JAN 21 1963

ACCELERATOR DEPARTMENT
(AGS)

BNL 6431

WFB-1

Internal Report

BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, L.I., N.Y.

COMPUTATIONS FOR AGS EXPERIMENTAL BEAMS

DESCRIPTION OF COMPUTER PROGRAM

Winslow F. Baker

December 15, 1961

MASTER

A program which optimizes the locations and strengths of magnets for experimental beams at the Brookhaven AGS has been written for the IBM 7090 computer.

Introduction

Computer programs¹ have been previously written which trace a ray through a system of magnets and determine its focusing properties (transfer matrix). An operator when using such a program examines the characteristics of the emergent beam and then varies the parameters of the system manually to optimize it. With the growing number of components in experimental beams at the larger accelerators, such a method has proven to be very time consuming.

In the program described here, the computer itself examines the emergent beam and varies the parameters to optimize the layout. Such a method has several difficulties and hazards inherent in it. First, some quantitative

¹ BEAM II written by J. Sandweiss and J. Sanford for the LGP-30 and IBM 650 computers.

Facsimile Price \$ 2.60
Microfilm Price \$ 1.86
Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

expression, or merit function, must be written which fully describes the desired properties of the beam. It should contain, for example; the required spatial distribution and momentum components. Second, if such a merit function were written as a function of all the components, the resultant set of simultaneous equations could not be solved analytically for the maximum value of the function. Third, the merit function can have many maxima in the n dimensional space, where n is the number of independent variables of the system. Without solving the problem analytically, it is not possible to know if a maximum arrived at is the absolute maximum, which is desired, or just a relative maximum.

Method

In this program rays are traced from the object (e.g. accelerator target) to the "image" (this is not necessarily an image in the optical sense) or detector. Since the linear theory is assumed, only one ray is traced for each momentum along with its transfer matrix, T , in the horizontal and vertical planes. The merit function written as a function of the position of these rays and their matrices at the image plane is then evaluated.

If requested the computer will search in relatively large steps of the parameters to find a set of possible starting values before attempting to maximize the merit function. This search is performed in a subroutine called HUNT in the program. Commencing with that set which gives the largest merit function, the computer maximizes the merit function by varying in turn each parameter and examining whether an increase or decrease in its value increases the merit function. It then sets the parameter equal to the new value which corresponds to a merit function increase. The next parameter of the system is varied and reset in the same fashion and so forth until all parameters have been varied; then the program returns to the first parameter and repeats the sequence.

This procedure continues until a variation in each parameter decreases the merit function or until the parameter has reached a limiting value at which point a maximum has been reached.

On request the computer will select the next best set of starting values and maximize again. If one obtains the same final result for several different sets of starting values, one has confidence that the best set of parameters has been reached.

Alternatively, the starting values may be read into the computer as data and the convergence procedure begins immediately. This method of starting reduces considerably the amount of computer time needed to optimize a system and is strongly recommended when possible. To obtain starting values, one may ignore small effects, such as focusing in a dipole magnet, and only consider deflection in a dipole and focusing in a quadrupole. Approximate values for quadrupole magnet settings may be obtained from available curves or from thin lens approximations.

By applying constraints to the system, the number of dependent variables and therefore the computing time can be decreased. At present one constraint may be imposed; specifically, that the beam be focused at the image in the vertical (or horizontal) plane. This requirement is used to specify the length of the final field free region of the system.

Each element of the system is permitted to have one variable; for a free flight path (GAP) it is the length, for a bending magnet (DIPOLE) it is the magnetic field, for a quadrupole (QUADPL) it is the gradient of the field, and for a collimator (COL) it is the width of the slit in the horizontal plane.

The central rays for all momenta are assumed to lie in one plane, the horizontal median plane of the accelerator. That is, all dipole magnets must deflect in the horizontal plane. The spatial properties of the beam are found

in both planes from the transfer matrices.

The linear theory is used in which all displacements from the axis are derived from the transfer matrices, T , in the horizontal and vertical planes,

$$\begin{vmatrix} X \\ X' \end{vmatrix} = \begin{vmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{vmatrix} \begin{vmatrix} X_o \\ X_o' \end{vmatrix}$$

where X is the displacement from the axis and X' is the slope. The thick lens formulae described in Courant and Snyder² are used for the quadrupole matrices. The dipole magnets are assumed to have parallel input and output faces and the vertical focusing at entrance and exit is treated as a thin lens effect.

