特別掲載

Real Time Dose Distribution Display by Digital Computer

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ディィジタル計算機による線量分布の実時間表示

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治療計画と治療記録作成のため新しく開発された計算機についてその性能概要と臨床応用例について述べた2部から成る論文のうちの1部である．本論文ではまずこの種の計算機の生れた背景と必要性，有用性について述べた後，性能，構成，使用方法を述べる．しかるのち線量計算方法を特に実時間性を損わない様に高速演算と高精度を両立させた面から述べ，計算結果の表示例を示して今後の研究の方針について述べる．

このシステムは体内放射線吸収量を治療医が直接に簡単に指示できる条件に従つて計算しその答を等線量曲線として即時に得て患者のケースに応じた最適なる照射技法を決定すること，及び実際に行われた治療の記録を自動的に行なうことができる．このシステムを利用する者はプログラムを作つたり，タイプライターをたたいたりする必要がないのである．10門までの任意の門からの予定積算線量，照射野，皮膚面とアイソセンタ間距離，体厚，照射角度，くさびフィルタ角度，斜入射角度，遮弊用ブロックの大きさと位置等の諸条件を専用入力装置のディジタルスイッチに設定し，スタートボタンを押すと16インチのブラウン管に，実寸大にて等線量曲線が表示される．1門照射の場合，約4秒で10門照射の場合でも約57秒で等線量曲線を得ることができる．

構成はNEAC-3100医用ディジタル計算機の中央処理装置，特に設計された専用入力装置とCRTディスプレイ装置，XY記録器その他の周辺装置から成る．線量計算プログラムは治療機種に応じてあらかじめ中央処理装置に格納されているので，専用入力装置とCRTディプレイ装置のみに面することにより会話する事ができる．線量計算は2.5㎜間隔の格子点上にて行われ，任意の線量の等線量曲線，最大線量も表示する．システムは治療技法そのものの発展にも寄与する可能性を有している．

1. Preface

It is said that the role of computer in the field of medicine is comparable with that of microscope performed in the old days. At present, its adopted area in the medical field is large; from the medical research itself to the so-called hospital automation where the practical services for the patients will be supplied. The introduction of the computer into the medical science has induced the demand for the computer further advanced and larger in scale. It has even a tendency of increasing in relation to the development of the medicine itself.

Of course, computers are useful in the field of radiology; in diagnosis, radiotherapy and nuclear medicine. There, the use of the computer has been more frequent and more advanced in method. Out of these three, the radiotherapy is the first to adopt the computer calculation system, where the dose calculation being the main subject. Moreover, the request for the treatment planning which follows up accuracy and speed enough to meet the today's remarkably advanced medical accelerators of large output and accurate irradiation has made the demand for the computer more enthusiastic.

However, up-to now, computers of dose calculation have been used mainly by research workers[1)~19)21)22)] and it seems that considerable time is still necessary for the radiotherapist, who has direct contacts with patients, to master it for the clinical purposes. The reason is rather because the computer with the functions expected by the radiotherapist has not been realized yet than because it has not been popular enough over this field. If this expected condition is attained, the radiotherapist will be free from such tasks as programming, typing etc., and he will be able to directly know the adequate way of treatment by the dose distribution curve displayed for him. It is requested that such a new-type machine is suitable for the all treatment technics submitted by the radiotherapist, and its answer is prompt and accurate enough to meet the practical use.[20)22)]

In a fixed economical condition, high-accuracy and high speed of calculation are incompatible each other. Theoretically, the fast scanning type analogue computer will allow the speediest calculation meeting the requirements for accuracy ($\pm 5\%$) for present diagnosis technic,[21)22)] however, it is less convenient and seriously expensive when the calculation to be performed is quite complicated, or when the various items should be computed.

While, the high accuracy and low cost may be realized by utilizing a large-scale digital computer commonly in a hospital. However, in this case, the machine is employed for the various purposes following their respective priority orders assigned, therefore, the instant use of the machine on the occurance of necessity is quite difficult. Moreover, it has a defect of the long turn-around time; from the occurance of problem to the acquisition of the answer. There will be still considerable days to see the realization of the peripheral computer connected to the large central computer as an on-line equipment, where all above problems will be solved.

Therefore, at present, it seems preferable to use small or medium scale computer specially installed at the department of radiology for two medical purposes; one as a dose distribution display, and the other during a spare time, as a general computer for medical research.

The dose distribution display computer discussed in this paper is just such a machine, by which the radiotherapist will be able to get dose distribution curve visually displayed, in the form of conversation with machine, without spoiling its high-speed, range of application and high-accuracy.

The following is the detailed discussion on the computer and on the result obtained during the clinical use.

2. General Performances

The advantage of this computer is to display isodose curve on a cathode ray tube as a visible data so that the radiotherapist can judge it suitable or not suitable for each patient.

If one program is already prepared for a certain radiotherapy machine, this computer can work to indicate isodose curve in several seconds or at most one minute from the time of setting numerical values corresponding to treatment conditions and pushing start button.

The performances and specifications of this computer are discribed below.

2.1 Performances and Specifications

Table 1 shows the outline of specifications of this computer. However, this is the specification in the immediate manufacturing days, since then, various kinds of amendment have been tried to expand the function. The detailed description on such an amendment performed will be given later. Moreover by the development of the programming, the radiotherapy machine can be used for various kinds of energy not only for the linac but also for cobalt, betatron, the interstitial or intracavity irradiation.

Table 2 shows the various input parameters and their allowable ranges.

These numerical parameters are directly inserted to the machine as a series of input data by operating the digital switches instead of the typewriter.

The convenience of this computer machine exists in the fact that a series of operations; parameter input, dose calculation, display of output etc. can be performed only by pushing the starting button, and also,next new dose calculation can be done quite easily whenever parameters are reset and the starting but

Table 1. Ability of the Computer

CRT Size		16 inches, Round
Spot Colour		Orange
Scale		1/2 or 1/1
Frame V Repetition Rate		12—20 Frames/Second
Dose for Normalizing		Maximum Dose or Preset Dose
Isodose Curves		100, 90, 80, 70, 60, 50 and 40%
Other Curves		Contour of Body, Tumour and Organ
Maximum Dose		up to 9999 rads
Spot Size		0.2—0.4 mm
Error of Display		0.4 mm maximum
Speed of Calculation	1 Portal	2—8 seconds
	N Portals	about 5N + 1 seconds
	10 Portals	57 seconds
Application		6 MeV LINAC X-ray Betatron Interstitial Method etc.

