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BEVATRON BEAM INJECTION PROGRAMS: INJECT, PHASE, HINJ

A User's Guide -- Volume I

E. Close, P. Germain, B. Holley

February 18, 1972

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VOLUME I

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0. INTRODUCTION

This report is divided into two volumes. Volume I deals mainly with the use of the programs. Volume II presents details of the calculations and of the programs that are necessary for understanding the program source listings. Those who are interested mainly in running the programs and obtaining results will find the necessary information in Volume I. Should further detailed knowledge be required for program modification, then Volume II can be consulted.

A general description of how we treat the bevatron injection problem is found in Section 1. In Sections 2, 3, 4, and 5 details are given pertaining to the running of the injection programs INJECT, PHASE, HINJ, and of a data storage program TWRITE. These sections describe the data input structure, the necessary control cards, and the output that the programs generate. The Appendices A1, A2, and A3 contain sample control card checks, input data cases, and selected program output.

1. RF TRAPPING OF THE INJECTED BEAM

We wish to study the process of injecting beam into the LBL Bevatron. To be more precise, we assume that a pulse of beam is delivered to the bevatron inflector and we wish to find out what fraction of this pulse survives the rf trapping; that is, what fraction of this pulse is trapped when the rf is turned on. We wish to study this trapping process as various injection parameters are varied. For example, we can vary the length of the injected pulse, the time of injection, the emittance of the injected beam, the momentum spread of the injected beam, the time at which the rf is turned on, the characteristics of the rf voltage buildup such as its time constant or shape, the rate of rise of the magnetic field during the injection trapping process. The programs INJECT, PHASE, and HINJ, when used in the manner described below, allow us to calculate the accepted beam as these parameters are systematically varied.

In order to effectively carry out these calculations, the process of injection has been separated into three separate parts and each part is separately calculated by one of the programs. Briefly, we call these acceptance, rf trapping, and accepted pulse. In the acceptance calculation, we determine what beam can be accepted into the machine as coasting beam. This is done by the program INJECT. The rf trapping calculation, PHASE, tells us what beam will be trapped as the rf voltage is turned on. The accepted pulse calculation, HINJ, uses the results of these two previous calculations to find out what fraction of an injected pulse survives the injection, rf trapping process. We describe below the rf trapping calculation, the accepted beam calculations, the manner in which these are used to calculate the accepted pulse, the parameters that can sensibly be varied, and conclude with a short summary of how the programs are to be employed.

1.1 RF Trapping

We assume, for these calculations, that the azimuthal and radial distribution of the coasting beam is known at the time that the rf voltage is turned on. The manner in which this is calculated is described in Sections 1.2 and 1.3. Essentially, the beam fills the aperture radially and for all practical purposes we can assume a uniform azimuthal distribution. Our calculations are limited to the radial plane; the vertical motion is not considered here. The coasting beam at rf turn on time is defined to be the totality of the injected beam that has survived at this time. Thus, it is the beam that has not, for whatever reason, hit the inflector, or the chamber walls, etc. One way of characterizing this beam distribution is to note that for every particle there corresponds an equilibrium orbit radius r that can be determined from the particle energy and the magnetic field at the time of injection of the particle, and that each particle oscillates about its equilibrium orbit radius with a maximum betatron amplitude x_β. Since the time taken to inject into one full turn is small, we can assume a uniform beam distribution around the machine and we can think of beam filaments instead of particles. That is, we have a filament of beam that has equilibrium orbit r and betatron amplitude x_β. Therefore, the points in the (r, x_β, θ) space can be thought of as beam density points and we simply ask the question: Given a known beam density $I = I(r, x_\beta, \theta)$, what fraction of this beam survives the rf turn on; that is, what fraction is trapped, and if it is trapped, what is its maximum radial excursion during the trapping process?

To answer this question, we make some simplifying assumptions. We assume that during the rf trapping process x_β is fixed and we consider the radial synchrotron oscillations to be independent from the betatron oscillations. With these assumptions, we can proceed as follows:

We choose a reference particle that is assumed to have an equilibrium orbit radius r_s, a rotational rate $\omega_s = \dot{\theta}$, and a total energy E_s. See Figure 1.

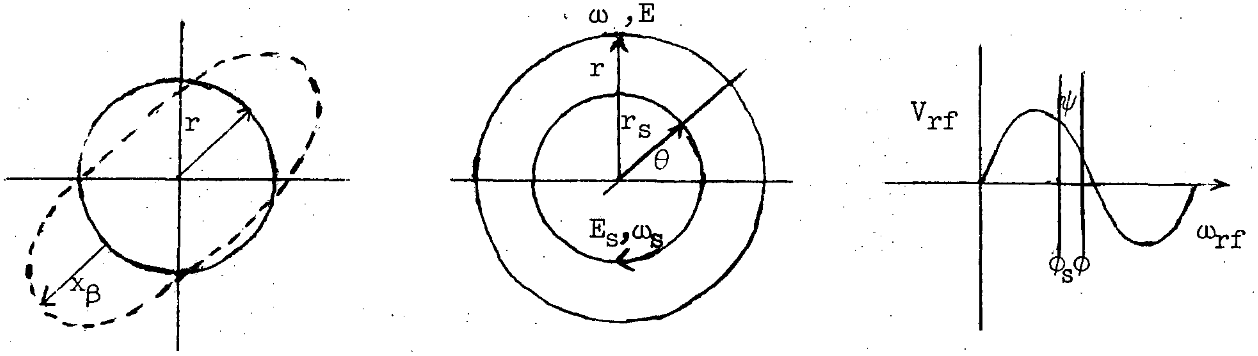


Figure 1

This particle may possibly not exist as a real physical particle, but that does not matter. We simply say that if such a particle existed in the machine, no matter how it got there, it would be such that it would forever travel around the orbit of constant radius r_s with rotational rate ω_s. This, then, fixes its energy gain rate to be such that it stays at a constant radius. We now define

$$\begin{aligned} \Delta E &= E - E_s \\ \psi &= \phi - \phi_s \\ \omega_1 &= \omega_{rf} - h\omega_s \end{aligned} \qquad (1)$$

where ϕ is the rf phase of a particle of energy E, ϕ_s is the rf phase of the reference (synchronous) particle, ω_1 measures the error in the rf frequency ω_{rf} where we have chosen the rotational rate of the reference particle as the standard, and ψ is the rf phase of the particle of energy E as measured from the synchronous phase of the reference particle. We can then use the standard phase equations to study the rf trapping process. For our case, these can be written as

$$\frac{d}{d\tau}\ \frac{\Delta E}{\omega s} = \frac{q}{2\pi\Omega}\ [V(\tau)\ \mathrm{Sin}\phi - \Delta\ T_s]$$

$$\frac{d}{d\tau}\ \psi = \frac{1}{\Omega}\ [\omega_1 + \frac{h\omega_s^2\ \Gamma}{E_s}\ \frac{\Delta E}{\omega_s}\ ]\ . \qquad (2)$$

For more details about the quantities in Equation (2), the reader may refer to Volume II, Section 2 of this report.

For each particle (beam filament) of equilibrium orbit radius r, we can find $\Delta r = r - r_s$ and thus $\Delta E/\omega_s$. We can then integrate (2) for various initial conditions and find what fraction of any beam filament is accepted. With this in mind, we look at the Δr, ψ plane, Figure 2.

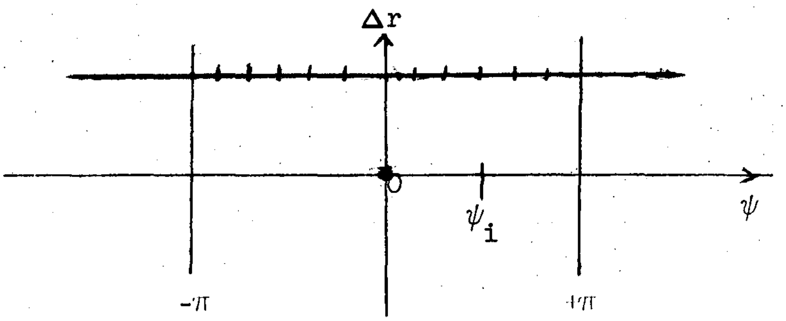


Figure 2

For a given Δr, we integrate for the initial values

$$-\pi < \psi_i \leq \pi \ , \ i = 1,2,\ldots,N$$

and find whether the particle is trapped. If the particle $(\Delta r, \psi_i)$ is trapped, then we assume that $1/N$ of the total beam at $(\Delta r, x_\beta)$ was accepted for that $(\Delta r, \psi_i)$. This corresponds to having a uniform azimuthal distribution of the beam. See Figure 3.

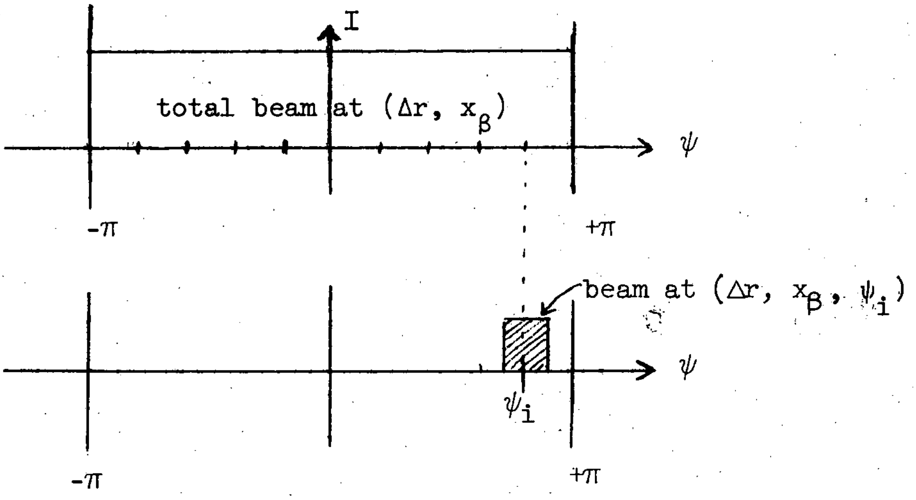


Figure 3

Extensions to other distributions are, in principle, not difficult should that be desirable.

If the beam is trapped by the rf for a given $(\Delta r, \psi_i)$, we then proceed to superimpose the maximum betatron amplitude x_β onto Δr, $x_{max} = \Delta r + x_\beta$, and we ask whether this will physically remain within the chamber. If $x_{max} > \frac{\text{chamber width}}{2}$, then the beam, while theoretically trapped by the rf, will not, in fact, survive the rf trapping process since it will be lost on the walls. If it is, however, trapped, then we have that for a given

$(\Delta r, x_\beta, \psi_i)$ the quantity $1/N$ of the beam existing at $(\Delta r, x_\beta)$ has been trapped. We scan the $(\Delta r, x_\beta)$ plane and accumulate for a given $(\Delta r, x_\beta)$ the fraction of the total beam that is accepted for each point in this space.

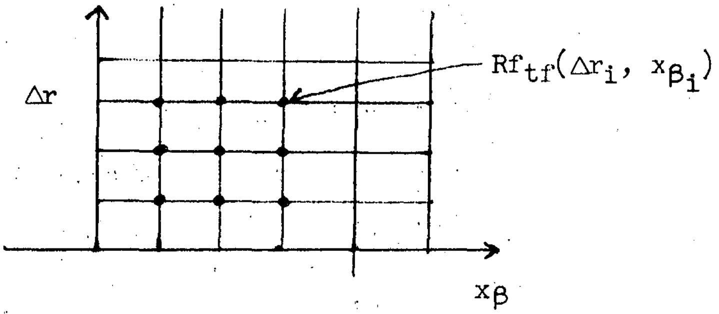


Figure 4

Therefore, if at time $t = 0$, the rf turn on time, we know the beam density distribution in the $(\Delta r, x_\beta)$ plane, we can easily calculate the accepted beam by multiplying the values of the trapped beam $RF_{tf}(\Delta r, x_\beta)$ times the values of the distribution array $RF_{t_0}(\Delta r, x_\beta)$.

To summarize, the rf trapping process has been decoupled from the rest of the problem by calculating a discrete set of values in the $(\Delta r, x_\beta)$ plane. These values, $Rf_{rf}(\Delta r_i, x_{\beta_i})$ represent the fraction trapped, during the rf trapping process, of the total beam that had the values $(\Delta r_i, x_{\beta_i})$ at rf turn on time. This means that we can, for a given set of rf trapping parameters, calculate the rf trapping array RF_{tf} and save it for future use.

1.2 Accepted Beam

In this calculation, we wish to determine whether the beam injected into the inflector is accepted as coasting beam. At the inflector, we have a beam that occupies some known area in the radial (x, x') space and this beam has some known momentum distribution about a central momentum and is injected into the bevatron at some given time; will it be accepted in the machine or will it be lost by, for example, hitting the inflector? To answer this question, we consider a particle, or equivalently, a single turn filament, to be injected with a given equilibrium orbit r and a given radial phase space position (x, x′). The equilibrium orbit r is determined both by the particle energy and the time of injection, since we are injecting into a rising field. We measure the equilibrium orbit as x_9 which is the distance of the equilibrium orbit from the outer radius of the inner wall of the inflector. See Figure 5.

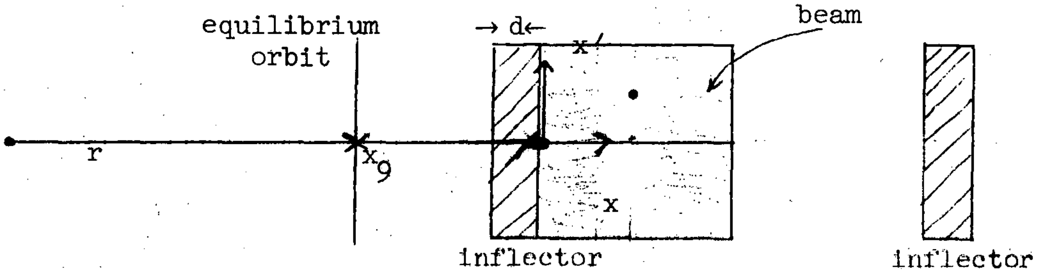


Figure 5

The particle is characterized by the value of (x, x', x_9). Given a three-dimensional space of these variables, we can, for any point in the space, ask whether the particle was accepted as coasting beam. We are principally interested in whether the particles clear the inflector. Since the field rise $\dot{B}$ is positive during the injection, the equilibrium orbit moves in (x_9 increases), and particles with the right (x, x', x_9) values will clear the inflector and be accepted as coasting beam. Figure 6 shows a particle injected at a time t>0. We have arbitrarily chosen the time origin at $x_9 = 0$.

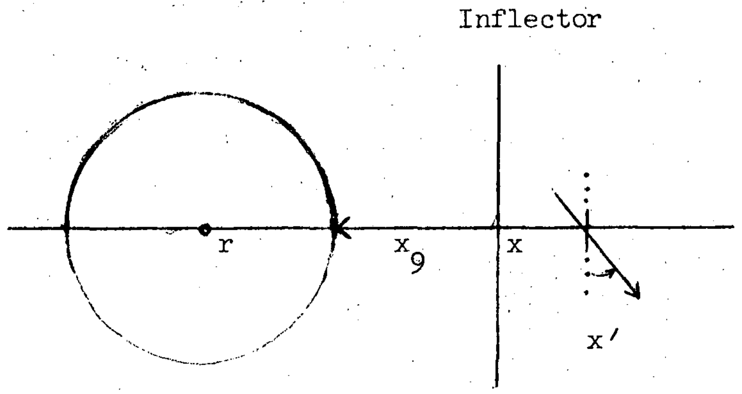


Figure 6

In order to calculate which (x, x', x_9) points are accepted, we trace the orbit paths of the particles for the first few turns. Once the equilibrium orbit has shrunk to a small enough value so that $r + x_\beta$, where x_β is the appropriate betatron amplitude, is less than the inflector radius, the particle is assumed to be accepted as coasting beam. During this calculation, we check that the particle stays within the available physical aperture.

The equations of motion used to describe the particle motion are given in Volume II, Section 1, of this report. We assume that the vertical and radial motion are independent and deal only with the radial motion of the beam. Because of the sensitivity of the particle to the field index value in clearing the inflector, we solve this orbit problem discretely at a number of steps around the circumference and use a measured average n value corresponding to the radius of the particle. The time dependence of the magnetic field is simulated by discretely shrinking the equilibrium orbit with an appropriate pitch.

Our calculations thus tell us what points are accepted in the (x, x', x_9) space and what betatron amplitude the accepted particles have.

Once the beam has been accepted, the beam can be linearly translated to the inside south faraday cup using a pitch that is determined by the field rise. This calculation in effect assumes that there is little change in betatron amplitude while moving in. The turn number that corresponds to this hitting of the south faraday cup is saved for future use in calculating beam intensities.

The calculations, as they are presently carried out, assume that the rf voltage is off while we are determining whether the beam is accepted as coasting beam.

1.3 Accepted Pulse

We wish now to use our previous results to determine what function of an injected pulse of beam is trapped in the machine. Briefly, what we must do is map the injected pulse into the (x, x', x_9) space, then the accepted beam can be translated into the machine until rf turn on time at which point in time we need to know the beam distribution in the $(\Delta r, x_\beta)$ space. We then have our results since we know from the PHASE calculation what fraction of the beam in this space survives the rf trapping process.

We shall first consider a short pulse of beam injected into the machine at an arbitrary time t_i. At any instant of time, the beam has a known distribution in the (x, x') plane and a known momentum distribution about some central momentum p_i. By known, we mean that we are expected to supply these distributions either as actual measured values or as reasonable approximations to the physical characteristics of the beam. Our beam is completely specified at time t_i by its distribution in the (x, x', p) space.

Along the momentum axis, we consider the beam to have a central momentum p_i and a distribution about this value. Since changes in momentum are equivalent to changes in equilibrium orbit radius, we can consider this distribution to be a function of x_9. See Figure 7.

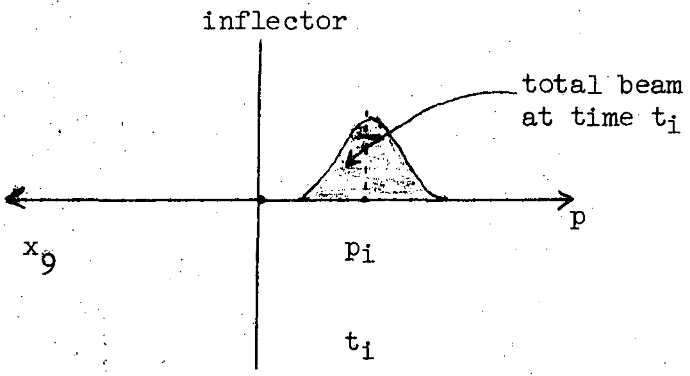


Figure 7

Similarly, since a change in time is equivalent to a change in magnetic field which is also equivalent to a change in equilibrium orbit radius, we can consider time to be measured by values of x_9.

We can establish a time origin by taking $t = 0$ to be the time at which a beam with central momentum p_o injected tangent to the inflector remains on the tangent circle. See Figure 8.

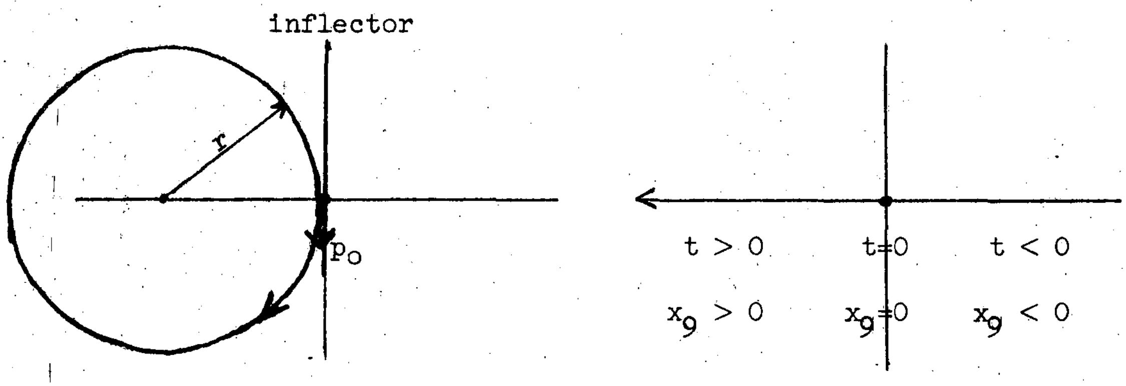


Figure 8

Thus $x_9 = 0$ for p_o = central momentum at $t = 0$.

Beam injected earlier will see a lower field since $\dot{B} > 0$ and will thus have equilibrium orbits of larger radii. Beam injected later will have equilibrium orbits of smaller radii. It is immediately obvious (Figure 9) that we are not limited to the same p_i for each t_i.

