-117	0	-176	0	0
10	-344	0	-339	0	-500	0	0
11	0	0	-204	0	-750	0	0
12	-711	0	-1013	0	-34	0	0
13	0	0	393	0	-1500	0	0
14	-971	0	-1809	0	-2000	0	0
15	-2000	0	-2000	0	-2000	0	0
16	-2000	0	-2000	0	-2000	0	0
17	0	0	2000	0	0	0	0

	30.22	30.23	30.24	30.25	30.26	30.27	30.28
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0

	30.29	30.30	30.31	30.32	30.33
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0

$^{11}B^{5+}$

	70.01	70.02	70.03	70.04	70.05	70.06	70.07
1	0	51	133	200	0	0	0
2	-372	-406	-424	-316	0	0	0
3	-371	-351	-331	-510	0	0	0
4	89	79	34	76	0	0	0
5	0	0	0	0	0	0	0
6	-28	-70	-122	-214	0	0	0
7	0	0	0	0	0	0	0
8	-100	-214	-377	-387	0	0	0
9	0	0	0	-161	0	0	0
10	-481	-660	-750	-650	0	0	0
11	0	0	0	-750	0	0	0
12	-873	-1442	-2000	-540	0	0	0
13	0	0	0	-1268	0	0	0
14	-1600	-2000	-2000	-2000	0	0	0
15	-2000	-2000	-1610	-2000	0	0	0
16	-2000	-2000	-2000	-2000	0	0	0
17	0	0	0	2000	0	0	0

	70.08	70.09	70.10	70.11	70.12	70.13
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0

$^{9}Be^{4+}$, $^{18}O^{8+}$

	75.01	75.02	75.03	75.04	75.05	75.06
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0

$^{16}O^{7+}$

	80.01	80.02	80.03	80.04	80.05	80.06	80.07
1	-515	-402	-324	-260	-224	-179	0
2	-184	-257	-296	-326	-284	-290	-389
3	-447	-455	-466	-472	-517	-524	-357
4	72	68	72	71	111	119	79
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
8	81	67	52	26	0	0	-75
9	0	0	0	0	0	0	0
10	170	142	97	27	-52	-209	-316
11	0	0	0	0	0	0	-22
12	397	342	211	29	-257	-412	-1119
13	0	0	0	0	0	0	706
14	394	371	302	128	0	-673	-1650
15	-671	-884	-1167	-1373	-2000	-2000	-2000
16	-1159	-1420	-1570	-2000	-2000	-2000	-2000
17	0	0	0	0	0	0	0

	80.08	80.09	80.10	80.11	80.12	80.13	80.14
1	0	20	198	0	0	0	0
2	-291	-299	-303	0	0	0	0
3	-319	-300	-503	0	0	0	0
4	0	-51	99	0	0	0	0
5	0	0	0	0	0	0	0
6	-76	-102	-176	0	0	0	0
7	0	0	0	0	0	0	0
8	-86	-332	-330	0	0	0	0
9	0	0	-156	0	0	0	0
10	-750	-750	-587	0	0	0	0
11	0	0	-632	0	0	0	0
12	-524	-1088	-756	0	0	0	0
13	-98	-628	-888	0	0	0	0
14	-2000	-2000	-2000	0	0	0	0
15	-2000	-2000	-1920	0	0	0	0
16	-2000	-2000	-2000	0	0	0	0
17	0	0	2000	0	0	0	0

	80.15	80.16
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0

$^{7}Li^{3+}$, $^{14}N^{6+}$

	85.01	85.02	85.03	85.04	85.05	85.06
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0

$^{12}C^{5+}$

	90.01	90.02	90.03	90.04	90.05	90.06	90.07
1	-750	-515	-347	-229	-151	-132	-41
2	40	-178	-282	-341	-369	-274	-321
3	-328	-295	-290	-287	-293	-365	-333
4	0	-36	-49	-54	-54	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
8	92	96	92	85	60	21	0
9	0	0	0	0	0	92	85
10	107	101	71	0	-59	-230	-339
11	0	0	0	0	0	0	-43
12	676	744	753	784	532	501	267
13	-37	-76	-193	-429	-280	-624	-703
14	-744	-821	-804	-696	-1020	-900	-1100
15	2000	2000	1911	1575	1306	761	198
16	-1586	-1706	-2000	-2000	-2000	-2000	-2000
17	0	0	0	0	0	0	0

	90.08	90.09	90.10	90.11	90.12	90.13	90.14
1	30	71	121	212	0	0	0
2	-330	-335	-343	-310	0	0	0
3	-297	-290	-290	-502	0	0	0
4	0	0	-27	105	0	0	0
5	0	0	0	0	0	0	0
6	0	-27	-101	-170	0	0	0
7	0	0	0	0	0	0	0
8	-57	-138	-254	-328	0	0	0
9	53	49	0	-165	0	0	0
10	-465	-633	-750	-584	0	0	0
11	-163	-222	-416	-668	0	0	0
12	98	-191	-202	-713	0	0	0
13	-975	-988	-1374	-965	0	0	0
14	-1235	-1535	-1531	-2000	0	0	0
15	-336	-795	-1361	-1980	0	0	0
16	-2000	-2000	-2000	-2000	0	0	0
17	0	0	0	2000	0	0	0

	90.15	90.16	90.17	90.18
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0

$^{10}B^{4+}$, $^{20}Ne^{8+}$,...

	100.01	100.02	100.03	100.04	100.05	100.06	100.07
1	-197	-150	-100	-39	50	117	0
2	-325	-300	-293	-336	-374	-359	0
3	-469	-488	-484	-454	-442	-467	0
4	86	106	129	111	77	91	0
5	0	0	0	0	0	0	0
6	33	34	33	0	-76	-110	0
7	0	0	0	0	0	0	0
8	24	0	-60	-197	-324	-376	0
9	0	0	0	0	0	0	0
10	0	-145	-314	-376	-565	-750	0
11	-64	0	0	-592	-750	-495	0
12	0	-653	-1292	-83	107	-922	0
13	-219	407	1044	-598	-1500	-818	0
14	219	-798	-2000	-2000	-2000	-1980	0
15	-2000	-2000	-2000	-2000	-2000	-2000	0
16	-1915	-2000	-2000	-2000	-2000	-2000	0
17	0	0	0	0	0	2000	0

	100.08	100.09	100.10	100.11
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0

$^{13}C^{5+}$

	105.01	105.02	105.03	105.04	105.05	105.06
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0

$^{16}O^{6+}$,...

	110.01	110.02	110.03	110.04	110.05	110.06	110.07
1	-362	-249	-198	-148	-132	64	179
2	-298	-399	-366	-323	-208	-232	-279
3	-435	-398	-427	-469	-554	-506	-482
4	60	25	53	93	201	189	146
5	0	0	0	0	0	0	0
6	30	89	71	64	0	0	-66
7	0	0	0	0	0	0	0
8	79	0	0	0	0	-99	-244
9	0	0	0	0	0	0	0
10	167	208	88	-65	-326	-401	-613
11	0	0	0	0	0	-214	-351
12	334	84	-160	-561	-1177	-668	-817
13	0	0	85	342	972	-229	-643
14	451	685	251	-555	-1889	-2000	-2000
15	-1107	-2000	-2000	-2000	-2000	-367	-1093
16	-1231	-974	-1555	-2000	-2000	-2000	-2000
17	0	0	0	0	0	0	0

	110.08	110.09	110.10	110.11	110.12	110.13	110.14
1	235	0	0	0	0	0	0
2	-300	0	0	0	0	0	0
3	-491	0	0	0	0	0	0
4	138	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	-120	0	0	0	0	0	0
7	0	0	0	0	0	0	0
8	-269	0	0	0	0	0	0
9	-158	0	0	0	0	0	0
10	-525	0	0	0	0	0	0
11	-622	0	0	0	0	0	0
12	-702	0	0	0	0	0	0
13	-829	0	0	0	0	0	0
14	-2000	0	0	0	0	0	0
15	-1856	0	0	0	0	0	0
16	-2000	0	0	0	0	0	0
17	2000	0	0	0	0	0	0

$^{14}N^{5+}$,...

	120.01	120.02	120.03	120.04	120.05	120.06	120.07
1	-90	-42	155	205	348	433	463
2	-290	-295	-262	-308	-393	-352	-340
3	-475	-476	-489	-506	-240	-208	-132
4	141	162	172	150	-77	-131	-176
5	0	0	0	0	0	0	0
6	62	34	-42	-111	-183	-268	-308
7	0	0	0	0	0	0	0
8	-29	-71	-156	-264	-370	-407	-371
9	31	-124	-129	-165	-141	-339	-498
10	-319	-167	-371	-526	-714	-750	-750
11	118	-561	-506	-646	-750	-750	-750
12	-1434	-250	-515	-644	-459	-670	-742
13	1225	-162	-672	-981	-1515	-2000	-2000
14	-1884	-2000	-2000	-1869	-2000	-2000	-2000
15	-2000	-2000	-864	-2000	-2000	-2000	-2000
16	-2000	-2000	-2000	-2000	-2000	-2000	-2000
17	0	0	0	2000	2000	2000	2000

	120.08	120.09	120.10
1	562	689	0
2	-393	-448	0
3	-40	76	0
4	-243	-310	0
5	0	0	0
6	-341	-363	0
7	0	0	0
8	-402	-423	0
9	-584	-663	0
10	-750	-750	0
11	-750	-750	0
12	-1083	-1407	0
13	-2000	-2000	0
14	-2000	-2000	0
15	-2000	-2000	0
16	-2000	-2000	0
17	2000	2000	0

$^{20}Ne^{7+}$

	125.01	125.02
1	526	683
2	-345	-463
3	-92	76
4	-178	-323
5	0	0
6	-293	-373
7	0	0
8	-367	-431
9	-506	-674
10	-750	-750
11	-750	-750
12	-786	-1423
13	-2000	-2000
14	-2000	-2000
15	-2000	-2000
16	-2000	-2000
17	2000	2000

$^{6}Li^{2+}$, $^{9}Be^{3+}$, $^{12}C^{4+}$,...