Table 2. Input Parameters

Input Parameters of Treatment Condition for Each Portal

Symbol	Name of Parameters	Allowable Range
N	Number of Portals	01—10 Portals
r	Integrated Dose	000—999 rads
L_1, Ls	Field Size	00.0—29.9 cm
d	Distance between Skin and Isocenter	01.5—29.9 cm
D	Thickness of Body	01.5—29.9 cm
θ	Irradiation Angle	000—360 degree
α	Wedge Angle	0, ±15, ±30, ±45 degree
β	Oblique Incidence Angle	−89 — +89 degree
h	Effectiveness of Shielding Block	−0.99 — −0.00
w_0	Width of Shielding Block	00.0—30.8 cm
p_0	Position of Shielding Block	−15.4 — +15.4 cm

Input Parameters for Calculation

Symbol	Name of Parameter	Allowable Range
r_0	Reference Dose of 100%	0000—9999 rads
Lu, Lv	Scope of Calculation	00.0—42.0 cm
Uo, Vo	Origin of Calculation	−28.5 — +28.5 cm
ΔU, ΔV	Mesh Intervals	2.5 mm or 5.0 mm
ε	Sampling Band of Curve	1, 2, 3, or 4%

ton pushed. These operations are realized by sending an external interruption signal into the central processor from the specific input unit. Detail of the specific input unit will be discussed later. One of the greatest features in hardware of this computer is that the output of the central processor is transmitted to CRT display directly from the main memory of the central processor repeatedly instead of from the specific buffer memory. This system is more economical compared with the CRT display unit with the buffer memory which is composed of core memory or magnetostrictive delay line. While a picture is appearing on the cathode ray tube, the central processor is being occupied. In such a case, calculation of other item by the same machine is impossible. However, this problem is not so serious from the fact that the machine is a dedicated one and that the calculation will be completed with a considerably short period of time.

2.2 Use

Fig. 1 shows block diagram of an ideal form of the computer to be used for the radiotherapy. In this drawing, arrows of solid lines indicate that this computer is applicable.

The work of this computer is to determine the condition of irradiation by getting the most fitted figure of the iso-dose curve and its corresponding set of treatment parameters so that the dose may be absorbed properly into the tumor detected by the diagnosis. This suitable condition of irradiation is not obtained from the single calculation but from the numerous calculations tried repeatedly in order to approach the ideal dose distribution. The radiotherapy machine starts operation immediately after the suitable condition of irradiation is obtained. Then, the used parameters of condition will be field as a data or a treat-

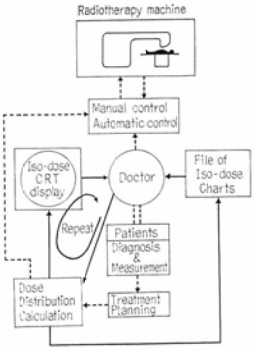


Fig. 1. Idealized Block Diagram for Use of Computer in Radiotherapy. The Solid Lines Shows the Role of the Dose Distribution Display Computer

ment record. There is a conception that, in future, the automatic control of the radiotherapy machine will be done directly by the computer under the preferable condition of irradiation obtained by the same computer.

Operating procedure of this computer is generally described below.

In using the dose distribution display computer, first make the central processor memorize a series of the dose calculation program written on the magnetic tape. Such operation is needed only once after that the dose calculation program has erased out due to the use of the same machine for the other purposes.

Once the program is memorized by the central processor, various dose calculations and their displays for a certain radiotherapy machine will be performed only by operating the specific input unit and CRT display unit.

First, set the input parameter by means of the digital switch installed in the specific input unit. For a instance, set the portal number for irradiation with N, area of position of calculation and display with L_u, L_v, Uo, Vo, integrated dose from each port with r_i, field size with L_l and L_s, distance between skin surface and iso-center with d_i, direction of beam with θ_i, and wedge filter angle with α_i, thickness of human body with D_i, oblique incidence angle with β_i, size and position of shielding block with h_i, W_{oi}, P_{oi}. After the completion of these setting, push the starting button. Then the iso-dose curve will appear on the CRT display scope within several seconds or several tens seconds. Calculation speed depends on number of portals and dimmension of region of calculation. If the output selection switch is turned toward the digital plotter, the curve does not appear on the CRT scope, instead, the output is sent to the digital plotter. When the switch for scale testing is turned on, scale calibration can be done by adjusting test patern appeared on the CRT to the scale of carsor. Potentiometers on the CRT panel are available to adjust magnification and position of the image on the CRT. When the scale test switch is turned-off, isodose curves appears again. On the cathode ray tube, seven isodose curves are displayed as dotted lines at the same time. Therefore, intensity modulation method is necessary to discriminate these lines. For example, when the button corresponding to 80% is pushed-on, its lamp lights, and the curve assigned for 80% becomes more intensive compared with others.

On the other hand, the maximum dose calculated within the specified area of calculation is also indicated with the figure of 4 digits in the numerical display tube situated just under the cathode ray tube. The isodose curves can be ranked by two modes. That is, one is to rank the dose levels on the basis of the 100%

value as the maximum dose calculated. The other is on the basis of the 100% value as the parameter r_0 selected by operation of digital switches. In the latter mode, isodose curves for arbitary dose can be observed.