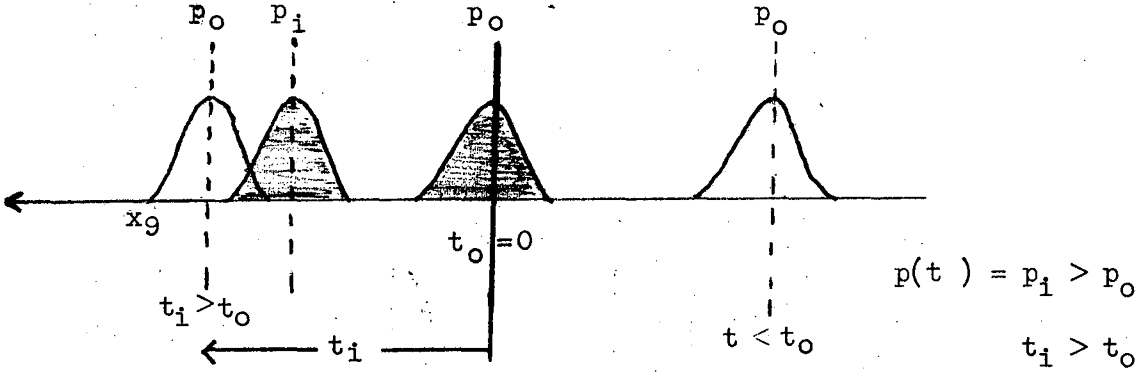


Figure 9

For each p_i, t_i we have a distributuion in the (x,x') plane. The distribution can, in principle, be oriented in any desired manner by a beam transport system. In practice, it will be near the inflector wall. We can thus map a short pulse at time t_i into the (x,x',x_9) space. See Figure 10.

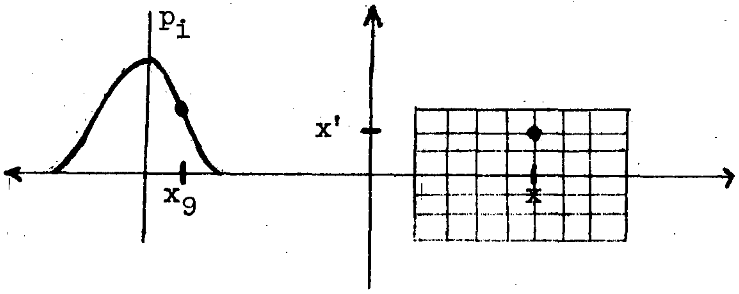


Figure 10

When our distributions are properly normalized, a point in this space represents the fraction of the total beam in the short pulse that is at the given coordinates. We now use the previous accepted beam calculation to determine whether this beam is accepted or rejected. If it is accepted, we know its maximum betatron oscillation amplitude and we can use the pitch determined by $\dot{B}$ to translate this beam into the machine to a time t_{rf} which represents the rf turn on time.

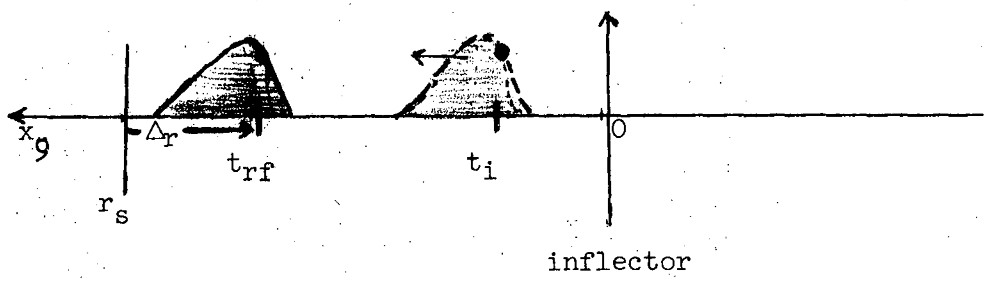


Figure 11

If the beam remains within the available radial aperture during this translation, this being determined by adding its betatron amplitude on to its equilibrium orbit radius, then we can accumulate this fraction of beam at the point (Δr, x_β) in the rf trapping plane. We do this over a discrete set of values in the (x, x', x_9) plane to obtain in the (Δr, x_β) plane a discrete distribution at time t_{rf} of the short pulse injected at time t_i with central momentum p_i.

We now repeat this process for a series of discrete pulses which represent a long pulse and thus construct in the (Δr, x_β) plane the beam distribution of a pulse injected over a finite time. See Figure 12.

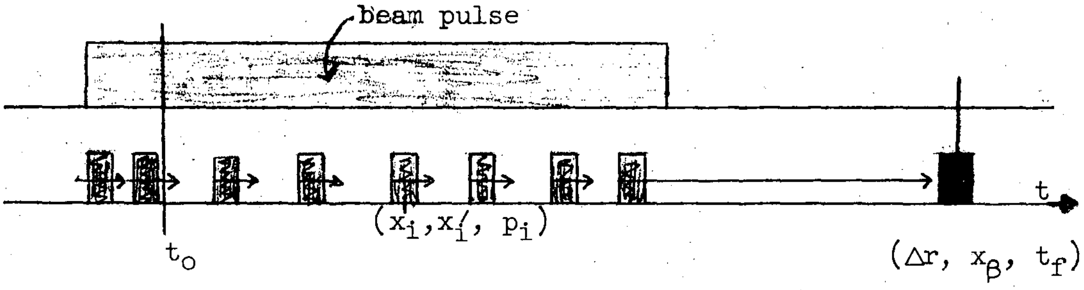


Figure 12

We can proceed to calculate the fraction of trapped beam, since for every point in the (Δr, x_β) space, we know what fraction of any beam that exists there is trapped.

It is, of course, assumed here that the distributions are properly normalized to the total injected beam. These and other details pertaining to this calculation can be found in Volume II, Section 3.1.

1.4 Parameter Variation

Corresponding to each of the basic calculations discussed above is a set of parameters that may be varied to determine what effect they have on the trapping of the injected beam. We deal first with those connected with the accepted pulse (HINJ) calculations, then the accepted beam (INJECT), and finally the rf trapping (PHASE).

1.4.1 Accepted pulse parameters.

For the accepted pulse calculation, we have available to us the timing and the distributions. That is, we can adjust the time at which the pulse is injected (the start of injection) and the length of the pulse (the end of the injection). We can also vary the central momentum p_i as a function of time and the distribution around that momentum. Likewise, we can vary the orientation, shape and size of the x, x′ phase space distribution and, in principle, this distribution could be a function of time and momentum.

The approach that was taken in calculations reported in [1] was to consider each pulse to have the same momentum and x, x′ distribution and to concentrate on the effects of timing (within physically obtainable limits) and to investigate the effects of the injected beam emittance, by using uniform and Gaussian distributions with different orientations, and the effects of momentum spread using Gaussian distributions.

1.4.2 Accepted beam parameters

The principal parameter available to us here is the magnetic field. Since the rf voltage is considered to be off during these calculations, we have no voltage parameters. The field rise $\dot{B}$ can be varied along with the field index values $n = n(r)$. We can also modify the field locally; i.e., a field bump can be introduced. We, of course, have the particle energy and charge; they must, however, be compatible with those used in both PHASE and HINJ. In general, we consider that we have chosen some particle and some injection energy and wish to investigate the effect of other parameters. We also assume here that the (x, x', x_9) space covers that needed for HINJ and that the physical aperture of the machine is not really a parameter in our sense.

1.4.3 rf trapping parameters

For the rf trapping process, we deal essentially with the rf voltage characteristics. We can thus introduce frequency errors versus time and such things as voltage buildup versus time and rise time constants to determine their effect on the beam. Other things such as reference particle energy, aperture widths, average field index are more in the nature of problem constants.

1.5 Summary of Injection Calculations

In order to effectively carry out these calculations, we establish all necessary problem constants such as particle energy, machine dimensions, etc., choose a reasonable set of values for the available parameters and proceed to run the programs. We must use INJECT to calculate an acceptance array $A(x, x', x_9)$ that establishes what beam is accepted as coasting beam.

We use PHASE to calculate a trapping array RF(Δr, x_β) to find out what fraction of available beam is trapped by the rf. These arrays are saved and can be used in HINJ as long as their basic parameters are not changed. We then use HINJ to calculate what fraction of the total beam survives the combined injection, rf trapping process. In short, we can obtain I the beam intensity of the trapped beam as the number of particles of trapped beam per milliamp of injected beam. I = I(a, b, c, ...) is a function of all the problem parameters a, b, c, ... and by systematically varying these parameters a profile of the injected beam can be constructed and an optimum choice of parameters can be made. Results of calculations of this type are presented in [1].

2. PROGRAM INJECT

This program is used primarily to determine whether injected particles are accepted or rejected. It is an orbit tracing program so it can also be used to trace individual particles in the bevatron. When determining the accepted beam, parameters are input that determine the machine characteristics, the particle injection energy, and the injection phase space. Particles in this phase space are traced through the machine turn-by-turn until they are either lost or accepted. Acceptances arrays A, N are generated and written out on disk for later use. The program is built so that it can handle many different cases in any one run. The data input and program output for simple examples are described in the following sections. The general manner in which INJECT solves the problem was given in Section 1.2. A detailed description of the program is given in Volume 2 of this report. In Appendix B, Table I is a detailed table describing the data input to this program.

The data saving program TWRITE can be considered as a "black box" program. It is adequately described in [3]. We have, for convenience, given a description of its use and data input record. Efficient use of the library tape that HINJ uses to fetch its data records will require that the actual reference be consulted.

2.1 Data Input

INJECT which calculates the accepted beam arrays AA and NT is built in small modular sections.

```
program   inject(input,out,tape 3, tape 4)
begin
L1:       ID:= read; if ID= -1 then go to end;
          if ID=... then
          begin  do whatever the value of ID indicates;
                 go to L1
          end;
end:      end of program
end
```

The first and last values read are the value of ID. The allowable values of ID are given in the data input table of Appendix B. All data is read from the file -input-. All program output is written on the file -out-. All stored arrays reside on file -tape 4-. Many values are preset in program data statements. The preset values are given in the data input table. All input is field free [2]. See also Appendix C. All data values are, by convention, assumed to be real numbers unless explicitly typed as *integer*, also denoted by *i*. The quantity IC is of type *integer*.

If the generated acceptance arrays AA, NT are to be later used by program HINJ, then it is necessary that the grid used to generate them agree exactly with that used in HINJ. This means that in the IC = 4 section, we must have the values

XXMJN	.025 [inch]
XXMAX	.575 [inch]
DXX	.05 [inch]

XXPMIN	-.002875	[r]
XXPMAX	.002875	[r]
DXXP	.00025	[r]
XX9MIN	-0.5	[inch]
XX9MAX	18.5	[inch]
DXX9	1.0	[inch]

HINJ 72/01/18

date

where the program version of HINJ is indicated by the date. It is also necessary that the arrays be saved by executing an IC = 5 section after generation with an IC = 100 section.

Generated arrays for as many cases as desired can be stored during any one run. Those that are saved will reside on file tape 4 as one file of data in standard data format suitable for input into program TWRITE 1, [3], which is used to append them to the library. They can then be later fetched from this library by program HINJ.

If the preset values are used for the program parameters, then very little data need be input to generate the arrays. The preset values are for the LBL Bevatron and are taken from the report [1] for the 19.3 MeV injection case.

Typical examples of data input are given in Appendix A1. The output generated by this program when generating full (12 × 24 × 20) arrays is copious and it has proved convenient to route the file -out- to microfiche.

2.2 Control Cards

Two control card decks for running INJECT on the LBL CDC 7600 are shown in Tables I and II of Appendix A1. The cards shown in Table I are suitable for running an example such as Example 2 when all output is routed to the file output. A complete run for generating and saving acceptance arrays for use in program HINJ is shown in Table II. The comments to the right of the control cards are self-explanatory. These control cards will no doubt be outdated as the LBL system changes. However, they serve as examples on how to go about executing the program.

We shall guide the reader through that of Table II.

After the job card and the routing information, we have three cards pertaining to the fetching and updating of the program. The program INJECT is usually stored in the LBL data cell as a CDC UPDATE Library. It is fetched from the data cell and updated. If there are no program modifications, the update data record is empty and this update serves to produce a source compile file. Presently, the source program now on IN is preprocessed by a program called BASTRIC to ensure that there are no blank lines. The RUN compiler does not like blank lines. The source deck then resides on file C1. The RUN compiler is called and then the object deck is on BINJECT and the compiler output on COUT. **The next three cards fetch the field free routines, compile them and place them on the user library file RULIB. The routines fetched are source decks usable on either the 7600 or 6600.**

The program INJECT is now executed. All of its program output goes onto file OUT, all of its card input is read from INPUT. A source listing is appended to the output from the program. This is quite useful in that it identifies which version of input generated the output. This output is then routed to microfiche. All arrays to be saved reside on TAPE4. This file is transferred to file DATA which is the default data input file to program TWRITE1. The file was cataloged to make sure it contained data in case of a later error exit. The program TWRITE1 is fetched from the data cell, compiled, and the object deck resides in BTW1. The library tape to which we wish to append the data is fetched as file LIB. The program TWRITE1 is executed; **appends the data records to file LIB and** places an updated director on file DIREC. This new directory on file DIREC is merged with the data records on file LIB. The file LIB contains the new, updated, library which should be saved. This is saved on tape 9804. If the run looks O.K., this library will be copied from tape 9804 back onto tape 10308 which is the LBL tape we presently used as the library. If the run is not O.K., appropriate corrections can be made and the job rerun.

The data records are as indicated. A data record for the UPDATE program, a data record for INJECT, a data record for TWRITE1, and a data record for the TAPE program.

2.3 Data Examples

Data for some examples are given in Table III. The */text/* are comments that the input routines ignore. We shall guide the reader through one example, Example 2. **Table I, Appendix B1 should also be referred to.**

The first number read is 2; thus, the IC = 2 section is executed. We wish to use the internally set values, so we read 0 values. Next IC = 3. We read one item which is TEMP(4) = FALSE. We have thus set the variable FULOUT to FALSE. Then comes IC = 4 and we read in nine values that specify the grid (x, x', x_9) over which we wish to generate the AA, NT acceptance arrays. The IC = 6 section sets the kinetic energy to 19.3, skips the rest mass so it has its preset value, sets the field rise to 7.58 and the average field index to .67. The arrays are then generated, IC = 100 and the generated arrays are saved, IC = 5, on TAPE4 and also output on file OUT. Since only one generation case is desired, the program is shut off, IC = -1.

The output generated by such a run is copious. A selected sample of output is given in Table IV and described below.

We have given in Table I of Appendix B a description of the various data parameters for INJECT. Most of the parameters are preset and those values are indicated there. The preset values correspond to 19.3 MeV injected beam as described in [1]. Most of the data items are adequately described in Table I. Remember, the program operates in a loop as indicated in Section 2.1. For each value of IC, there is a section in Table I and the program does what is indicated in that section.

2.4 Description of INJECT Output

This example is produced by the data set, Example 2, given in Table II, Appendix A1. We have here a case where a 19.3 MeV particle has been injected at an x_9 equilibrium orbit radius of 8.5". We have looked at all particles in the (x, x') space for which .025 [inch] $\leq x \leq$ .575 [inch], -2.875 [mr] $\leq x' \leq$ 2.875 [mr] and the mesh spacing is .05 [inch] by .25 [mr]. We have used internally set field index values $n = n(r)$. We have generated the acceptance array elements corresponding to the chosen grid points and printed out the arrays $AA(I, J, K) = AA(x, x', x_9)$ and $NT(I, J, K) = NT(x, x', x_9)$. We shall guide the reader through the selected output.

The first line of output is a program output identification line used to lable microfiche or printed program output. The ID is the

YY/DD/MM. HH.MM.SS. = 72/08/22. 17.03.35.

This appears in the array data lable, on the next page, and helps us locate the fiche that contains the output for a given generation run.

The rest of the output on this first page is generated as we go through the various data input sections of INJECT. In general, it simply outputs the input value, or present values, that exist at the time the program passes through that data input section. It then verifies that the variables are actually set. For example, the field index values are listed, program variables such as the maximum number of allowable turns (here 30) the shrinkage factor of the equilibrium orbit, etc. The reader should refer to the data input table, Appendix B, to see what these quantities are.

The next page contains in a readable format all the problem parameter values that were actually used in this generation of the acceptance arrays. The first section is called the full lable. It contains all the parameters and their values. The second section, the line of output called the short lable, is a summary of the pertinent quantities in the full lable. The array ID plus the first 15 items in the full lable are listed here. When the IC=5 section of inject is executed these two lables along with the two arrays AA, NT are saved on TAPE4 for future use. When the arrays are later used, for example in HINJ, these lables furnish the values of the parameters used to generate the arrays. The ID furnished as the first line of the full lable and the first two words of the short lable is used to fetch these arrays when they are later used. This is the ID that must be furnished to program HINJ.

The next few lines of data define some of the quantities appearing in the lable. They also furnish the code values stored in the AA array when the particle is not trapped as a coasting beam. Most of the items appearing in the long lable are self explanatory and perusal of the data input table for INJECT should help to identify these quantities.

The code numbers stored in AA tell what happened to particles that were not accepted. The particles can be lost by going out of the defined field range at a large radius, -4, at a small radius, -5, or it can hit the inflector wall, -3. Particles that we say have hit the south faraday cup will, in reality, not be stopped in that way in the machine since this is retracted under normal operating conditions. We thus record the hitting of the south faraday cup, but track the particles further to determine if they will eventually collide with the inflector, -1, or go out of range, -3.

The AA array contains either a positive number, the maximum betaturn amplitude, or one of these codes. The NT array tells when this happened. If the AA value is positive, the corresponding NT item tells when that particle will hit the south faraday cup. If the AA value is negative, then the NT array item tells on what turn the south faraday cup was hit (if it was hit) or on what turn the particle hit the inflector or went out of range. We shall describe these arrays in more detail shortly.

We then have for each element in the (x, x', x_9) grid a line of output telling what happened to the particle. We have shown here only a few such lines. We have the turn number NQ, the stating value of the particle X0, XP0, X90, the final condition of the particle (on turn NQ) X, XP, the value of the array elements AA(IA,JA,KA) and

NT(IA,JA,KA), the indices of the elements that have these values IA, JA, KA, the particle radius RX, the equilibrium orbit radius, RO, the maximum displacement from the reference arc ZMAX, the current shrinkage per turn factor S2 that has been calculated by the program for radius RO. For example we note that the first particle in the grid hit the inflector on turn 8, but the next eight particles were accepted. The turn number for accepted particles is the turn on which the program determined that there was no further possibility of colliding with the inflector.

The generated arrays are written out and we can by looking at them see what beam was accepted and what beam rejected. We have shown here the $X_9 = 8.5$ inch elements for the AA and NT arrays. The rest of the array elements for this example are zero since this is the only value in the X_9 grid. We have indicated on the output that the columns correspond to various x values for a given x' value and that the x value increases from left to right. The first item (upper left corner) corresponds to the point $(x,x') = (.025$ inch, -2.875 mr) and the last point (lower right corner) corresponds to $(x,x') = (.575$ inch, 2.875 mr). The grid spacing is as indicated in the long lable. $\Delta x = .050$ inch, $\Delta x' = .25$ mr. We have outlined the accepted beam in both arrays. As an example we have that point $(x,x') = (IA,JA) = (1,2) = (.025$ inch, 2.625 mr) is accepted, has a maximum betatron amplitude of 9.322 inch and will hit the south faraday cup or turn 274.861 = 274. All particles with large negative divergences that hit the inflector did so on turn 8, those with large positive divergences that hit the inflector did so on turn 5.

The output from the generation of a full (x,x',x_9) grid is substantially the same as we have shown. There is a lot more of it since each case generated goes through 12 × 24 × 20 = 5760 points. The generation of these arrays is the most time consuming part of our calculation. Full details on how the program works can be found in Volume II of this report in the section devoted to INJECT.

3. PROGRAM PHASE

Phase can be used to calculate orbits in the $(\Delta r,\psi)$ phase where Δr is the displacement of the particle equilibrium orbit from the reference orbit and ψ is the rf phase of the particle as measured from the reference particle phase. It can also calculate orbits in the $(\overline{p},\psi)$ phase where $\overline{p}$ is the canonical momentum associated with ψ. In this canonical space small displacements lead to nearly circular orbits. The orbits that are calculated can be plotted on a Cal. Comp. plotter. This program also can be used to generated rf trapping arrays and it can save those arrays for future use in program INJECT. The accepted beam can be plotted. A description of the necessary data input to accomplish this is given below. Examples are given in Appendix A2. A general description of the PHASE calculation was given in section 1.1.

3.1 Data Input

The program operates in a loop of the following type.

```
program phase 1(tape 99,input,out,tape 4)
begin
L1:     ic: = read; if ic = -1 goto end;
        comment do what ever is indicated in the section dealing with the
                value of ic;
        goto L1;
end:    comment end of program
end
```

Table II of Appendix B gives the allowable value of IC and the action that the program takes for that value. Most of the values cause parameter data to be input. Most program parameters are preset in data statements to values suitable for the bevatron at 19.3 MeV injector energy. [1] The preset values are indicated. By convention all input numbers are real numbers unless specified as type integer which we indicate as i . Note IC is of type integer. The first and last numbers read by PHASE are the value of IC. All data is input from file -input- using field free routines described in [2]. See **Appendix** C.

For example if our data for PHASE consists of the numbers

2, 600.0, .67, -1,

then we have read in the values of IC as 2, 600.0'' for the reference radius and .67 for the field index and then terminated execution by setting IC to -1. A rather short run! Below we describe a more reasonable example in detail. Note that if the parameters are not changed by reading them in, then the preset values will be used. For example, if the input/output length unit of [inch] is suitable there is no need to execute the section with IC = 0.

When generating rf trapping arrays that are to be saved for future use in program HINJ, it is necessary that the grid over which this generation takes place be identical to the one used in HINJ. This means that in the IC = 11 section we must have set the following values.