Axes for five different momenta are traced, and the transfer matrix for each is found. These momenta are P_o the median momentum on whose axis the elements of the system are assumed to be centered, $P_o \pm \Delta P_1$ and $P_o \pm \Delta P_2$. X_o is the size of the object (or target) which is datum required by the program; for X_o' the maximum opening angle accepted by the system is computed and used.

The calculation sequence is shown in the simplified flow chart.

Description of the Subroutines

The computer program consists of a main program and twenty-one subroutines all written in the FORTRAN language.

1. Main Program This reads in all the data, calls for the search for starting values if desired, calls for the variation of the parameters, and compares the result of each variation to maximize the merit function. The main program calls for printing out of the beam layout and its properties after each pass through the system if so directed, and also when the convergence process is completed.

²E.D. Courant and H.S. Snyder, Annals of Physics 3, 1 (1958)

The convergence is completed when a variation in each parameter decreases the merit function, when the limits on the parameters are reached, or when a variation in the parameters leads to no solution for the dependent variable.

2. HUNT Subroutine This routine computes $2^{JHUNT} + 1$ equally spaced values for each variable parameter of the system and computes the merit function for all possible combinations of these values. There are $(2^{JHUNT} + 1)^N$ such combinations, where JHUNT is read into the program as data and where N is the number of variable parameters.
3. STEP Subroutine A variable parameter of the system may be increased or decreased by a given increment by calling for this routine. It will be indicated (by an IFLAG) if a limiting value of that parameter has been reached.
4. TRACK Subroutine This routine traces the rays of five momenta through the system evaluating the acceptance angles of the system subtended at the target.
5. MERIT Subroutines Allowance is made for six subroutines which calculate the value of the merit function to be maximized. Only one of these is used in any computation and is specified by the value of JMERIT that is read in as data. Any one of these may be replaced by a merit function of one's own choice.

MERIT 1 : (JMERIT = 01)

$$\phi_1 = \sum_{\substack{P = P_0 \\ P = P_0 \pm \Delta P_1 \\ P = P_0 \pm \Delta P_2}} (F \cdot \Delta \Omega)_P$$

where F is the fraction of the beam cross-sectional area that overlaps the counter or chamber. $\Delta \Omega$ is the solid angle subtended by the system at the center of the object (accelerator target).

This merit function is used when the maximum flux is desired over some range of momenta without regard for what happens outside of that range.

MERIT 2 : (JMERIT = 02)

$$\phi_2 = \sum_{\substack{P = P_0 \\ P = P_0 \pm \Delta P_1}} (F \cdot \Delta \Omega)_P - \sum_{P_0 \pm \Delta P_2} (F \cdot \Delta \Omega)_P$$

This function rejects momenta outside the band from $P_0 - \Delta P_1$ to $P_0 + \Delta P_1$.

MERIT 3 : (JMERIT = 03)

$$\phi_3 = \sum_{\substack{P = P_0 \\ P = P_0 \pm \Delta P_1}} (F \cdot \Delta \Omega)_P - 5 \sum_{P_0 \pm \Delta P_2} (F \cdot \Delta \Omega)_P$$

This is the same as the previous but with more stringent rejection.

MERIT 4 : (JMERIT = 04)

$$\phi_4 = \sum_{\substack{P_0 \\ P_0 \pm \Delta P_1 \\ P_0 \pm \Delta P_2}} \left(\frac{\Delta \Omega}{\text{TH}(2,2) + \text{TV}(2,2) + 1} \right)_P$$

This is intended to produce a parallel beam. TH and TV are the horizontal and vertical transfer matrices respectively.

MERIT 5 : (JMERIT = 05)

$$\begin{aligned} \phi_5 = & \sum_{\substack{P_0 \\ P_0 \pm \Delta P_1}} (F \cdot \Delta \Omega)_P - 2 \sum_{\substack{P_0 \pm \Delta P_2 \\ P_0 \pm \Delta P_1 \\ P_0 \pm \Delta P_2}} (F \cdot \Delta \Omega)_P \\ & - 2 \sum_{\substack{P_0 \\ P_0 \pm \Delta P_1 \\ P_0 \pm \Delta P_2}} \left[(1 - F) \cdot \Delta \Omega \right]_P \end{aligned}$$

The last term rejects any particle from passing outside of the counter or chamber.

MERIT 6 : (JMERIT = 06)

This is a dummy routine which may be replaced with any desired merit function.