3. System Configulation

The system configuration of the dose distribution display system is as shown in Fig. 2. This system is composed of specific input unit, CRT display unit and NEAC-3100 computer system. The specific input unit and the CRT display unit are installed in the operation room of radiotherapy machine linac. The NEAC-3100 computer system is installed in the computer room. Such a configuration is provided for performing the dose calculation only by operating the specific input unit and the CRT display unit, and

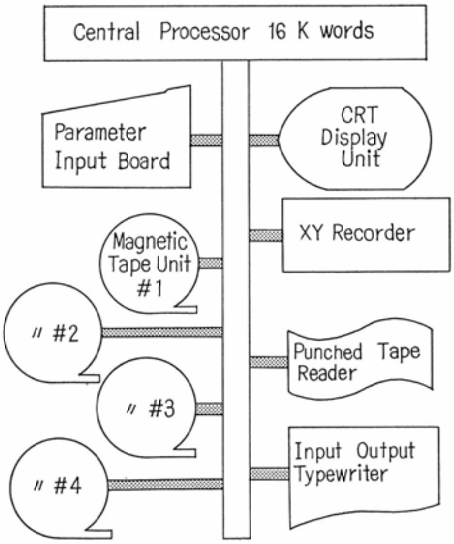


Fig. 2. System Configuration

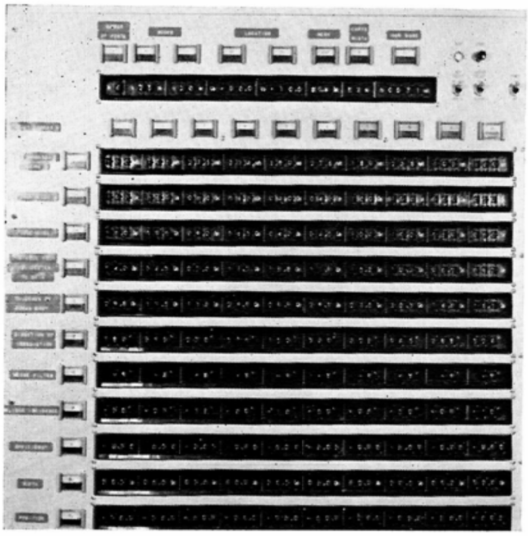


Photo. 1.

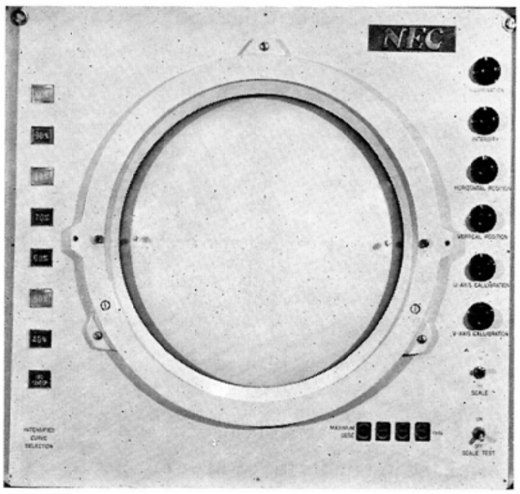


Photo. 2.

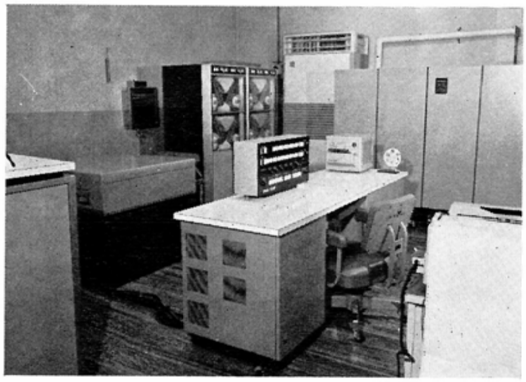


Photo. 3.

for doing the irradiation treatment by promptly operating the linac under the most favorable condition thus obtained. When utilizing the NEAC-3100 system for other purposes, appropriate operation on the console of central processor will be necessary.

The specific input unit and the CRT display unit are as shown in Photo. 1 & 2. Photo. 3 shows the NEAC-3100 central processor, magnetic tape units, operation console, input-output typewriter, XY plotter, line printer, and punched tape reader.

3.1 Specific Input Unit

This unit is composed of three kinds of functions; parameter input board, parameter input controller and CRT display controller.

3.1.1 Parameter Input Board

Digital switches are provided on this board, to select arbitrary values of parameters before performing the various kinds of dose distribution calculations and indicate the parameters even after calculation.

There are switching circuits by which the parameters set by digital switches are scanned and transfered to the parameter input controller.

An external interruption signal is generated for the central processor by pushing the starting button, and the parameter is activated to start the dose calculation even at the time of input/output access of other peripheral units or the central processor processing. It is programmed that the result of the calculation is displayed immediately after dose calculation is over. Therefore, only by pushing the starting button, overall calculating process—calculation and display—starts at once. Whether the calculation result should be diaplyed by the CRT or it should be recorded by the digital plotter is determined by the output selection switch.

When the value of the parameter set on the parameter input board is beyond its limited range, the error lamp lights and computation halts to show the parameter with the error. The computer starts the calculation again by pushing the starting button after the correction of the parameter. Busy indication lamp shows that the data are being transfered from the specific input unit to the central processor, or from the CRT display unit to the central processor, and vice versa.

3.1.2 Parameter Input Controller

This controller controls the parameter input board by decoding the control signal sent from the central processor in order to transfer the parameter which is set at the parameter input board to the central processor. These decoding and controlling operations are done by practicing the PDT (Peripheral Data Transfer) Instruction and PCB (Peripheral Control and Branch) Instruction. As both PDT and PCB Instructions are included within a series of statement in the dose calculation program, the specific input unit operates according to the program memorized by the main memory of the central processor.

3.1.3 CRT Display Controller

This controller controls and decodes the data of the co-ordinates which compose the isodose curve and the data of maximum dose sent from the central processor to be displayed by the CRT display unit. These controlling and decoding are also performed in accordance with the PDT and PCB Instructions contained in the program which will be carried out by the central processor.

There, discrimination of data between co-ordinates and maximum dose, classification of the discriminated co-ordinates into the respective group of percentages, and distinction between ordinate or abcissa are done before transmitting them into the DA converter. A co-ordinates of a isodose dot is indicated in one word, 18 bits. The output interval between the dots is 50 μsec. That is to say, there is a time interval of 50 μsecond until next dot or spot is illumined since first spot was illumined.

Besides, the circuits are provided to keep the frame rate constant so that brightness of the pictures should not be changed according to numbers of dots.

3.2 CRT Display

This unit performs DA conversion of coordinates-data of isodose plot sent from the CRT display control section, displays it as an intensified plot on CRT and operates the numeric display tube to show data in 4-bit decimal receiving the maximum dose data.

The CRT has a 16″ scope and is able to cover sufficiently the cross sector of human body in its real dimensions. Spot color is orange.

Moreover, this unit employs a CRT for radar indicator and its functions of peripheral equipments to increase the accuracy of display.

