PERFORMING BRACHYTHERAPY DOSIMETRY ON PERSONAL COMPUTERS

A Thesis

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DEDICATION

" The roots of true achievement lie in the will to become the best that you can become."
(Harold Taylor)

As I reflect on the message of Harold Taylor, I remember the kind and inspiring messages of my mother's continuous encouragement and commitment to my education.

As the findings of my research move into the future and offer benefit to all those individuals battling against cancer, I may take each instance and dedicate them to my mother. As she too struggled with cancer, my work will forever remain as an instrument of her belief in my ability and her certainty of my achievement.

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ABSTRACT

High Dose Rate Brachytherapy with remotely controlled afterloading has recently gained popularity, mainly because of its simplicity in treatment, short treatment time, and negligible radiation exposure to medical staff. The important component in High Dose Rate Brachytherapy is a computer planning system which can estimate the dose distribution and compute the source dwell time. Because of the complex dose optimization algorithms implemented in computer planning system, the computer planning needs careful attention for better dose optimization. Today, Personal Computers are capable of executing simple algorithm programs in treatment planning which leads to an improved quality control . PC based spreadsheets have the ability to do complex and repetitive calculations used in different fields such as Brachytherapy treatment planning.

A Nucletron micro-selectron HDR remote afterloader that uses a single ^{192} Ir source with its computer treatment planning system and a Capintec RT110 Treatment Planning Computer with standard ^{137}Cs sources are currently in use at the Mary Bird Perkins Cancer Center for HDR and LDR Brachytherapy cases. One of the objectives of this study is to compare HDR and LDR loadings for Tandem and Ovoids applicators and evaluate isodose distributions for each type of treatment. Another objective is to develop a code in Microsoft Excel to compute the dwell time of an ^{192} Ir source, by using the coordinates of the dwell positions and the prescribed dose points. This can be used to evaluate the isodose distributions surrounding different applicators, such as Vaginal Cylinders, and develop an atlas of different configurations in obtaining the best isodose distribution.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Brachytherapy is a method of treatment in which sealed radioactive sources are used to deliver a dose to a tumor at short distance by interstitial, intracavitary, intralumenal or surface application. In this type of therapy, a high radiation dose can be delivered locally to the tumor with rapid dose reduction in the surrounding tissue. The dose rate is high near the radioactive sources but it falls off very rapidly within a few centimeters.

Brachytherapy has been used since the discovery of radium by Marie and Pierre Curie in 1898 [1]. The effect of radioactive sources was discovered first by Henry Becquerel, when he observed a skin reaction from carrying a radium source in his waistcoat pocket. Then Pierre Curie concluded that there might be medical applications for radium. Five years after discovery of radium the principle of afterloading was proposed in the medical literature (Munich 1903) and different brachytherapy techniques such as surface moulds, intracavitary and interstitial techniques were applied [2].

The placement of radioactive sources in the uterus, around the cervix, and in the vagina has been proven so beneficial in the treatment of patients with gynecological malignancies that it is considered as a standard procedure. After 1930, a didactic system of interstitial therapy at the Holt Radium Institute of the Christie Hospital in Manchester, England was developed by Ralston Patterson, Herbert Parker, and John

Meredith. This system would become the Manchester system, which was designed to deliver constant dose rates to certain points near the cervix, irrespective of variation in size and shape of the uterus and vagina [3].

After Henschke devised the first remote afterloading brachytherapy machine for gynecological applications, several designs of remote afterloader have been manufactured. The first remote afterloaders operated at low dose rate (LDR), but after the invention of Cathetron, high dose rate (HDR) brachytherapy treatment became very practical and popular [4].

High dose rate remote afterloading brachytherapy devices are becoming more common all around the world as well as the United States. The radioactive nuclides used in HDR devices are ^{60}Co, ^{137}Cs, and ^{192}Ir. The first two radioactive nuclides offer longer half-lives but lower specific activities. Therefore, cobalt and cesium sources are used in devices designed for intracavitary treatment in applicators with larger inner diameter. Higher specific activity ^{192}Ir sources with smaller diameters (about 1-mm) are best for intraluminal treatments. However, the half-life of ^{192}Ir (74.2 days) necessitates 3 to 4 source changes in the device yearly.

^{192}Ir has a complicated gamma-ray spectrum, including approximately 24 lines occurring in the energy range from 9-885 keV [5],[6]. A significant advantage of HDR brachytherapy is the short application time, which is favorable in terms of patient tolerance and logistics. Remote afterloading of radioactive sources maximizes radiation protection of personnel by eliminating source handling. Also, the applicators can be rigidly secured for the short treatment times common with HDR therapy.