6. DEPND Subroutines: Six subroutines are allowed which determine the length of the final field free space of the system (final element of the system). The subroutine to be used is specified by the value of JDEPND read in as data. The final gap length is made the dependent variable of the system under the constraints specified below. If there is no solution for the dependent variable, it will be indicated (by a JFLAG) and treated as though a limit were reached.

DEPND 1 (JDEPND = 1) : Final gap length is determined by the requirement that the mean momentum, P_0 , has a focus in the vertical plane.

DEPND 2 (JDEPND = 2) : Final gap is determined by a horizontal focus for the mean momentum.

DEPND 3 (JDEPND = 3) : Final gap length is a constant equal to the maximum length (XMAX) permitted.

DEPND 4, DEPND 5, DEPND 6 : These are dummy routines.

7. CAIMAT: The type of element (gap, dipole, quadrupole or collimator) is determined, and one of the subroutines below is called for to calculate its transfer matrices.

8. GAP : The horizontal and vertical transfer matrices for a field free region or collimator are calculated by this.

9. DIPOLE : The axis for any momentum is traced and its transfer matrices are computed in this subroutine for a bending magnet with parallel input and output edges on the pole tips. The vertical focusings at entrance and exit are treated as thin lenses, according to the transfer matrices

$$\begin{vmatrix} 1 & 0 \\ -\frac{\tan \theta}{\rho} & 1 \end{vmatrix}$$

where θ is the angle between the axial ray and the normal to the entrance, or exit, plane of the magnet and is taken positive in the direction of bending. ρ is the radius of curvature of the trajectory.

10. QUAPL: This subroutine calculates the transfer matrices for a quadrupole magnet using

$$\begin{vmatrix} \cos k\ell & \frac{1}{k} \sin k\ell \\ k \sin k\ell & \cos k\ell \end{vmatrix} \text{ and } \begin{vmatrix} \cosh k\ell & \frac{1}{k} \sinh k\ell \\ k \sinh k\ell & \cosh k\ell \end{vmatrix}$$

in the focusing and defocusing planes respectively. ℓ is the length of the quadrupole, and $k = \left[17.62 \times 10^{-7} \text{ G/P} \right]^{1/2}$ where G is the gradient in gauss/inch and P the momentum in Bev/C of a singly charged particle.

11. MATMUL: This performs matrix multiplication to determine over-all transfer matrices.

12. PRINT: When called for, this routine reads out the layout of the system and its properties.

Using the Program

The data cards, which are read in following the program deck, have the format specified in Table I. The matrices for the trajectories in the fringe field of the Brookhaven AGS are obtained from the BEAM program of E.D. Courant³. If only a portion of a system is being treated, the cumulative matrices for the preceding elements should be used instead.

³E.D. Courant, Brookhaven National Laboratory, Accelerator Department, Internal Report EDC-36 (unpublished).

The closer the upper and lower limits, XMAX and XMIN, are to each other the smaller is the range over which the program must hunt for starting values and, therefore, the shorter the time required for a calculation.

The number of combinations of the independent variables examined in the Hunt routine is $(2^{JHUNT} + 1)^N$, where N is the number of independent variables. This routine can, therefore, consume considerable computer time.

When XMAX = XMIN for an element, that element is no longer an independent variable, and the N in the foregoing expression is reduced accordingly. One should be able to estimate each variable to within a factor of two; so that the limits on each variable, XMIN and XMAX, are about a factor of two different from each other. Under this condition JHUNT = 1 is usually sufficient. In any case JHUNT > 2 requires considerable computer time. If the number of elements in the system is on the order of 10 or more, it is advisable to break the system up into segments and to solve them independently using the HUNT routine only. These results can then be used as starting values for the complete system read in as data and bypassing the HUNT routine.

For a complex system, one could also determine approximate starting values and read them in directly. In any case, it is advisable to read in starting values whenever possible.

Sign Conventions

A positive BEND angle means clockwise rotation, and a positive displacement is to the right of the beam axis.

In a dipole magnet a positive field (upward) produces a positive BEND angle for a positive particle. For a quadrupole a positive gradient implies vertical focusing for a positive particle and horizontal focusing for a negative particle, the opposite is implied by a negative gradient. A positive gradient means that the field in the right half of the horizontal median plane of the quadrupole is upward when viewed in the direction the beam travels.

A simple system is shown in Figure 1. All measurements transverse to the beam are half-widths.