	130.01	130.02	130.03	130.04	130.05	130.06	130.07
1	-750	-750	-750	-661	83	288	394
2	-199	-156	-60	-122	-679	-750	-750
3	24	-79	-196	-194	-207	-226	-219
4	-63	-59	-23	-26	-50	-38	-66
5	0	0	0	0	0	0	0
6	27	20	0	0	0	0	37
7	0	0	0	0	0	0	0
8	65	86	106	113	115	113	81
9	0	0	0	0	0	0	0
10	129	176	193	198	218	178	104
11	0	0	0	0	0	0	0
12	312	427	485	491	321	186	-46
13	0	0	0	0	0	0	0
14	65	111	114	97	725	740	540
15	82	47	-71	-145	-1029	-1491	-1950
16	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0

	130.08	130.09	130.10	130.11	130.12	130.13	130.14
1	471	570	-56	113	215	257	382
2	-750	-750	-294	-573	-284	-296	-384
3	-228	-227	-356	-363	-477	-483	-229
4	-52	-35	148	56	161	165	-60
5	0	0	0	0	0	0	0
6	49	59	45	0	-67	-82	-160
7	0	0	0	0	0	0	0
8	69	42	-26	-131	-194	-225	-345
9	0	0	-86	-115	-153	-159	-143
10	21	-110	-200	-311	-415	-476	-685
11	0	0	-288	-491	-595	-612	-750
12	-287	-659	-800	-750	-513	-639	-478
13	0	0	468	63	-868	-814	-1443
14	71	-198	-1927	-2000	-2000	-2000	-2000
15	-1184	-1652	-2000	-2000	-1152	-1718	-2000
16	-2000	-2000	-2000	-2000	-2000	-2000	-2000
17	0	0	0	0	0	2000	2000

	130.15	130.16	130.17	130.18	130.19	130.20
1	437	505	628	718	0	0
2	-356	-360	-409	-419	0	0
3	-212	-103	0	74	0	0
4	-93	-184	-226	-266	0	0
5	0	0	0	0	0	0
6	-214	-298	-300	-313	0	0
7	0	0	0	0	0	0
8	-377	-370	-377	-390	0	0
9	-242	-504	-555	-614	0	0
10	-750	-750	-750	-750	0	0
11	-750	-750	-750	-750	0	0
12	-504	-758	-993	-1247	0	0
13	-1871	-2000	-2000	-2000	0	0
14	-2000	-2000	-2000	-2000	0	0
15	-2000	-2000	-2000	-2000	0	0
16	-2000	-2000	-2000	-2000	0	0
17	2000	2000	2000	2000	0	0

$^{16}O^{5+}$,...

	140.01	140.02	140.03	140.04	140.05	140.06	140.07
1	84	139	14	411	456	570	715
2	-239	-242	-294	-379	-322	-366	-415
3	-481	-497	-367	-219	-157	-60	66
4	204	213	133	-51	-125	-188	-254
5	0	0	0	0	0	0	0
6	68	0	-35	-148	-254	-283	-299
7	0	0	0	0	0	0	0
8	0	-96	-231	-333	-332	-360	-378
9	-45	-133	-125	-145	-423	-511	-593
10	-194	-315	-491	-679	-750	-750	-750
11	-269	-484	-603	-750	-750	-750	-750
12	-366	-474	-591	-493	-451	-820	-1174
13	-232	-618	-775	-1435	-2000	-2000	-2000
14	-1904	-2000	-1776	-2000	-2000	-2000	-2000
15	-29	-778	-1746	-2000	-2000	-2000	-2000
16	-2000	-2000	-1998	-2000	-2000	-2000	-2000
17	0	0	2024	2000	2000	2000	2000

	140.08
1	750
2	-335
3	147
4	-317
5	0
6	-325
7	0
8	-398
9	-684
10	-750
11	-750
12	-1542
13	-2000
14	-2000
15	-2000
16	-2000
17	2000

$^{7}Li^{2+}$, $^{14}N^{4+}$,...

	150.01	150.02	150.03	150.04	150.05	150.06	150.07
1	-701	-447	-320	-318	-178	-132	-76
2	-118	-289	-305	-270	-314	-299	-278
3	-206	-140	-431	-469	-457	-477	-472
4	-21	-61	75	97	111	135	167
5	0	0	0	0	0	0	0
6	0	33	54	62	78	91	97
7	0	0	0	0	0	0	0
8	119	114	104	94	85	73	44
9	0	0	0	0	0	0	0
10	211	202	190	122	58	-48	-219
11	0	0	0	0	0	0	0
12	541	433	337	169	-52	-285	-521
13	0	0	0	0	0	0	0
14	30	137	573	255	194	-265	-946
15	264	-577	-1500	-1352	-2000	-2000	-2000
16	-627	0	-773	-1804	-1504	-2000	-2000
17	0	0	0	0	0	0	0

	150.08	150.09	150.10	150.11	150.12	150.13	150.14
1	-35	22	250	306	451	513	650
2	-262	-306	-352	-336	-419	-436	-358
3	-482	-449	-446	-225	-179	-111	-79
4	204	170	163	-38	-80	-170	-162
5	0	0	0	0	0	0	0
6	66	33	0	-56	-123	-153	-251
7	0	0	0	0	0	0	0
8	0	-152	-205	-374	-425	-591	-398
9	0	0	-110	0	0	0	-407
10	-461	-610	-473	-750	-750	-750	-750
11	0	0	-565	0	-750	-750	-750
12	-778	-1500	-570	-2000	-531	-863	-1051
13	0	0	-908	-332	-1507	-1802	-2000
14	-1724	-2000	-1790	-2000	-2000	-2000	-2000
15	-2000	-2000	-1744	-2000	-2000	-2000	-2000
16	-2000	-2000	-2000	-1911	-2000	-2000	-2000
17	0	0	2000	2000	2000	2000	2000

	150.15
1	717
2	-396
3	54
4	-227
5	0
6	-273
7	0
8	-355
9	-560
10	-750
11	-750
12	-1068
13	-2000
14	-2000
15	-2000
16	-2000
17	2000

$^{12}C^{3+}$, $^{16}O^{4+}$, $^{20}Ne^{5+}$,...

	160.01	160.02	160.03	160.04	160.05	160.06	160.07
1	-750	-687	-504	-436	-388	353	613
2	-205	-124	-159	-179	-174	-657	-750
3	0	-164	-105	-94	-86	-256	-227
4	-66	-46	-151	-155	-153	-28	0
5	0	0	0	0	0	0	0
6	28	25	49	58	68	78	98
7	0	0	0	0	0	0	0
8	76	112	118	117	111	109	88
9	0	0	0	0	0	0	0
10	151	216	198	169	118	63	-63
11	0	0	0	0	0	0	0
12	364	506	487	398	239	-240	-604
13	0	0	0	0	0	0	0
14	83	125	-373	-437	-544	63	-166
15	99	-93	992	719	350	-1080	-1646
16	0	0	-2000	-2000	-2000	-1702	-2000
17	0	0	0	0	0	0	0

	160.08	160.09	160.10	160.11	160.12	160.13	160.14
1	692	750	750	32	485	412	398
2	-750	-750	-750	-345	-589	-332	-222
3	-181	-176	-163	0	-60	-151	-82
4	0	0	-36	0	-94	-94	-166
5	0	0	0	0	0	0	0
6	101	43	-20	0	0	-49	-74
7	0	0	0	0	0	0	0
8	31	-82	-145	-142	-374	-517	-674
9	0	0	-203	-147	0	0	0
10	-276	-565	-274	-393	-750	-750	-750
11	0	0	-750	-578	0	0	0
12	-991	-1346	-572	-478	-2000	-2000	-2000
13	0	0	-494	-907	0	-907	-1365
14	-655	-1513	-2000	-1754	-2000	-2000	-2000
15	-2000	-2000	-2000	-1599	-2000	-2000	-2000
16	-2000	-2000	-2000	-2261	-2000	-2000	-2000
17	0	0	0	2400	2000	2000	2000

	160.15	160.16	160.17	160.18
1	677	750	750	750
2	-422	-449	-350	-277
3	0	77	92	144
4	-193	-256	-240	-301
5	0	0	0	0
6	-121	-134	-262	-295
7	0	0	0	0
8	-627	-706	-344	-367
9	0	0	-580	-656
10	-750	-750	-750	-750
11	-750	-750	-750	-750
12	-1004	-1326	-1174	-1467
13	-2000	-2000	-2000	-2000
14	-2000	-2000	-2000	-2000
15	-2000	-2000	-2000	-2000
16	-2000	-2000	-2000	-2000
17	2000	2000	2000	2000

$^{9}Be^{2+}$, $^{18}O^{4+}$,...

	165.01	165.02	165.03	165.04	165.05	165.06	165.07
1	-166	750	272	367	447	613	750
2	-296	-750	-256	-305	-338	-385	-429
3	-72	-196	-478	-217	-124	-69	66
4	0	37	237	0	-112	-148	-235
5	0	0	0	0	0	0	0
6	117	70	22	-27	-44	-113	-121
7	0	0	0	0	0	0	0
8	106	0	-138	-323	-551	-571	-674
9	0	0	0	0	0	0	0
10	-80	-435	-690	-750	-750	-750	-750
11	0	0	0	0	0	-750	-750
12	-363	-1139	-1530	-2000	-2000	-778	-1255
13	0	0	0	-289	-1063	-2000	-2000
14	-990	-1157	-2000	-2000	-2000	-2000	-2000
15	-684	-1950	-1833	-2000	-2000	-2000	-2000
16	-2000	-2000	-1654	-1936	-2000	-2000	-2000
17	0	0	2000	2000	2000	2000	2000

	165.08
1	750
2	-275
3	0
4	-215
5	0
6	-270
7	0
8	-406
9	-495
10	-750
11	-750
12	-1454
13	-2000
14	-2000
15	-2000
16	-2000
17	2000

$^{14}N^{3+}$,...

	170.01	170.02	170.03	170.04	170.05	170.06	170.07
1	-432	-330	-370	-251	-278	-149	-129
2	-279	-319	-165	-271	-116	-256	-255
3	-134	-122	-82	-127	-60	-75	-63
4	-53	-46	-145	0	-116	31	40
5	0	0	0	0	0	0	0
6	44	58	85	96	125	119	115
7	0	0	0	0	0	0	0
8	127	127	122	128	112	84	58
9	0	0	0	0	0	0	0
10	214	153	110	37	-37	-178	-264
11	0	0	0	0	0	0	0
12	451	336	193	-42	-264	-591	-777
13	0	0	0	0	0	0	0
14	133	-478	-544	-773	-927	-1116	-1229
15	-514	538	131	-216	-540	-1011	-1274
16	0	-2000	-2000	-2000	-2000	-2000	-2000
17	0	0	0	0	0	0	0

	170.08	170.09	170.10	170.11	170.12	170.13	170.14
1	-186	-91	-96	361	435	621	689
2	-94	-260	-105	-311	-329	-400	-408
3	0	-44	23	-220	-143	-72	0
4	-89	39	-128	0	-85	-125	-193
5	0	0	0	0	0	0	0
6	113	72	30	-27	-37	-102	-117
7	0	0	0	0	0	0	0
8	28	-43	-154	-321	-499	-520	-625
9	0	0	0	0	0	0	0
10	-393	-491	-710	-750	-750	-750	-750
11	0	0	0	0	0	-750	-750
12	-800	-1225	-1593	-2000	-2000	-799	-1035
13	0	0	0	-280	-903	-1821	-2000
14	-1738	-1501	-2000	-2000	-2000	-2000	-2000
15	-1084	-1893	-1990	-2000	-2000	-2000	-2000
16	-2000	-2000	-1578	-1946	-2000	-2000	-2000
17	0	0	2000	2000	2000	2000	2000

	170.15	170.16
1	750	750
2	-296	-283
3	0	124
4	-174	-274
5	0	0
6	-224	-271
7	0	0
8	-375	-345
9	-433	-616
10	-750	-750
11	-750	-750
12	-1252	-1328
13	-2000	-2000
14	-2000	-2000
15	-2000	-2000
16	-2000	-2000
17	2000	2000

$^{10}B^{2+}$, $^{15}N^{3+}$, $^{20}Ne^{4+}$, $^{40}Ar^{8+}$,...