HINJ date	72/01/18	
NCENT	21	line corresponding to the reference particle radius
DDR	1.0 [inch]	delta r grid spacing
DABETA	1.0 [inch]	X_β grid spacing

This will properly match the (20 × 30) grid of the generated trapping array DF1 with the (20 × 30) accepted beam distribution array DF in HINJ the version of which is indicated above. This array is then saved on file-tape 4- by executing an IC = 12 section.

All generated rf trapping arrays that have been saved (IC = 12) will reside on tape 4 as one file of data records in standard data format suitable for input into program TWRITE1. All plots reside on tape 99. This file is an LBL Calcomp plot file. All program output will reside on file -out-.

When generated rf trapping arrays (IC = 11), or just tracking phase plane orbits (IC = 100), it is desirable to print out intermediate steps. The output generated can at times be copious and routing the file out to microfiche may be desirable.

Examples of program data input can be found in Appendix A2, Table III. An example of the output from phase is also presented in Appendix A2.

3.2 Control Cards

Two control card decks for running PHASE on the LBL CDC 7600 are shown in Table I and II of Appendix A2. The cards in Table I are suitable for running on the data given in examples 1 and 2 of Table III in that Appendix. The cards shown in Table II are suitable for a complete RF trapping array generation run where it is desired to generate the array, save it for future use on a library tape, and route all output of the run to microfiche. The comments listed beside the control cards are self-explanatory.

For the simpler case given by the cards in Table I we basically proceeed as follows. We fetch from the IBM data cell the program which has been stored as a CDC UPDATE library. We update the source program. The output from this update is source code to be compiled. During the update the source program can be modified if that should be necessary. We compile the program PHASE. We fetch the integration routine ZAM and compile it. We then fetch the field free input routine. These routines are presently fetched as source decks set up for the CDC 6600/7600, hence the cumbersome fetching process. This may be modified in the near future. Since source decks are available, they could easily be incorporated into PHASE. We then execute PHASE on the given data set in the program data record. The output of such a run using the data of examples 1 and 2 of Table III is described in Section 3.4.

The control card example of Table II is similar in structure to that of Table I which we have just described. There are, however, a number of cards added that enable us to save the generated rf trapping arrays and to route the listable output to the microfiche. After executing the program we copy the compiler listable output (source listings) onto the file OUT. This file then contains all program generated output plus the source listings of the code that was executed and it is saved on microfiche. We then transfer the rf trapping arrays that were written on TAPE4 to the file DATA which is the default data input file for program TWRITE1. Program TWRITE1 is fetched from the data cell and compiled. The data library tape is fetched and written onto file LIB which is the default library file for program TWRITE1. Program TWRITE1 is then executed and appends the data records to LIB and writes a new directory on DIREC. These two file are then merged to form a new library on file NLIB. This file which contains the old library plus the data generated by PHASE during this run is our new updated library and it is saved using the TAPE program. The system program KATALOG is used to determine how full the tape is and also to obtain check sums that could prove useful later in case of suspected tape failure. Because of the manner in which the CDC 7600 stages tapes, a separate short job is later run to insure that the tape is readable. If it looks as if the process was executed successfully, then tape 9804 is copied back onto tape 1308 and the new library is ready for using in program HINJ. Although this process looks a bit cumbersome and redundent, it has in practice worked well and the generated arrays are automatically stored with little chance of losing the library.

3.3 Data For Examples

We give in Table III of Appendix A2 two simple illustrative examples. The reader should also refer to Table II, Appendix B when following these examples.

Example 1 calculates and plots the separatrix orbit for the 19.3 MeV injected particles. Since the internal data statements are set to values corresponding to the 19.3 MeV case, it is not necessary to input many of the parameters.

The first 3 cards are comments as is anything written as */text/*. The input routine ignores this. Referring to Table IV we see that IC = 0,2,3 sections are not executed; hence the present values are used. The reference radius is 600", the field index n is .67 and the energy is 19.3 MeV. The fourth card executes the IC = 4 section. We thus integrate from 0.0 to 17.0 with the internally set maximum step size of 4π/100. This latter value because we skipped setting the step size by furnishing an empty field of data. We next set the voltage rise time to 0 which in effect causes a constant rf voltage to be used. We then set the print interval to 25 causing every 25th maximum integration step to be printed. Since our step size is 4π/100 and 2π is about one synchrotron oscillation we are printing every 1/2 revolution. We then set the field rise to 7.58 Kg/sec and the rf parameters to 25.5KV maximum double gap voltage with an effective length of 137 inches.

The next set of cards sets plot parameters, IC = 10. We turn on the plot and furnish three plot lable cards. We then furnish a list of plot parameter values starting with OPTION = 2 and ending with SCALE = 1.0. These are explained in the IC = 10 section of table II, Appendix B.

We then define the grid of initial values over which the integration will take place. Each initial value corresponds to tracing one orbit. By using IC = 1 we have choosen to define these initial values, and to print out the orbit results, in the (R,ψ) plane. We could have just as easily used IC = 9 to define and print these in the cononical space.

We then execute the program integration section using the above set value of the parameters. This execution causes the orbits to be integrated over all our specified initial values and, since we have the plot option on, they will also be plotted. After this is done the program reads an IC = -1 and terminates. If this card were not present, then the data from Example 2 could be read and that example executed. This is actually what was done when obtaining the sample output described in the next section and presented in Table IV of Appendix A2.

The second example generates an RF array and plots the points that were accepted. It is quite similar to the first example and we shall simply note some of the differences. We see that the time constant has been changed to 270 μs in the IC = 5 section. Also the plot parameters have been changed. We have a FALSE for the value of JOIN since we do not want the pen down between plotted points. We have furnished a value 45 for SYMBOL since we wish to plot using crosses. We then execute the IC = 11 section to generate the rf trapping array. In this section the number of time constants is left unchanged, we have 36 phase axis intervals thus we use 10° increments, the 600" reference radius is placed on line 28 of this rf array. The grid spacing is left at the present values of 1" X 1" but the chamber width is increased to 30". If it were desired to save this array on file TAPE4 for future use, we would next execute an IC = 12 section, but in this example we instead terminate execution with an IC = -1. It should be noted that since we moved the reference orbit radius in relation to the rf trapping array, we went from 21 to 28, this array is not suitable as input to program HINJ since that program assumes line 21 is 600". We could, however move the reference radius to 593" at the same time and then we have a suitable array for INJECT. In our example we simply wanted to move the array grid further out in radius so the 30 Δr values would sample farther out in radius. This is why the chamber width was increased to 30".

Sample output from these two runs is given in Table IV of Appendix A2 and described below. Further details on program calculations can be found in Volume II of this work in the section dealing with programs PHASE and HINJ.

3.4 Description of PHASE Output

We give here a description of selected portions of the results output from PHASE when run on the data presented in Table III. The output appears in Table IV of Appendix A2.

If the reader will refer to the data of Example 1, Table III, he will see that the first page of output is merely the input data as it is encountered. Each section of PHASE that reads data also writes out the values used in order that they may be verified as being correct. The definition of the quantities is as given in the appropriate section of Table IV.

When the IC = 100 section is executed the program begins to integrate for orbits and this is indicated by issuing a message to this effect. At that time, the input parameter values that define the input data are printed. This lable serves to establish just what the values of the parameters were when the orbits were integrated. The first line is an ID that is used to lable this particular case. We next output the charge, restmass, synchronous (reference) particle kinetic energy, main field rise, average field index, maximum double gap voltage, effective length, harmonic number, frequency error, time constant, reference radius, integration grid, delta r grid, phase grid, cononical momentum grid, straight section length, plot option, and an ID which is used to identify the output. We see on the first page of Table IV that this appears as the first line of output and is used to identify the microfiche output.

The next half page of output is printed while integrating for the orbits. Each orbit is defined by initial conditions and at the start of the integration process a line is printed establishing the values of parameters that are calculated from the data and the initial values. Some of this is redundent. When compared with the lable we see that we could eliminate some values; however, we choose to print it out again.

This line of data contains the reference orbit radius, the average n value, the straight section length factor, the momentum compaction (some authors have 1/A), the time scaling factor which is also the frequency of the small amplitude synchrotron oscillation, the double gap maximum voltage, the single gap maximum voltage, the energy gain per turn of the reference particle, the stable phase of the reference particle, the field rise, the value of the Hamiltonian for the system (only when we have a constant voltage case, i.e., $t_c = 0$), σ_{pr} which is $(dp/p)/(dr/r) = 1-n$.

After these initial values are printed, PHASE begins the orbit integration and prints out one line of data every 25 steps since we set the print interval to 25. The initial values are on line N = 0 and the final values appear as labled on the last line. We print here the line count, integration variable, time, orbit displacement in inches, phase value as measured from the stable phase, the cononical momentum, the maximum orbit excursion, the current kinetic energy of the reference particle, γ of the synchronous particle (Es/Eo), rotation freqmency of the reference particle, $\Delta E/E$ the relative difference between the particle energy and the reference particle energy, $\Delta p/p$ the relative momentum error, $\Delta w/w$ the relative frequency error (all these in percent), the change in the Hamiltonian (valid only for the constant voltage case), a measure of the correctness of assuming that the constant voltage Hamiltonian is correct, $\sigma_{ER} = (dE/E)/(dr/r)$, $\sigma_{wr} = (dw/w)/(dr/r)$. these last two quantities both are measured with respect to the synchronous particle.

This output of initial values and current values is repeated for every initial condition specified in the Δr, $\Delta\psi$ grid.

In Example 2 we generated an rf trapping array. The output from this generation is similar to that obtained from the first example and we have not shown that part of the output. The trapping array was printed. When it is saved, a lable and the array values are printed. These are what we have shown. This lable serves to define the array data. The first line is an id which is used to fetch the array once it has been stored. We actually print and save two lables, the full lable and a one line lable consisting of the first part of the full lable. These lables and the array are later used by the program HINJ.

The trapping array contains the fraction of the beam trapped by the rf for a given initial value Δr and a given betatron amplitude x_β. The print out starts with the (1,1) element in the upper left hand corner. In our case we see from the lable on the preceeding page that the minimum x_β is .5" and the grid size 1". Thus x_β reads from left to right .5, 1.5, ..., 19.5". The Δr grid starts at 627" and has a grid spacing of 1". The center line is at line 28 that is at 600".

The orbits of example 1 are plotted as they are generated. This plot is shown in Figure 1 of Appendix A2. In Example 2 we plot the initial values of the particles that are trapped by the rf. This plot is shown in Figure 2 of Appendix A2. Remember that for illustrative purposes the walls have been moved out to 30 inches. Ordinarily 20 inches is used and particles outside this are lost by hitting the outside wall.

It is of some interest to compare the plot of the trapped particles with the **trapping** array. At $\Delta r = -2$ inches one initial value is shown as **trapped**. Thus out of 360° we have $\frac{10}{360} = 2.8$ percent of the beam trapped. The value is given in the bottom line of the rf trapping array and we see that it is trapped for all betaturn amplitudes $.5 \le x_\beta \le 19.5$. A similar type of reasoning can be applied to the other points in the plot of the trapped beam to obtain a correspondence with the rf trapping array.

4. Program HINJ

This program calculates the accepted pulse and the trapped pulse. It assumes that appropriate acceptance and rf trapping arrays have been generated by the programs INJECT and PHASE. It reads these arrays from a data library tape, it reads data that defines the beam distribution and the necessary parameters to define the beam pulse width, timing and the rf turn on time. It then calculates the beam that is accepted as coasting beam and that which is trapped by the rf. These results are printed out in terms of particle accepted per milliamp of injected beam and particle trapped per milliamp of injected beam. Many cases can be run on a single computer run thus allowing the user to obtain the behavior of the injection process as the parameters are systematically varied.

4.1 Data Input

The data input structure is best described in terms of a short Algol routine given below. The data input is formated. The data items are described and the formats are given in Table III of Appendix B.

In that table are given the values of the lable, the variables read for that section of code, a description of what is read, the format that is to be used. The lable values correspond to those given below in the short schematic input program. In section 4.3 below we describe in detail the data input for a specific example.

```
program hinj (input,output,tape4,tape3);
begin comment schematic input for program HINJ;
L1:     AID:=read; call acpt; comment fetch acceptance array;
L2:     RID:=read; call trap; comment fetch rf trapping array;
L3:     comment set up the beam density function; call dinj;
L4:     comment define the pulse parameters;
        if  DX > 0 then
        begin calculate the accepted pulse; go to  L4 end;
        print summary page
        if  DX = -1.0 go to L3;
        if  DX = -2.0 go to L1;
        if  DX = 3.0 go to L2;
end: comment end of program
end
```

All data cards are read from file -input- . All program output is on file -output- . Summaries are on file -tape 3-. A data library in standard library format [3] is expected to be furnished on file -tape 4- .

The program is rather easy to run. The ID values AID and RID are read so that the correct acceptance and rf trapping arrays are fetched. A beam density function is calculated from given input parameters. The beam pulse position and width are specified along with an rf turn on time and then that particular case is executed. The process can be repeated as indicated above in the schematic data input listing. Summaries of the cases run are kept on tape 3; complete output from these cases resides on file -output- .

4.2 Control Cards

The control cards necessary for running HINJ are given in Table I and II of Appendix A3. These cards are for executing on the LBL CDC 7600. In Table I we illustrate a run in which all output is printed on line. In Table II is illustrated a case where only the summaries are printed on line while the general output is routed to microfiche. The comments to the right of the control cards are self-explanatory. We shall guide the reader through the first example of Table I.

The first three cards consist of a job card and two routing cards. We see that although HINJ is a relatively fast program it does take up some space, 134000_8, since it is necessary to store both acceptance arrays and the rf trapping array. Each acceptance array is 12 X 24 X 20 and the rf trapping array is 20 X 30.

We fetch the update library off of the IBM data cell. We then update the source deck, if necessary. Once updated it is compiled and the object deck resides on file BHINJ. The update program requires a data record. If no source modifications are necessary, this record may be empty. In our example we actually have six data cards. The data statement changes from the present source version of 50 MeV to a 19.3 MeV injection energy. The microfiche lable and routing information has been changed to agree with the current user. The update routine is the CDC UPDATE program and a users manual [4] is available which describes the data structure for that program. File HINJ1 which we fetched from the data cell is an UPDATE library.

We next request our data library tape. This tape contains the acceptance and rf arrays that will be used by HINJ. The program object code is then loaded and executed. This requires a program data record. All generated output goes onto the standard output file. Upon completion of the run the summaries are appended to that file.

The next three cards are error exit cards which give a core dump and insure that the summaries are transfered to the standard print file.

The example given in Table II looks much the same. The significant change is that the program generated output has been sent to file -out- . Only the compiler listable output and the summaries have been sent to the standard print file. Upon completion of the run the program generated output has been routed to microfiche.

The program data record has in it data that has been used to generate an example, selected parts of which appear in Table III of Appendix A3. Both the data record cards and the resultant output are described below.

4.3 Data For Examples

We give in the program data records on Tables I and II, Appendix A3 data for a simple example. The output generated by that example is discussed in the next section. We shall guide the reader through this example by explaining each card. In this discussion reference will be made to Table III of Appendix B.

The first two cards read are the AID and RID identification. These id lables which are used to fetch the acceptance and rf arrays are explained in section L1, L2 of Table III. The program reads these and automatically fetches the corresponding arrays.

The next card read is under the L3 section. These parameters define the momentum **distribution.** It is helpful here to refer to Figure 11 of Section 1.3. As we indicated in the discussion of section 1, a momentum spread in the injected beam corresponds to a radical spread of equilibrium orbits along the x_9 axis. We assume this distribution to be Gaussian with a given standard deviation σ_E which in our case was input as SE = 3.0 [inch]. We have that given a energy spread ΔT corresponding to half height at full maximum we can obtain Δr the corresponding radical spread from

$$\frac{\Delta T}{\Delta r} = \frac{(pc)^2}{E} \; \frac{(1-n)}{r}$$

and the appropriate standard deviation from

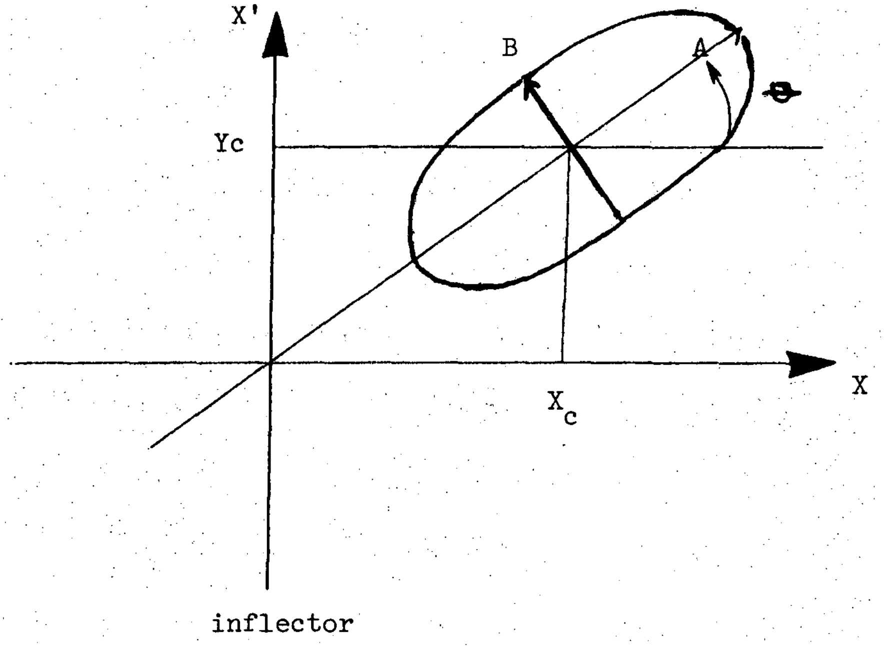
$$\Delta r = 2.36\sigma_E$$

The details pertaining to these calculations can be found in Volume II of this work, section 3.1 where we discuss the program INJECT.

We can also inject the beam with an injection energy that is a function of time. For each time slice, there are up to 30 of them, we can represent a shift in central momentum by shifting the central momentum along the X_9 axis by so many inches. Thus we read in here 30 values of NTIM the units of which are inches. The relation between Δr and ΔT is given above. In the example given here there is no bias on the momentum position and thus all time slices have the same central momentum.

The next card read establishes the x,x' beam distribution. We assume in the program that the emittance of the injected beam can be adequately represented by an ellipse and that the distribution of the beam in this ellipse is Gaussian along the major and minor axis.

To establish this beam distribution ellipse we furnish the center of the ellipse as measured from the inflector, and we supply the standard



deviations σ_A = SA, σ_B = SB along the major and minor axis. These are measured in inches. The angle of rotation is also furnished. In our example the ellipse center is displace .18 [in] from the inflector, sits on the X' = 0 [mr] axis and is not rotated. The standard deviation along the A, here x, axis is .12 [in] and along the B, here x', axis is .80 [mr].

Physically we know the half axis of an ellipse that contains some percentage of the beam, say 90%. If a,b represent these half axes, then we calculate the appropriate σ_x, σ_z from

$$a = 2.15\sigma_x = k\sigma_x$$

$$b = 2.15\sigma_z = k\sigma_z$$

If some other percentage is used, then the factor 2.15 must be changed. In general if we are working with an ellipse the contour of which represents d per cent of the central values, then we will have within this contour 100-d percent of the beam and we can obtain the factor k from

$$e^{-\frac{k^2}{2}} = d\text{x}10^{-2} .$$

Further details of this calculation can be found in Volume II section 3.1. In our particular case, the d=10% was used. Thus the values a,b obtained with k = 2.15 give an ellipse within which 90% of the beam is obtained.

We have now arrived at the L4 section. Three items are read here and this section will be repeated until the second item is less than or equal to zero. The action of the program for these latter values is given in Table III.

We input here the start of the pulse XA, the length of the beam pulse DX, and the rf turn on time TF. In our example, the first case has a pulse that starts at -2 [in], i.e., outside the inflector by 2 inches, and has a duration of 17 [in]. The rf is turned on at 14 [in]. We thus have a pulse that lasts right up until rf turn on time. Because of the manner in which the pulse is discretized we have one more unit in our pulse than the time span. Or to put it another way, XA = 14, DX = 1, XF = 14 gives a one inch pulse injected right at rf turn on time. Because of basic assumptions built into the program the rf should not be turned on inside the pulse. The example run here shows a pulse that is as long as it can be starting at -2 [in].

We should comment that the axis along which we measure the pulse is the X_9 axis, Figure 11 Section 1 of this report. We consider $X_9 = 0 = t$ to be at the inflector. This is a relative time scale and we have arbitrarily chosen the origin to be such that a particle injected at t = 0 has momentum such that the equilibrium orbit is tangent to the inflector; equivalently it has a zero betatron ampilitude. For the example run, 19.3 MeV, 1 [in] = 27[μs]. For 50 MeV we have that 1[in] = 44 [μs]. The precise value is not really needed since the program will furnish this number as output from a given run. Further details about this shrinkage per turn can be found in Volume II, Section 1.

The next six cases are examples of short pulses. In each case we have used 1 [in] pulses. These are the shortest available. The rf turn on time has been left at 14 [in] and we inject at -2, 4, 6, 10, 14 [in] to see what these short pulses do. These are essentially time slices of the long pulse. We could work with short pulses and construct results that tell what happens to a long pulse. It is usually easier to work with various long pulses and let the program construct these results. However, if the acceptance arrays are time dependent it is possible to use short pulses and obtain results. This is rather tedious and if any amount of work were to be done the program should be modified to do it.