Output Format The results for one example are shown on pages 20 & 21. The first line contains the horizontal and vertical half-width of the target and the mean momentum of the beam, P_0 . The second line gives the half-widths of the chamber or counter into which the beam is sent. Following this is the merit function.

The columns contain the properties of the beam as it leaves each element in the order in which the elements are traversed. The first column numbers the elements sequentially. The second column contains the title of that element as it appeared on the data card. The third column gives the value to which the variable of the element should be set. The fourth tells the angle through which that element bends the axis of the mean momentum, P_0 , beam. Column five gives the cumulative path length through the element in inches. The sixth and seventh columns give the cumulative transfer matrices in the horizontal plane through that element; and columns eight and nine give the cumulative vertical transfer matrices.

The momentum dispersion properties of the beam are given on the next page. The data are grouped in columns of two, with each group corresponding to one momentum. From the left these momenta are $P_0 - \Delta P_2$, $P_0 - \Delta P_1$, P_0 , $P_0 + \Delta P_1$, and $P_0 + \Delta P_2$. The value of the momentum is listed above each group. X is the displacement of the axis for that momentum from the P_0 axis; and X' is its slope with respect to the P_0 axis. Below these columns are listed the transfer matrices for the system for each momentum. Next the opening angles subtended by the system at the center of the target are given. Should any one of these four angles be negative, then the axis for that momentum does not penetrate the system. Following this are the solid angles subtended at the center of the target.

The last two lines give the maximum size of the beam at the end of the system in inches.

Acknowledgements: Thanks are due members of the Applied Mathematics Department particularly Arlene Larsen, and also Kurt Jellett for assistance in coding some of the routines.

Many helpful discussions with Dr. Ernest Courant were invaluable for all phases of this work.

WFB:ab

12/15/61

Distribution: B1, B3

FLOW CHART

T A B L E 1

DATA CARDS

NO. OF CARDS	COLUMNS ON CARD	SYMBOL	EXAMPLE	IDENTIFICATION
1				Main Control Card
				If column is left blank or 0 then the following instructions are not carried out
	1	CON 1	1	Print out HUNT solutions
	2	CON 2	1	Do HUNT only
	3	CON 3	1	Converge for best 3 HUNT solutions
	4	CON 4	1	Converge for all 10 HUNT solutions
				N.B. if CON 3 = CON 4 = 0 or blank then converge for one best HUNT solution
	5	CON 5	1	Print out after each pass through system; i.e., each time final element of system is reached
<hr/>				
1	1→3	MAXPAS	010	Maximum number of passes through the system that is permitted.

NO. OF CARDS	COLUMNS ON CARD	SYMBOL	EXAMPLE	IDENTIFICATION
1	1→2	JHUNT	02	2^{JHUNT} is the number of intervals into which each variable is divided when hunting for starting values. All possible combinations are then taken.
1	1→2	JDEPND	01	Determines which element of the system is a dependent variable and what the constraint is; e.g. 01 determines the output gap for vertical focusing, 02 determines the output gap for horizontal focusing.
1	1→2	JMERIT	03	Identifies the merit function to be used (see description of merit functions).
1	1→12	P_o	10.000	Mean momentum (in Bev/c).
	13→24	ΔP_1	0.100	First increment in momentum (in Bev/c) program traces rays for $P_o + \Delta P_1$ and $P_o - \Delta P_1$.
	25→36	ΔP_2	0.400	Second increment; traces $P_o + \Delta P_2$ and $P_o - \Delta P_2$.
	37→48	DHTARG	0.100	Horizontal half-width of target (or object) perpendicular to beam axis in inches.
	49→60	DVTARG	0.050	Vertical half-width of target.
1	1→12	SHCR	1.000	Horizontal half-width into which the beam is desired (e.g. counter, chamber, etc.) (in inches).
	13→24	SVCR	0.500	Vertical half-width desired.

NO. OF CARDS	COLUMNS ON CARD	SYMBOL	EXAMPLE	IDENTIFICATION
	25 → 36	SHPCR	0.005	Desired horizontal slope (not needed for the merit functions available at present).
	37 → 48	SVPCR	0.005	Desired vertical slope (not needed now).

The following two cards describe the path of the P_0 ray through the field of the accelerator magnet. For this data can be obtained using the beam program of E.D. Courant. If there is no fringe field effect the matrix can be set equal to the unit matrix and $D(1) = 0$.