	175.01	175.02	175.03	175.04	175.05	175.06	175.07
1	-152	-128	-100	-54	0	90	422
2	-257	-256	-259	-270	-205	-250	-323
3	-78	-64	-49	-30	-77	0	-163
4	30	44	53	27	86	0	-54
5	0	0	0	0	0	0	0
6	123	126	116	42	0	0	-28
7	0	0	0	0	0	0	0
8	97	76	37	-99	-120	-247	-438
9	0	0	0	0	0	0	0
10	-146	-234	-351	-620	-603	-750	-750
11	0	0	0	0	-234	0	0
12	-524	-732	-982	-1415	-1004	-1879	-2000
13	0	0	0	0	-394	-148	-710
14	-1070	-1213	-1375	-1810	-2000	-2000	-2000
15	-928	-1241	-1619	-2000	-1471	-2000	-2000
16	-2000	-2000	-2000	-2000	-2000	-1854	-2000
17	0	0	0	0	2000	2000	2000

	175.08	175.09	175.10	175.11
1	613	750	750	750
2	-395	-393	-261	-170
3	-89	40	0	26
4	-97	-184	-165	-212
5	0	0	0	0
6	-89	-95	-214	-252
7	0	0	0	0
8	-473	-609	-365	-383
9	0	0	-429	-516
10	-750	-750	-750	-750
11	-750	-750	-750	-726
12	-709	-1092	-1260	-1583
13	-1755	-2000	-2000	-2000
14	-2000	-2000	-2000	-2000
15	-2000	-2000	-2000	-2000
16	-2000	-2000	-2000	-2000
17	2000	2000	2000	2000

$^{16}O^{3+}$, $^{32}S^{6+}$,...

	180.01	180.02	180.03	180.04	180.05	180.06	180.07
1	-750	-467	-358	-361	-282	-288	-154
2	-168	-258	-302	-160	-253	-120	-255
3	-55	-137	-124	-80	-146	-64	-76
4	-58	-52	-47	-143	0	-117	32
5	0	0	0	0	0	0	0
6	27	43	58	85	86	125	127
7	0	0	0	0	0	0	0
8	89	129	133	121	136	126	99
9	0	0	0	0	0	0	0
10	175	225	194	109	87	0	-144
11	0	0	0	0	0	0	0
12	419	475	375	180	99	-154	-520
13	0	0	0	0	0	0	0
14	98	155	75	-587	-674	-874	-1075
15	100	-425	-742	232	75	-366	-894
16	0	0	0	-2000	-2000	-2000	-2000
17	0	0	0	0	0	0	0

	180.08	180.09	180.10	180.11	180.12	180.13	180.14
1	-113	-83	-213	47	97	199	402
2	-253	-263	-146	-289	-237	-286	-318
3	-54	-39	20	0	0	128	205
4	51	47	-112	34	0	-109	-126
5	0	0	0	0	0	0	0
6	120	85	61	43	0	0	-60
7	0	0	0	0	0	0	0
8	53	-31	-95	-117	-261	-450	-467
9	0	0	0	0	0	0	0
10	-297	-488	-584	-665	-750	-750	-750
11	0	0	0	0	0	0	-750
12	-848	-1236	-1386	-1500	-1932	-2000	-754
13	0	0	0	0	-173	-802	-1828
14	-1284	-1515	-1668	-2000	-2000	-2000	-2000
15	-1363	-1941	-2000	-1768	-2000	-2000	-2000
16	-2000	-2000	-2000	-1660	-1904	-2000	-2000
17	0	0	0	2000	2000	2000	2000

	180.15	180.16
1	495	0
2	-334	0
3	265	0
4	-220	0
5	0	0
6	-219	0
7	0	0
8	-379	0
9	-416	0
10	-750	0
11	-750	0
12	-1185	0
13	-2000	0
14	-2000	0
15	-2000	0
16	-2000	0
17	2000	0

$^{6}Li^{1+}$, $^{12}C^{2+}$, $^{16}O^{3+}$, $^{24}Mg^{6+}$,...

	190.01	190.02	190.03	190.04	190.05	190.06	190.07
1	-750	-750	-750	-697	-613	-519	-392
2	-210	-142	-95	-122	-179	-226	-292
3	0	-83	-127	-164	-153	-141	-127
4	-71	-53	-44	-43	-47	-51	-47
5	0	0	0	0	0	0	0
6	31	27	27	31	37	42	55
7	0	0	0	0	0	0	0
8	81	95	103	119	127	130	136
9	0	0	0	0	0	0	0
10	161	187	199	228	234	231	214
11	0	0	0	0	0	0	0
12	383	444	468	523	525	495	435
13	0	0	0	0	0	0	0
14	99	100	94	155	132	159	115
15	83	100	80	-108	-150	-313	-585
16	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0

	190.08	190.09	190.10	190.11	190.12	190.13	190.14
1	-291	-193	-186	-137	-99	-39	50
2	-302	-289	-289	-257	-254	-263	-281
3	-114	-89	-84	-71	-46	-27	0
4	-33	0	0	43	58	39	44
5	0	0	0	0	0	0	0
6	76	124	125	141	124	68	56
7	0	0	0	0	0	0	0
8	135	139	127	110	47	-62	-102
9	0	0	0	0	0	0	0
10	148	38	0	-150	-328	-537	-646
11	0	0	0	0	0	0	0
12	227	-143	-216	-561	-922	-1315	-1465
13	0	0	0	0	0	0	0
14	0	-315	-863	-1106	-1332	-1562	-2000
15	-1149	-1766	-437	-1040	-1488	-1997	-1703
16	0	0	-2000	-2000	-2000	-2000	-1682
17	0	0	0	0	0	0	2000

	190.15	190.16	190.17	190.18
1	140	312	402	587
2	-242	-344	-299	-385
3	32	123	175	357
4	0	-77	-145	-309
5	0	0	0	0
6	0	-58	-172	-266
7	0	0	0	0
8	-261	-366	-340	-413
9	0	0	-319	-504
10	-750	-750	-750	-750
11	0	-750	-750	-748
12	-1993	-503	-800	-1505
13	-185	-1593	-2000	-2000
14	-2000	-2000	-2000	-2000
15	-2000	-2000	-2000	-2000
16	-1975	-2000	-2000	-2000
17	2000	2000	2000	2000

$^{7}Li^{1+}$, $^{14}N^{2+}$, $^{28}Si^{4+}$

	195.01	195.02
1	323	641
2	-379	-306
3	181	368
4	-199	-210
5	0	0
6	-110	-169
7	0	0
8	-564	-340
9	0	-417
10	-750	-750
11	-750	-750
12	-743	-1332
13	-2000	-2000
14	-2000	-2000
15	-2000	-2000
16	-2000	-2000
17	2000	2000

$^{16}O^{2+}$, $^{32}S^{4+}$, $^{40}Ar^{5+}$,...

	200.01	200.02	200.03	200.04	200.05	200.06	200.07
1	-598	-427	-316	-317	-165	-192	-87
2	-112	-172	-319	-138	-260	-96	-251
3	-114	-89	-118	-68	-84	0	-39
4	-137	-144	-35	-122	31	-79	66
5	0	0	0	0	0	0	0
6	54	77	79	124	142	161	130
7	0	0	0	0	0	0	0
8	133	140	147	146	137	95	42
9	0	0	0	0	0	0	0
10	233	198	168	92	-52	-200	-349
11	0	0	0	0	0	0	0
12	568	437	338	70	-329	-676	-972
13	0	0	0	0	0	0	0
14	-340	-420	-485	-696	-967	-1170	-1356
15	1265	770	472	0	-657	-1155	-1576
16	-2000	-2000	-2000	-2000	-2000	-2000	-2000
17	0	0	0	0	0	0	0

	200.08	200.09	200.10	200.11	200.12	200.13
1	-23	64	332	397	405	581
2	-258	-255	-589	-318	-402	-328
3	-20	0	241	182	257	325
4	48	65	-111	-86	-242	-222
5	0	0	0	0	0	0
6	83	78	50	-39	-111	-192
7	0	0	0	0	0	0
8	-44	-75	-322	-395	-612	-357
9	0	0	0	0	0	-416
10	-513	-615	-750	-750	-750	-750
11	0	0	0	-750	-750	-750
12	-1275	-1413	-2000	-615	-982	-1258
13	0	0	0	-1741	-2000	-2000
14	-1544	-2000	-2000	-2000	-2000	-2000
15	-1937	-1599	-2000	-2000	-2000	-2000
16	-2000	-1711	-2000	-2000	-2000	-2000
17	0	2000	2000	2000	2000	2000