Consequently, undesired applicator movement during prolonged hospital stays required with LDR therapy is eliminated. A very small diameter high activity ^{192} Ir source in a HDR remote afterloading unit allows the treatments of interstitial and intraluminal sites (bronchus, esophagus, and bile duct) previously untreated or treated only with difficulty with conventional LDR manual afterloading techniques.

Some of the commercially available remote afterloading systems are the Micro-Selectron, the Curietron, the Gamma Med, and the Buchler[6] . The microSelectron HDR features a 4.5mm long ^{192}Ir capsule with an eighteen channel indexer for use with either interstitial or gynecological applicators[7]. The unit moves a 370-MBq (10 Ci) ^{192}Ir source welded to the end of a flexible cable over 12 cm long using forty eight steps separated by 2.5 mm, or 24 cm using forty-eight steps of 5 mm. The source can be precisely positioned at any point in the implanted catheters or applicators. By programming dwell position and dwell time of the source, desired isodose distributions can be obtained. The Mary Bird Perkins Cancer Center has a Nucletron microSelectron HDR remote afterloader that uses a single ^{192} Ir source. There are various applicators and catheters available from Nucletron to use with this unit.

1.2 Principles and Methods for the HDR afterloading procedure

HDR remote afterloaders offer four essential features:

1) A storage safe to contain the source when not in use.

2) A mechanism to move the source from the storage safe into applicator in the patient.

3) A system to maintain the source in the applicator for a set time and to determine its position.

4) A mechanism to return the source to the storage safe during power failures or emergencies[7].

After the applicator is placed in the patient, radio-opaque markers are put in the applicator . Then a set of radiographs such as orthogonal films are taken. The radiation oncologist can then localize and prescribe the dose to the treatment volume. The physicist is responsible for doing the treatment plan and the isodose distributions. It is very important that the simulation and treatment planning be done in an accurate and timely fashion to shorten the patient's discomfort. There is a computer planning system that can estimate the dose distribution and compute the source dwell time. There are different techniques for computation of dose and dwell positions that some of them might be very complex. In most of the HDR procedures, the computer planning is done when the patient is on the treatment bed. Thus, to do the computer planning correctly, one should pay attention to all the details. Sometimes, because of the complex structure of the algorithms it is not very easy to correct a mistake and one might need to start all over again. Therefore, an independent check of the computer plan seems to be a good choice to avoid any mistakes and to maintain a good quality assurance program.

The main concern in this study is to develop a program to compute the dwell time, by using the coordinates of the dwell positions and the prescribed dose points. Another objective of this study is to evaluate the isodose distributions surrounding

different GYN applicators. This can be used to develop an atlas of different configurations in obtaining the best isodose distribution. The theoretical background for the dwell time computation is explained in chapter two. In this chapter, a method of calculating the dose to an arbitrary point by summing the contribution of each dwell position of the source to that point will be discussed in details. In chapter three the development of the theoretical expressions introduced in chapter two is presented. This includes the structure of the program and the matrix calculations. Some generated isodose distributions for vaginal cylinder applicators are presented in chapter four. Chapter five is a comparison between HDR and LDR loadings and isodose distributions for tandem and ovoids applicators. The final chapter summarizes the conclusions of this study and suggests important extensions of the presented work.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Introduction

The dose to an arbitrary point is calculated by summing the contribution of each dwell position of the source to that point. For example, in figure 2.1 the total dose to point p is contributed from the sources located on y-axis. The total dose to point p can be formulated as following ;

$$Total\ Dose = \sum_{i=1}^{n} D_i \qquad 2.1.1$$

Where n is the number of total dwell positions. D_i (the dose contributed from dwell position i) is a function of distance and activity. To derive an expression for calculating the absorbed dose to a single dose point, many factors should be considered. The first factor, which applies only to photons, is exposure. Exposure is a measure of ionization in air by photons and cannot be used for photon energies above 3 Mev. The Roentgen is a unit of exposure. The exposure is calculated using the following formula:

$$\text{Exposure in air} = (\Gamma.A \,.\, T) / d^2 \qquad 2.1.2$$

Where :