The last card indicates a pulse length of -10 [in]. Physically this is ridiculous. We see from Table III that this is simply a way of shutting off the program. Had we wished to use different acceptance arrays we could have instead put -1.0. As we see from the previously discussed schematic data input program, Section 4.1, the section L1 through L4 are sequential. From L4 we can enter L1, L2, L3 or repeat L4, but once we enter one of these sections all the remaining are executed.

4.4 Description of Hinj Output

The output that we describe was generated when HINJ was run on the data just previously discussed in Section 4.3 and which appears in the program data record of Table I. The output which is presented in Table III of Appendix A3 has been edited. The full output can be voluminous; all we need for our description is some representative excerpts.

Upon execution Hinj prints out some array constants and some problem constants. The first four quantities are IM the number of points in the x grid, JM the number of points in the s' grid, KM the number of points in the x_9 grid, NM the number of points in the momentum grid, KFMX the number of points in the x_9 grid for the final beam distribution (i.e., the number of Δr grid points at rf turn on time), DMIN the minimum density value (all densities less than this are effecting zero), XMX the chamber width in inches.

The first five values 12, 24, 20, 31, 30 are essentially array sizes and inch limits and are not readily changed.

We then have some problem constants. BDOT is the magnetic field rise rate which for this example is 7.58Kg/s. This effectively establishes the shrinkage per turn of the orbits. The factor FSPI converts to seconds per inch. We have that the second per inch of orbit shrinkage is FSPI/BDOT. The number given here as 204.66 is for an energy of 19.3 MeV and a set of field index values corresponding to the bevatron. Since the shrinkage per turn, or pitch, of the orbit depends on not only $\dot{B}$ but on the field index and the energy, this factor furnished here in the program is an average value that was determined by separately calculating this quantity for a number of values of r and then determining a suitable average value.

The quantity PPMAS is the number of particles per milliamps per second. We assume a singly charged particle. The quantity SPI gives us the micro seconds per inch. This depends on FSPI and so is an average value.

The last quantity PPMAI gives us the particles per milliamp per inch of injected beam. As we have previously noted it is convenient for us to measure the injected pulse in inches instead of microseconds. This constant allows us to find out how many particles are in the pulse.

Whenever HINJ fetches an acceptance or trapping array it prints the lable that defines the parameters that generated that array. These lables were stored with the arrays when they were generated by programs INJECT and PHASE. These lables are described in the sections of this report dealing with those two programs. We shall not describe these lables again here.

After the rf trapping array lable comes a print out of the rf trapping array. This array is printed in such a manner that it immediately shows the accepted beam in the $(\Delta r, X_9)$ space. The Δr axis is vertical with the machine center 600" indicated by an asterisk. The larger radii in 1 inch intervals proceed upward and the smaller values downward. The columns going from left to right are the associated betatron amplitude.

The first column is for .5 inch and the increment is 1 inch. The entries in this array show what percentage of the beam with these values of $(\Delta r, x_\beta)$ will be trapped. If we know the beam density distribution in this space at rf turn on time, then we need simply multiply those densities by these percentages to find out what beam survives the rf trapping process. This is of course what HINJ does for us.

The next page of output pertains to the beam distributions. The parameters necessary to define this distribution were input in the L3 section of the data input table previously discussed in section 4.3 The parameters that have been input are output here. The 90% area is the x,x' phase space area that contains 90% of the beam as calculated using the Gaussian distributions. If our distributions have a real physical meaning they should show some agreement with an actual emittance measurement.

All of the distributions are normalized to unity. In HINJ integrals are approximated by simple Riemann sums. This has been satisfactory for the calculation so far performed. We, however, print out these normalization sums to insure that our grid is not too coarse. If we take the standard deviations SA, SB or SE too small, this will in effect make the grid too large and our sums will not be correct. Similarly if the deviations are too large the beam will be outside the grid limits. The values used here have given satisfactory results and correspond to reasonable approximations to the bevatron 19.3 MeV injected beam.

Following these normalization sums is a line of calculated values. S and C are the Sin(Φ) and Cos(Φ) of the x,x' phase space rotation angle. EMORM and ABMORM are the normalization factors used in the Gaussian energy and x,x' space distributions. Remember that these integrals have been replaced by Riemann sums and the grid spacing appears in the normalization factor. Further detail regarding this normalization can be found in Volume II, Section 4.1 of this report. PE, PA, PB are the exponent constant factors in the energy, (x,x') distribution. They are $\frac{1}{2\sigma^2}$ where σ is the appropriate standard deviation.

The final quantity FDT is a factor used to normalize the beam distribution function to unit beam in the acceptance grid. If we should, for example, run cases where half of the injected beam landed outside the acceptance grid, then FDT would be 2 . We haven't used this feature in this run. We see from PRISM = .934237 that most of our beam is within the grid. Presently use of this feature requires a set of update cards to modify the source code.

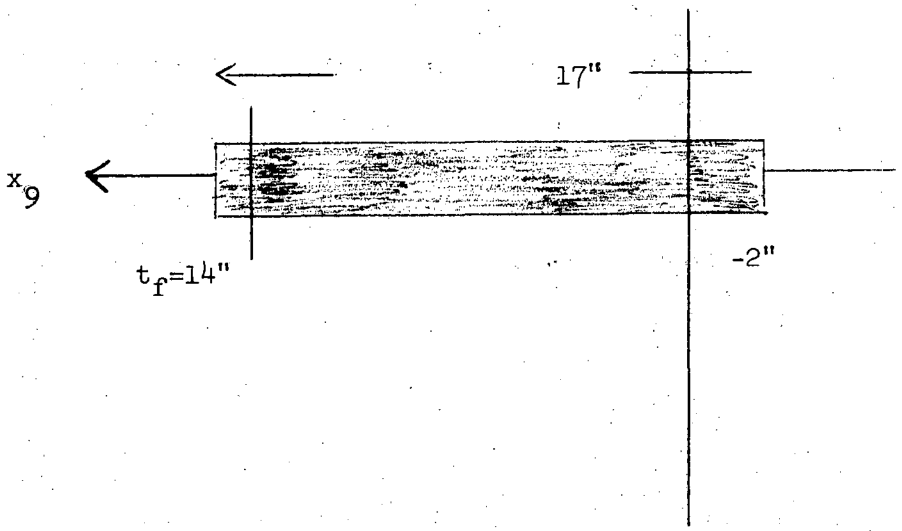
The next page of output shows us the energy, (x,x') distributions. There are 31 values of the energy distribution and these are printed out starting at $\frac{+\Delta p}{p}$ with the central momentum p located at the 16th value. The x,x' distribution lies in a grid that is identical to that used by INJECT to generate the acceptance arrays. Given a point (x,x') in that grid, INJECT tells HINJ whether or not that point was accepted. If it was accepted then the (x,x') beam distribution at that point tells how much beam was accepted. This grid is, then, only defined as a space of points; what points they are is defined by the INJECT run. In our particular example we have that

$$x = .025,\ .575(.05) \quad [\text{inch}]$$

$$x' = -2.875,\ 2.875(2.5)[\text{mr}]$$

These values can be found in the acceptance array lable which is printed when HINJ fetches these arrays using an AID card.

The next three pages are output generated by injecting a particular pulse of beam with given timing conditions. We have here a pulse extending from -2 inches for a length of 17 inches. The rf voltage is turn on at 14 inches. This is the maximum pulse that can be calculated correctly since we inject up until the rf turn on time.



As we have noted earlier, the one inch descrepency between the pulse length and the rf turn on time is because of the way the program discretizes the pulse. The quantities of LA, LM, LB, LF are the internal index values used by the program for this pulse.

At rf turn on time, $t_f = 14"$, HINJ calculates the fraction of the total beam accepted. This is printed as DTOT. In this case 71% of the beam injected was accepted at rf turn on time. This means that we have circulating in the machine at rf turn on time 71% of all the beam injected in this 17 inch pulse.

The next quantity, DTUN, is an intermediate quantity. If we know the factor (PPMAI) particles per milliamp per inch of injected beam, then the length of the pulse times this gives us the particles per milliamp of injected beam and then we need to multiply by DTOT to obtain the particles accepted per milliamp of injected beam. (PAC). Thus PAC = PPMAI X DTUN. The factor PPMAI is furnished by HINJ on the first page of output.

We next obtain two lines of output that tell us which pulse time slices contribute to the accepted beam. For each 1 inch time slice from -2 inches to 14 inches we print the fraction of the total beam in that pulse that was accepted. If each pulse contributed 50% of its beam to the total accepted beam, then our total accepted intensity would be 50% of the total pulse. We see that in the example the pulse at -2 inch contributes only 18% of its total beam while the one at 12 inches contributes 91%. of its beam. Thus if we could compress the whole pulse and inject it at 12 inches we would have a higher accepted beam. This is, of course unrealistic; however, we see that extending the pulse to less than -2 inches will contribute little beam.

The next few lines give the signal that would appear on a faraday cup located in the south straight section if we were to monitor the beam as it is injected and not turn on the rf but instead simply let the beam spiral in as the main field rises. The first value is -2 inches and the intervals are in 1 inch (27μsec). This calculated signal could be compared with an oscilliscope pick up of the south faraday cup signal.

On the next page we give the beam distribution at rf turn on time, t_f = 14 inches in this example. The grid is identical to the rf trapping array grid previously discussed. The beam distribution is normalized to 1, hence the numbers printed here are in tenths of a percent. It tells us what percent of the total beam is accepted at each point in the $(\Delta r, X_9)$ grid. For example, the line with the aserisk corresponds to a particle whose equilibrium orbit radius is 600 inches and we see that only .11% of the injected beam had this equilibrium orbit radius and a betatron amplitude of 3.5 inches at rf turn on time while .54% of the injected beam had an equilibrium orbit radius of 603 inches and a betatron amplitude of 9.5 inches at rf turn on time. The sum of all these accepted fractions should give us the total fraction of the beam accepted DTOT which is 71% in this case. It should be noted that the rf trapping process will be calculated by multiplying this array times the rf trapping array discussed above. Thus placing the outline of the accepted beam on top of the rf trapping array will show us in a qualitative manner how we must adjust the pulse timing to effect the best coupling of the accepted beam and trapping arrays.

The line below the accepted beam array is a one line summary of the INJECT parameters used to generated the acceptance arrays A,N used in calculating this accepted beam distribution. The values here are taken from the array lable shown previously. The next three lines are summaries of the HINJ beam distribution parameters; these were described above. Then we have the pulse timing. We see here the actual time in microseconds corresponding to the pulse specified in inches. The start of the pulse is at -54 μ sec and the pulse lasts for 459 μ sec. The rf is turned on at 405μ seconds. Our time origin is not absolute since we are unable to measure the main field of the bevatron to sufficient accuracy to obtain a precise absolute reference. However, the results can always be translated in time and the curve shapes obtained should be correct.

We see that for this pulse 71% of the total pulse was accepted and that this corresponds to 2.03 X 10^{12} particles per milliamp of injected beam. The last line is an output id that allows us to find the program output should that be necessary. It consists of the data and the time of the run. This is used to lable the microfiche output.

The next page of output looks quite similar to the one we have just described. It is, however, for the trapped beam. The distribution given here is taken at time t_f = 14", the rf turn on time. But it shows us what beam is trapped by the rf after full voltage has been obtained. It is the distribution of the beam that will be trapped when the rf turns on. The calculation of the beam distribution after the trapping process takes place is tedious and time consuming and we have not attempted to do that.

There is a new summary line added here, it is the lable summary of the parameters generating the rf trapping array that was used to obtain this trapped density distribution. This rf trapping lable is fetched along with the rf trapping array and was described above.

We see that although 71% of the beam is accepted as coasting beam only 35% is trapped, the rest having been lost during the rf trapping process.

In order to demonstrate how the program works on short pulses we look at 1 inch pulses injected at -2, 4, 6, 10, 14 inches. These are effectively slices of the original long pulse. The output pages, three per pulse, are the same as just described. We show one such case here corresponding to -2 inches. Note, however, that the normalization is to unit injected beam, so the numbers look different than before. However, the value DTOT will be the same as in the long pulse for each individual 1 inch pulse. This working with short pulse can sometime be useful since any long pulse is an accumulation of short pulses. For example, this is one way that a time dependent acceptance array can be handled. The example we have given here is one of the optimum 19.3 MeV cases.

5. Program TWRITE1

This program is used to save the generated arrays that the programs INJECT and PHASE write on file tape 4. For our purposes it will be considered to be a black box data saving program. We have

```
program twrite 1(lib, data, direc, input, output);
comment The data records on file -data- are appended
to file -lib- . The updated directory resides on file
-direc- . It is assumed that files lib and data are
in standard library and data format respectively, [3].
A new library tape is made by merging the file direc
with the data records on file lib. This can be done
using a COPY routine. The exact manner in which this
is to be done is printed when twrite1 is executed.
Output is written on file -output- . Input is read
from file -input-. The data on file input is in field
free format [2], Appendix C of this report.
```

For our purposes we have that file tape 4 as output from programs INJECT and PHASE is to be used as the file -data- when saving the generated arrays. We assume that the library tape is given and that tape is used as file -lib-. The actual use of this program is illustrated in Appendix A.1 and A.2, Tables II.

In these examples the generated arrays are saved on a new library tape on the same run that generated them. This is not necessary. The file -tape 4- on these INJECT, PHASE runs could be saved and a separate run could be made later to append to the library using TWRITE1. This latter method has the advantage of allowing us to delete some of the cases on a multiple case run should be have accidentally generated unwanted cases, i.e., incorrect input data, etc.

The data input to program TWRITE1 that appears on file input is illustrated in these examples. It consists of the tape number of the library tape upon which the updated library will reside. The output from TWRITE1 consists of information pertaining to the new library. A tape and directory summary are printed. A summary of the data records appended is given. A summary of the new library is given. This output is described and illustrated in [3]. We shall not describe these here. For our present purposes we simply note that all the ID's necessary to fetch the data arrays back off of the tape are furnished by TWRITE1 when the tape is updated.

Appendix A Sample Control Cards/Input/Output

We present in Appendix A some sample control card packages to run on the LBL 7600, some data examples and selected output from these examples. Appendix A is subdivided into A1 INJECT, A2 PHASE, A3 HINJ. The tables presented here are described in the corresponding program sections.

A1 Program INJECT

TABLE I

INJECT 7600 CONTROL CARDS

```
INJECT,12,300,70000.490501,CLOSE        JOB CARD
*7600
FLOOR(3)
LIBCOPY(ERCBEV,LIB,INJECT3)   FETCH INJECT UPDATE LIBRARY
UPDATE(P=LIB ,C=IN,F)        UPDATE INJECT
LIBCOPY(ERCLIB,BASTRIC,BASTRIC)         FETCH BASTRIC SOURCE DECK
RUN(S,,,BASTRIC,NULL,ASTRIC,100000)     COMPILE BASTRIC
LINK(F=ASTRIC,B=XEQ1)        LOAD BASTRIC OBJECT CODE
XEQ1(IN,C1)                  EXECUTE BASTRIC, ELIMINITAES BLANK LINES
RUN(S,,,C1,,BINJECT,300000)  COMPILE INJECT SOURCE CODE
RETURN(LIB,BASTRIC,ASTRIC,XEQ1,C1,IN)   RELEASE FILES
LIBCOPY(ERCLIB,IO/BR,/R,SIN,SFORIO)     FETCH FIELD FREE ROUTINES     1
RUN(S,I=IO,B=ULIB,O=NULL)                                             2
LIBGEN(F=ULIB,P=RULIB)                                                3
LOADL(BINJECT,RULIB)         LOAD INJECT AND FIELD FREE OBJECT CODE
EXECUTE.                     EXECUTE PROGRAM INJECT
COPY(OUT/RBR,OUTPUT)         INJECT OUTPUT IS PLACED ON OUTPUT
EXIT.                        ERROR EXIT
DMP(70000)
COPY(OUT/RBR,OUTPUT)
789                          UPDATE DATA RECORD
789                          INJECT DATA RECORD
6789                         END OF JOB
```

TABLE II

INJECT 7600 CONTROL CARDS

```
INJECT,1,1200,70000.490501,CLOSE       JOB CARD
*7600
FLOOR(3)
LIBCOPY(ERCBEV,LIB,INJECT3)  FETCH PROGRAM UPDATE LIBRARY
UPDATE(P=LIB ,C=IN,F)        UPDATE PROGRAM IF NECESSARY
LIBCOPY(ERCLIB,BASTRIC,BASTRIC)        FETCH BASTRIC SOURCE
RUN(S,,,BASTRIC,NULL,ASTRIC,100000)    COMPILE BASTRIC
LINK(F=ASTRIC,B=XEQ1)        LOAD OBJECT DECK OF BASTRIC
XEQ1(IN,C1)                  EXECUTE BASTRIC. CHANGES BLANK LINES TO COL 1 *
RUN(S,,,C1,COUT  ,BINJECT,300000)      COMPILE INJECT
COPYSBF(COUT,OUTPUT)         COMPILER LISTING ON OUTPUT
RETURN(LIB,BASTRIC,ASTRIC,XEQ1,C1,IN)  RELEASE FILES
LIBCOPY(ERCLIB,IO/BR,/R,SIN,SFORIO)    FETCH FIELD FREE ROUTINES    1
RUN(S,I=IO,B=ULIB,O=NULL)                                           2
LIBGEN(F=ULIB,P=RULIB)                                              3
LOADL(BINJECT,RULIB)         LOAD INJECT AND FIELD FREE ROUTINES
EXECUTE.                     EXECUTE INJECT
COPY(COUT/RB,OUT/BR)         APPEND COMPILER LISTING TO INJECT OUTPUT
DISPOSE(OUT=MF)              SAVE OUTPUT ON MICROFICHE
REWIND(TAPE4)                INJECT ACCEPTANCE ARRAYS THAT WERE SAVED
KATALOG(TAPE4,N=1)
COPY(TAPE4/RBU,DATA/RBR)     TRANSFER TO FILE DATA
LIBCOPY(ERCLIB,TW1,TWRITE1)  FETCH TWRITE1 SOURCE
RFL(70000)
RUN(S,,,TW1,OUTPUT,BTW1,100000)        COMPILE TWRITE1
RETURN(TW1,BINJECT,NULL)     RELEASE FILES
REQUEST(LIB,HI,X,R) 10308 ERCXXX       FETCH LIBRARY TAPE TO SAVE ARRAYS
                                       ON FILE DATA
LOADL(BTW1,RULIB)            LOAD TWRITE1 AND IO ROUTINES
EXECUTE.                     EXECUTE TWRITE1. THIS APPENDS TO LIB
COPY(LIB/RB,201R,NULL/RBR)   SKIP DIRECTORY ON THE LIBARAY TAPE
COPY(DIREC/RBR,1FM,LIB/BR,1F,NULL,1F,NLIB/RBR)   SAVE NEW LIBRARY ON NLIB
KATALOG(NLIB,N=1)
TAPE(NLIB,HI,X,W) 9804 ERCBEA          WRITE NLIB ONTO A TAPE. THIS IS
                                       THE NEW LIBRARY CONTAINING THE ARRAYS
EXIT.                        ERROR EXIT
DMP(70000)
COPY(COUT/RB,OUT/RB,OUTPUT)  COMPILER LISTING TO OUTPUT
789                          UPDATE DATA CARDS TO UPDATE INJECT
789                          INJECT DATA RECORD
789                          TWRITE DATA RECORD
10308,                       */ TAPE NUMBER OF LIBRARY TAPE/*
789                          TAPE PACKET DATA RECORD
*WRITE
*WEOF
*REWIND
*UNLOAD
6789                         END OF JOB CARD
```