APPENDIX B: Listing of RECORDS

```
1 REM
2 REM THIS IS THE PROGRAM 'RECORDS'
3 REM 09/30/80
4 REM
100 PRINT"":PRINT""
104 REM
105 REM INITIALIZE AND DIMENSION PROGRAM PARAMETERS
106 REM
110 KM=0:C=0:D=0
120 INPUT"ENTER THE MONTH(S) AND YEAR";M$
130 P$="@1: "+M$
140 PP$="1: "+M$
150 DIM D$(120),E(120),B$(120),M(120)
160 DIM Q(120),N$(120),C$(120),N(120)
170 DIM A$(120),H(120),A(120)
180 GOTO 2440
184 REM
185 REM LOAD DATA BASE FROM TAPE
186 REM
190 PRINT"REWIND PROGRAM TAPE AND REPLACE WITH":PRINT""
200 PRINT"  CURRENT DATA TAPE.":PRINT"":PRINT""
210 PRINT"ADVANCE TAPE UNTIL LEADER HAS BEEN":PRINT""
220 PRINT"  FULLY WOUND ONTO TAKE-UP REEL.":PRINT"":PRINT""
230 PRINT"STOP THE TAPE.":PRINT"":PRINT""
240 PRINT"WHEN READY PRESS 'RETURN'.":PRINT"":PRINT""
250 GET G$:IF G$="" THEN 250
260 G$=""
270 OPEN 1,1,0
280 PRINT"LOADING"
290 FOR K=1 TO 120
300 INPUT#1,K
310 INPUT#1,D$(K)
320 INPUT#1,E(K)
330 INPUT#1,M(K)
340 INPUT#1,B$(K)
350 INPUT#1,Q(K)
360 INPUT#1,C$(K)
370 INPUT#1,N(K)
380 INPUT#1,A$(K)
390 INPUT#1,N$(K)
400 IF LEFT$(D$(K),1)="D" THEN 420
410 KM=K
420 NEXT K
430 K=KM
440 CLOSE 1
450 PRINT""
460 PRINT"REWIND THE DATA TAPE.":PRINT"":PRINT""
470 PRINT"WHEN READY PRESS 'RETURN'."
480 GET G$:IF G$="" THEN 480
490 G$=""
500 GOTO 1020
510 PRINT""
514 REM
515 REM UPDATE THE DATA BASE
516 REM
520 PRINT"ENTER THE FOLLOWING INFORMATION:"
530 PRINT""
540 K=K+1
550 I=K
560 GOSUB 580
570 GOTO 500
```

```
574 REM ____________________________________
575 REM SUBROUTINE TO ENTER DATA FROM KEYBOARD
576 REM
580 PRINT"ENTRY NUMBER";I
590 PRINT""
600 IS=I
610 INPUT "DATE";D$(I)
620 INPUT "ENERGY";E(I)
630 INPUT "MASS";M(I)
640 INPUT "ION";B$(I)
650 INPUT "CHARGE STATE";Q(I)
660 INPUT "CAVE";C$(I)
670 INPUT "NUMBER OF SHIFTS";N(I)
680 H(I)=8*N(I)
690 INPUT "AVERAGE INTENSITY";A$(I)
700 INPUT "EXPERIMENTER";N$(I)
710 PRINT"":PRINT""
720 I=IS
730 IF MM=3 THEN 750
740 KM=K
750 RETURN
760 PRINT""
764 REM____________________________
765 REM MAKE CORRECTIONS TO DATA BASE
766 REM
770 KS=K
780 INPUT"INPUT NUMBER OF ERRONEOUS ENTRY";J
790 K=J
800 PRINT D$(K);TAB(9);E(K);TAB(15);M(K);TAB(18);B$(K);TAB(22);Q(K):PRINT""
810 PRINT C$(K);TAB(3);N(K);TAB(6);A$(K);TAB(14);N$(K)
820 PRINT""
830 I=K
840 PRINT"WHEN READY PRESS 'RETURN'.":PRINT""
850 GET G$:IF G$="" THEN 850
860 G$=""
870 GOSUB 580
880 K=KS
890 GOTO 1020
900 PRINT""
904 REM ____________________________
905 REM STORE UPDATED DATA BASE ON TAPE
906 REM
910 PRINT"INSERT DATA TAPE INTO CASSETTE DECK.":PRINT""
920 PRINT"REWIND THE DATA TAPE, THEN ERASE ABOUT":PRINT""
930 PRINT"  TEN TURNS THEREOF.":PRINT"":PRINT""
940 PRINT"REWIND TAPE.":PRINT"":PRINT""
950 PRINT"ADVANCE TAPE UNTIL LEADER HAS BEEN":PRINT""
960 PRINT"  FULLY WOUND ONTO TAKE-UP REEL.":PRINT"":PRINT""
970 PRINT"AFTER ONE MORE TURN, STOP THE TAPE.":PRINT"":PRINT""
980 PRINT"WHEN READY PRESS 'RETURN'."
990 GET G$:IF G$="" THEN 990
1000 G$=""
1010 GOTO 2710
1020 PRINT""
1024 REM ____________________________
1025 REM OFFER SEVEN PROGRAM OPTIONS
1026 REM
1030 PRINT"  SELECT ONE OF THE FOLLOWING OPTIONS:":PRINT"":PRINT""
1040 PRINT"1.  EXAMINE RECORDS":PRINT""
1050 PRINT"2.  UPDATE  RECORDS":PRINT""
1060 PRINT"3.  CORRECT RECORDS":PRINT""
1070 PRINT"4.  STORE   RECORDS ON TAPE":PRINT""
1080 PRINT"5.  ANALYZE RECORDS":PRINT""
1090 PRINT"6.  CHECK   RECORDS ENTRY":PRINT""
1100 PRINT"7.  STORE   RECORDS ON DISK":PRINT""
1110 INPUT MM
1120 ON MM GOTO 1280,510,760,900,3260,3480,3630
```

```
1130 PRINT"":PRINT"":PRINT""
1134 REM ----------------------------
1135 REM INPUT ANALYSIS PARAMETERS
1136 REM
1140 IF MM=5 AND NN>1 THEN 1170
1150 INPUT"LOWER ENERGY LIMIT";E1
1160 INPUT"UPPER ENERGY LIMIT";E2
1170 IF MM=5 AND NN>3 THEN 1190
1180 INPUT"MASS";M1
1190 INPUT"ION";B1$
1200 IF MM=5 AND NN>2 THEN 1280
1210 INPUT"CHARGE STATE";Q1
1220 GOTO 1280
1230 PRINT""
1240 INPUT "CAVE";C1$
1250 GOTO 1280
1260 PRINT""
1270 INPUT "EXPERIMENTER";N1$
1280 PRINT""
1284 REM ----------------------------------------
1285 REM GENERATE HARD-COPY PRINTOUT OF DATA BASE
1286 REM
1290 KS=K
1300 PRINT"CONNECT PET TO PRINTER--":PRINT""
1310 PRINT"  THEN PRESS 'RETURN'.":PPINT""
1320 GET G$:IF G$="" THEN 1320
1330 G$=""
1340 H(K)=8*N(K)
1350 SS=.000000001
1360 OPEN 4,4,1:CMD 4
1370 IF MM=5 THEN 3060
1380 PRINT#4,"BEAMS SUMMARY FOR ";M$
1390 PRINT#4,"":PRINT#4,""
1400 PRINT#4,"       DATE      ENERGY     MASS   ION.   CHG   CAVE   HRS   AVG AMT";
1410 PRINT#4,"   EXPERIMENTER":PRINT#4,""
1420 FOR K=1 TO KS
1430 IF MM=1 THEN 1750
1434 REM ----------------------------------------
1435 REM DATA SORT ROUTINE FOR ANALYSIS OPTION
1436 REM
1440 IF MM=5 AND NN>1 THEN 1470
1450 IF E(K)<E1 THEN 2270
1460 IF E(K)>E2 THEN 2270
1470 IF MM=5 AND NN>3 THEN 1490
1480 IF M(K)<>M1 THEN 2270
1490 IF MM=5 AND NN>4 THEN 1580
1500 IF LEFT$(B$(K),1)<>LEFT$(B1$,1) THEN 2270
1510 IF LEN(B1$)=1 THEN 1560
1520 IF LEN(B$(K))<>LEN(B1$) THEN 2270
1530 IF MID$(B$(K),2,1)<>MID$(B1$,2,1) THEN 2270
1540 IF LEN(B1$)=2 THEN 1560
1550 IF MID$(B$(K),3,1)<>MID$(B1$,3,1) THEN 2270
1560 IF MM=5 AND NN>2 THEN 1580
1570 IF Q(K)<>Q1 THEN 2270
1580 IF MM=5 AND NN>5 THEN 1650
1590 IF MM=5 AND NN<5 THEN 1750
1600 IF LEN(C$(K))<>LEN(C1$) THEN 2270
1610 IF LEFT$(C$(K),1)<>LEFT$(C1$,1) THEN 2270
1620 IF LEN(C1$)=1 THEN 1750
1630 IF RIGHT$(C$(K),1)<>RIGHT$(C1$,1) THEN 2270
1640 GOTO 1750
```

```
1650 IF N1$="◆"THEN 1740
1660 IF LEN(N$(K))<>LEN(N1$) THEN 2270
1670 IF LEFT$(N$(K),1)<>LEFT$(N1$,1) THEN 2270
1680 IF MID$(N$(K),2,1)<>MID$(N1$,2,1) THEN 2270
1690 IF LEN(N1$)=2 THEN 1750
1700 IF MID$(N$(K),3,1)<>MID$(N1$,3,1) THEN 2270
1710 IF LEN(N1$)=3 THEN 1750
1720 IF MID$(N$(K),4,1)<>MID$(N1$,4,1) THEN 2270
1730 GOTO 1750
1740 IF RIGHT$(N$(K),1)<>"◆" THEN 2270
1750 FOR S=1 TO 200:NEXT S
1760 IF K<100 THEN PRINT#4," ";
1770 IF K<10 THEN PRINT#4," ";
1780 PRINT#4,K;"";D$(K);" ";
1790 IF E(K)<100 THEN PRINT#4," ";
1800 IF E(K)<10 THEN PRINT#4," ";
1810 PRINT#4,E(K);
1820 IF E(K)=INT(E(K)) THEN PRINT#4,"  ";
1830 PRINT#4,"MEV";
1840 IF M(K)<100 THEN PRINT#4," ";
1850 IF M(K)<10 THEN PRINT#4," ";
1860 PRINT#4,M(K);"   ";B$(K);
1870 IF RIGHT$(B$(K),1)=">" THEN C=C+1
1880 IF RIGHT$(B$(K),1)="◆" THEN D=D+1
1890 IF LEN(B$(K))=3 THEN PRINT#4," ";
1900 IF LEN(B$(K))=2 THEN PRINT#4,"  ";
1910 IF LEN(B$(K))=1 THEN PRINT#4,"   ";
1920 PRINT#4,"+";
1930 IF Q(K)<10 THEN PRINT#4," ";
1940 PRINT#4,Q(K);"  ";C$(K);
1950 IF LEN(C$(K))<2 THEN PRINT#4," ";
1960 PRINT#4,"  ";
1970 H(K)=8◆N(K)
1980 IF H(K)<100 THEN PRINT#4," ";
1990 IF H(K)<10 THEN PRINT#4," ";
2000 IF H(K)<1 THEN PRINT#4," ";
2010 PRINT#4,H(K);"  ";
2020 IF LEFT$(A$(K),1)="<" THEN PRINT#4," ";A$(K);:GOTO 2220
2030 A(K)=VAL(A$(K))
2040 IF A(K)<1 THEN PRINT#4,"  ";A$(K);:GOTO 2170
2050 IF A(K)<10 THEN PRINT#4," ";A$(K);:GOTO 2120
2060 PRINT#4,A$(K);
2070 IF LEN(A$(K))=7 THEN 2220
2080 IF LEN(A$(K))=6 THEN PRINT#4," ";:GOTO 2220
2090 IF LEN(A$(K))=5 THEN PRINT#4,"  ";:GOTO 2220
2100 IF LEN(A$(K))=4 THEN PRINT#4,"   ";:GOTO 2220
2110 PRINT#4,"     ";:GOTO 2220
2120 IF LEN(A$(K))=6 THEN 2220
2130 IF LEN(A$(K))=5 THEN PRINT#4," ";:GOTO 2220
2140 IF LEN(A$(K))=4 THEN PRINT#4,"  ";:GOTO 2220
2150 IF LEN(A$(K))=3 THEN PRINT#4,"   ";:GOTO 2220
2160 PRINT#4,"     ";:GOTO 2220
2170 IF LEN(A$(K))=5 THEN 2220
2180 IF LEN(A$(K))=4 THEN PRINT#4," ";:GOTO 2220
2190 IF LEN(A$(K))=3 THEN PRINT#4,"  ";:GOTO 2220
2200 IF LEN(A$(K))=2 THEN PRINT#4,"   ";:GOTO 2220
2210 PRINT#4,"     ";:GOTO 2220
2220 IF RIGHT$(N$(K),1)="◆"THEN 2240
2230 PRINT#4,"  ";N$(K):GOTO 2260
2240 N2=LEN(N$(K)):N2=N2-1
2250 PRINT#4,"  ";LEFT$(N$(K),N2)
2260 SS=SS+H(K)
2270 NEXT K
```

```
2280 SS=INT(SS)
2290 IF MM=5 THEN 3360
2300 PRINT#4,"                                                                    ----"
2310 PRINT#4,"                                                TOTAL HOURS    ";
2320 IF SS<1000 THEN PRINT#4," ";
2330 IF SS<100 THEN PRINT#4," ";
2340 IF SS<10 THEN PRINT#4," ";
2350 PRINT#4,SS
2360 PRINT#4,""
2370 IF C>0 THEN PRINT#4,"":PRINT#4,"<ION> = POLARIZED BEAM":PRINT#4,""
2380 IF D>0 THEN PRINT#4,"":PRINT#4,"ION* = AXIALLY INJECTED BEAM":PRINT#4,""
2390 PRINT#4,"":PRINT#4,"BEAM INTENSITIES EXPRESSED IN MICROAMPERES"
2400 CLOSE 4
2410 S1=SS
2420 K=KS
2430 GOTO 1020
2434 REM_____________________________________________
2435 REM DETERMINE IF DATA TAPE HAS BEEN INITIALIZED
2436 REM
2440 PRINT"  WILL THIS BE THE FIRST ENTRY FOR":PRINT""
2450 INPUT "THE CURRENT RECORDS PERIOD";G$:PRINT"":PRINT""
2460 IF LEFT$(G$,1)="Y" THEN 2500
2470 INPUT"IS DATA ON TAPE OR DISK";Q$:PRINT"":PRINT""
2480 IF LEFT$(Q$,1)="D" THEN 3850
2490 GOTO 190
2494 REM_____________________
2495 REM INITIALIZE DATA TAPE
2496 REM
2500 PRINT"":PRINT"  REWIND PROGRAM TAPE AND STORE IT.":PRINT""
2510 PRINT"":PRINT"  INSERT DATA TAPE INTO CASSETTE":PRINT""
2520 PRINT"DECK AND REWIND IT.":PRINT""
2530 PRINT"  ADVANCE TAPE UNTIL LEADER HAS BEEN":PRINT""
2540 PRINT"FULLY WOUND ONTO THE TAKE-UP REEL.":PRINT""
2550 PRINT"  ALLOW THE TAPE TO ADVANCE FOR ONE":PRINT""
2560 PRINT"FULL TURN, THEN STOP THE TAPE.":PRINT""
2570 PRINT"  WHEN READY PRESS 'RETURN'.":PRINT""
2580 GET G$:IF G$="" THEN 2580
2590 G$=""
2594 REM _____________________
2595 REM INITIALIZE DATA BASE
2596 REM
2600 FOR K=1 TO 120
2610 D$(K)="DATE"
2620 E(K)=0
2630 M(K)=0
2640 B$(K)="BEAM"
2650 Q(K)=0
2660 C$(K)="CAVE"
2670 N(K)=0
2680 A$(K)="AMT"
2690 N$(K)="NAME"
2700 NEXT K
```

```
2704 REM ____________________
2705 REM WRITE DATA ON TAPE
2706 REM
2710 FS=-1:FD=0:FC=191
2720 OPEN 1,1,1
2730 PRINT"WRITING"
2740 FOR K=1 TO 120
2750 PRINT#1,K
2760 PRINT#1,D$(K)
2770 PRINT#1,E(K)
2780 PRINT#1,M(K)
2790 PRINT#1,B$(K)
2800 PRINT#1,Q(K)
2810 PRINT#1,C$(K)
2820 PRINT#1,N(K)
2830 PRINT#1,A$(K)
2840 PRINT#1,N$(K)
2850 Z1$=STR$(K):Z2$=STR$(E(K)):Z3$=STR$(M(K))
2860 Z4$=STR$(Q(K)):Z5$=STR$(N(K))
2870 L1=LEN(Z1$)+LEN(Z2$)+LEN(Z3$)+LEN(Z4$)+LEN(Z5$)
2880 L2=LEN(D$(K))+LEN(B$(K))+LEN(C$(K))+LEN(N$(K))+LEN(A$(K))
2890 L=L1+L2+1
2900 FE=INT((FS+L)/FC)
2910 IF FE=FD THEN 2980
2920 FS=-1
2930 POKE 59411,53
2940 T=TI
2950 IF (TI-T)<5 THEN 2950
2960 POKE 59411,61
2970 GOTO 2990
2980 FS=FS+L
2990 NEXT K
3000 CLOSE 1
3010 K=0
3020 PRINT""
3030 PRINT"FINISHED--REWIND THE DATA TAPE.":PRINT"":PRINT""
3040 IF MM=4 THEN 1030
3050 GOTO 4200
3054 REM ____________________________________
3055 REM GENERATE HEADING FOR ANALYSIS PRINTOUT
3056 REM
3060 PRINT#4,"BEAMS SUMMARY FOR ";M$;
3070 PRINT#4,":  ";
3080 IF NN>4 THEN 3200
3090 IF NN>1 THEN 3140
3100 PRINT#4,E1;
3110 IF E1=E2 THEN 3130
3120 PRINT#4,"-";E2;
3130 PRINT#4," MEV ";
3140 IF NN>3 THEN 3160
3150 PRINT#4,M1;" ";
3160 PRINT#4,B1$;
3170 IF NN>2 THEN PRINT#4,"":GOTO 3250
3180 PRINT#4," +";01
3190 PRINT#4,"":GOTO 1390
3200 IF NN>5 THEN 3230
3210 PRINT#4,"CAVE ";C1$
3220 PRINT#4,"":GOTO 1390
3230 IF N1$="*"THEN PRINT#4,"OUTSIDE USERS":GOTO 3250
3240 PRINT#4,N1$
3250 PRINT#4,"":GOTO 1390
```

```
3260 PRINT""
3264 REM ____________________
3265 REM OFFER ANALYSIS OPTIONS
3266 REM
3270 PRINT"SELECT ONE OF THE FOLLOWING PARAMETERS:":PRINT"":PRINT""
3280 PRINT"1.  BEAM (E, M, ION, Q)":PRINT""
3290 PRINT"2.  PARTICLE (M, ION, Q)":PRINT""
3300 PRINT"3.  ISOTOPE (M, ION)":PRINT""
3310 PRINT"4.  ION":PRINT""
3320 PRINT"5.  CAVE":PRINT""
3330 PRINT"6.  EXPERIMENTER":PRINT""
3340 INPUT NN
3350 ON NN GOTO 1130,1130,1130,1130,1230,1260
3360 PRINT#4,"":PRINT#4,""
3370 S1=.000000001
3380 FOR K=1 TO KS
3390 H(K)=8*N(K)
3400 S1=INT(S1+H(K))
3410 NEXT K
3420 PRINT#4,"SUBTOTAL HOURS=";SS
3430 PRINT#4,"":PRINT#4,""
3440 S2=INT(SS*10000/S1)/100
3450 PRINT#4,"PERCENT OF TOTAL=";S2;"%"
3460 CLOSE 4
3470 GOTO 1020
3480 PRINT""
3484 REM ____________________________
3485 REM DISPLAY MOST RECENT ENTRY ON SCREEN
3486 REM
3490 PRINT"":PRINT""
3500 K=KM
3510 PRINT K;D$(K);TAB(12);E(K);TAB(18);M(K);TAB(21);B$(K):PRINT""
3520 PRINT Q(K);TAB(3);C$(K);TAB(6);N(K);TAB(9);A$(K);TAB(18);N$(K)
3530 KM=K
3540 PRINT""
3550 GOTO 1030
3554 REM ____________
3555 REM DISK OPTIONS
3556 REM
3560 PRINT"  VERIFY THAT THE PROPER DATA DISK":PRINT""
3570 PRINT"IS INSERTED IN DRIVE #1 AND THAT THE":PRINT""
3580 PRINT"DRIVE DOOR IS CLOSED.":PRINT"":PRINT""
3590 PRINT"  WHEN READY PRESS 'RETURN'.":PRINT"":PRINT""
3600 GET G$:IF G$="" THEN 3600
3610 G$=""
3620 RETURN
```

```
3630 PRINT"":PRINT"":GOSUB 3560
3634 REM ____________________
3635 REM STORE DATA BASE ON DISK
3636 REM
3640 OPEN 15,8,15
3650 PRINT#15,"I1"
3660 GOSUB 4120
3670 CR$=CHR$(13)
3680 OPEN 2,8,2,P$+",S,W"
3690 GOSUB 4120
3700 PRINT"WRITING ";M$
3710 GOSUB 4120
3720 PRINT#2,STR$(KM)CR$;
3730 GOSUB 4120
3740 KM=VAL(STR$(KM))
3750 FOR K=1 TO KM
3760 PRINT#2,STR$(K)","D$(K)","STR$(E(K))","STR$(M(K))","B$(K)CR$;
3770 GOSUB 4120
3780 PRINT#2,STR$(Q(K))","C$(K)","STR$(N(K))","A$(K)","N$(K)CR$;
3790 GOSUB 4120
3800 NEXT K
3810 CLOSE 2
3820 CLOSE 15
3830 OPEN 1,8,15:CLOSE 1
3840 GOTO 1020
3850 PRINT"":PRINT"":GOSUB 3560
3854 REM ____________________
3855 REM READ DATA BASE FROM DISK
3856 REM
3860 OPEN 15,8,15
3870 PRINT#15,"I1"
3880 GOSUB 4120
3890 OPEN 2,8,2,PP$+",S,R"
3900 GOSUB 4120
3910 PRINT"LOADING ";M$
3920 INPUT#2,KM
3930 GOSUB 4050
3940 FOR K=1 TO KM
3950 INPUT#2,K,D$(K),E(K),M(K),B$(K)
3960 GOSUB 4050
3970 INPUT#2,Q(K),C$(K),N(K),A$(K),N$(K)
3980 GOSUB 4050
3990 NEXT K
4000 CLOSE 15
4010 CLOSE 2
4020 OPEN 1,8,15:CLOSE 1
4030 K=KM
4040 GOTO 1020
4044 REM ________________
4045 REM READ DISK STATUS
4046 REM
4050 RS=ST
4060 GOSUB 4120
4070 IF RS=64 THEN 4000
4080 IF RS<>0 THEN 4100
4090 RETURN
4100 PRINT"BAD DISK STATUS IS";RS
4110 GOTO 4160
4114 REM ________________
4115 REM READ ERROR CHANNEL
4116 REM
4120 INPUT#15,EN$,EM$,ET$,ES$
4130 IF EN$="00" THEN RETURN
4140 PRINT"ERROR ON DISK":PRINT""
4150 PRINTEM$,EN$,ET$ES$
4160 CLOSE 2
4170 CLOSE 15
4180 OPEN 1,8,15
4190 CLOSE 1
4200 END
```