Though the radar is designed to be used or observed in a dark room, this CRT display can be observed clearly even in a light room by providing an intensity adjuster. 1/1 or 1/2 is selectable for the displaying scale. The function of the calibration by a test pattern is provided with this unit. Image can be freely moved as that of a synchroscope to the right or the left and up or down on the displaying scope. The scale of the isodose chart is also changeable independently vertical or horizontal. The scale illumination will allow accurate observation and provide convenience in taking photographs.

3.3 The NEAC-3100 Computer System

The processor of the dose distribution display computer system is a NEAC-3100 computer. The NEAC-3100 (Computer) System is composed of the following units;

1) Central Processor
2) Magnetic Tape Unit (4)
3) Punched Tape Reader
4) Input-Output Typewriter
5) Line Printer
6) Digital Plotter

The central processor has a main memory of 16 K words; a word consists of 18 bits and its memory cycle time is 2.0 μsec.

The high-speed arithmetic unit, interrupt lines, and two trunks of read-write channel, which are all optional, are provided in this central processor.

This system also allows direct data transmission between the main memory and the peripheral units with a maximum transferring speed of 5000 × 10^3 characters per second (one word consists of three characters).

Four units of magnetic tape are used in this system. The software called operating system can employ FORTRAN compiler and two kinds of assembler to compile and assemble source programs

This NEAC-3100 Computer System was so designed as to be applicable for other purposes as well as for calculation of dose distribution; for example, to use this system as a general medical computer.

Sufficient memory capacity and peripherals are equipped for the application of diagnosis and nuclear medicine as well as of radiotherapy.

Even though on-line connection of DA/AD converter is not practiced for the moment, it can be connected as a peripheral unit to NEAC-3100 computer. Input-output typewriter and digital plotter are especially used for treatment recording. After the specific input unit and the CRT display being used, the most fitted iso-dose curve for a patient is recorded by the digital plotter. Treatment condition to obtain the most fitted iso-dose curve is also printed by the typwritere with the name of patient, year and date, name of medical doctor, and position of tumor.

Of course, the results will be printed out by means of the line printer if programmed.

4. Dose Calculation Method

As for the dose calculation method, most of the workers use the same method,[1)~15)8)] that is, first to make an empirical formula fitting for the practically measured values and next to determine the dose following the formula. At present, however, no empirical formula to calculate the practical absorbed dose inside the body is introduced or established.

The point to which our effort paid mostly was to speed up the calculation without decreasing the precision of calculation. The accuracy and the speed are incompatible each other. However, after studying its relationship from various points of view, a method described hereinafter is established to satisfy the both factors. Basically, as a traditional method shows, the method to multiply the depth dose curve by the decrement value is employed. But the difference exists in utilizing approximation by linear function and ability of judgement with comparatively less calculation time especially in computers, in stead of utilizing exponential and trigonometrical functions which need longer calculation time.

In case that curvilinear portion of functions such as for a penumbra region should be treated, hyperbolic approximation is used instead of parabolic approximation. This advantage is speedy calculation because of rare instruction of performance "divide". Besides, it is found that hyperbolic approximation is better than parabolic approximation when the results of calculation is compared with practical iso-dose

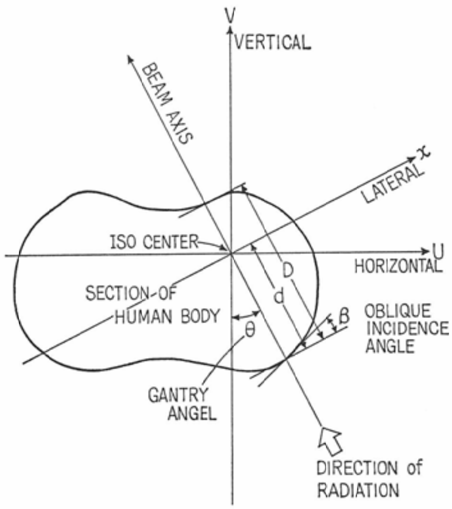


Fig. 3. Difinition of Coordinate System

curve.

The following shows its calculation method.

4.1 Equation of Dose Calculation

The dose distribution is calculated on sampling mesh points on the UV co-ordinate. The origin of the co-ordinates is the iso-center as shown in Fig. 3. The mesh interval of sampling points is selectable to be either of 2.5 mm and 5 mm. The region for display and calculation is defined by a rectangular on UV plane. Here, length of horizontal and vertical sides are given by L_u and L_v respectively, and the center of the rectangular by (U_o, V_o).

Both UV and xy plane coincide with the plane made by X-ray source rotation. U-axis is in parallel with the horizon and V-axis is vertical. The y-axis is beam axis of irradiation and the positive direction of represent the direction of irradiation.

The equation of co-ordinates conversion between xy and UV co-ordinates, assuming irradiation angle of θ_i (i = 1, 2, 3, ..., N), is given by

$$\begin{pmatrix} x_i \\ y_i \end{pmatrix} = \begin{pmatrix} \mathrm{Cos}\,\theta_i & \mathrm{Sin}\,\theta_i \\ \mathrm{Sin}\,\theta_i & \mathrm{Cos}\,\theta_i \end{pmatrix} \begin{pmatrix} U \\ V \end{pmatrix} \quad \cdots\cdots(1)$$

where, N represents number of portals. Here, as for the effects of oblique incidence and wedge filter, a method to deform the iso-dose curves by means of co ordinates conversion is employed. In assumption that co-ordinates of a iso-dose points is (x, y), in which neither of wedge filter nor oblique incidence is considered, and that wedge filter angle is α_i and oblique incidence angle β_i, the co-ordinates of the iso-dose curve is newly given by co-ordinates $(x,\ y-x\tan\alpha_i - x\tan\frac{\beta_i}{2})$.