A = Activity of the radioactive source

Γ = Exposure rate constant

T = Time of exposure

d = distance from the source

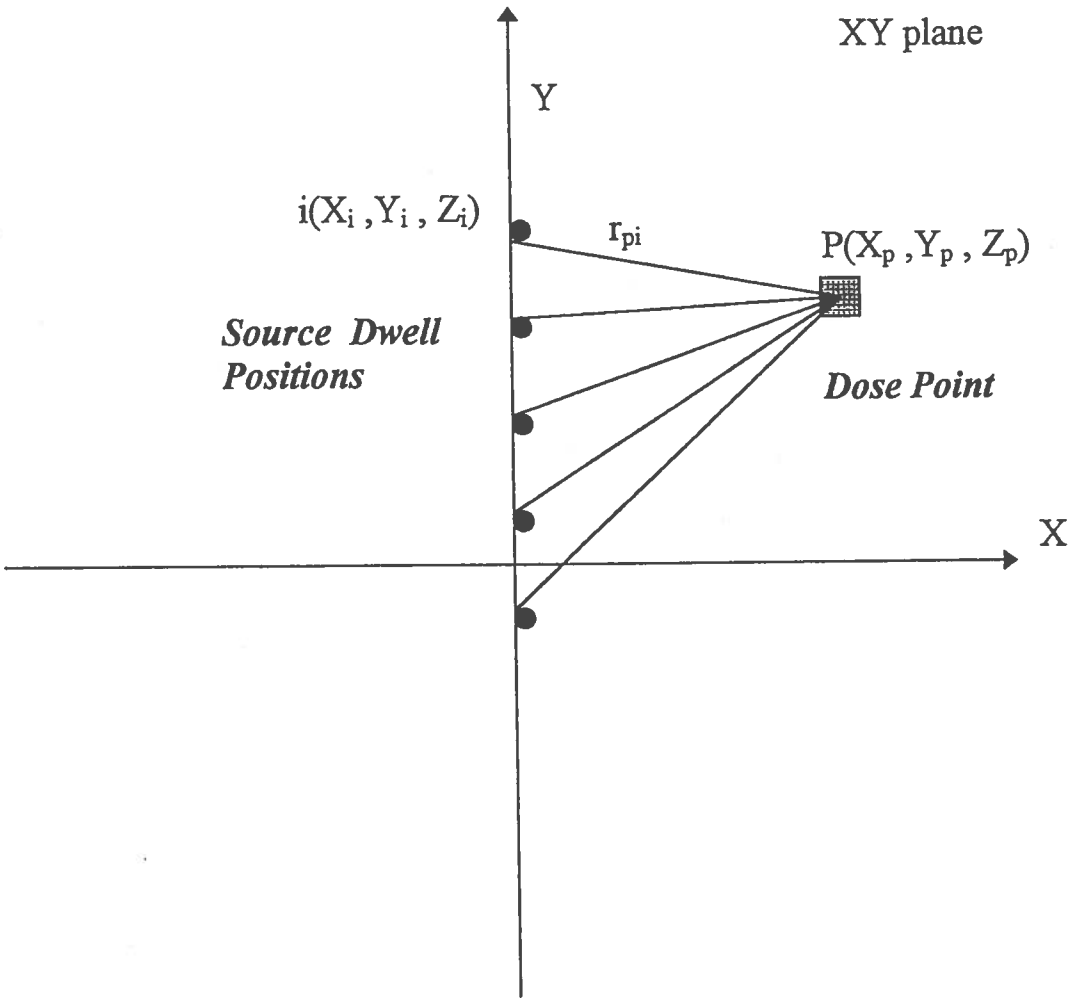


Figure 2.1: Schematic Representation of Source and Dose Point Relative Position

The quantity of energy absorbed for all types of ionizing radiation, all energies, and all materials is called absorbed dose. Absorbed dose is a measure of the biological effects produced by ionizing radiation. The SI unit for absorbed dose is the Gray (Gy) and absorbed dose, or simply dose, is calculated by using the following formula:

$$\textbf{Dose in water} = \textbf{(Exposure in air).M.k.(w/e).}(\mu/\rho)_{air}^{water} \quad \textbf{2.1.3}$$

Dose in the tissue is calculated from equation 2.1.3, simply by multiplying this equation by some other factors as following ;

$$\textbf{Dose in tissue} = \textbf{(Dose in water).}\ (\mu/\rho)_{water}^{muscle}$$

$$\textbf{Dose in tissue} = \textbf{(Exposure in air) . M . k . (w/e) .}\ (\mu/\rho)_{air}^{muscle}$$

$$\textbf{Dose in tissue} = (\ (\Gamma.A.T)/d^{2}\ )\ .\ M\ .\ k\ .\ (w/e).\ (\mu/\rho)_{air}^{muscle} \quad \textbf{2.1.4}$$

Where, in the above equations (μ/ρ) is the mass attenuation coefficient(1.1 is the Nucletron value for this coefficient), w/e is the average energy absorbed per unit charge of ionization (33.85 J/C), k which is the exposure to dose conversion factor is equal to $2.58*10^{-4}$ (C/Kg)/R, and M is the Meisberger Factor which is discussed next.