1	1 → 12	D(1)	222.22	Length of path in fringe field (in inches).
	13 → 24	MH ₁₁	1.00	Horizontal transfer matrix of fringe field, or of elements preceding the system being optimized.
	25 → 36	MH ₁₂	222.22	
	37 → 48	MH ₂₁	0.0	
	49 → 60	MH ₂₂	1.00	

1	1 → 12	MV ₁₁	1.00	Vertical transfer matrix of fringe field or of preceding elements.
	13 → 24	MV ₁₂	222.22	
	25 → 36	MV ₂₁	0.0	
	37 → 48	MV ₂₂	1.00	

An example is given below for each type of element:

One	1 → 2	KIND	01	Identifies this element as a field free region (GAP).
-----	-------	------	----	---

NO. OF CARDS	COLUMNS ON CARD	SYMBOL	EXAMPLE	IDENTIFICATION
Card For Each Element Of The System In Order	3→10	XMIN	0.00	The minimum gap length desired (in inches).
	11→18	XMAX	100.00	Maximum gap length desired (in inches)
	19→25	DXMAX	10.00	Maximum increment in gap length desired for the convergence (in inches).
	26→30	DXMIN	0.10	Minimum increment
	57→68	TITLE	GAP	Any title the operator chooses NOTE: A GAP card must appear between any two elements which are not gaps, even if XMAX = 0.0
	1→2	KIND	02	Identifies a bending magnet (DIPOLE).
	3→10	XMIN	0.0	Minimum field (in gauss).
	11→18	XMAX	20000.0	Maximum field (gauss).
	19→25	DXMAX	500.0	Maximum increment in field (gauss).
	26→30	DXMIN	20.0	Minimum increment in field (gauss).
	31→35	AH	9.0	Horizontal half-width of magnet aperture (inches).
	36→40	AV	3.0	Vertical half-width of magnet aperture (inches).
	41→46	D	72.0	Length of field (inches)
	57→68	TITLE	6 x 18 DIPOLE	Any title.
	1→2	KIND	03	Identifies a quadrupole magnet (QUAD)
	3→10	XMIN	- 3000.0	Minimum field gradient (in gauss/inch).
	11→18	XMAX	0.0	Maximum field gradient.

NO. OF CARDS	COLUMNS ON CARD	SYMBOL	EXAMPLE	IDENTIFICATION
	19 → 25	DXMAX	- 100.0	Maximum increment in gradient (gauss/ inch).
	26 → 30	DXMIN	- 5.0	Minimum increment in gradient (negative if X negative).
	31 → 35	AH	4.0	Horizontal half-aperture (inches).
	36 → 40	AV	4.0	Vertical half-aperture.
	41 → 46	D	24.0	Length of field (inches).
	57 → 68	TITLE	8 QUAD 24	Any title.
	1 → 2	KIND	04	Identifies a collimator (COL).
	3 → 10	XMIN	0.2	Minimum half-width of collimator desired (inches).
	11 → 18	XMAX	1.0	Maximum half-width.
	19 → 25	DXMAX	0.1	Maximum increment in half-width (inches)
	26 → 30	DXMIN	0.005	Minimum increment.
	36 → 40	AV	3.0	Vertical half-width of collimator (inches)
	41 → 46	D	40.0	Length of collimator (inches).
	57 → 68	TITLE	6 COL 40	Any title.
1	1 → 2	START	00	This card notifies computer that all data is read in and the calculation commences. NOTE: This is the last card if the computer is to look for its own start- ing values.
1	1 → 2	READ	- 1	If instead of the previous card this is read, the computer will procede to read in starting values and not go through the HUNT routine.

NO. OF CARDS	COLUMNS ON CARD	SYMBOL	EXAMPLE	IDENTIFICATION
ONE	1→7	X(2)	100.0	Enough cards to contain all the starting values with 7 columns allowed per value, from the first element following the fringing field to the last.
FOR	8→14	X(3)	- 113.4	
EACH	15→21	X(4)	100.0	
9	22→28	X(5)	1.0	
	29→35	X(6)	10000.0	
ELEMENTS	36→42	X(7)	200.0	
	43→49	X(8)	236.2	
	50→56	X(9)	0.0	
	57→63	X(10)	- 99.2

EXAMPLE OF BEAM LAYOUT

TARGET CONDITIONS

TARGET SIZE H = 0.200 IN. V = 0.200 IN.
CHAMBER SIZE H = 1.000 IN. V = 1.500 IN.