Being combined with predescribed co-ordinates conversion by irradiation angle θ_i; next equation will be obtained.

$$\begin{pmatrix} x_i \\ y_i \end{pmatrix} = \begin{pmatrix} G_{1i} & G_{2i} \\ G_{3i} & G_{4i} \end{pmatrix} \begin{pmatrix} U \\ V \end{pmatrix} \quad \cdots\cdots(2)$$

where,

$$\left.\begin{aligned} G_{1i} &= \mathrm{Cos}\,\theta_i \\ G_{2i} &= \mathrm{Sin}\,\theta_i \\ G_{3i} &= \mathrm{Sin}\,\theta_i - \mathrm{Cos}\,\theta_i\ (\tan\alpha_i + \tan\frac{\beta_i}{2}) \\ G_{4i} &= \mathrm{Cos}\,\theta_i - \mathrm{Sin}\,\theta_i\ (\tan\alpha_i + \tan\frac{\beta_i}{2}) \end{aligned}\right\} \quad \cdots\cdots(3)$$

The integrated absorbed dose (rad) at each point (U, V) inside the body, is given as the summation of the integrated dose for each portal:

$$R(U, V) = \sum_{i=1}^{N} r_i A(\alpha_i)\ \eta\,(L_i)\ \left(\frac{F}{F-d_i}\right)^2 \frac{P(y_i)}{100}\ \{Q(x_i) + T(x_i)\} \quad \cdots\cdots(4)$$

In equation (4) r_i represents an integrtaed dose from each portal of the radiotherapy machine. This value is defined as absorbed dose at a place of 1.5 cm depth in water on the iso-center in the case of 6 MeV Linac X-ray.

A (α_i) is a correction factor for the attenuation of X-ray beam on axis under the condition of wedge filter inserted, and its value is as follows:

$$\text{if } \alpha_i = 0, \qquad A(\alpha_i) = 1$$

η_i is a also correction co-efficient, which compensate the difference of dose (maximum dose) at build-up point due to magnitude of the field size (small or large),

if the field size is 10×10 cm; $\eta_{(i)} = 1$

F represents the distance between radiating source and the isocenter and values as follows;

in case of 6 MeV linac, $F = 100$ cm

d is a depth of tumor; distance between skin surface and the isocenter.

$P_{(y_i)}$ represents the distribution of the absorbed dose shown by a percentage depth dose curve and is a function of y_i with the field size as a parameter. Fig. 4 shows function $P_{(y_i)}$ of 6 MeV X rays.

$Q(x_i)$ represents the distribution of the absorbed dose along the line in parallel with x_i-axis in x_iy_i plane and is correspond to flatness curve in phantom. Fig. 5 shows the function of $Q(x_i)$.

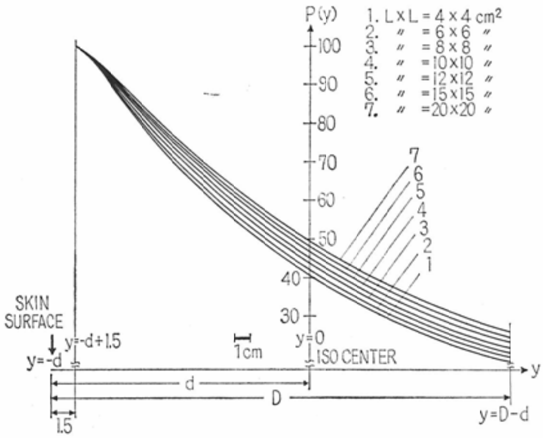
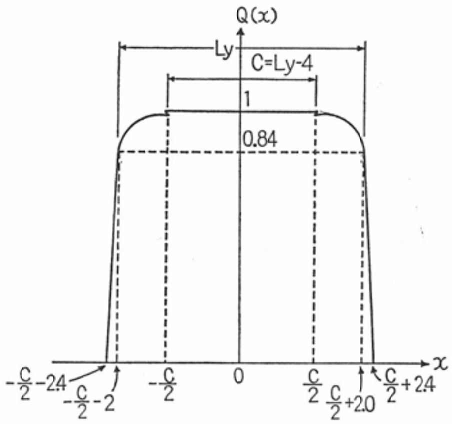


Fig. 4. Function P(y) for 6 Mev Linac X-ray



C=Ly-4 Ly is field size at y=y

$$Q \equiv \begin{cases} 0 & x < -\frac{c}{2} - 2.4 \\ 2.1\left(x + \frac{c}{2} + 2.4\right) & -\frac{c}{2} - 2.4 \leqq x < -\frac{c}{2} - 2.0 \\ 1.01 - \dfrac{0.047}{x + \frac{c}{2} + 2.27} & -\frac{c}{2} - 2.0 \leqq x \leqq -\frac{c}{2} \\ 1 & -\frac{c}{2} < x < \frac{c}{2} \\ 1.01 - \dfrac{0.047}{-x + \frac{c}{2} + 2.27} & \frac{c}{2} \leqq x \leqq \frac{c}{2} + 2 \\ 2.1\left(-x + \frac{c}{2} + 2.4\right) & \frac{c}{2} + 2 < x \leqq \frac{c}{2} + 2.4 \\ 0 & \frac{c}{2} + 2.4 < x \end{cases}$$

Fig. 5. Function Q(x) for 6 MeV Linac X-ray

$T(x_i)$ is a rectangular function to be added to $Q(x_i)$ in order to simulate the effect of the shielding block and this function has three parameters of h, w_o, p_o defined at the iso-center.

where, h: Rate of decrease of dose. Values are as follows;

if all radiation is shielded, $h = -1$ and

if half-shielded, $h = -0.5$.

w_o: Shielding area at iso-center in parallel direction with x-axis given in the unit of cm.

p_o: Central position of the shielded area given in the unit of cm.

Fig. 6 shows representative functions of T and Q + T, and Fig. 7 shows relationships among functions

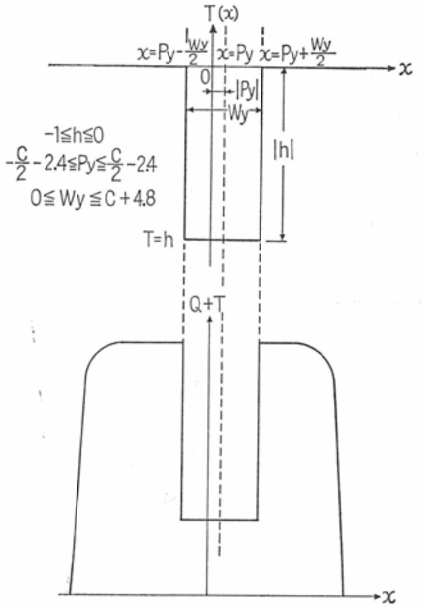


Fig. 6. Function T(x) and Q(x) +T(x)