2.2 Meisberger Factor

The absorption and scattering of radiation in the tissue alter the dose distribution around the radioactive sources. The correction factor due to the absorption and scattering is considered in the calculations by computer methods. There have been a number of determinations for attenuation in tissue such as those based on the experimental data for ^{198} Au, ^{192} Ir, ^{137} Cs, ^{226} Ra and ^{60} Co. Meisberger, Keller, and Shalek determined the effective absorption for the above-mentioned isotopes[8] . A

third order polynomial was fitted for each isotope to get the ratio of absorbed dose in water to that in air.

In Equation 2.1.4, M is Meisberger factor which includes scattering and attenuation by the tissue. The following equation calculates the attenuation in water for gamma rays from a point source.

$$M = A + Br + Cr^2 + Dr^3 \qquad \textbf{2.2.1}$$

Where r is the distance between a source and a dose point. A, B, C, and D are coefficients given in reference 8 for different sources. For Ir-192 these values are :

$A=1.0128*10^{0}$ $B=5.019*10^{-3}$ $C=-1.178*10^{-3}$ $D=-2.008*10^{-5}$

The Nucletron treatment planning computer system uses a different fitting equation. It uses a modified version of Van Kleffens and Star equation[9] which expresses the dose rate in water to the dose rate in air as a function of distance r.

$$E(r) = c(1+ar^2)/(1+br^2) \qquad \textbf{2.2.2}$$

Equation 2.2.2 is the Nucletron fitting equation with a and b as constants determined from experimental data. Constant c is a normalization factor, used to get a better agreement with the Meisberger polynomial. The advantage of this equation is that it takes a shorter time to calculate than the Meisberger polynomial.

2.3 Mathematical background

Based on the definition of matrix multiplication, a set of linear equations can be written as following ;

$$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n = b_1$$

$$a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n = b_2$$

.

.

$$a_{n1}x_1 + a_{n2}x_2 + \ldots + a_{nn}x_n = b_n$$

These set of equations is simplified in matrix notation as $\mathbf{AX = B}$, where

$$\mathbf{A}= \begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ a_{21} & a_{22} & \ldots & a_{2n} \\ . & & & \\ . & & & \\ a_{n1} & a_{n2} & \ldots & a_{nn} \end{bmatrix} ,$$

$$\mathbf{X}= \begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ x_n \end{bmatrix} \quad \text{and}$$

$$\mathbf{B}= \begin{bmatrix} b_1 \\ b_2 \\ . \\ . \\ b_n \end{bmatrix}$$

A is a square and non-singular matrix and X can be calculated easily by using the following formula;

$$\mathbf{X = A^{-1} * B} \qquad 2.3.1$$

Microsoft Excel version 5.0 is used in this study to solve equation 2.3.1 for an HDR device with an Iridium source. Using this algorithm, we can calculate the dwell times of the source.

CHAPTER 3

DEVELOPMENT OF THE PROGRAM

3.1 Introduction

Microsoft Excel, used in this study, includes several features that help put spreadsheet knowledge to work right away. Therefore, in this research Excel is used not only for data entry but also for performing the mathematical aspects of the problem. Before getting into the different parts of the program, it is useful to review the dosimetry calculations to see how the dwell times will be obtained.

3.2 Review of dosimetry calculations

Equation 2.1.4 is summarized as a multiplication of dose rate by total treatment time ($D = D^{\circ} . T$). It can be shown that:

$$\mathbf{D} = ((A.\ \Gamma.f.\mathbf{M})/d^2)\ .\ \mathbf{T} \qquad \textbf{3.2.1}$$

Where: $\{ f = k.\ (w/e).\ (\mu/\rho)_{air}^{muscle} \}$

The distance between dwell position i and the dose point p is calculated as following ;

$$r_{pi} = [(x_i - x_p)^2 + (y_i - y_p)^2 + (z_i - z_p)^2]^{0.5} \qquad \textbf{3.2.2}$$