APPENDIX C: Listing of CYCREC

```
4 REM ----------------------------
5 REM THIS IS THE PROGRAM 'CYCREC'
6 REM 04/17/80
7 REM
10 UD=0:MM=0:PQ=0:PP=0
14 REM ----------------------------------------------
15 REM INITIALIZE AND DIMENSION PROGRAM PARAMETERS
16 REM
20 DIM C$(6,16),T$(6,16),JM(6),M$(6)
30 INPUT"ENTER THE MONTH";MT
40 IF MT<3 THEN KT=10:GOTO 60
50 KT=11
60 M$(1)="JAN-FEB "
70 M$(2)="MAR-APR "
80 M$(3)="MAY-JUNE "
90 M$(4)="JULY-AUG "
100 M$(5)="SEPT-OCT "
110 M$(6)="NOV-DEC "
120 PRINT"":INPUT"ENTER THE YEAR";Y$
130 Y$="'"+RIGHT$(Y$,2)
140 FOR P=1 TO 6
150 M$(P)=M$(P)+Y$
160 NEXT P
170 P=INT((MT+1)/2)
180 IS=0
190 IM=0
200 FOR I=1 TO 6
210 JM(I)=0
220 NEXT I
230 DS=0
240 DM=0
250 IF MM=7 AND K>1 THEN 3420
260 IF MM=7 THEN 4110
270 K=0:K$=STR$(K)
280 KM=0
290 GOTO 4480
300 PRINT"":PRINT"":INPUT"    KM=";K$:K=VAL(K$)
310 GOTO 3980
314 REM ----------------------
315 REM INITIALIZE DATA TAPE
316 REM
320 PRINT""
330 PRINT"  INSERT AUXILIARY TAPE INTO CASSETTE":PRINT""
340 PRINT"DECK AND REWIND IT.":PRINT"":PRINT""
350 PRINT"  ADVANCE TAPE UNTIL LEADER HAS BEEN":PRINT""
360 PRINT"FULLY WOUND ONTO THE TAKE-UP REEL.":PRINT"":PRINT""
370 PRINT"  ALLOW THE TAPE TO ADVANCE FOR ONE":PRINT""
380 PRINT"MORE TURN, THEN STOP THE TAPE.":PRINT"":PRINT""
390 PRINT"  WHEN READY PRESS 'RETURN'.":PRINT""
400 GET G$:IF G$="" THEN 400
410 G$="":PRINT"KM=";K$
420 GOSUB 440
430 GOTO 520
434 REM ------------------------
435 REM INITIALIZATION SUBROUTINE
436 REM
440 FOR I=1 TO 6
450 JM(I)=0
460 FOR J=1 TO 15
470 C$(I,J)="CODE"
480 T$(I,J)="TIME"
490 NEXT J
500 NEXT I
510 RETURN
```

```
514 REM ____________________________
515 REM WRITE DATA BLOCK ON TAPE
516 REM
520 FS=-1:FD=0:FC=191
530 POKE 243,122:POKE 244,2
540 OPEN 1,1,1,K$
550 PRINT"WRITING ";K$
560 FOR I=1 TO 6
570 PRINT#1,JM(I)
580 FOR J=1 TO 15
590 PRINT#1,C$(I,J)
600 PRINT#1,T$(I,J)
610 Z$=STR$(JM(I))
620 L=LEN(Z$)+LEN(C$(I,J))+LEN(T$(I,J))+1
630 FE=INT((FS+L)/FC)
640 IF FE=FD THEN 710
650 FS=-1
660 POKE 59411,53
670 T=TI
680 IF (TI-T)<5 THEN 680
690 POKE 59411,61
700 GOTO 720
710 FS=FS+L
720 NEXT J
730 NEXT I
740 CLOSE 1
750 IF MM=7 THEN 3530
760 D=DS:I=IS
770 GOTO 4700
774 REM ____________________
775 REM EXAMINE DATA OPTION
776 REM
780 PRINT"":PP=PP+1
790 DS=D:IS=I
800 FOR I=1 TO 6
810 IF MT<9 AND VAL(K$)>5 THEN D=6*(VAL(K$))+I-37:GOTO 840
820 IF MT>8 AND VAL(K$)>5 THEN D=6*(VAL(K$))+I-36:GOTO 840
830 D=6*(VAL(K$)-1)+I
840 IF D=0 THEN D=31
844 REM ____________________________
845 REM PRINT DATA BLOCK ON SCREEN
846 REM
850 PRINTTAB(6*(I-1));D
860 PRINTTAB(6*(I-1));JM(I)
870 IF JM(I)=0 THEN 910
880 FOR J=1 TO JM(I)
890 PRINTTAB(6*(I-1));C$(I,J);T$(I,J)
900 NEXT J
910 PRINT""
920 NEXT I
930 PRINT"":PRINT""
940 PRINT"":PRINT"CHECK FOR ENTRY ERRORS":PRINT""
950 PRINT"  WHEN READY PRESS 'RETURN'."
960 GET G$:IF G$="" THEN 960
970 G$=""
980 D=DS:I=IS
990 GOTO 4480
```

```
994 REM ____________________
995 REM UPDATE DATA OPTION
996 REM ____________________
1000 PRINT"":PP=PP+1
1010 IF UD>0 THEN 1190
1020 OPEN 4,4,1:CMD 4
1024 REM ____________________________
1025 REM LIST OF ACTIVITIES AND CODES
1026 REM ____________________________
1030 PRINT#4,"CODE#1=BEAM DEVELOPMENT"
1040 PRINT#4,"     CODE#2=TUNING"
1050 PRINT#4,"     CODE#3=OPTICS"
1060 PRINT#4,"     CODE#4=ON TARGET"
1070 PRINT#4,"     CODE#5=SCHEDULED MAINTENANCE"
1080 PRINT#4,"     CODE#6=UNSCHEDULED MAINTENANCE"
1090 PRINT#4,"     CODE#7=WAITING FOR EXPERIMENTER"
1100 PRINT#4,"     CODE#8=OTHER (BEAM OFF)"
1110 PRINT#4,"     CODE#9=HOLIDAY/SHUTDOWN"
1120 PRINT#4,"     CODE#0=NO FURTHER ENTRIES"
1130 CLOSE 4
1140 PRINT"  THIS ROUTINE IS TO BE USED TO ENTER":PRINT""
1150 PRINT"ONE DAY'S DATA.  UP TO 15 ENTRIES MAY":PRINT""
1160 PRINT"BE MADE EACH DAY.":PRINT"":PRINT""
1170 PRINT"  YOU MUST USE CODE #0 FOR THE DAY'S":PRINT""
1180 PRINT"LAST ENTRY WITH 2400 AS ITS TIME.":PRINT"":PRINT""
1190 UD=UD+1
1200 I=IS
1210 I=I+1:IF I>6 THEN 1450
1220 IF MT<9 AND VAL(K$)>5 THEN D=6*(VAL(K$))+I-37:GOTO 1250
1230 IF MT>8 AND VAL(K$)>5 THEN D=6*(VAL(K$))+I-36:GOTO 1250
1240 D=6*(VAL(K$)-1)+I
1250 W=0:IF D=0 THEN D=31
1260 IF MM=3 THEN 1300
1270 DS=D:IS=I
1280 GOSUB 1300
1290 GOTO 4480
1294 REM ____________________
1295 REM DATA ENTRY SUBROUTINE
1296 REM ____________________
1300 PRINT"DATA FOR DAY";D:PRINT""
1310 FOR J=1 TO 15
1320 INPUT "ENTER THE TIME";T$(I,J)
1330 INPUT "ENTER THE CODE";C$(I,J)
1340 PRINT""
1350 W=W+1
1360 IF C$(I,J)="0" THEN 1400
1370 IF W=14 THEN PRINT "THIS WILL BE YOUR LAST ENTRY":PRINT""
1380 IF W=15 THEN 1400
1390 NEXT J
1400 JM(I)=W
1410 IF MM=3 THEN 1440
1420 D=DS:I=IS
1430 DM=D:IM=I
1440 RETURN
1450 I=I-1
1460 PRINT"":PRINT"  THE CURRENT DATA BLOCK IS FILLED.":PRINT""
1470 PRINT"DATA SHOULD NOW BE STORED ON TAPE.":PRINT""
1480 DS=D:IS=I:GOTO 4490
```

```
1484 REM ____________________
1485 REM CORRECT DATA OPTION
1486 REM
1490 PRINT"":PP=PP+1
1500 DS=D:IS=I
1510 M=0
1520 INPUT "FOR WHICH DAY";D
1530 IF D=31 AND VAL(K$)=6 THEN I=1:GOTO 1570
1540 IF MT<9 AND VAL(K$)>5 THEN I=D-(6*(VAL(K$)))+37:GOTO 1570
1550 IF MT>8 AND VAL(K$)>5 THEN I=D-(6*(VAL(K$)))+36:GOTO 1570
1560 I=D-(6*(VAL(K$)-1))
1570 IF JM(I)=0 THEN PRINT"NO ENTRIES":PRINT"":GOTO 4490
1580 FOR J=1 TO JM(I)
1590 PRINTC$(I,J);T$(I,J)
1600 NEXT J
1610 PRINT""
1620 JM(I)=0:W=0
1630 FOR J=1 TO 15
1640 C$(I,J)="CODE"
1650 T$(I,J)="TIME"
1660 NEXT J
1670 PRINT"WHEN READY PRESS 'RETURN'."
1680 GET G$:IF G$="" THEN 1680
1690 G$=""
1700 GOSUB 1310
1710 IF PP=0 AND MM=3 THEN PQ=PQ+1:GOTO4480
1720 D=DS:I=IS
1730 GOTO 4480
1734 REM ____________________________
1735 REM DETERMINE DATA DLOCK TO BE CORRECTED
1736 REM
1740 PRINT""
1750 INPUT "FOR WHICH DAY";D
1760 IF MT/2=INT(MT/2) THEN 1810
1770 IF D=31 THEN K=6:GOTO 1790
1780 K=INT(((D-1)/6)+1)
1790 PRINT"K=";K:PRINT"":INPUT"K$=";K$
1800 GOTO 4110
1810 IF D=31 THEN K=11:GOTO 1860
1820 IF MT>8 THEN 1850
1830 K=INT(((D+30)/6)+1)
1840 PRINT"K=";K:PRINT"":INPUT"K$=";K$:GOTO 4110
1850 K=INT(((D+29)/6)+1)
1860 PRINT"K=";K:PRINT"":INPUT"K$=";K$:GOTO 4110
1864 REM ____________________________
1865 REM RECORD DATA BLOCK ON OBJECT TAPE
1866 REM
1870 PRINT"  INSERT DATA TAPE INTO CASSETTE":PRINT""
1880 PRINT"DECK WITHOUT REWINDING IT.":PRINT"":PRINT""
1890 PRINT"  WHEN READY PRESS 'RETURN'.":PRINT""
1900 GET G$:IF G$="" THEN 1900
1910 G$=""
1920 FS=-1:FD=0:FC=191
1930 POKE 243,122:POKE 244,2
1940 OPEN 1,1,1,K$
1950 POKE 59411,53
1960 T=TI
1970 IF (TI-T)<30 THEN 1970
1980 POKE 59411,61
1990 GOTO 550
```

```
1994 REM ___________________
1995 REM STORE DATA OPTION
1996 REM ___________________
2000 PRINT"":IS=I:DS=D:PP=PP+1:IF PQ>0 THEN 2030
2010 IF K>1 AND I=6 THEN 1870
2020 IF I=6 THEN 2050
2030 PRINT"  INSERT AUXILIARY TAPE INTO CASSETTE":PRINT""
2040 PRINT"DECK AND REWIND IT.":PRINT"":PRINT"":GOTO 2070
2050 PRINT"  INSERT DATA TAPE INTO CASSETTE":PRINT""
2060 PRINT"DECK AND REWIND IT.":PRINT"":PRINT""
2070 PRINT"  ADVANCE TAPE UNTIL LEADER HAS BEEN":PRINT""
2080 PRINT"FULLY WOUND ONTO THE TAKE-UP REEL.":PRINT"":PRINT""
2090 PRINT"  ALLOW THE TAPE TO ADVANCE FOR ONE":PRINT""
2100 PRINT"MORE TURN, THEN STOP THE TAPE.":PRINT"":PRINT""
2110 PRINT"  WHEN READY PRESS 'RETURN'.":PRINT""
2120 GET G$:IF G$="" THEN 2120
2130 G$=""
2140 GOTO 520
2144 REM ___________________
2145 REM ANALYZE DATA OPTION
2146 REM ___________________
2150 PRINT"":IS=I:PP=PP+1
2160 PRINT"  INSERT THE CURRENT DATA TAPE IN THE":PRINT""
2170 PRINT"PET CASSETTE DECK AND REWIND IT.":PRINT"":PRINT""
2180 PRINT"  ADVANCE TAPE UNTIL LEADER HAS BEEN":PRINT""
2190 PRINT"FULLY WOUND ONTO TAKE-UP REEL.":PRINT"":PRINT""
2200 PRINT"  STOP THE TAPE.":PRINT"":PRINT""
2210 PRINT"WHEN READY PRESS 'RETURN'.":PRINT"":PRINT""
2220 GET G$:IF G$="" THEN 2220
2230 G$=""
2240 FOR K=1 TO KT
2250 GOSUB 440
2260 PRINT"K=";K:PRINT"":INPUT"K$=";K$
2270 OPEN 1,1,0,K$
2280 PRINT"LOADING ";K$
2290 FOR I=1 TO 6
2300 INPUT#1,JM(I)
2310 FOR J=1 TO 15
2320 INPUT#1,C$(I,J)
2330 INPUT#1,T$(I,J)
2340 NEXT J
2350 NEXT I
2360 CLOSE 1
2370 PRINT"":IF K>1 THEN 2410
2380 FOR C=1 TO 9
2390 B(C)=0
2400 NEXT C
2410 FOR I=1 TO 6
2420 IF JM(I)=0 THEN 2570
2430 FOR J=1 TO JM(I)-1
2440 E=VAL(T$(I,J))
2450 C1=VAL(C$(I,J))
2460 H=INT(E/100)
2470 M=E-100*H
2480 T1=M+60*H
2490 D=VAL(T$(I,J+1))
2500 C2=VAL(C$(I,J+1))
2510 H=INT(D/100)
2520 M=D-100*H
2530 T2=M+60*H
2540 B(C1)=B(C1)+T2-T1
2550 B(C1)=ABS(B(C1))
2560 NEXT J
2570 NEXT I
2580 NEXT K
```

```
2590 SS=.000000001
2600 FOR C=1 TO 9
2610 B(C)=B(C)/60
2620 SS=SS+B(C)
2630 NEXT C
2640 S=SS-B(9)
2650 FOR C=1 TO 8
2660 B1(C)=(B(C)/S)*100
2670 NEXT C
2680 FOR C=1 TO 8
2690 X=B(C):Y=B1(C)
2700 X=X*100:Y=Y*100
2710 X=INT(X):Y=INT(Y)
2720 X=X/100:Y=Y/100
2730 B(C)=X:B1(C)=Y
2740 NEXT C
2750 X=B(9)
2760 X=X*100
2770 X=INT(X)
2780 X=X/100
2790 B(9)=X
2794 REM ____________________________
2795 REM GENERATE BIMONTHLY REPORT
2796 REM ____________________________
2800 OPEN 4,4,1:CMD 4
2810 PRINT#4,"TIME ACCOUNTING FOR ";M$(P):PRINT#4,""
2820 PRINT#4,"                                        TOTAL HOURS    PERCENT"
2830 PRINT#4,""
2840 FOR C=1 TO 8
2850 FOR Z=1 TO 200:NEXT Z
2860 PRINT#4,CODE$(C);".......    ";
2870 IF B(C)<100 THEN PRINT#4," ";
2880 IF B(C)<10 THEN PRINT#4," ";
2890 PRINT#4,B(C);
2900 G(C)=B(C):IF G(C)=INT(G(C))THEN PRINT#4,"          ";:GOTO 2990
2910 G(C)=10*G(C):IF G(C)=INT(G(C))THEN PRINT#4,"        ";:GOTO 2990
2920 G(C)=10*G(C):IF G(C)=INT(G(C))THEN PRINT#4,"       ";:GOTO 2990
2930 G(C)=10*G(C):IF G(C)=INT(G(C))THEN PRINT#4,"       ";:GOTO 2990
2940 G(C)=10*G(C):IF G(C)=INT(G(C))THEN PRINT#4,"       ";:GOTO 2990
2950 G(C)=10*G(C):IF G(C)=INT(G(C))THEN PRINT#4,"       ";:GOTO 2990
2960 G(C)=10*G(C):IF G(C)=INT(G(C))THEN PRINT#4,"       ";:GOTO 2990
2970 G(C)=10*G(C):IF G(C)=INT(G(C))THEN PRINT#4,"       ";:GOTO 2990
2980 G(C)=10*G(C):IF G(C)=INT(G(C))THEN PRINT#4,"       ";
2990 IF B1(C)<10 THEN PRINT#4," ";
3000 PRINT#4,B1(C)
3010 NEXT C
3020 PRINT#4,"                                          --------"
3030 PRINT#4,"    SUBTOTAL                             ";
3040 IF S<1000 THEN PRINT#4," ";
3050 IF S<100 THEN PRINT#4," ";
3060 PRINT#4,S;"  HOURS "
3070 PRINT#4,"":PRINT#4,""
3080 PRINT#4,CODE$(9);".......    ";
3090 IF B(9)<100 THEN PRINT#4," ";
3100 IF B(9)<10 THEN PRINT#4," ";
3110 PRINT#4,B(9)
3120 PRINT#4,"                                          --------"
3130 PRINT#4,"    TOTAL                                ";
3140 IF SS<1000 THEN PRINT#4," ";
3150 IF SS<100 THEN PRINT#4," ";
3160 PRINT#4,SS;"  HOURS"
3170 PRINT#4,"":PRINT#4,""
```

```
3180 TS=B(2)+B(3)+B(4)+B(7)+B(8):TT=TS-INT(TS)
3190 IF TT>.5 THEN TS=INT(TS)+1:GOTO 3210
3200 TS=INT(TS)
3210 PRINT#4,"TOTAL EXPERIMENTAL TIME..........  ";
3220 IF TS<1000 THEN PRINT#4," ";
3230 IF TS<100 THEN PRINT#4," ";
3240 IF TS<10 THEN PRINT#4," ";
3250 PRINT#4,TS;"  HOURS  ";
3260 B1S=B1(2)+B1(3)+B1(4)+B1(7)+B1(8)
3270 PRINT#4,B1S;"%"
3280 CLOSE 4
3290 I=IS
3294 REM ____________________________
3295 REM STORE ANALYSIS RESULTS ON DISK
3296 REM
3300 PRINT""
3310 PRINT"":PRINT"DO YOU WANT TO STORE THE ";M$(P):PRINT""
3320 INPUT"DATA ON DISK";G$
3330 IF LEFT$(G$,1)="Y" THEN 3620
3340 PRINT"":PRINT"REWIND THE DATA TAPE AND STORE IT.":PRINT""
3350 GOTO 4770
3354 REM ____________________
3355 REM CHECK DATA ENTRY OPTION
3356 REM
3360 PRINT"":PRINT"":PRINT"":PP=PP+1
3370 PRINT"LAST ENTRY WAS FOR DAY";
3380 IF DM>=DS THEN PRINT DM
3390 IF DM>=DS THEN 3410
3400 IF DS>DM THEN PRINT DS
3410 PRINT"":PRINT"":GOTO 4490
3420 PRINT""
3430 PRINT"  INSERT DATA TAPE INTO CASSETTE":PRINT""
3440 PRINT"DECK WITHOUT REWINDING IT.":PRINT"":PRINT""
3450 GOTO 4170
3454 REM ___________________
3455 REM TRANSFER DATA OPTION
3456 REM
3460 PRINT"":PP=PP+1
3470 PRINT"  THIS ROUTINE IS TO BE USED WHEN":PRINT""
3480 PRINT"RECORDING DATA FOR PERMANENT STORAGE":PRINT"":PRINT""
3490 FOR K=1 TO KT
3500 GOSUB 440
3510 PRINT"K=";K:PRINT"":INPUT"K$=";K$
3520 GOTO 180
3530 PRINT""
3540 PRINT"FINISHED":PRINT""
3550 PRINT"DO NOT REWIND DATA TAPE":PRINT""
3560 PRINT"REMOVE THE TAPE AND STORE IT.":PRINT"":PRINT""
3570 NEXT K
3580 K=KS:K$=STR$(K):PRINT""
3590 PRINT"  ALL DATA BLOCKS HAVE BEEN SAVED FOR":PRINT""
3600 PRINT"THE CURRENT REPORT PERIOD.":PRINT""
3610 GOTO 4490
```

```
3614 REM ____________
3615 REM WRITE TO DISK
3616 REM
3620 PRINT"":PRINT""
3630 PRINT"  VERIFY THAT THE PROPER DATA DISK":PRINT""
3640 PRINT"IS INSERTED IN DRIVE #1 AND THAT":PRINT""
3650 PRINT"THE DRIVE DOOR IS CLOSED.":PRINT"":PRINT""
3660 PRINT"  PRESS 'RETURN' WHEN READY":PRINT""
3670 GET G$:IF G$="" THEN 3670
3680 G$=""
3690 P$(1)="1: 1-2 "+Y$
3700 P$(2)="1: 3-4 "+Y$
3710 P$(3)="1: 5-6 "+Y$
3720 P$(4)="1: 7-8 "+Y$
3730 P$(5)="1: 9-10 "+Y$
3740 P$(6)="1: 11-12 "+Y$
3750 PRINT""
3760 OPEN 15,8,15
3770 PRINT#15,"I1"
3780 GOSUB 3910
3790 OPEN 2,8,2,P$(P)+",S,W"
3800 CR$=CHR$(13)
3810 GOSUB 3910
3820 PRINT"WRITING ";M$(P)
3830 FOR C=1 TO 9
3840 PRINT#2,STR$(B(C))CR$;
3850 NEXT C
3860 CLOSE 2
3870 CLOSE 15
3880 PRINT"":PRINT""
3890 PRINT"FINISHED--REWIND THE DATA TAPE"
3900 GOTO 4770
3904 REM ____________________
3905 REM CHECK FOR DISK ERRORS
3906 REM
3910 INPUT#15,EN$,EM$,ET$,ES$
3920 IF EN$="00" THEN RETURN
3930 PRINT"ERROR ON DISK":PRINT""
3940 PRINTEM$,EN$,ET$ES$
3950 CLOSE 2
3960 CLOSE 15
3970 GOTO 4770
3980 PRINT""
3990 PRINT"  REWIND THE PROGRAM TAPE AND REMOVE":PRINT""
4000 PRINT"IT FROM THE PET CASSETTE DECK.":PRINT"":PRINT""
4010 PRINT"  VERIFY THAT THE INTERFACE AND THE":PRINT""
4020 PRINT"TI ASR 700 SWITCHES ARE ON 'PET'."
4030 PRINT"":PRINT""
4040 PRINT"  WHEN READY PRESS 'RETURN'."
4050 GET G$:IF G$="" THEN 4050
4060 G$=""
```

```
4070 PRINT""
4080 PRINT"  HAVE YOU INITIALIZED THE DATA TAPE":PRINT""
4090 INPUT "FOR THE CURRENT DATA BLOCK";G$:PRINT"":PRINT""
4100 IF LEFT$(G$,1)="N" THEN 320
4110 PRINT""
4114 REM ____________________________
4115 REM LOAD DATA BLOCK FROM TAPE
4116 REM ____________________________
4120 PRINT"  INSERT THE CURRENT DATA TAPE IN THE":PRINT""
4130 PRINT"PET CASSETTE DECK AND REWIND IT.":PRINT"":PRINT""
4140 PRINT"  ADVANCE TAPE UNTIL LEADER HAS BEEN":PRINT""
4150 PRINT"FULLY WOUND ONTO TAKE-UP REEL.":PRINT"":PRINT""
4160 PRINT"  STOP THE TAPE.":PRINT"":PRINT""
4170 PRINT"WHEN READY PRESS 'RETURN'.":PRINT"":PRINT""
4180 GET G$:IF G$="" THEN 4180
4190 G$=""
4200 OPEN 1,1,0,K$
4210 PRINT"LOADING ";K$
4220 FOR I=1 TO 6
4230 INPUT#1,JM(I)
4240 FOR J=1 TO 15
4250 INPUT#1,C$(I,J)
4260 INPUT#1,T$(I,J)
4270 NEXT J
4280 IF LEFT$(C$(I,1),1)="C" THEN 4300
4290 IS=I:IM=IS
4300 NEXT I
4310 CLOSE 1
4320 IF PP=0 AND MM=3 THEN PRINT"":PRINT"DATA FOR DAY";D:PRINT"":GOTO 1540
4330 IF PP>0 THEN 4360
4340 IF IM=6 AND MM=2 THEN PRINT"DATA BLOCK FILLED";PRINT"":GOTO 4770
4350 ON MM GOTO 780,1000,1490,2000,2150,3360,3460
4360 I=IM:IS=I:K=VAL(K$)
4370 PRINT"":IF I<6 AND MM<>7 THEN 4460
4380 PRINT"  FINISHED":PRINT""
4390 IF MM=7 THEN 4410
4400 K=K+1:KM=K:K$=STR$(K):I=0:IM=I:IS=I
4410 PRINT"DO NOT REWIND DATA TAPE":PRINT""
4420 PRINT"REMOVE THE TAPE AND STORE IT.":PRINT"":PRINT""
4430 IF MM=7 AND K=1 THEN 2050
4440 IF MM=7 THEN 1870
4450 GOTO 330
4460 PRINT"  FINISHED--REWIND THE DATA TAPE.":PRINT"":PRINT""
4470 GOTO 4490
```

```
4474 REM ____________________
4475 REM OFFER OPTIONS MENU
4476 REM ____________________
4480 PRINT""
4490 PRINT"  SELECT ONE OF THE FOLLOWING OPTIONS:":PRINT"":PRINT""
4500 PRINT"1.  EXAMINE  DATA":PRINT""
4510 PRINT"2.  UPDATE   DATA":PRINT""
4520 PRINT"3.  CORRECT  DATA":PRINT""
4530 PRINT"4.  STORE    DATA ON TAPE":PRINT""
4540 PRINT"5.  ANALYZE  DATA":PRINT""
4550 PRINT"6.  CHECK    DATA ENTRY":PRINT""
4560 PRINT"7.  TRANSFER DATA TO OBJECT TAPE":PRINT""
4570 INPUT MM
4580 CODE$(1)="BEAM DEVELOPMENT..........."
4590 CODE$(2)="TUNING....................."
4600 CODE$(3)="OPTICS....................."
4610 CODE$(4)="ON TARGET.................."
4620 CODE$(5)="SCHEDULED MAINTENANCE....."
4630 CODE$(6)="UNSCHEDULED MAINTENANCE...."
4640 CODE$(7)="WAITING FOR EXPERIMENTER..."
4650 CODE$(8)="OTHER (BEAM OFF)..........."
4660 CODE$(9)="HOLIDAY/SHUTDOWN..........."
4670 IF PP>0 THEN 4690
4680 ON MM GOTO 300,300,1740,2000,2150,300,3460
4690 ON MM GOTO 780,1000,1490,2000,2150,3360,3460
4700 PRINT"":PRINT""
4710 IF I<6 THEN 4750
4720 PRINT"FINISHED--":PRINT""
4730 PRINT"DO NOT REWIND THE DATA TAPE!":PRINT""
4740 PRINT"REMOVE THE TAPE FROM THE DRIVE AND":PRINT"":GOTO 4760
4750 PRINT"  FINISHED--REWIND THE AUXILIARY TAPE.":PRINT""
4760 PRINT "MARK THE TAPE 'KM=";K$;"'."
4770 END
```