TABLE III

INJECT DATA EXAMPLES

```
*/ EXAMPLE 1/*
*/ PROGRAM DATA 19.3(MEV) /*
*/2,  NUM,(I,N(I),I=1,NUM), FIELD INDEX VALUES/*
2,17,                                     */ 17 N VALUES READ/*
1,.958,2,.765,3,.753,4,.782,5,.743,6,.743,7,.733,8,.761,9,.733,
10,.734,11,.731,12,.751,13,.785,14,.809,15,.773,16,.777,17,1.397,
*/3, VARIABLE PARAMETERSARE SELECTIVFLY INPUT/*
3,  1,4,FALSE
*/4, XMIN,XMAX,DX,XPMIN,XPMAX,DPX,X9MIN,X9MAX,DX9/*
4,  */ SET UP GRID FOR USE IN PROGRAM HINJ/*
0.025,.575,.05,    -.002875,.002875,.00025, -.50,18.5,1.0,
 */ 6, KINETIC ENERGY(MEV), REST MASS(MEV), DBDT(KG/SEC), FIELD INDEX
       (AVERAGE VALUE)/*
6,  19.3,,7.58,.67,            */ REST MASS NOT CHANGED/*
*/ 100, EXECUTE PROBLEM, GENERATE ACCEPTANCE ARRAYS/*
100,
*/ 5,  WRITE AA AND NT ON TAPE, SAVED FOR FUTURE USE IN HINJ/*
5,
*/ NEW CASE ON SAME RUN/*
*/ 2, NUM,(I,N(I),I=1,NUM), FIELD INDEX VALUES/*
2,17,                */ 17 N VALUES INPUT/*
1,.778,2,.625,3,.613,4,.642,5,.603,6,.603,7,.593,8,.621,9,.593,
10,.594,11,.591,12,.612,13,.645,14,.669,15,.633,16,.637,17,.997,
100,5,          */ GENERATE ARRAYS AND SAVE ON TAPE/*
*/ -1 STOP PROGRAM/*
-1,


*/ EXAMPLE 2/*
*/ PROGRAM DATA 19.3(MEV) /*
*/2,  NUM,(I,N(I),I=1,NUM)/*
2,  0,          */ USE INTERNALLY SET FIELD INDEX VALUES/*
*/3, VARIABLE PARAMETERS/*
3,  1,4,FALSE         */ DO NOT WANT FULL OUTPUT/*
*/4, XMIN,XMAX,DX,XPMIN,XPMAX,DPX,X9MIN,X9MAX,DX9/*
4,  */ SET UP X,XPRIME,X9 GRID FOR USE IN PROGGAM HINJ/*
0.025,.575,.05,    -.002875,.002875,.00025, 8.5,8.5,1.0,
*/ 6, KINETIC ENERGY(MEV),REST MASS(MEV),FIELD RISE(KG/SEC),
      FIELD INDEX(AVERAGE VALUE)/*
6,  19.3,,7.58,.67,      */ SKIP INTERNALLY SET VALUE OF REST MASS/*
*/ 100, EXECUTE PROBLEM, GENERATE ACCEPTANCE ARRAYS/*
100,
*/ 5,  WRITE AA AND NT ON TAPE/*
5,
-1   */ STOP PROGRAM/*
```

```
*/ EXAMPLE 3/*
*/ PROGRAM DATA FOR 19.3(MEV) INHECTION CASE/*
2,  0,    */ USE INTERNAL FIELD INDEX VALUES/*
*/ TRACE ONLY ONE PARTICLE STARTING AT X=1.0(INCH),XPRIME=0.0(RAD),
      X9= 19.5(INCH)/*
4,  -1.0,-1.0,1.0,  0.0,0.0,1.0,  19.5,19.5,1.0,
*/ FIELD RISE SET TO ZERO,I.E. A CONSTANT FIELD/*
6,  19.3,,0.0,.67,
*/ SET VARIABLE INPUT PARAMETERS, 3 ITEMS ARE CHANGED, THE MAXIMUM
      NUMBER OF TURNS IS 100, THE NUMBER OF STEPS/90 DEG. IS 8,
      SUPRESS FULL CNTPUT.  THEN EXECUTE THE PROBLEM, I.E. TRACE
      THE ORBIT STARTING AT THE POSITION SET ABOVE WITH IC= 4/*
3,  3,  1,100 ,  3,8,  4,FALSE,  100,
5,  */ WRITE THE OUTPUT ARRAYS ON TAPE 4/*
*/ IF YOU LOOK AT THESE ARRY ELEMENTS, ONLY ONE ITEM IS GENERATED FOR
      EACH ARRAY.  THESE ARE STORED IN AA(1,1,1) AND NT(1,1,1).  THIS
      ARRAY CAN NOT BE USED IN PROGRAM HINJ/*
  -1,     */ STOP THE PROGRAM/*


*/ EXAMPLE 4/*
*/ PROGRAM DATA 50.0(MEV) /*
*/2,  NUM,(I,N(I),I=1,NUM, SET THE FIELD INDEX VALUES/*
2,  0,               */ USE THE INTERNALLY SET VALUES/*
*/3, VARIABLE PARAMETERS/*
3,  2,  1,100,  4,FALSE,'    */ 50 MEV NEEDS AROUND 100 TURNS TO BE SURE
                                       THAT THE INFLECTOR IS CLEARED/*
*/4, XMIN,XMAX,DX,XPMIN,XPMAX,DPX,X9MIN,X9MAX,DX9/*
4,         */ SET UP ACCEPTANCE ARRAY GRID FOR USE IN PROGRAM HINJ/*
0.025,.575,.05,     -.002875,.002875,.00025, -.50,18.5,1.0,
6,  50.0,,7.58,.67,*/6, KE(MEV),M0(MEV),DBDT(KG/SECT,N(AVE)/*
*/ 100, EXECUTE PROBLEM/*
100,
*/ 5,  WRITE AA AND NT ON TAPE/*
5,
*/ -1 STOP PROGRAM/*
-1,
```

TABLE IV
INJECT OUTPUT

```
T 72/08/22. 17.03.35.INJECT,CLOSE,FLOOR(3)
 N VALUES
   .868   .695   .683   .712   .673   .673   .660   .691
   .663   .664   .661   .682   .715   .739   .703   .707
  1.197
 NQ,S2(INCH),K2,FULOUT,DRIFTL(INCH),R9(INCH),D9(INCH),ROMIN(INCH),SCUP(INCH)
  30  .075     8     F  120.000  619.375      .040  575.375  583.265
 XMIN,XMAX,DX=       .025       .575      .050
 XPMIN,XPMAX,XP=    -.003       .003      .000
 X9MIN,X9MAX,X9=    8.500      8.500     1.000


 KE(MEV),M0(MEV),DBDT(KG/SEC),RON(AVERAGE)
    19.300   938.232     7.580       .670



  72/08/22. 17.03.35.
 INJECT ACCEPTANCE ARRAY DATA
 Q(E+)=                  1.000
 E0(MEV)=              938.232
 KE(MEV)=               19.300
 DB/DT=                  7.580
 N(AVE)=                  .670
 INF. RAD(INCH)=       619.375
 INJ. WIDTH(INCH)=       .0400
 ROMIN(INCH)=          575.375
 SCUP(INCH)=           583.265
 XMIN(INCH)=              .025
 XMAX(INCH)=              .575
 XPMIN(RAD)=          -.002875
 XPMAX(RAD)=           .002875
 X9MIN(INCH)=            8.500
 DX9(INCH)=              1.000
 X9MAX(INCH)=            8.500
 DX(INCH)=                .050
 DXP(RAD)=             .000250
 MAX.NO. TURNS=         30.000
 NO. STEPS/MAG.=         8.000
 DRIFT L(INCH)=        120.000
 N VALUES EVERY 3 INCHES FROM 575.357 INCH
    .868    .695    .683    .712    .673
    .673    .660    .691    .663    .664
    .661    .682    .715    .739    .703
    .707   1.197
 WEST FIELD BUMP
 B1TD(KG)=               0.000
 DB1DT(KG/SEC)=          0.000
 DT1(MICRO SEC)=         0.000

 OUTPUT ID= 72/08/22. 17.03.35.
 72/08/22. 17.03.35./ 1/ 938/19.3/7.58/ .67/619/ 40/575/583/ .025/ .575/-2.88/ 2.88/8.50/1.00/


 NUMBER OF TURNS TRACED=   30
 SHRINKAGE/TURN(INCH)=    .0750
 STEPS/QUADRANT=    8
 STRAIGHT SECTION/2.0=  120.000
 INFLECTOR RADIUS(INCH)=  619.375
 INFLECTOR WIDTH(INCH)=      .040
 MINIMUM RADIUS(INCH)=  575.375
 SOUTH CUP RADIUS(INCH)=  583.265
 DELTX CODE
 HIT SFC.A.INFLECTOR= -1
 HIT SFC.A.OUT OF RANGE= -2
 HIT INFLECTOR= -3
 OUT OF FIELD RANGE= -4
 R0 TOO SMALL= -5
```

```
NQ,X0,XP0,X90,X,XP,AA,NT,IA,JA,KA,RX,R0,ZMAX,S2,BIN

BEGIN RAY TRACE
INFLECTOR TURN=
  8    .025  -.00288   8.500   9.092   .00132   -3.000    8.000  1  1  1   619.344   610.252  .440  .0769  .0000
 12    .025  -.00253   8.500  -7.385  -.00355    9.322  274.861  1  2  1   619.268   609.946  .436  .0560  .0000
 10    .025  -.00238   8.500   3.849  -.00646    9.199  277.037  1  3  1   619.297   610.099  .431  .0660  .0000
  9    .025  -.00213   8.500  -7.532   .00296    9.105  278.612  1  4  1   619.280   610.175  .427  .0660  .0000
  8    .025  -.00188   8.500   8.335   .00235    9.019  280.070  1  5  1   619.271   610.252  .422  .0660  .0000

DIRECTORY/LABLE/A/N WRITEN ON TAPE    4
AA
```

CODE NUMBER

BETATRON AMPLITUDE

IA x →

JA x' ↓

```
 -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000
  9.322    9.369    9.416    9.464   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000
  9.199    9.247    9.295    9.343    9.391    9.439    9.487    9.535   -3.000   -3.000   -3.000   -3.000
  9.105    9.153    9.201    9.248    9.296    9.345    9.392    9.439    9.488    9.537    9.586    9.635
  9.019    9.068    9.136    9.185    9.233    9.282    9.331    9.380    9.429    9.478    9.527    9.575
  8.962    9.012    9.062    9.117    9.167    9.217    9.267    9.317    9.367    9.417    9.467    9.517
  8.903    8.954    9.004    9.055    9.105    9.155    9.205    9.256    9.306    9.357    9.407    9.458
  8.843    8.894    8.944    8.994    9.044    9.104    9.155    9.205    9.256    9.306    9.356    9.406
  8.808    8.859    8.909    8.960    9.012    9.063    9.113    9.164    9.215    9.266    9.316    9.367
  8.764    8.823    8.875    8.927    8.978    9.030    9.081    9.133    9.184    9.236    9.287    9.338
  8.751    8.802    8.853    8.904    8.955    9.007    9.058    9.109    9.160    9.211    9.263    9.314
  8.735    8.787    8.839    8.890    8.942    8.993    9.045    9.097    9.148    9.200    9.251    9.303
  8.722    8.773    8.824    8.876    8.928    8.979    9.031    9.083    9.135    9.186    9.238    9.290
  8.737    8.788    8.839    8.890    8.942    8.993    9.044    9.095    9.146    9.198    9.249    9.300
  8.750    8.802    8.854    8.905    8.957    9.008    9.060    9.111    9.162    9.214    9.265    9.317
  8.764    8.816    8.868    8.919    8.971    9.023    9.074    9.126    9.178    9.230    9.281    9.333
  8.803    8.854    8.905    8.956    9.006    9.056    9.107    9.157    9.208   -3.000   -3.000   -3.000
  8.864    8.914    8.987    9.035    9.084    9.131    9.186   -3.000   -3.000   -3.000   -3.000   -3.000
  8.970    9.019    9.068    9.117   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000
  9.051    9.101   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000
 -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000
 -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000
 -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000
 -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000   -3.000
```

KA=1

x_q= 8.5"

```
NT
```

IA x →

JA x' ↓

```
  8.000    8.000    8.000    8.000    8.000    8.000    8.000    8.000    8.000    8.000    8.000    8.000
274.861  274.149  273.286  272.571    8.000    8.000    8.000    8.000    8.000    8.000    8.000    8.000
277.037  276.155  275.429  274.549  273.672  272.944  272.071  271.341    8.000    8.000    8.000    8.000
278.612  277.888  277.006  276.130  275.412  274.512  273.658  272.943  272.058  271.313  270.429  269.546
280.070  279.333  278.144  277.248  276.510  275.618  274.726  273.985  273.095  272.207  271.470  270.594
281.101  280.182  279.429  278.426  277.510  276.754  275.842  274.934  274.177  273.273  272.375  271.623
282.164  281.229  280.466  279.539  278.616  277.855  276.934  276.014  275.249  274.333  273.421  272.661
283.245  282.311  281.383  280.625  279.696  278.622  277.856  276.933  276.014  275.253  274.343  273.436
283.785  282.843  282.072  281.129  280.190  279.419  278.488  277.560  276.791  275.868  274.950  274.173
284.619  283.550  282.593  281.812  280.862  279.916  279.135  278.194  277.257  276.477  275.543  274.614
284.827  283.874  282.926  282.152  281.207  280.266  279.491  278.553  277.620  276.845  275.913  274.986
285.059  284.099  283.317  282.362  281.411  280.630  279.682  278.739  277.958  277.018  276.084  275.305
285.259  284.486  283.534  282.583  281.798  280.842  279.892  279.108  278.162  277.222  276.285  275.504
285.040  284.087  283.310  282.360  281.413  280.638  279.698  278.761  277.986  277.052  276.122  275.348
284.833  283.873  282.918  282.136  281.185  280.241  279.462  278.522  277.585  276.836  275.871  274.940
284.622  283.663  282.707  281.925  280.973  280.023  279.238  278.291  277.349  276.565  275.629  274.696
283.853  282.913  282.147  281.203  280.442  279.511  278.583  277.820  276.898    5.000    5.000    5.000
282.765  282.010  280.728  279.830  278.938  278.213  277.235    5.000    5.000    5.000    5.000    5.000
280.992  280.081  279.339  278.435    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000
279.598  278.676    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000
  5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000
  5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000
  5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000
  5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000    5.000
```

KA=1

x_q= 8.5"

TABLE IX CONT.

INJECT OUTPUT

A2 Program Phase

TABLE 1
LBL CDC 7600 CONTROL CARDS FOR PROGRAM PHASE

```
PHASE,12,500,70000.490501,CLOSE             JOB CARD
*7600
FLOOR(3)
LIBCOPY(ERCBEV,LIB,PHASE2)        FETCH UPDATE LIBRARY OF PHASE
UPDATE(P=LIB ,C=IN,F)             UPDATE PHASE
LIBCOPY(ERCLIB,BASTRIC,BASTRIC)   FETCH BASTRIC SOURCE
RUN(S,,,BASTRIC,NULL,ASTRIC,100000)    COMPILE PROGRAM BASTRIC
LINK(F=ASTRIC,B=XEQ1)             LOAD BASTRIC OBJECT CODE
XEQ1(IN,PHASE)                    EXECUTE BASTRIC,CHANGES BLANK TO ASTRIC
RUN(S,,,PHASE ,OUTPUT,BPHASE,300000)   COMPILE PROGRAM PHASE
LIBCOPY(SOURCE,  SZAM/BR,ZAM)     FETCH ZAM INTEGRATOR
RUN(S,,,SZAM,OUTPUT,BPHASE)       COMPILE ZAM
LIBCOPY(ERCLIB,IO/BR,/R,SIN,SFORIO)    FETCH FIELD FREE ROUTINES    1
RUN(S,I=IO,B=ULIB,O=NULL)
LIBGEN(F=ULIB,P=RULIB)                                       7
RETURN(XEQ1,PHASE,SZAM,IO,NULL)        RETURN UNUSED FILES
RETURN(LIB,IN,BASTRIC,ASTRIC,ULIB)
LOADL(BPHASE,RULIB)                    LOAD PHASE OBJECT CODE AND I/O CODE
EXECUTE(PHASE1,PLOT)              EXECUTE PHASE
COPY(OUT/RB,OUTPUT)               PRINT PHASE OUTPUT
EXIT.                             ERROR EXIT
DMP(70000)
COPY(OUT/RB,OUTPUT)               PRINT PHASE OUTPUT
789                                    UPDATE DATA RECORD
789                                    PHASE DATA RECORD
6789                                   END OF JOB CARD
```

TABLE 2
LBL CDC 7600 CONTROL CARDS FOR PROGRAM PHASE

```
PHASE,12,500,70000.490501,CLOSE          JOB CARD
*7600
FLOOR(3)
LIBCOPY(ERCBEV,LIB,PHASE2)               FETCH PHASE UPDATE LIBRARY
UPDATE(P=LIB ,C=IN,F)                    UPDATE PHASE
LIBCOPY(ERCLIB,BASTRIC,BASTRIC)          FETCH PROGRAM BASTRIC
RUN(S,,,BASTRIC,NULL,ASTRIC,100000)      COMPILE BASTRIC
LINK(F=ASTRIC,B=XEQ1)                    LOAD BASTRIC
XEQ1(IN,PHASE)                           EXECUTE BASTRIC
RUN(S,,,PHASE,COUT  ,BPHASE,300000)      COMPILE PHASE
LIBCOPY(SOURCE,  SZAM/BR,ZAM)            FETCH ZAM INTEGRATOR
RUN(S,,,SZAM,COUT  ,BPHASE)              COMPILE ZAM
COPY(COUT/RBR,OUTPUT)                    PRINT COMPILER OUTPUT
LIBCOPY(ERCLIB,IO/BR,/R,SIN,SFORIO)      FETCH FIELD FREE ROUTINES    1
RUN(S,I=IO,B=ULIB,O=NULL)                                             2
LIBGEN(F=ULIB,P=RULIB)                                                3
RETURN(XEQ1,PHASE,SZAM,IO,NULL)          RETURN UNUSED FILES
RETURN(LIB,IN,BASTRIC,ASTRIC,ULIB)
LOADL(BPHASE,RULIB)                      LOAD PHASE AND I/O ROUTINES
EXECUTE(PHASE1,PLOT)                     EXECUTE PHASE
COPY(COUT/RB,OUT/BR)                     APPEND COMPILER OUTPUT TO PHASE OUTPUT
DISPOSE(OUT=MF)                          WRITE ALL OUTPUT ON MICROFICHE
COPY(TAPE4/RBU,DATA/RBR)                 OPEN FILE DATA FOR TWRITE1
LIBCOPY(ERCLIB,TW1,TWRITE1)              FETCH PROGRAM TWRITE1
RFL(70000)                               SET THE FIELD LENGTH
RUN(S,,,TW1,NULL  ,BTW1,100000)          COMPILE PROGRAM TWRITE1
REQUEST(LIB,HI,X,R) 10308 ERCXXX         FETCH DATA LIBRARY
LOADL(BTW1,RULIB)                        LOAD TWRITE1 AND I/O ROUTINES
EXECUTE.                                 EXECUTE TWRITE1.
COPY(LIB/RB,201R,NULL/RBR)               SKIP OLD LIBRARY DIRECTORY
COPY(DIREC/RBR,1FM,LIB/BR,1F,NLIB/RBR)   MAKE NEW DATA LIBRARY
KATALOG(NLIB,N=1)                        CATALOG THE NEW LIBRARY
TAPE(NLIB,HI,X,W) 9804 ERCBEA            SAVE THE NEW LIBRARY
EXIT.                                    ERROR EXIT
COPY(COUT/RB,OUT/RB,OUTPUT)              PRINT COMPILER AND PHASE OUTPUT
789                                      UPDATE DATA RECORD
789                                      PHASE DATA RECORD
789                                      TWRITE1 DATA RECORD
10308,
789                                      TAPE DATA RECORD
*WRITE
*WEOF
*REWIND
*UNLOAD
6789                                     END OF JOB CARD
```

TABLE 3
PHASE EXAMPLE DATA

```
*/ EXAMPLE 1/*
*/ PLOT THE SEPARATRIX /*
*/ PROGRAM DATA 19.3 MEV/*
4,  0.0,17.0,,
4,  0.0,17.0,,                              */ INTEGRATION RANGE/*
5,  0.0,                                    */ TIME CONSTANT/*
6,  25,                                     */ PRINT INTERVAL/*
7,  7.58,                                   */ FIELD RISE/*
8,  25.5,137.0,                             */ RF VOLTAGE AND GAP/*
*/ PLOT PARAMETERS, LAYOUT GRID/*
10,  TRUE,
DELTA PHI(DEG)
DELTA R(INCH)
19.3(MEV) SEPARATRIX
2,1,5.0,8.0,40.0,2.0,TRUE,1,0,1.0
*/ END OF PLOT PARAMETER/*
1,  0.0,0.0,1.0,  -145.0,936.0,360.0,       */ SEPARATRIX/*
100,                                        */  INTEGRATE PHASE ORBITS/*
-1,                                         */ STOP THE PROGRAM/*
```

```
*/ EXAMPLE 2/*
*/ GENERATE THE RF TRAPPING ARRAY AND PLOT THE TRAPPED PARTICLES/*
*/ PROGRAM DATA 19.3 MEV/*
5,  270.0,                                  */ SET THE TIME CONSTANT/*
6,  25,                                     */ PRINT INTERVAL/*
7,  7.58,                                   */ FIELD RISE/*
8,  25.5,137.0,                             */ RF VOLTAGE AND GAP/*
*/ PLOT PARAMETERS, LAYOUT GRID/*
10,  TRUE,
DELTA PHI(DEG)
DELTA R(INCH)
19.3(MEV) RF TRAP
2,1,5.0,8.0,40.0,2.0,FALSE,1,45,1.0,
*/ END OF PLOT PARAMETER/*
11,,36,28,,,30.0,                           */ GENERATE RF ARRAY/*
-1,                                         */ STOP PROGRAM/*
```

TABLE 4
PHASE OUTPUT

```
T 72/08/30. 20.24.59.PHASE1,CLOSE,FLOOR(3)
 IC=     4
 INFUT TAUMIN,TAUMAX,DELTA TAU
    0.0000   17.0000      .1257

 IC=     5
 INPUT TIME CONSTANT(MICROSEC)
    0.0000

 IC=     6
 INFUT PRINT INTERVAL
        25

 IC=     7
 DES/DT(KG/SEC)
    7.5800

 IC=     8
 VMAX(KEV), RF LENGTH(INCH), IN THE DOUBLE GAP
   25.5000  137.0000

 IC=    10
 DELTA PHI(DEG)
 DELTA R(INCH)
 19.3(MEV) SEPARATRIX
 OPTION,XYVAR,XCENT,YCENT,DELX,DELY,JOIN,DELS,SYMBOL,SCALE
  2    1    5.0    8.0  40.000    2.000     T    1    0   1.0

 IC=     1
 INFUT RMIN,RMAX,DR,PHIMIN,PHIMAX,DPHI,(INCH,DEG)
    0.0000     0.0000     1.0000 -145.0000  936.0000  360.0000

 IC=   100
 BEGIN INTEGRATION
```