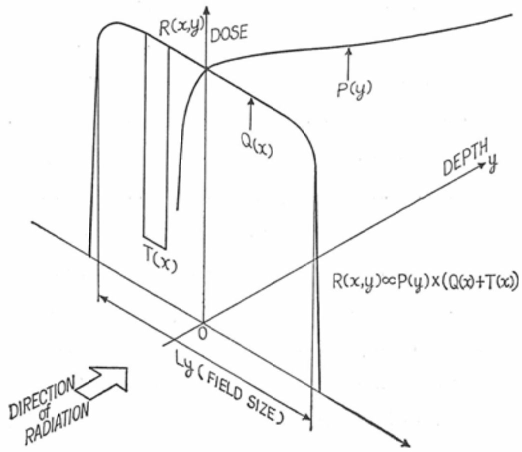


Fig. 7. Functions R(x, y), P(y), Q(x) and T(x)

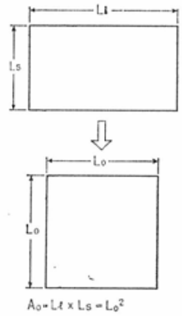


Fig. 8. Conversion of rectangular field to square field.

of R(x, y), P(y), Q(x) and T(x).

4.2 How to Deal With Field Size

Field size for tumor which can be put in by the specific input unit is a rectangle defined at the iso-center. In assumption that long and short sides of the rectangle have length of L_l and L_s respectively, the area is obtained by multiplying L_l by L_s. Moreover, the rectangle is converted into a square with the same area as A_o and the length of one side as L_o shown by Fig. 8. L_l/L_s ratio is limited to 1.5 at maximum, and if it is beyond the value, an error lamp lights.

Next, using the field size A_o defined at the iso-center, the field size on skin surface is obtained as follows;

$$A = A_o \left(\frac{F-d}{F}\right)^2 = L' \times L' \quad \cdots\cdots(5)$$

This equation shows a compensation for that the field size becomes small or large in case skin surface is located in the forward from the iso-center (near radiating source) or in the backward respectively.

The percentage depth dose curve differs due to the field sizes. The maximum absorbed dose at build-up point also differs due to this field size. These factors are corrected based on length of one side L′ of the

Table 3. Selection of value L × L according to the field size L′ × L′ on the skin surface.

L′ × L′	L × L
0 × 0 L′ × L′ = 5 × 5	4 × 4
5 × 5 < 〃 = 7 × 7	6 × 6
7 × 7 < 〃 = 9 × 9	8 × 8
9 × 9 < 〃 = 11 × 11	10 × 10
11 × 11 < 〃 = 13.5 × 13.5	12 × 12
13.5 × 13.5< 〃 = 17.5 × 17.5	15 × 15
17.5 × 17.5< 〃 = 30 × 30	20 × 20

Table 4. Collection factors $\eta(L)$ for dose on the buildup point versus L

L	$\eta(L)$
4	0.952
6	0.971
8	0.990
10	1.000
12	1.01
15	1.02
20	1.03

square of the field size on skin surface in equation (5). That is, dividing the size of L′ into 7 regions, the representative value L is defined as shown in Table 3.

As mentioned above, by selecting seven disceete values of L it will be possible to keep down error for the function P(x) due to field size differences within 1.5%. Furthermore, the predescribed $\eta(Li)$ is divided as shown in Table 4.

4.3 Programing

The program for dose calculation is separated into 11 subprograms for easy assembling and debugging. The assembler, loader and object program which is assembled from source program of dose calculation are written on a magnetic tape. The name of assembler language is SPASE 1.

Fixed point calculation is employed in stead of floating point to practice speedy calculation. Moreover, the mesh points, whose doses are apparently zero, are out of sampling to avoid duplicate calculation.

The doeses are calculated on the sampling points on co-ordinates (U, V) measured using the unit cm, and iso-dose points are displayed with a real scale using the unit cm also. But the data of the iso-dose points are sent to the display unit as integer (m, n) of mesh points given with 0.25 cm steps in order to eliminate excess redundancy.

Fig. 9 shows the block diagram of the program.

External interruption will be allowed by pushing the start button of the specific input unit. And a series of routine for parameter input, dose calculation and output of iso-dose curves are performed. As soon as the interruption is processed, the system resumes state for next interruption. Namely, the system is always set to enable a new dose calculation; the start button allows always to start calculation from bigining of this dose calculation program.