APPENDIX D: Listing of STRAGGLE

```
10 REM STRAGGLE  12/10/79
80 PRINT"
85 A$=""
90 PRINT"        ENERGY LOSS STRAGGLING":PRINT"":PRINT""
100 PRINT"THIS PROGRAM CALCULATES DELTA E, THE    ENERGY STRAGGLING FWHM."
101 PRINT""
110 PRINT"ENTER THE FOLLOWING INFO ABOUT THE      ABSORBER":PRINT""
120 PRINT"Z=";
130 INPUT Z1
140 PRINT"A=";
150 INPUT A1
160 PRINT"THICKNESS (UG/CM**2) =";
170 INPUT T
200 PRINT"":PRINT""
210 PRINT"ENTER THE FOLLOWING INFO ABOUT THE      BEAM...":PRINT""
220 PRINT"Z=";
230 INPUT Z2
240 PRINT"A=";
250 INPUT A2
260 PRINT"ENERGY (MEV) =";
270 INPUT E
280 PRINT""
400 LT=.1203*A2*Z1/E*LOG(E/.0451/A2/Z1)
410 LT=((LT+1)*Z1*T/A1)^.5
420 DE=Z2*1*LT
430 PRINT"DELTA E (FWHM)=";
435 DE=.001*INT(1000*DE)
436 PC=.1*DE/E
437 PC=.001*INT(1000*PC)
440 PRINT DE;:PRINT" KEV";
450 PRINT"  (";:PRINTPC;:PRINT" %";:PRINT")"
490 PRINT"":PRINT"DO YOU WISH ANOTHER ENERGY (Y/N) ?"
492 INPUTA$:IF A$="Y"THEN260
495 IF A$="" THEN495
500 GOTO 80
READY.
```