TABLE 4 CONT.
PHASE OUTPUT

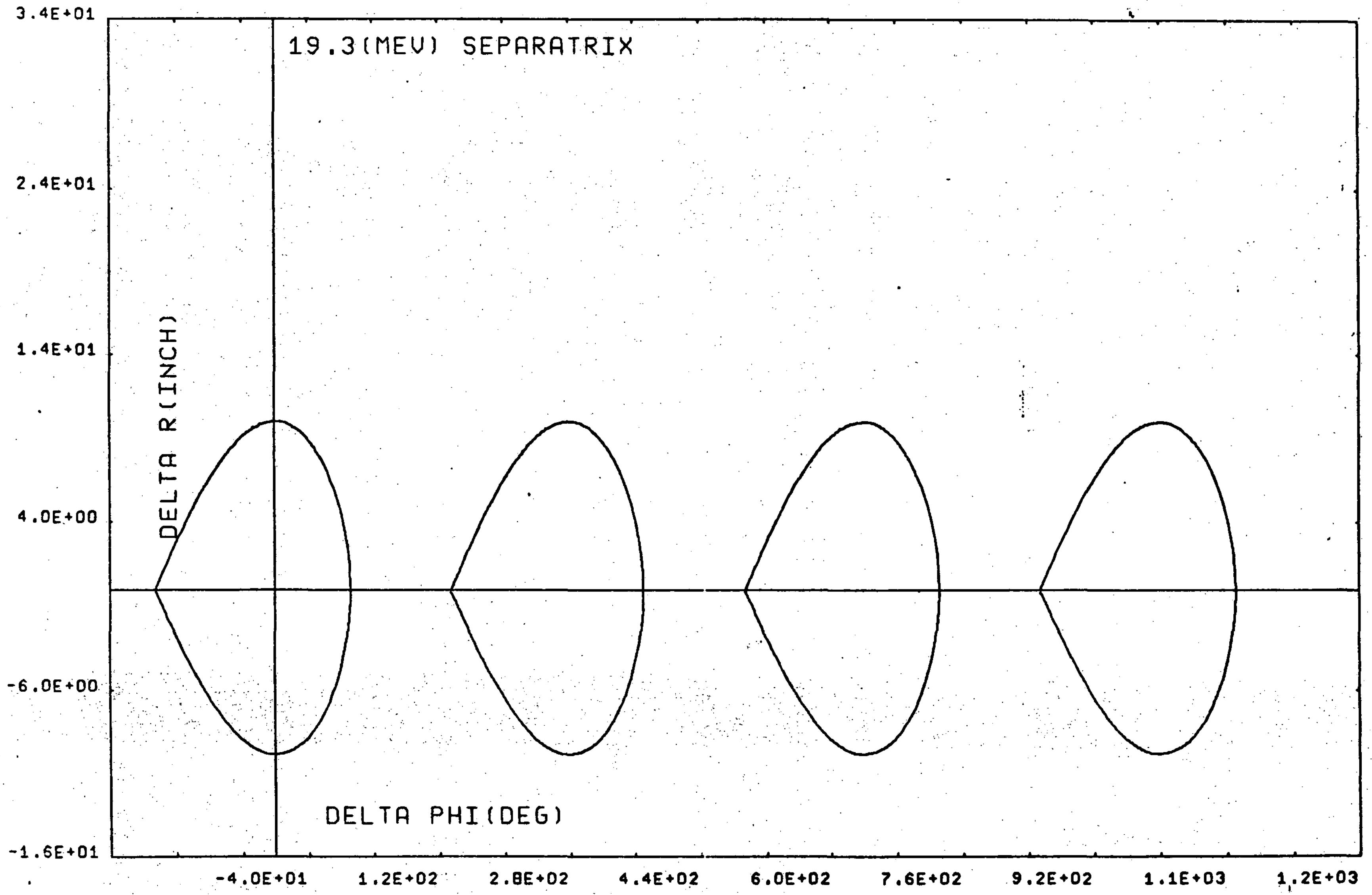
```
 72/08/30. 20.24.59.
RF ORBIT TRACKING DATA
Q(E+)                      1.000
EO(MEV)=                 938.232
ESBAR(MEV)=               19.300
DBS/DT(KG/SEC)=            7.580
N(AVE)=                     .670
VMAX,SG,(KV)=             25.500
RFL(INCH)=               137.000
H=                         1.000
W1/OMEGA=                  0.000
TC(SEC )=                   0.000
RO(INCH=                600.000
TMIN(RAD)=                 0.000
TMAX(RAD)=                17.000
DELT(RAD)=                  .126
RMIN(INCH)=                0.000
RMAX(INCH)=                0.000
DR(INCH)=                  1.000
PMIN(DEG)=              -145.000
PMAX(DEG)=               936.000
DP(DEG)=                 360.000
CPMIN(DEG/RAD)=                I
CPMAX(DEG/RAD)=                I
DCP(DEG/RAD)=                  I
L(INCH)=                 240.000
PLOT=                          T
OUTPUT ID= 72/08/30. 20.24.59.


RS(INCH),N,K,A,OMEGA(KG),DGVM(KV),SGVM(KV),DEL ES(KEV/TURN),PHIS(DEG),DBSDT(KG/SEC),HO((DEG/RAD)+2,SFR
600.000  .6700  1.255  .4140   2.583  25.500    4.641   1.388 162.599   7.580 3958.351   .330

N,TAU(RAD),T(MSEC),DR(INCH),DPHI(DEG),CONP(DEG/RAD),DRM(INCH),TS(MEV),GS,WS(MH),DE/E(PC),DP/P(PC),DW/W(PC),DHO,I(PC),SER,SWR
    0    0.000  0.000   0.000  -145.000      0.000    0.000    19.30  1.02057  .49849  0.00  0.00 -0.00  0        .000   .01  -.48
    1    3.142   .194    .256  -142.907      2.278     .256    19.43  1.02071  .50016   .00   .01   .02  1E-04   .004   .01  -.48
    2    6.283   .387   5.151   -95.435     45.917    5.151    19.57  1.02086  .50184   .01   .28   .41  8E-02   .009   .01  -.48
    3    9.425   .581  -1.187    90.424    -10.622    9.966    19.70  1.02100  .50351  -.00  -.07  -.10  8E-02   .013   .01  -.48
    4   12.566   .774  -4.032  -106.948    -36.198    9.966    19.84  1.02115  .50519  -.01  -.22  -.32  3E-01   .018   .01  -.48
    5   15.708   .968   -.196  -143.517     -1.769    9.966    19.98  1.02129  .50686  -.00  -.01  -.02  2E-01   .022   .01  -.48
 FINAL INTEGRATION VALUES
    6   17.090  1.053   -.068  -144.944      -.613    9.966    20.04  1.02135  .50760  -.00  -.00  -.01  2E-01   .024   .01  -.48


RS(INCH),N,K,A,OMEGA(KG),DGVM(KV),SGVM(KV),DEL ES(KEV/TURN),PHIS(DEG),DBSDT(KG/SEC),HO((DEG/RAD)+2,SFR
600.000  .6700  1.255  .4140   2.583  25.500    4.641   1.388 162.599   7.58010422.671   .330

N,TAU(RAD),T(MSEC),DR(INCH),DPHI(DEG),CONP(DEG/RAD),DRM(INCH),TS(MEV),GS,WS(MH),DE/E(PC),DP/P(PC),DW/W(PC),DHO,I(PC),SER,SWR
    0    0.000  0.000   0.000   215.000      0.000    0.000    19.30  1.02057  .49849  0.00  0.00 -0.00  0        .000   .01  -.48
    1    3.142   .194    .256   217.093      2.278     .256    19.43  1.02071  .50016   .00   .01   .02  1E-04   .004   .01  -.48
    2    6.283   .387   5.151   264.565     45.917    5.151    19.57  1.02086  .50184   .01   .28   .41  8E-02   .009   .01  -.48
    3    9.425   .581  -1.187   450.427    -10.622    9.957    19.70  1.02100  .50351  -.00  -.07  -.10  3E-01   .013   .01  -.48
    4   12.566   .774  -4.033   253.046    -36.202    9.957    19.84  1.02115  .50519  -.01  -.22  -.32  6E-01   .018   .01  -.48
    5   15.708   .968   -.207   216.385     -1.866    9.957    19.98  1.02129  .50686  -.00  -.01  -.02  5E-01   .022   .01  -.48
 FINAL INTEGRATION VALUES
    6   17.090  1.053   -.111   214.669      -.999    9.957    20.04  1.02135  .50760  -.00  -.01  -.01  5E-01   .024   .01  -.48
```

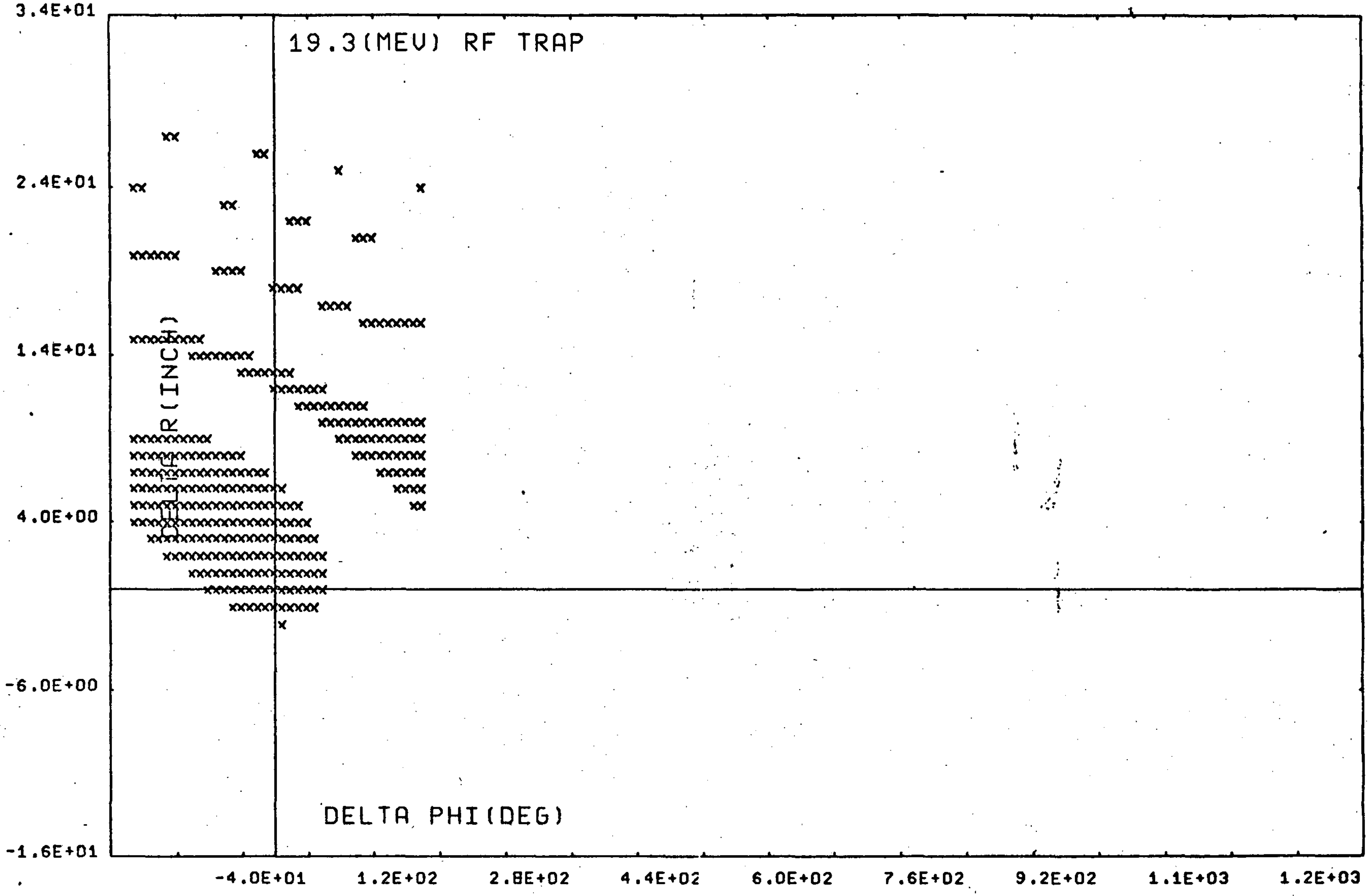
TABLE 4 CONT.
PHASE OUTPUT

```
 72/08/30. 20.25.00.
RF TRAPPING ARRAY GENERATION DATA
Q(E+)                      1.000
E0(MEV)=                 938.232
ESBAR(MEV)=               19.300
DBS/DT(KG/SEC)=            7.580
N(AVE)=                     .670
VMAX,SG,(KV)=             25.500
RFL(INCH)=               137.000
H=                         1.000
W1/OMEGA=                  0.000
TC(SEC )=              .0002700
R0(INCH)=                 600.000
NCENT=                    28.000
RMAX(INCH)=              627.000
DDR(INCH)                  1.000
XBMIN(INCH)=                .500
DABETA(INCH)=              1.000
AWIDTH(INCH)=             30.000
DPHI(DEG)=                10.000
RF(XBETA,R)=             (20,30)
L(INCH)=                 240.000
PLOT=                          T
OUTPUT ID= 72/08/30. 20.24.59.

72/08/30. 20.25.00./ 1/ 938/19.3/7.58/ .67/25.5/137.0/1/0.0/ 270/600.0/28/627.0/1.0/ .5/1.0/30/
```

TABLE 4 CONT.
PHASE OUTPUT

```
 FF ACCEPTANCE ARRAY (PERCENT)

     5.6     5.6     5.6     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
     5.6     5.6     5.6     5.6     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
     2.8     2.8     2.8     2.8     2.8     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
     8.3     8.3     8.3     8.3     8.3     8.3     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
     5.6     5.6     5.6     5.6     5.6     5.6     5.6     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
     8.3     8.3     8.3     8.3     8.3     8.3     8.3     8.3     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
     8.3     8.3     8.3     8.3     8.3     8.3     8.3     8.3     8.3     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
    16.7    16.7    16.7    16.7    16.7    16.7    16.7    16.7    16.7    16.7     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1    11.1     0.0     0.0     0.0     0.0     0.0     0.0     0.0
    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2     0.0     0.0     0.0     0.0     0.0     0.0
    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0     0.0     0.0     0.0     0.0     0.0
    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2    22.2     0.0     0.0     0.0     0.0
    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4     0.0     0.0     0.0
    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4    19.4     0.0     0.0
    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0    25.0     0.0
    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1    36.1
    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3
    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9
    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9
    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9
    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9    63.9
    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1    61.1
    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3    58.3
    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6    55.6
    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2    47.2
    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7    41.7
    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6    30.6
     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8     2.8

72/08/30. 20.25.00./ 1/ 938/19.3/7.58/ .67/25.5/137.0/1/0.0/ 270/600.0/28/627.0/1.0/ .5/1.0/30/

IC=    -1

END OF RUN
```


19.3(MEV) SEPARATRIX
DELTA R(INCH)
DELTA PHI(DEG)
3.4E+01
2.4E+01
1.4E+01
4.0E+00
-6.0E+00
-1.6E+01
-4.0E+01
1.2E+02
2.8E+02
4.4E+02
6.0E+02
7.6E+02
9.2E+02
1.1E+03
1.2E+03
72/08/31. 09.31.02.



72/08/31. 09.31.02.

A3 Program Hinj

TABLE I
LBL CDC 7600 CONTROL CARDS

```
HINJ,12,100,114000.490501,CLOSE                        JOB CARD
*7600
FLOOR(3)
LIBCOPY(ERCBEV,LIB,HINJ2)
UPDATE(P=LIB,C=HINJ,F)                                 UPDATE PROGRAM
RUN(S,,,HINJ,OUTPUT,BHINJ,300000)                      COMPILE HINJ
REQUEST(TAPE4,HI,X,10308)                              FETCH DATA LIBRARY
LINK(F=BHINJ,B=XEQ1)                                   LOAD OBJECT DECK
XEQ1.
COPY(TAPE3/RBR,OUTPUT)                                 PRINT SUMMARIES
EXIT.                                                  ERROR EXIT
DMP(70000)
COPY(TAPE /RBU,OUTPUT)                                 PRINT SUMMARIES
789                                                    UPDATE DATA RECORD
*IDENT 19MEV
*D HINJ.30
       DATA BDOT,FSPI,PPMAMS/7.58,204.66,0.624E10/
*IDENT ERCID
*D HINJ.39
   98 FORMAT(*T*,2A10,* HINJ,CLOSE,FLOOR 3*)
789                                                    PROGRAM DATA RECORD
 71/09/13. 10.04.14.
 71/11/15. 16.23.41.
 3.0
 0.18        0.0         0.12        0.80        0.0
 -2.0        17.0        14.0
 -2.0        1.0         14.0
 4.00        1.0         14.0
 6.00        1.0         14.0
 10.0        1.0         14.0
 14.0        1.0         14.0
             -10.0
6789                                                   END OF JOB
```

TABLE 2
LBL CDC 7600 CONTROL CARDS

```
HINJ,12,100,114000.490501,CLOSE                   JOB CARD
*7600
FLOOR(3)
LIBCOPY(ERCBEV,LIB,HINJ1)                         FETCH LIHN UPDATE LIBRARY
UPDATE(P=LIB,C=HINJ,F)                            UPDATE PROGRAM
RUN(S,,,HINJ,COUT  ,BHINJ,300000)                 COMPILE HINJ
REQUEST(TAPE4,HI,X,9804)                          FETCH DATA LIBRARY
LINK(F=BHINJ,B=XEQ1)                              LOAD OBJECT DECK
XEQ1(INPUT,OUT)                                   EXECUTE HINJ
COPY(TAPE3/RBR,1F,COUT/RBR,1F,OUT/BR)             SAVE SUMMARIES AND COMPILER
◆                                                 LISTING
DISPOSE(OUT=MF)                                   ROUTE OUTPUT TO MICORFICHE
COPY(COUT/BRU,TAPE3/RBU,OUTPUT)                   PRINT SUMMARIES AND COMPILER
◆                                                 LISTING
EXIT.                                             ERROR EXIT
DMP(70000)
COPY(COUT/RBU,OUT/RBU,TAPE3/RBU,OUTPUT)           PRINT LISTABLE OUTPUT
789                                               UPDATE DATA RECORD
*IDENT 19MEV
*D HINJ.30
      DATA BDOT,FSPI,PPMAMS/7.58,204.66,0.624E10/
*IDENT ERCID
*D HINJ.39
   98 FORMAT(*T*,2A10,* HINJ,CLOSE,FLOOR 3*)
789                                               PROGRAM DATA RECORD
 71/09/13. 10.04.14.
 71/11/15. 16.23.41.
 3.0
 0.18        0.0         0.12        0.80        0.0
 -2.0        17.0        14.0
 -2.0        1.0         14.0
 4.00        1.0         14.0
 6.00        1.0         14.0
 10.0        1.0         14.0
 14.0        1.0         14.0
             -10.0
6789                                         END OF JOB CARD
```

TABLE 3
HINT OUTPUT

```
    IM=   12
    JM=   24
    KM=   20
    NM=   31
  KFMX=   30

  CMIN=   .000001
   XMX=   40.0000

  BDOT=    7.5800
  FSPI=  204.6600
PPMAMS=  6.240000E+09
   SPI=   27.0000
 PPMAI=  1.684800E+11



 71/09/13. 10.04.14.
INJECT ACCEPTANCE ARRAY DATA
Q(E+)=                    1.000
EC(MEV)=                938.232
KE(MEV)=                 19.300
DB/DT=                    7.580
N(AVE)=                    .670
INF. RAD(INCH)=         619.375
INF. WIDTH(INCH)=          .040
ROMIN(INCH)=            575.375
SCUP(INCH)=             583.265
XMIN(INCH)=                .025
XMAX(INCH)=                .575
XPMIN(RAD)=              -.0029
XPMAX(RAD)=               .0029
X9MIN(INCH)=              -.500
DX9(INCH)=                1.000
X9MAX(INCH)=             18.500
DX(INCH)=                  .050
DXF(RAD)=                .00025
MAX.NO. TURNS=           30.000
NO. STEPS/MAG.=           8.000
DRIFT L(INCH))          240.000
N VALUES EVERY 3 INCHES FROM  575.357 INCH
    .868     .695     .683     .712     .673
    .673     .660     .691     .663     .664
    .661     .682     .715     .739     .703
    .707    1.197
71/09/13. 10.04.14./ 1/ 938/19.3/7.58/ .67/619/ 40/575/583/ .025/ .575/-2.88/ 2.88/-.50/1.00/
DATA OBTAINED FROM LRL TAPE=      10308
```

TABLE 3 CONT.
HINJ OUTPUT

```
 71/11/15. 16.23.41.
RF TRAPPING ARRAY GENERATION DATA
Q(E+)                      1.000
E0(MEV)=                 938.232
ESBAR(MEV)=               19.300
DES/DT(KG/SEC)=            7.580
N(AVE)=                     .670
VMAX,SG,(KV)=             25.500
RFL(INCH)=               137.000
H=                         1.000
W1/OMEGA=                  0.000
TC(SEC )=               .0002700
R0(INCH)=                600.000
NCENT=                    21.000
RMAX(INCH)=              620.000
DDR(INCH)                  1.000
XBMIN(INCH)=                .500
DABETA(INCH)=              1.000
AWIDTH(INCH)=             20.000
DPHI(DEG)=                20.000
RF(XBETA,R)=             (20,30)
L(INCH)=                 240.000
PLCT=                          T
OUTPUT ID= 71/11/15. 16.15.17.

71/11/15. 16.23.41./ 1/ 938/19.3/7.58/ .67/25.5/137.0/1/0.0/ 270/600.0/21/620.0/1.0/ .5/1.0/20/
DATA OBTAINED FROM LRL TAPE=      10308


  PERCENTAGE OF INJECTED INTENSITY TRAPPED BY RF   TRF X 100.


   0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  11.1  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  11.1 11.1  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  11.1 11.1 11.1  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  22.2 22.2 22.2 22.2  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  22.2 22.2 22.2 22.2 22.2  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  22.2 22.2 22.2 22.2 22.2 22.2  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  22.2 22.2 22.2 22.2 22.2 22.2 22.2  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  22.2 22.2 22.2 22.2 22.2 22.2 22.2 22.2  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  22.2 22.2 22.2 22.2 22.2 22.2 22.2 22.2 22.2  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  38.9 38.9 38.9 38.9 38.9 38.9 38.9 38.9 38.9 38.9  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  66.7 66.7 66.7 66.7 66.7 66.7 66.7 66.7 66.7 66.7 66.7 55.6  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 55.6  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 55.6 50.0  0.0  0.0  0.0  0.0  0.0  0.0
  61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 55.6 50.0 44.4  0.0  0.0  0.0  0.0  0.0
  61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 61.1 55.6 55.6 50.0 44.4 33.3  0.0  0.0  0.0  0.0
  55.6 55.6 55.6 55.6 55.6 55.5 55.6 55.6 55.6 55.6 55.6 55.6 50.0 44.4 38.9 33.3 22.2  0.0  0.0  0.0
  55.6 55.6 55.6 55.6 55.6 55.6 55.6 55.6 55.6 55.6 55.6 50.0 50.0 38.9 38.9 27.8 16.7 15.7  0.0  0.0
  50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 50.0 44.4 44.4 33.3 33.3 22.2 11.1  0.0  0.0  0.0
  44.4 44.4 44.4 44.4 44.4 44.4 44.4 44.4 44.4 44.4 44.4 38.9 33.3 27.8 16.7  0.0  0.0  0.0  0.0  0.0
  27.8 27.8 27.8 27.8 27.8 27.8 27.8 27.8 27.8 27.8 27.8 27.8 22.2  5.6  0.0  0.0  0.0  0.0  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
```

TABLE 3 CONT.