P = 5.000 BEV/C

COMPONENT LAYOUT
NO. ELEMENT

SET AT

BEND
(DEGREES)
FIXED

S
(INCHES)

MERIT 2 = 0.90130E-03

CUMULATIVE TRANSFER MATRICES

HORIZONTAL

VERTICAL

NO.	ELEMENT	SET AT	BEND (DEGREES) FIXED	S (INCHES)	HORIZONTAL	VERTICAL
1	FRINGE	FIXED	FIXED	40.00	1.0000 40.0000	1.0000 40.0000
2	VGAP	75.300 IN	0.	115.30	0. 1.0000	0. 1.0000
3	8Q28	3214.75 GS/IN	0.	143.30	1.0000 115.3000	1.0000 115.3000
4	VGAP	88.700 IN	0.	232.00	0. 1.0000	0. 1.0000
5	8Q28	-2348.25 GS/IN	0.	260.00	1.1983 167.9887	0.8140 120.0978
6	GAP	10.000 IN	0.	270.00	0.0146 2.8832	-0.0129 -0.6683
7	2X4COL20	1.000 IN	0.	290.00	2.4945 423.7267	-0.3264 60.8163
8	GAP	10.000 IN	0.	300.00	0.0146 2.8832	-0.0129 -0.6683
9	18D80	14000.00 GS	9.792	380.00	2.5429 442.6671	-0.7503 49.9484
10	VGAP	163.676 IN	0.	543.68	-0.0112 -1.5621	-0.0181 -0.1260
					2.4306 427.0463	-0.9316 48.6884
					-0.0112 -1.5621	-0.0181 -0.1260
					2.2060 395.8049	-1.2941 46.1684
					-0.0112 -1.5621	-0.0181 -0.1260
					2.0936 380.1841	-1.4754 44.9083
					-0.0112 -1.5621	-0.0181 -0.1260
					1.1983 255.6742	-2.8988 34.2107
					-0.0112 -1.5621	-0.0173 -0.1405
					-0.6402 0.0000	-5.7351 11.2204
					-0.0112 -1.5621	-0.0173 -0.1405

Accelerator Department (AGS)

WFB-1

December 15, 1961

DISPERSIVE PROPERTIES

NO.	P =	4.8000 BEV/C	P =	4.9000 BEV/C	P =	5.0000 BEV/C	P =	5.1000 BEV/C	P =	5.2000 BEV/C
	X	X-PRIME	X	X-PRIME	X	X-PRIME	X	X-PRIME	X	X-PRIME
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5	0.	-0.	0.	-0.	0.	-0.	0.	-0.	0.	-0.
6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	0.28453	0.00714	0.13935	0.00350	0.	0.	-0.13386	-0.00336	-0.26256	-0.00659
10	1.45302	0.00714	0.71164	0.00350	0.	0.	-0.68362	-0.00336	-1.34085	-0.00659

TRANSFER MATRICES

HORIZONTAL	-0.8997	-46.5607	-0.7654	-22.5641	-0.6402	0.0000	-0.5234	21.2434	-0.4144	41.2670
	-0.0124	-1.7511	-0.0118	-1.6538	-0.0112	-1.5621	-0.0107	-1.4754	-0.0102	-1.3935
VERTICAL	-6.1714	-32.0598	-5.9475	-9.7921	-5.7351	11.2204	-5.5335	31.0690	-5.3419	49.8374
	-0.0185	-0.2584	-0.0179	-0.1976	-0.0173	-0.1405	-0.0168	-0.0866	-0.0162	-0.0357

OPENING ANGLES (MILLIRADIANS)

LEFT	RIGHT	2.51833	2.51833	2.52229	2.52229	2.52650	2.52650	2.53092	2.53092	2.53554	2.53554
UP	DOWN	33.56760	33.56760	33.43380	33.43380	33.30618	33.30618	33.18432	33.18432	33.06785	33.06785

SOLID ANGLE (MILLISTERADIANS)

0.338137	0.337319	0.336592	0.335948	0.335379
----------	----------	----------	----------	----------

IS CENTRAL RAY TRANSMITTED

(I=NO)	0	0	0	0
--------	---	---	---	---

IMAGE SIZE

LEFT	RIGHT	0.2972	0.2972	0.2100	0.2100	0.1280	0.1280	0.1584	0.1584	0.1875	0.1875
UP	DOWN	2.3105	2.3105	1.5169	1.5169	1.5207	1.5207	2.1377	2.1377	2.7164	2.7164