APPENDIX E: Listing of SCATTER

```
 10 REM SCATTER 12/10/79
 80 PRINT"
 85 A$=""
 90 PRINT"            MULTIPLE SCATTERING":PRINT"":PRINT"
100 PRINT"THIS PROGRAM CALCULATES THETA(1/2), THE HALF ANGLE AT HALF MAX."
101 PRINT""
110 PRINT"ENTER THE FOLLOWING INFO ABOUT THE      SCATTERER...":PRINT""
120 PRINT"Z=";
130 INPUT Z1
140 PRINT"A=";
150 INPUT A1
160 PRINT"THICKNESS (UG/CM**2) =";
170 INPUT T
200 PRINT"":PRINT""
210 PRINT"ENTER THE FOLLOWING INFO ABOUT THE      BEAM...":PRINT""
220 PRINT"Z=";
230 INPUT Z2
240 PRINT"A=";
250 INPUT A2
260 PRINT"ENERGY (MEV) =";
270 INPUT E
280 PRINT""
400 LT=LOG(211.9*T*(Z1+1)/(Z1^.66667*Z2^.66667)/A1/Z1)
410 DT=(3.922*10^-8)*T*Z1*(Z1+1)*Z2^2/A1/E^2
420 THET2=((DT*LT)^.5)/1.71
430 PRINT"THETA(1/2)=";
440 PRINTTHET2;:PRINT"RADIANS"
490 PRINT"":PRINT"DO YOU WISH ANOTHER ENERGY (Y/N)?"
492 INPUTA$:IF A$="Y" THEN260
495 IF A$="" THEN495
500 GOTO 80
READY.
```