HINT OUTPUT

```
DINJ ...  GAUSSIAN DISTRIBUTIONS IN ENERGY, X, AND X-PRIME.

X CENTER(INCHES)  XC=      .1800     XPRIME CENTER(MR)  YC=     0.0000

STANDARD DEVIATIONS OF X-XPRIME DISTRIBUTION.  SA=      .1200     SB=      .8000

STANDARD DEVIATION OF ENERGY DISTRIBUTION (INCHES).  SE=    3.0000

ROTATION ANGLE OF X-XPRIME DIST. (RADIANS)  THETA=    0.0000

X CENTER DISPERSION  XDSF=   -0.0000
XPRIME CENTER DISPERSION  YDSP=   -0.0000

SHIFT IN CENTRAL MOMENTUM FOR TIME INTERVALS NTIM
-0  -0  -0  -0  -0  -0  -0  -0  -0  -0
-0  -0  -0  -0  -0  -0  -0  -0  -0  -0
-0  -0  -0  -0  -0  -0  -0  -0  -0  -0
 90 PER CENT AREA=   1.13*PI CM*MR

SUM OVER ENERGY DIST.      DESM=  1.000000

SUM OVER X-XPRIME DIST.  DABSM=   .934237

SUM OVER ENERGY AND X-XPFIME DIST.  DISM=   .934237

PRSM=DESM X DABSM=   .934237

S, C, ENORM, ABNORM, PE, PA, PB, FDT
         0.000000  1.000000   .132981   .020723   .055556 34.722222   .781250         I


ENERGY DISTRIBUTION OF INJECTED BEAM  DE
    .00000  .00000  .00001  .00004  .00016  .00051  .00148  .00380  .00874  .01800  .03316  .05467  .08066  .10648  .12579
    .13298  .12579 ..10648  .08066  .05467  .03316  .01800  .00874  .00380  .00148  .00051  .00016  .00004  .00001  .00000
    .00000

X-XPRIME DISTRIBUTION  DABP
      .000014    .000022   .000029    .000032    .000030    .000024    .000016    .000009    .000004    .000002    .000001    .000000
      .000041    .000065   .000086    .000095    .000089    .000070    .000046    .000025    .000012    .000005    .000002    .000000
      .000110    .000172   .000228    .000252    .000236    .000185    .000122    .000067    .000031    .000012    .000004    .000001
      .000264    .000415   .000548    .000608    .000567    .000445    .000293    .000163    .000076    .000030    .000010    .000003
      .000577    .000907   .001197    .001328    .001239    .000972    .000641    .000355    .000165    .000065    .000021    .000006
      .001143    .001796   .002371    .002631    .002455    .001925    .001269    .000703    .000328    .000128    .000042    .000012
      .002054    .003226   .004260    .004727    .004410    .003459    .002280    .001264    .000589    .000231    .000076    .000021
      .003348    .005258   .006941    .007703    .007186    .005636    .003715    .002059    .000959    .000376    .000124    .000034
      .004948    .007770   .010258    .011384    .010621    .008329    .005491    .003043    .001418    .000555    .000183    .000051
      .006632    .010415   .013750    .015260    .014236    .011164    .007360    .004079    .001900    .000744    .000245    .000068
      .008062    .012662   .016716    .018551    .017307    .013572    .008947    .004958    .002310    .000905    .000298    .000082
      .008889    .013961   .018431    .020454    .019082    .014965    .009865    .005467    .002547    .000997    .000328    .000091
      .008889    .013961   .018431    .020454    .019082    .014965    .009865    .005467    .002547    .000997    .000328    .000091
      .008062    .012662   .016716    .018551    .017307    .013572    .008947    .004958    .002310    .000905    .000298    .000082
      .006632    .010415   .013750    .015260    .014236    .011164    .007360    .004079    .001900    .000744    .000245    .000068
      .004948    .007770   .010258    .011384    .010621    .008329    .005491    .003043    .001418    .000555    .000183    .000051
      .003348    .005258   .006941    .007703    .007186    .005636    .003715    .002059    .000959    .000376    .000124    .000034
      .002054    .003226   .004260    .004727    .004410    .003459    .002280    .001264    .000589    .000231    .000076    .000021
      .001143    .001796   .002371    .002631    .002455    .001925    .001269    .000703    .000328    .000128    .000042    .000012
      .000577    .000907   .001197    .001328    .001239    .000972    .000641    .000355    .000165    .000065    .000021    .000006
      .000264    .000415   .000548    .000608    .000567    .000445    .000293    .000163    .000076    .000030    .000010    .000003
      .000110    .000172   .000228    .000252    .000236    .000185    .000122    .000067    .000031    .000012    .000004    .000001
      .000041    .000065   .000086    .000095    .000089    .000070    .000046    .000025    .000012    .000005    .000002    .000000
      .000014    .000022   .000029    .000032    .000030    .000024    .000016    .000009    .000004    .000002    .000001    .000000
```

TABLE 3 CONT.

HINT OUTPUT

```
(INJECT START) XA=   -2.0000           LA=    0

(INJECT WIDTH) DX=   17.0000           LM=   17           (INJECT STOP) LB=   16

(FINAL) XF=   14.0000           LF=   16


TOTAL ACCEPTED INTENSITY.(NORMALIZED TO UNIT INJECTED BEAM)   DTOT=   .710387

TOTAL ACCEPTED INTENSITY (TIMES PULSE LENGTH)   DTUN= 12.076587

ACCEPTED INTENSITY DTIME(L) AS FUNCTION OF TIME INTERVAL L (NORMALIZED TO UNIT INJECTED BEAM IN EACH INTERVAL)

 .182912   .271469   .373846   .481029   .583011   .671631   .742979   .796456   .835749   .862820

 .883646   .895597   .900984   .906976   .912391   .899024   .870066

SIGNAL AT SOUTH FARADAY CUP ( NORMALIZATION - INJECTED BEAM = 100.)

  0.0000    0.0000     .0007     .0180     .1766    1.0443    2.3524    2.8644    3.9802    5.2126

  6.3848    7.3569    7.8851    8.0401    7.7571    7.0547    5.5521    3.4320    1.4778     .4681

   .0962     .0113     .0004    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
```

TABLE 3 CONT.
HINJ OUTPUT

```
FINAL ACCEPTED DISTRIBUTION  DF X 1000

   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .0    .0    .0    .0    .0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .0    .0    .0    .0    .0    .0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .0    .1    .1    .1    .1    .1    .0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .1    .1    .1    .2    .2    .2    .2    .0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .2    .3    .3    .4    .5    .4    .4    .4    .1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .3    .6    .7    .8    .9    .9    .9    .9    .9    .3   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .6   1.2   1.3   1.5   1.7   1.7   1.6   1.7   1.6   1.7    .7   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   1.1   1.9   2.1   2.5   2.8   2.7   2.6   2.7   2.7   2.8   2.8   1.4   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   1.6   2.8   3.1   3.7   4.2   4.0   3.8   4.0   4.0   4.1   4.1   3.9   2.6   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   2.1   3.7   4.0   4.9   5.5   5.3   5.0   5.3   5.2   5.4   5.4   5.2   5.4   3.8   0.0   0.0   0.0   0.0   0.0   0.0
   2.4   4.4   4.8   5.8   6.5   6.3   6.0   6.3   6.2   6.4   6.4   6.1   6.4   6.4   5.0   0.0   0.0   0.0   0.0   0.0
   2.6   4.6   5.0   6.1   6.9   6.6   6.3   6.6   6.6   6.8   6.7   6.5   6.8   6.7   6.3   6.3   0.0   0.0   0.0   0.0
   2.4   4.4   4.8   5.8   6.5   6.3   6.0   6.3   6.2   6.4   6.4   6.1   6.4   6.4   6.0   6.7   6.2   0.0   0.0   0.0
   2.1   3.7   4.0   4.9   5.5   5.3   5.0   5.3   5.2   5.4   5.4   5.2   5.4   5.4   5.0   5.7   5.9   5.2   0.0   0.0
   0.0   2.8   3.1   3.7   4.2   4.0   3.8   4.0   4.0   4.1   4.1   3.9   4.1   4.1   3.8   4.3   4.4   4.5   3.9   0.0
   0.0   0.0   2.0   2.5   2.8   2.7   2.6   2.7   2.7   2.8   2.8   2.7   2.8   2.8   2.6   2.9   3.0   3.1   3.1   2.6
   0.0   0.0   0.0   1.1   1.7   1.7   1.6   1.7   1.6   1.7   1.7   1.6   1.7   1.7   1.6   1.8   1.8   1.9   1.9   1.6
   0.0   0.0   0.0   0.0    .7    .9    .9    .9    .9    .9    .9    .9    .9    .9    .9   1.0   1.0   1.0   1.0    .8
   0.0   0.0   0.0   0.0   0.0    .4    .4    .4    .4    .4    .4    .4    .4    .4    .4    .5    .5    .5    .4   0.0
   0.0   0.0   0.0   0.0   0.0   0.0    .1    .2    .2    .2    .2    .2    .2    .2    .2    .2    .2    .2   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0    .1    .1    .1    .1    .1    .1    .1    .1    .1    .1   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0    .0    .0    .0    .0    .0    .0    .0    .0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0    .0    .0    .0    .0    .0    .0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

71/09/13. 10.04.14./ 1/ 938/19.3/7.58/ .67/619/ 40/575/583/ .025/ .575/-2.88/ 2.88/-.50/1.00/

DINJ TYPE,NDIN,SE,SA,XC,SB,YC,THETA,XDSP,YDSP  GAUSSIAN    1 0.00  .12  .18  .80 0.00 0.00-0.00-0.00
NTIM  -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0
90 PER CENT AREA=   1.13*PI CM*MR

  XA=  -2.0    DX=  17.0    YF=  14.0     (INCHES)
  TA= -54.0    DT= 459.0    TF= 405.0     (MICROSECONDS)

  TOTAL FRACTION ACCEPTED  DTOT= .7104        PARTICLES ACCEPTED PER MA INJECTED  PAC=  2.034663E+12
 72/08/29. 15.01.17.
```

TABLE 3 CONT.
HINJ OUTPUT

```
FINAL TRAPPED (ACCELERATED) DENSITY DISTRIBUTION  DTRF X 1000

   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .0    .0    .0    .0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .0    .0    .0    .0    .0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .0    .0    .0    .0    .0    .0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .0    .0    .0    .0    .0    .0    .0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .0    .1    .1    .1    .1    .1    .1    .1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .1    .1    .2    .2    .2    .2    .2    .2    .2   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .3    .4    .5    .6    .7    .6    .6    .6    .6    .7   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
    .6   1.2   1.3   1.5   1.7   1.7   1.6   1.7   1.6   1.7   1.7   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   1.0   1.9   2.0   2.5   2.8   2.7   2.5   2.7   2.7   2.7   2.7   2.2   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   1.3   2.3   2.5   3.0   3.4   3.2   3.1   3.2   3.2   3.3   3.3   3.2   3.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   1.5   2.7   2.9   3.5   4.0   3.8   3.6   3.8   3.8   3.9   3.9   3.7   3.6   3.2   0.0   0.0   0.0   0.0   0.0   0.0
   1.6   2.8   3.1   3.7   4.2   4.0   3.9   4.1   4.0   4.1   4.1   4.0   3.8   3.4   2.8   0.0   0.0   0.0   0.0   0.0
   1.5   2.7   2.9   3.5   4.0   3.8   3.6   3.8   3.8   3.9   3.9   3.4   3.6   3.2   2.6   2.2   0.0   0.0   0.0   0.0
   1.1   2.1   2.2   2.7   3.1   2.9   2.8   2.9   2.9   3.0   3.0   2.9   2.7   2.4   2.0   1.9   1.3   0.0   0.0   0.0
   0.0   1.6   1.7   2.1   2.3   2.2   2.1   2.2   2.2   2.3   2.3   2.0   2.1   1.6   1.5   1.2    .7    .8   0.0   0.0
   0.0   0.0   1.0   1.3   1.4   1.4   1.3   1.4   1.3   1.4   1.4   1.2   1.2    .9    .9    .6    .3   0.0   0.0   0.0
   0.0   0.0   0.0    .5    .8    .7    .7    .7    .7    .8    .7    .6    .6    .5    .3   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0    .2    .2    .2    .2    .2    .3    .3    .2    .2    .1   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

71/09/13. 10.04.14./ 1/ 938/19.3/7.58/ .67/619/ 40/575/583/ .025/ .575/-2.88/ 2.88/-.50/1.00/
71/11/15. 16.23.41./ 1/ 938/19.3/7.58/ .67/25.5/137.0/1/0.0/ 270/600.0/21/620.0/1.0/ .571.0/20/

DINJ TYPE,NDIN,SE,SA,XC,SB,YC,THETA,XOSP,YOSP  GAUSSIAN    1 3.00  .12  .18  .80 0.00 0.00-0.00-0.00
NTIM  -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0
90 PER CENT AREA=   1.13*PI CM*MR

  XA=  -2.0    DX=  17.0    XF=  14.0     (INCHES)
  TA= -54.0    DT= 459.0    TF= 405.0     (MICROSECONDS)

  TOTAL FRACTION ACCEPTED  DTOT= .7104        PARTICLES ACCEPTED PER MA INJECTED  PAC=  2.034663E+12

   TOTAL FRACTION TRAPPED  DTSM= .3442        PARTICLES TRAPPED PER MA INJECTED  PTRP=  9.859293E+11
 72/08/29. 15.01.17.
```

TABLE 3 CONT.

HINJ OUTPUT

```
(INJECT START) XA=   -2.0000          LA=    0

(INJECT WIDTH) DX=    1.0000          LM=    1          (INJECT STOP) LB=    0

(FINAL) XF=   14.0000          LF=   16


TOTAL ACCEPTED INTENSITY.(NORMALIZED TO UNIT INJECTED BEAM)   DTOT=   .182912

TOTAL ACCEPTED INTENSITY (TIMES PULSE LENGTH)   DTUN=   .182912

ACCEPTED INTENSITY DTIME(L) AS FUNCTION OF TIME INTERVAL L (NORMALIZED TO UNIT INJECTED BEAM IN EACH INTERVAL)

 .182912

SIGNAL AT SOUTH FARADAY CUP ( NORMALIZATION - INJECTED BEAM = 100.)

  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000     .0112     .0446     .1250

   .3259     .7339    1.5024    2.6272    4.5053    4.9012    3.5144    0.0000    0.0000    0.0000

  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
```

TABLE 3 cont.

HINJ OUTPUT

```
FINAL ACCEPTED DISTRIBUTION  OF X 1000

   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  35.1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0  47.6   1.4   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0  34.3  10.8   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
*  0.0   0.0   0.0  19.4   6.8   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0  12.1   3.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   6.0   1.4   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   2.5    .8   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0    .9    .3   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0    .3    .1   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0    .1    .0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

71/09/13. 10.04.14./ 1/ 938/19.3/7.58/ .67/619/ 40/575/583/ .025/ .575/-2.88/ 2.88/-.50/1.00/

DINJ TYPE,NDIN,SE,SA,XC,SB,YC,THETA,XDSP,YDSP  GAUSSIAN    1 3.00  .12  .18  .80 0.00 0.00-0.00-0.00
NTIM  -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0
90 PER CENT AREA=   1.13*PI CM*MR

  XA=  -2.0   DX=   1.0   XF=  14.0     (INCHES)
  TA= -54.0   DT=  27.0   TF= 405.0     (MICROSECONDS)

  TOTAL FRACTION ACCEPTED  DTOT= .1829         PARTICLES ACCEPTED PER MA INJECTED  PAC=  3.081709E+10
 72/08/29. 15.01.17.
```

Appendix B Program Data Input Tables

This appendix contains tables that show how to input the data to the programs INJECT, PHASE, HINJ, TWRITE1. The use of these tables is described in the main text in the respective program descriptions under the section dealing with data input.

TABLE I

TABLE OF DATA INPUT FOR INJECT

71/01/13

Value IC	comment
-1	stop program execution with a program STOP
2	Set the field index values as a function of radius R in the field index array N. There are 17 values here which are preset in a data statement. They cover the range indicated in Figure 4, Sec. 2.1, Vol. II. The value N(1)=n(ROMIN)=n(575.375) and the grid spacing is 3" intervals. The preset values are: .868, .695, .683, .712, .673, .673, .660, .691, .663, .664, .661, .682, .715, .739, .703, .707, 1.197 NUM the number of items read. 0 is valid I, N(I) . . . I,N(I) } NUM of these items. Note, NUM and I are of type integer.
3	Program parameters are set here. Only those parameters that have values different than the preset values need be changed.

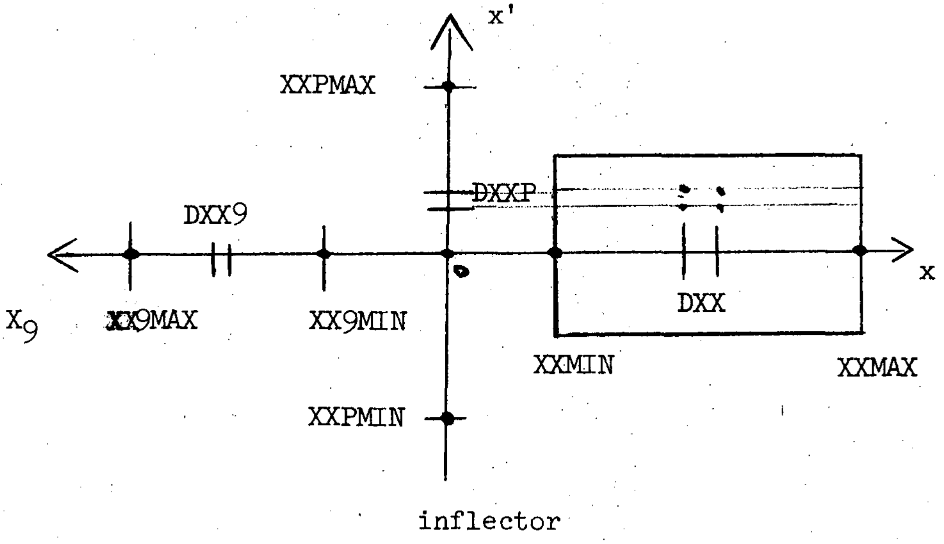
Value IC	comment
	The parameters are read into an array TEMP. We read NUM the number of items to be read and each item consists of I, TEMP(I). We have the following values. Preset values are indicated below.