4.4 Application to Other Radiotherapy Machines

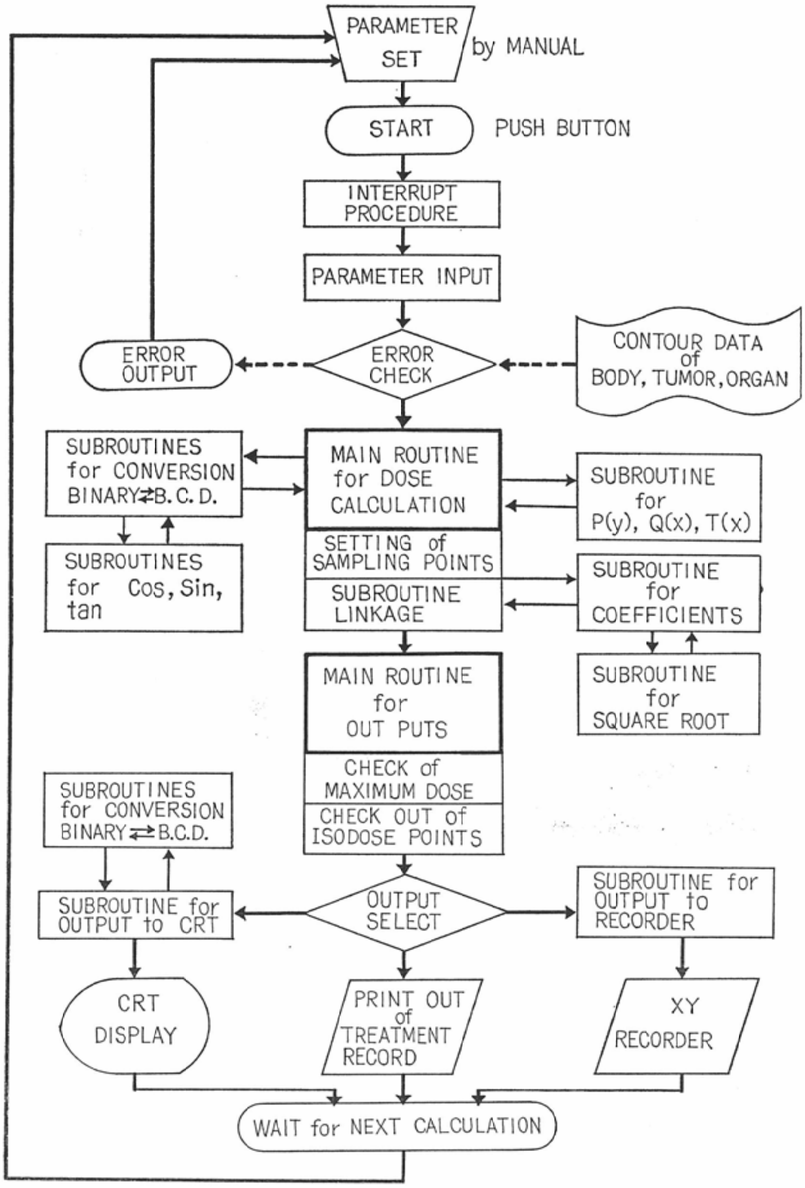


Fig. 9. Block Diagram of Programm

In case of other external beam irradiation, it is required to change functions of Q(x), P(y) and correction factors. For different energy sources of linac, cobalt and betatron, each dose distribution curve is obtained by this method.

However, in case of batatron, more input parameters are required to be added to those mentioned before.

In this case, it is desirable to be able to insert or appoint parameters using typewriter.

As for intracavity irradiation and interstitial irradiation, dose calculation equation itself should be changed. It is desirable to make a new program, and besides, parameters such as position of radioactive source, shape, dose, etc. should be inserted by the input-output typewriter. Insertion of these parameters by means of the specific input unit is also possible by means of changing program.

On the other hand, the CRT display can be used as it is. The result of a combined treatment of external irradiation and intracavity or interstitial irradiation can be displayed on CRT by superposing absorbed dose by external irradiation and that by intracavity or interstitial irradiation at the same samplihg point and grouping iso-dose points in each percentage. Moreover, this CRT display can display contour of body and also width and position of tumor.

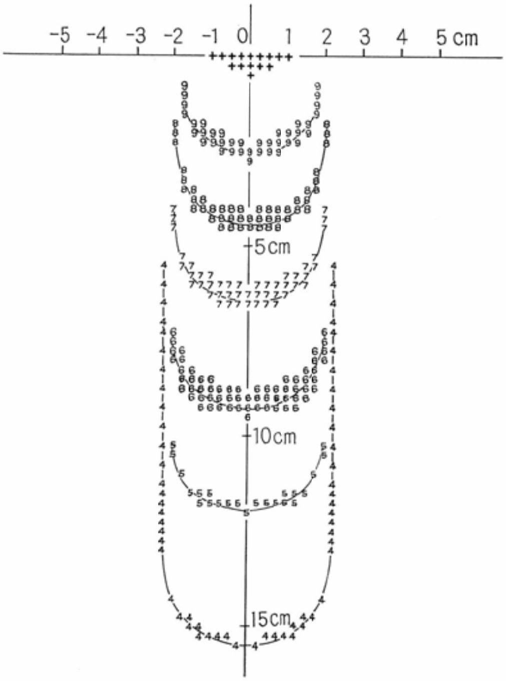
In case of treatment recording, optimum iso-dose curves obtained for a patient are written by the digital plotter. Date, name of patient, its fitted treatment condition and others are printed out by the typewriter.

Therefore this makes it possible to take the treatment recordings in a photograph in place of a digital plotter. However, this recording method cannot always obtain full scale chart as that in the digital plotter.

5. Examples of Dose Calculation for External Irradiation of 6 MeV Linac X-ray

Photo. 4 shows isodose curves on the CRT in the case of field size 6 cm × 8 cm with 45° wedge filter.

Fig. 10 shows isodose curves of field size 4 cm × 4 cm which is drawn by the XY plotter. The build up point is on the iso-center. The scale along beam axis indicates the length from iso-center in stead of that from skin-surface. The origin of the co-ordinate is always isocenter in this system.



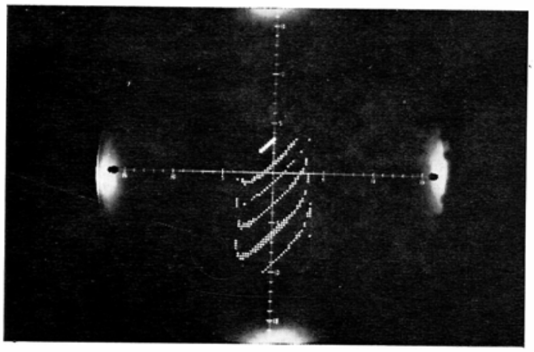
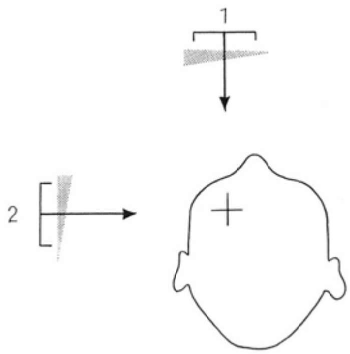


Photo. 4.

Fig. 10. An Iso-dose Curve Drawn by XY plotter. Field Size 4 cm × 4cm. 6 MeV X-ray. Mark + shows 100%. Mark 9, 8, 7, 6, 5 and 4 show 90%, 80%, 70%, 60%, 50% and 40% respectively.



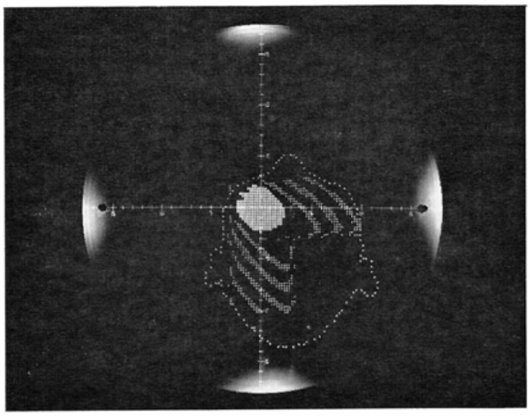
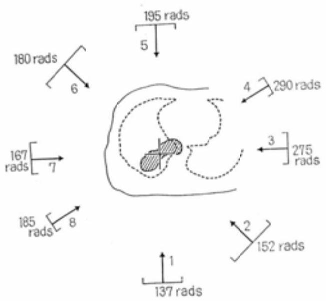


Photo. 5.