APPENDIX F: Listing of STRIP

```
 10 REM STRIP 12/10/79
 15 PRINT"
 20 PRINT"THIS PROGRAM PROVIDES INFO ON THE CHARGE STATE DISTRIBUTION OF 88-INCH
"
 22 PRINT"CYCLOTRON BEAMS AFTER PASSING THRU A    STRIPPER FOIL..."
 24 PRINT"THE CALCULATIONS ARE NOT VALID FOR      BEVATRON ENERGIES."
 26 PRINT"FOR ENERGIES UP TO 40 MEV/NUCLEON THESE CALCULATIONS ARE IN GENERAL";
 28 PRINT" AGREEMENT   WITH UNPUBLISHED REPORTS FROM GSI AND   GANIL FOR FORM";
 29 PRINT"VAR FOILS.  IT IS ASSUMED THAT  FOIL IS THICK ENOUGH TO ESTABLISH";
 30 PRINT" AN EQUILIBRIUM DISTRIBUTION OF CHARGE   STATES":PRINT"":PRINT""
 99 PRINT"ENTER 'Z' OF THE BEAM":GOTO 110
 100 PRINT"":PRINT"ENTER 'Z' OF THE NEXT BEAM"
 110 INPUT Z
 120 PRINT"ENTER MASS OF THE BEAM IN AMU"
 130 INPUT A
 140 PRINT"ENTER BEAM ENERGY IN MEV"
 150 INPUT E
 200 V=(10^8)*13.9*(E/A)^.5
 210 CF=.444+.106134*Z-.0068746*Z^2+2.21524E-4*Z^3-3.5184E-6*Z^4+2.16656E-8*Z^5
 220 IF Z>53 THEN CF=1.031
 225 VR=V/2.188E8
 230 F=(.71*Z^.0527)
 240 T=F^VR
 250 QAV=Z*(1-CF*T)
 253 QAV=.01*INT(100*(QAV+.005))
 255 PRINT"THE AVERAGE EQUILIBRIUM CHARGE STATE IS"
 260 PRINT"          ";:PRINTQAV
 270 IF E<20 THEN GOTO 100
 300 SIG=.27*(Z)^.5:FWHM=2.35*SIG
 305 FWHM=.1*INT(10*(FWHM+.05))
 310 PRINT""
 320 PRINT"THE NATURAL CHARGE STATE DISTRIBUTION   WIDTH FWHM  =";
 330 PRINTFWHM
 340 IF (QAV+1.2*SIG)<Z THEN GOTO400
 350 GOTO100
 400 AMP=1.09-.1238*Z+9.1188E-3*Z^2-3.822924E-4*Z^3+9.142328E-6*Z^4
 410 AMP=AMP-1.2306566E-7*Z^5+8.66030677E-10*Z^6-2.474E-12*Z^7
 420 Z1=INT(QAV):Z2=Z1+1
 430 P1=AMP*EXP(-((Z1-QAV)^2)/(2*SIG^2))
 440 P2=AMP*EXP(-((Z2-QAV)^2)/(2*SIG^2))
 450 PRINT""
 460 PRINT"    CHARGE              PERCENT"
 470 PRINT"     STATE             POPULATED"
 480 PRINT""
 483 P1=INT(100*(P1+.005))
 484 P2=INT(100*(P2+.005))
 490 PRINT"       ";Z1;"              ";P1;"%"
 492 PRINT"       ";Z2;"              ";P2;"%"
 980 PRINT"":PRINT""
 990 GOTO 100
 999 STOP
READY.
```

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