I	TEMP(I)	
1	RNQ	maximum # of turns traced (30) <u>integer</u> if the particle clears the inflector in, say, 8 turns the program will only trace 8 turns.
2	S2	$\frac{\text{shrinkage}}{[\text{inch}][1/4\ \text{revolution}]}$ (.075) of the equilibrium orbit due to the field rise $\dot{B}$. Program presently calculates this factor so it need not be input here. In fact this number is presently not used internally
3	RK2	the number of $\Delta\theta$steps/90° quadrant(8) <u>integer</u>
4	FULOUT	<u>if</u> TRUE <u>then</u> print orbit out after each transformation <u>if</u> FALSE <u>then</u> supress orbit print after each transformation (FALSE).
5	DRIFTL	1/2 length [inch] of one full drift section (120.0")
6	R9	outer radius [inch] of the inner inflector wall inflector (619.375")

Value IC	comment
	7 D9 inflector width [inch] (.040")
	8 ROMIN inner most field radius [inch]. (575.375")
	9 SCUP radius [inch] of south faraday cup (583.265")

```
NUM, (I,TEMP(I), J = 1, NUM
 i    i
```

4 Set the grid in this (x,x',x_9) space for which the acceptance arrays will be calculated.



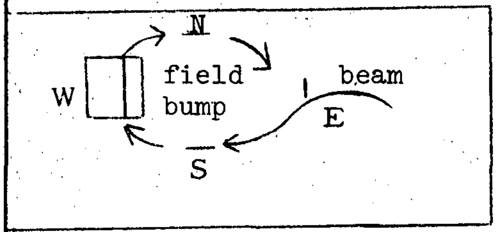
The arrays are dimensioned $(12,24,20) = (x,x',x_9)$. There are available 12X24X20 points. We have that

(1,1,1) → (XXMIN,XXPMIN,XX9MIN)

(2,2,2) → (XXMINN+DXX,XXPMIN+DXXP,XX9MIN+DXX9)

Value IC	comment
	The variables are specified in ([inch],[rad],[inch]). While the grid spacing and limits are arbitrary for this program, they must match HINJ when the generated arrays are used in input to that program XXMIN,XXMAX,DXX,XXPMIN,XXPMAX,DXXP XX9MIN,XX9MAX,DXX9
5	write the last generated acceptance arrays AA,NT on TAPE4 and on file OUT. This is how we save these arrays for future use. Upon exit from the program TAPE4, consists of 1 file of data in standard data format suitable for use as input to program TWRITE1, [3].
6	Set the kinetic energy [MeV], rest mass [MeV], field rise [kg/sec], average field index for the calculation of the shrinkage per inch factor S2. Our present values are respectively (19.3 , 938.232, 7.58, .67) KE, MO, DBDT, RON
7	Parameters to define West field bump are input B1TO [kg] field at time t = 0 DB1TO [kg/sec] field derivative $\frac{dB}{dt}$ of the bump

Value IC	comment
	DT1 [μ sec] the time δt at which this calculation starts as measured from t = 0. These three quantities establish the field bump value at time t + δt which is used as the field at turn zero.



When the field bump is nonzero, then the acceptance arrays are time dependent as measured from t = 0. This must be taken into account when the arrays AA and NT are used in inject. The preset values are all zero

B1T0, DB1T0, DT1

---

100 Use the current program parameter values to generate the acceptance arrays AA, NT by ray tracing through not more than NO turns. Note the array elements calculated are starting at AA(1,1,1) and NT(1,1,1). The amount of the arrays filled depends on the values input in IC = 4. We have that

(1,1,1) (XXMIN,XXPMIN,XX9MIN)

(2,2,2) (XXMIN + DXX, XXPMIN + DXXP, XX9MIN + DXX9)

TABLE II

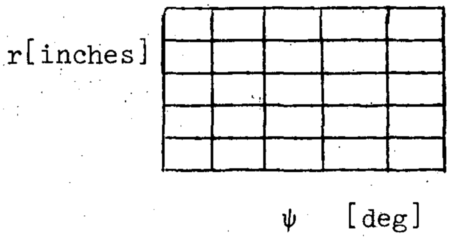
Table of Data Input for PHASE

71/01/13

IC	comment
-1	terminate execution with a program STOP
0	Set the unit conversion factor. The internal units are MKS. Units to convert the input data to MKS units. Length (.0254), B field (.1), Voltage (1000.), energy (1.60207E-13), charge (1.60207E-19), angle (.01745329251994), where the input quantities have dimension. L[inch], B[kg], V[kV], E[MeV], Angle[deg], Q [signed # of changes] L, B, V, E, Q, A Units to convert the internal results to the required output units. Length (.0254), B field (.1), Voltage (1000.), energy (1.60207E-13), charge (1.60207E-19), angle (.01745329251994), where the output quantities have dimensions L [inch], B[kg], V[kv], E[MeV], Angle [deg], Q [signed # of charges]. L, B, V, E, Q, A

IC

1 Specify the grid over which the phase equations will be integrated. Those are the initial values corresponding to $t = \tau = 0$.



This grid is used to integrate for orbits in the (r, ψ) plane

RMIN, RMAX, DR, PMIN, PMAX, DP

2 Set the reference orbit radius R0(6000.0") and the average field index value N(.67). The reference (synchronous) particle is assumed to move on a circular orbit with this radius in the magnetic field.

R0,N

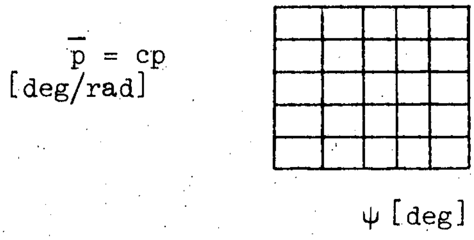
3 Set the injection energy (19.3Mev), starting energy of the reference particle at $t = \tau = 0$, and the rf harmonic number H(1.0)

ESBAR,H

IC	
4	Set the integration variable τ grid. We integrate from τ_{min} to τ_{max} in steps of delta τ. The units are dimensionless such that $\tau = 2\pi$ is one synchronotron oscillation for small Δr, ψ. DELT is set to $(4\pi/100)$ in a data statement Restriction TMIN = 0.0 TMIN,TMAX,DELT
5	Set the voltage rise time constant TC[μ sec](270.0). **Note,** TC = 0 gives the constant voltage case TC
6	Set the print interval (2). If this value is 1 then the integration results will be printed every time the variable step integrator lands on a maximum step size set above when IC = 4 as DELT. Otherwise this print out will occur every PRT*DELT steps. PRT integer
7	Set the field rise $\frac{dB}{dt}$ [kg/sec] of the main field (6.28) DBSDT
8	Set the maximum rf double gap voltage VMAX(29.6Kv) and the maximum double gap length RFL (137"). VMAX,RFL
9	Specify the grid over which the phase equations will be integrated.

IC

9 These are values corresponding to $\bar{t} = \tau = 0$.



This grid is used to integrate for orbits in the $(\bar{p},\psi)$ plane

CPMIN, CPMAX, DCP, PMIN, PMAX, DP

10 Set plotting parameters, layout new grid

CPLOT logical if CPLOT then turn on plot
else turn off plot;

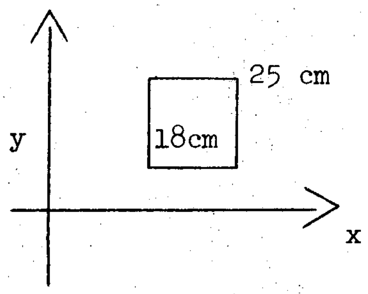
if CPLOT then

begin the following data is read.
3 lable cards of 30 characters each are read

	user supplied
XLABLE(I), I = 1,3	x axis lable
YLABLE(I), I = 1,3	y axis lable
IDENT(I), I = 1,3	identification printed across top of plot

next the plot is set up by choosing various options and parameter values

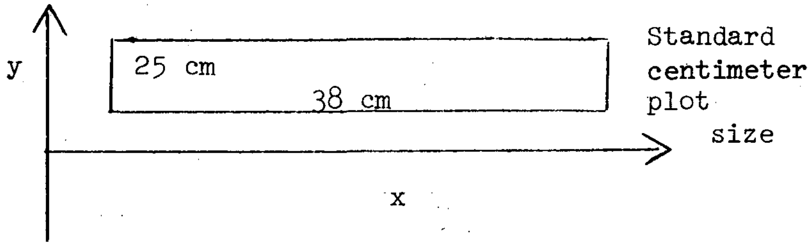
OPTION = 1



Standard centimeter plot paper size

IC

10 OPTION = 2

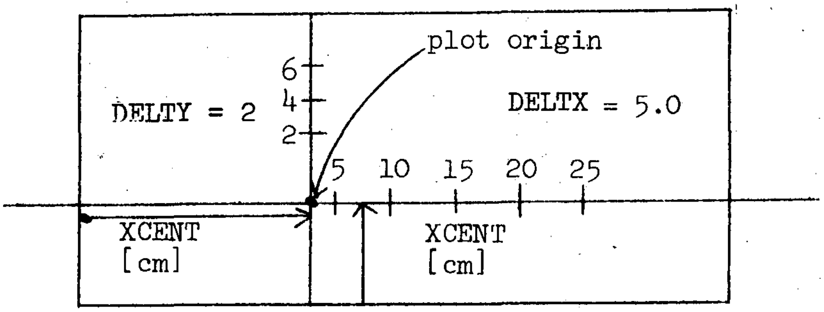


XYVAR	x	y
1	ψ	Δr
2	ψ	$\bar{p}$
3	Δr	ψ
4	$\bar{p}$	ψ
5	ψ	Δr

ploted as a function of τ. Chooses which variable on plotter and along which axis

ψ incremented by 360° every dels plot points

XCENT, YCENT, DELX, DELY



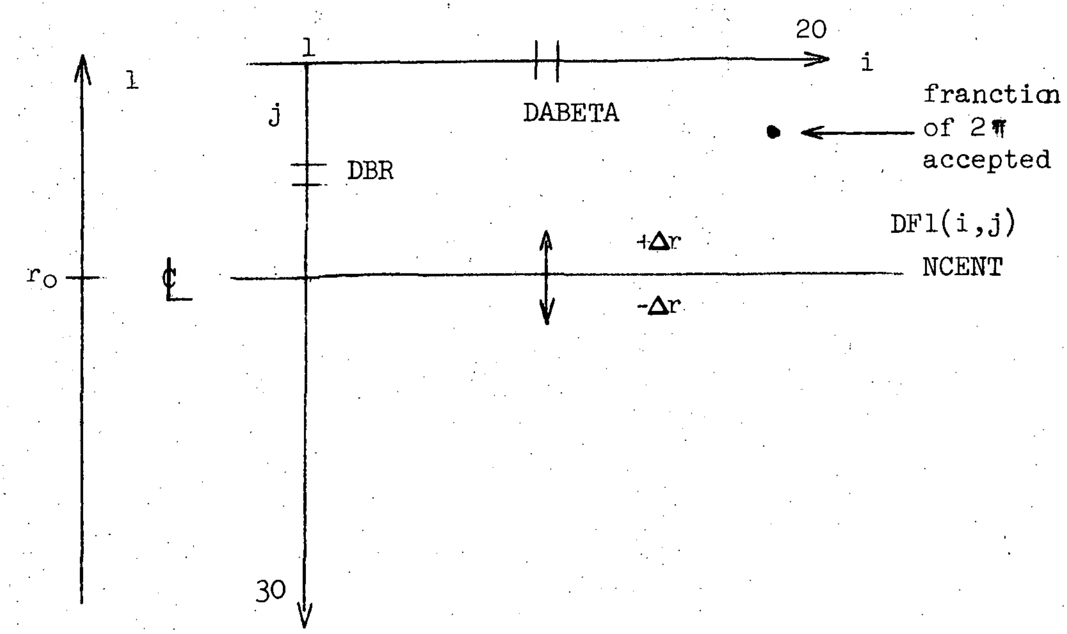
locate the origin with respect to the plot. Establish the grid values per cm for the plot. Note the units are those established by setting UPINCH. See IC = 13 Section.

JOIN =	TRUE	pen down between symbols
	FALSE	pen up between symbols
DELS	plot a symbol every DELS print lines	
SYMBOL	standard LBL Calcomp plot symbols	

IC			
10	Value	SYMBOL	
	0	No symbol	
	1	· dot	
	2	- horizontal bar	
	3	| vertical bar	
	4	\ bend dexter	
	5	/ bend sinister	
	6	◇ diamond	
	7	□ square	
	8	△ delta	
	9	▽ del	
	45	X	symbols can be composed as in these three examples
	89	⧖	
	23	†	

IC	comment
10	SCALE scale graph by this factor. Preset to (1) Note do not change, results unpredictable 71/01/13. OPTION, XYVAR, XCENT, YCENT, DELTX, DELTY, JOIN, $\underline{i}$ $\underline{i}$ $\underline{\ell}$ DELS, SYMBOL, SCALE $\underline{i}$ $\underline{i}$ A new grid is set up and all plots are put on that grid until this section is again executed, either to shut off the plot or to layout a new grid.
11	Set rf acceptance parameters and generate the rf acceptance array TCNUM The minimum number of time constants (4.0) over which the integration will take place starting with $\tau = 0$. The value of the time constant must have been set in the IC = 5 section. NUMPHI The number of intervals (18) into which the phase axis $-\pi < \psi \leq \pi$ is divided. The value 18 corresponds to 20 degree steps. NCENT The index (21) in the rf acceptance array $DF1(x_\beta,\Delta r)$ corresponding to $\Delta r = 0$.

IC



bevatron radius. r_o is the radius of the reference particle.

DDR	Δr grid spacing (1.0")
DABETA	X_β grid spacing (1.0")
AWIDTH	chamber acceptance 1/2 width (20") in the Δr plane. We always assume the chamber extends ± AWIDTH from Δr = 0

$\boxed{\text{TCNUM, NUMPHI, NCENT, DDR, DABETA, AWIDTH}}$

i i

12 Write the last generated rf acceptance array DF1 on file TAPE4 in standard data format suitable for use with program TWRITE1 [3]. This is how we save a previously generated array for use in program INJECT. Note an array must have been generated in an IC = 11 section

IC

13 Change the paper size and plot layout parameters. This must be followed by an IC = 10 section.

UPINCH (2.54)

BOT (1.5)

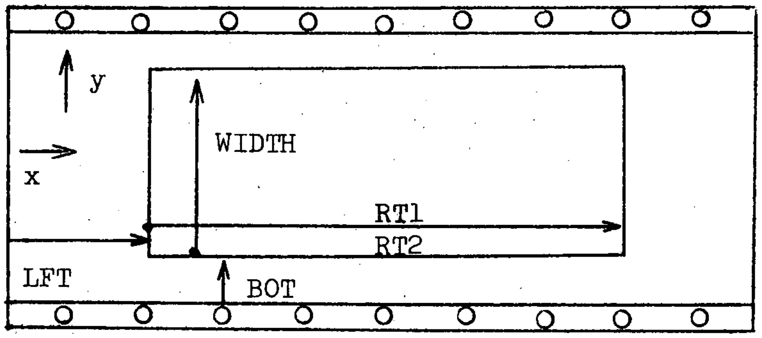
WIDTH (25.0)

LFT (5.0)

RT1 (18.0)

RT2 (38.0)

INTX1 (9)



RT1 OPTION = 1
RT2 OPTION = 2

INTX1 (9)

INTX2 (18) # of subdivisions

INTY (5)

The units of BOT, WIDTH, LFT, RT1, RT2 are those established by UPINCH. The value 2.54 makes these units centimeters. The units associated with IC = 10 section are those established by UPINCH. The plots are set in data statements for standard centimeter paper. Note that the values RT1 = 18 and INTX1 = 9 give tick marks every two units, i.e., every 2 cm. when UPINCH = 2.54. Similarly for INTX2 and RT2.

```
UPINCH, BOT, WIDTH, LFT, RT1, RT2, INTX1, INTX2, INTY
                                     i      i
```

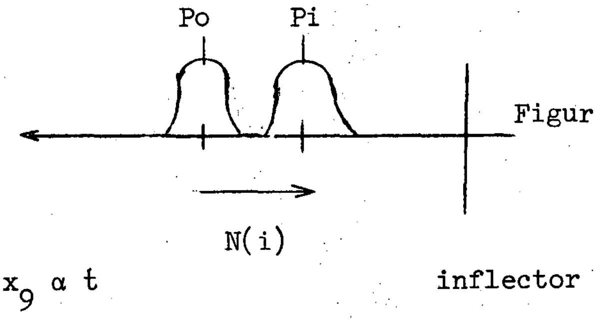
IC	
14	Set the frequency error parameter ω_1. See section 1.1, equation (1) and Section 3.1, equation (1). We actually input here the value FREQER = ω_1/Ω. (0.0) FREQER
100	Execute the integration section. The synchrotron phase equations are integrated from TMIN to TMAX for all initial conditions. The initial conditions are RMIN $\leq$ R $\leq$ RMAX PMIN $\leq \psi \leq$ PMAX or CPMIN $\leq \overline{p} \leq$ CPMAX PMIN $\leq \psi \leq$ PMAX as set in IC=1 or IC = 9. Note, the most recently set values are used.

TABLE III

Program HINJ Data Table

71/01/18

VALUE OF LI	Variables Read	Comments	Format
LI	AID	This is a two word 10 character identifier of the form YY/MM/DD.␣ HH.SS.MM. that is used to fetch the acceptance arrays. It must be exactly as an output by INJECT at the time these arrays were generated. It is expected that tape 4 contains a library in standard library format [3] and that this identifier exists in the library. Identifier errors will cause a program stop. The two arrays A,NSF that correspond to this identifier will be fetched by the call to ACPT.	(2A10)
L2	RID	Exactly the same as the description for AID except this identifier corresponds to an rf trapping array generated by PHASE. The	(2A10)

Value of LI	Variables Read	Comments	Format
		array TRF corresponding to this identifier is fetched by the call to TRAP	
L3	SE	The standard deviation corresponding to the momentum spread. This is in the units [inch]. See section 3.1, Vol. II equation (1), (3) and the discussion there on how to relate real measurements to the value σ_E.	
	NTIM	There are available here 30 values that can be used to displace the momentum $P_i = p(ti)$ of the injected beam at time t_i, $1 \leq i \leq 30$, from the central momentum P_o that defines the time axis. The units of displacement are [inch].  Figure(a)	

Value of ID	Variables Read	Comments	Format
		N(i) > 0 implies $P_i > P_o$. In the above figure P_o is the position at time t of the central momentum of the momentum distribution. P_i is the beam slice at time t_i, and it has a higher momentum than P_o since its displacement N(i) > 0. N(1) time slice 1 ⋮ N(30) time slice 30 The units in Figure a along the x_9 axis are inches. The relation between momentum and radius is given in by equation (2) section 3.1, Volume II. Note both n=n(r) and r enter into this calculation.	
L3		(SE,(NTIM(I),I = 1,30))	(F10.4,30I2)
L3	XC YC SA SB	Center of beam ellipse [inches] Center of beam ellipse [mr] σ_A standard deviation [inch] σ_B standard deviation [mr] see Figure 9, section 3.1, Vol II and the discussion there about how the standard deviation are related	

Value of ID	Variables Read	Comments	Format
		to measured quantities.	
	THETA	Angle with respect to X axis of beam phase ellipse.	
	XDSP YDSP	The momentum dispersion of the beam as measured from the central momentum. XDSP(YDSP) is the shift in X(X') center in inches (mr) for a one standard deviation shift from the injected beam central momentum. The central momentum (N=16) has center XC, YC. The other momenta have a center determined by XP = XC + (N-16) x XDSP/SE YP = YC + (N-16) x YDSP/SE	
		(XC,YC,SA,SB,THETA,XDSP,YDSP)	(8F10.4)
L4	XA	Start of pulse [inch]	
	DX	Pulse length [inch]	
	XF	rf turn on time [inch]	
		See Figure 1, section 3.1, Vol II and the discussion there. The rf turn on time must be after the pulse. $XF \geqslant XA + DX + 1.0$. These are the values along the x_9 axis. $X_9 = 0 = t$.	

L4		Note that DX 0 has no meaning physically, but that it is used to control the action of the program.	

		if (DX = -1.0) go to L3;
		if (DX = -2.0) go to L1;
		if (DX = -3.0) go to L2;
		(XA,DX,XF)
			(8F10.4)

TABLE IV

TWRITE1 DATA TABLE

File Name	Data type	 item	comment
INPUT	i	NTAPE	New library LBL tape number
LIB			1 file in standard library format. This is the old library to which data is appended.
DATA			1 file in standard data format pertaining to the data to be appended. TAPE4 of programs PHASE, INJECT is suitable.

Appendix C Field Free Data

Some of the programs use field free data routines described in [2]. These routines can be used as black box input routines. We give below an explanation of what constitutes valid data.

Integers are of the form ± NN...N where N are decimal digits. A real number is of the form ± NN...N.N...N or else ±NN...N.N...NE±NNN. Logical values are specified by T, F or TRUE, FALSE. Any number can be followed by RNN...N where N are decimal digits. This causes the number to be read NN...N times. Comments can be injected anywhere as */text/* and are ignored. Items to be input are separated by deliminators. This is either a traling comma or else 2 or more blanks. Empty fields are skipped. Quantities are read as incountered,as many on any one card as is convenient. Below are some samples of valid input data

```
+5.2, T, TRUE, 6.5E3R5, */EXAMPLE/*
```

References

[1] E. Close, P. Germain, W. Holley, Trapping in The Bevatron at Injection, Bev-2057, Jan. 27, 1972, LBL Berkeley, Calif.

[2] E. Close, An Extended Set of Fortran Input/Output Routines, UCRL-19463, Feb. 16, 1972, LBL Berkeley, Calif.

[3] E. Close, A Collection of Programs and Subroutines for Variable Format Data Storage, LBL-728, LBL Berkeley, Calif.

[4] Control Data 6000/7000 Update Reference Manual, 9/15/71, Computer Library, LBL Berkeley, Calif.

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