Port Number	1	2
Gantry Angle	180°	270°
Tumor Depth	4.3 cm	4.8 cm
Oblique Incidence Angle	5°	−10°
Field Size	6 cm × 6 cm	6 cm × 6 cm
Wedge Filter	−45°	+45°

Fig. 11. An Example of Treatment Planning for Radiation to Maxillary Antrum.



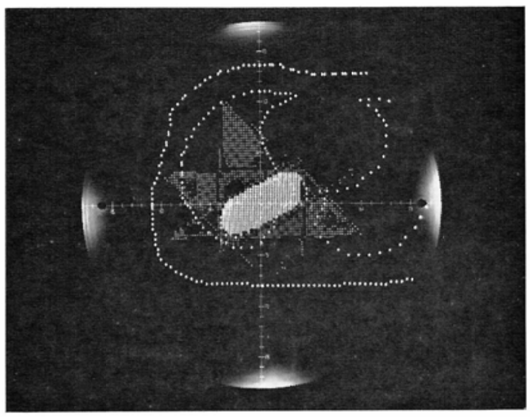


Photo. 6.

Port Number	1	2	3	4	5	6	7	8
Gantry Angle	0°	45°	90°	120°	180°	225°	270°	300°
Tumour Depth	8.4 cm	10.2 cm	19.2 cm	18.8 cm	13.6 cm	13.3 cm	11.3 cm	11.8 cm
Oblique Incidence Angle	−5°	−30°	+10°	+10°	0°	+5°	0°	0°
Field Size	8 cm × 8 cm	10 cm × 10 cm	6.5 cm × 6.5 cm	4 cm × 4 cm	8 cm × 8 cm	10 cm × 10 cm	6.5 cm × 6.5 cm	4 cm × 4 cm

Fig. 12. An Example of Treatment Planning for Radiation to Cancer of lungs.

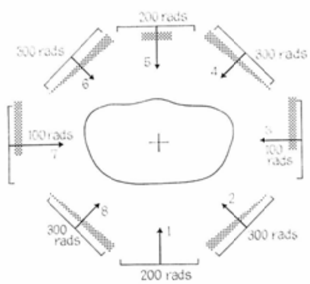
These calculated iso-dose curves of standard type are available for confirmation of calculation accuracy and calibration of scale by comparing with the measured isodose curves. It has been found that the results of calculation coincide very well with the measured dose distribution.

An example of treatment planning for cancer in maxillary antrum and its dose distribution are shown in Fig. 11 and Photo. 5 respectively. Photo. 5 was taken when 100% dose area(namely maximum dose area) glowed brighter than other levels of dose. Other isodose curves are for 40%, 36%, 32% and 28% in the order from inside to outside.

Scale of the chart is 1/1, namely full scale. It is clearly shown that the tumour is covered with 100% dose area and dose drops abruptly at the peripheral zone of tumour.

Fig. 12 and Photo 6 shows an example of treatment planning and dose distribution for cancer in lung. Contour of the body, the lung, tumour and 100% dose area are brighter. Photo. 6 shows that the 100% dose area covers just the tumor. We could confirm that the very small doses were distributed to the other part of tissue.

An example of treatment planning utilizing shielding blocks and its dose distribution for irradiation to a swelling of periuteric lymphglands are shown in Fig. 13 and Photo. 7. The area of 100% dose glows with higher intensity.



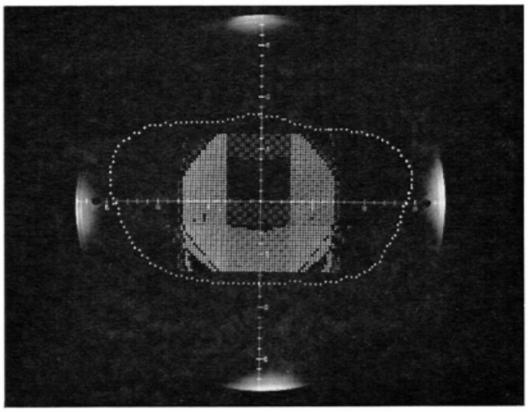


Photo. 7.

Port Number	1	2	3	4	5	6	7	8
Gantry Angle	0°	45°	90°	135°	180°	225°	270°	315°
Tumour Depth	8 cm	14.5 cm	14.5 cm	14.5 cm	8 cm	14.5 cm	14.5 cm	14.5 cm
Oblique Incidence Angle	0°	−30°	0°	+30°	0°	−30°	0°	+30°
Field Size	15 cm × 15 cm	15 cm × 15 cm	15 cm × 15 cm	15 cm × 15 cm	15 cm × 15 cm	15 cm × 15 cm	15 cm × 15 cm	15 cm × 15 cm
Wedge Filter		+30°		−45°		+45		−30°
Integrated Dose	200 R	300 R	100 R	300 R	200 R	300 R	100 R	300 R
Shielding Blocks h			−0.8		−0.99		−0.8	
Shielding Blocks w_D			10 cm		6 cm		10 cm	
Shielding Blocks p_D			+3 cm		0 cm		−3 cm	

Fig. 13. An Example of Treatment Planning for Irradiation to Swelling of Periuteric Lymphglands.

It has been found very helpful for radio-therapist to make treatment planning utilizing parameters of shielding blocks: shielding effect h, position p_o, and width w_o.

6. Conclusion

Outline of the newly developed dose distribution display computer and several examples of its application was reported in this paper. It has been proved that expected ability of precision and speed of both calculation and display is realized and the system is very useful for treatment planning and recording of radiotherapy.

We can obtain infinite numbers of dose distribution charts according to infinite combinations of treatment parameters. This computer, therfore, is mostly applicable to find optimum treatment for numerous kind of tumor spread. In addition to this, it indicates the possibilities that the system may be a tool for developing new technique of treatment what was never tried.

There remain many problemes to be solved by computers in the field of therapeutic radiology. In order to solve these problems, it is necessary to realize the appropriate man-machine system for radiotherapist themselves who perceive those problems. In this view point, this real time systme seems to quicken the progress in electronic data process in this field. We are going to improve and enlarge the abilities of the system. Application to automatic control of linear accelerator is also being contemplated.

Another paper containing more detaile report of actual clinical use and further enlarged abilities will be published.

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