In equation 3.2.1, the dose rate can be defined as a multiplication of a constant by the ratio of Meisberger factor to distance. The total dose is calculated by summing the contribution of each dwell position of the source to the point p.

$$D_p = (\Gamma \times A \times f) \times \sum_{i=1}^{pn} \frac{M_{pi}}{r_{pi}^2} \times T_i \qquad \textbf{3.2.3}$$

We can have as many as m dose points. The following equations can be used to calculate the total dose to each point .

$$D_1 = K((M_{11} \cdot T_1) / (r_{11})^2 + (M_{12} \cdot T_2) / (r_{12})^2 + \ldots + (M_{1n} \cdot T_n) / (r_{1n})^2)$$

$$D_m = K((M_{m1} \cdot T_1) / (r_{m1})^2 + (M_{m2} \cdot T_2) / (r_{m2})^2 + \ldots + (M_{mn} \cdot T_n) / (r_{mn})^2) \qquad \textbf{3.2.4}$$

Where $K = \Gamma \times f \times A$

The last equation can be shown in matrix form as following ;

$$\begin{bmatrix} D_1 \\ D_2 \\ D_3 \\ \bullet \\ \bullet \\ D_m \end{bmatrix} = A\Gamma f \times \begin{bmatrix} M_{11}/(r_{11})^2 & M_{12}/(r_{12})^2 & \bullet & M_{1n}/(r_{1n})^2 \\ M_{21}/(r_{21})^2 & M_{22}/(r_{22})^2 & \bullet & M_{2n}/(r_{2n})^2 \\ M_{31}/(r_{31})^2 & M_{32}/(r_{32})^2 & \bullet & M_{3n}/(r_{3n})^2 \\ \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet \\ M_{m1}/(r_{m1})^2 & M_{m2}/(r_{m2})^2 & \bullet & M_{mn}/(r_{mn})^2 \end{bmatrix} \times \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ \bullet \\ \bullet \\ T_n \end{bmatrix}$$

The dwell time is computed from the following equation (equation3.2.5) :

$$\begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ \bullet \\ \bullet \\ T_n \end{bmatrix} = 1/(A\Gamma f) \times \begin{bmatrix} M_{11}/(r_{11})^2 & M_{12}/(r_{12})^2 & \bullet & M_{1n}/(r_{1n})^2 \\ M_{21}/(r_{21})^2 & M_{22}/(r_{22})^2 & \bullet & M_{2n}/(r_{2n})^2 \\ M_{31}/(r_{31})^2 & M_{32}/(r_{32})^2 & \bullet & M_{3n}/(r_{3n})^2 \\ \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet \\ M_{m1}/(r_{m1})^2 & M_{m2}/(r_{m2})^2 & \bullet & M_{mn}/(r_{mn})^2 \end{bmatrix}^{-1} \times \begin{bmatrix} D_1 \\ D_2 \\ D_3 \\ \bullet \\ \bullet \\ D_m \end{bmatrix}$$

Equation 3.2.5, can be written in a vector notation as shown in 2.3.6.

$$\mathbf{T} = (1/A\Gamma f) \cdot (\mathbf{M})^{-1} \cdot \mathbf{D} \qquad \textbf{3.2.6}$$

Where, **D** is a dose vector, **M** is the matrix of ratios of the Meisberger factor to the square of the distance. Equation 3.2.6, will be used in Excel worksheet to compute the dwell time.

3.3 Program structure

The "Time" program consists of the following parts; data entry, matrix calculations, optimization and dwell times computation. Also, it includes some information about the patient and formulas used. In performing the computation, the following flowchart (figure 3.1) shows different parts of the program used in dwell time computation.

I) Data entry

Coordinates of each dwell positions and dose points in a Cartesian system are the first inputs of the program. These coordinates are obtained from graph papers made from a radiograph of dwell positions of the source inside the applicator. Coordinates can be also obtained from any computer treatment planning system such as Nucletron that uses a digitizer and light box. Since a square matrix is required in the algorithm, some of the elements must be set to zero when the number of dose points is different from the number of dwell positions. Another input, besides the corrected activity of the source, is the prescribed dose to each dose point.

II) Matrix #1

Coordinates of the dwell positions and dose points are used in the first matrix to compute the distance between each source and each point. This matrix which is a 50 by 50 square matrix is called " Matrix of distance". Excel uses equation 3.2.2 to calculate the distance between each existing dwell position and dose point and gives the rest of the matrix elements which do not have any data a value of one. This allows us to work with small matrices using only one 50 by 50 spread sheet.

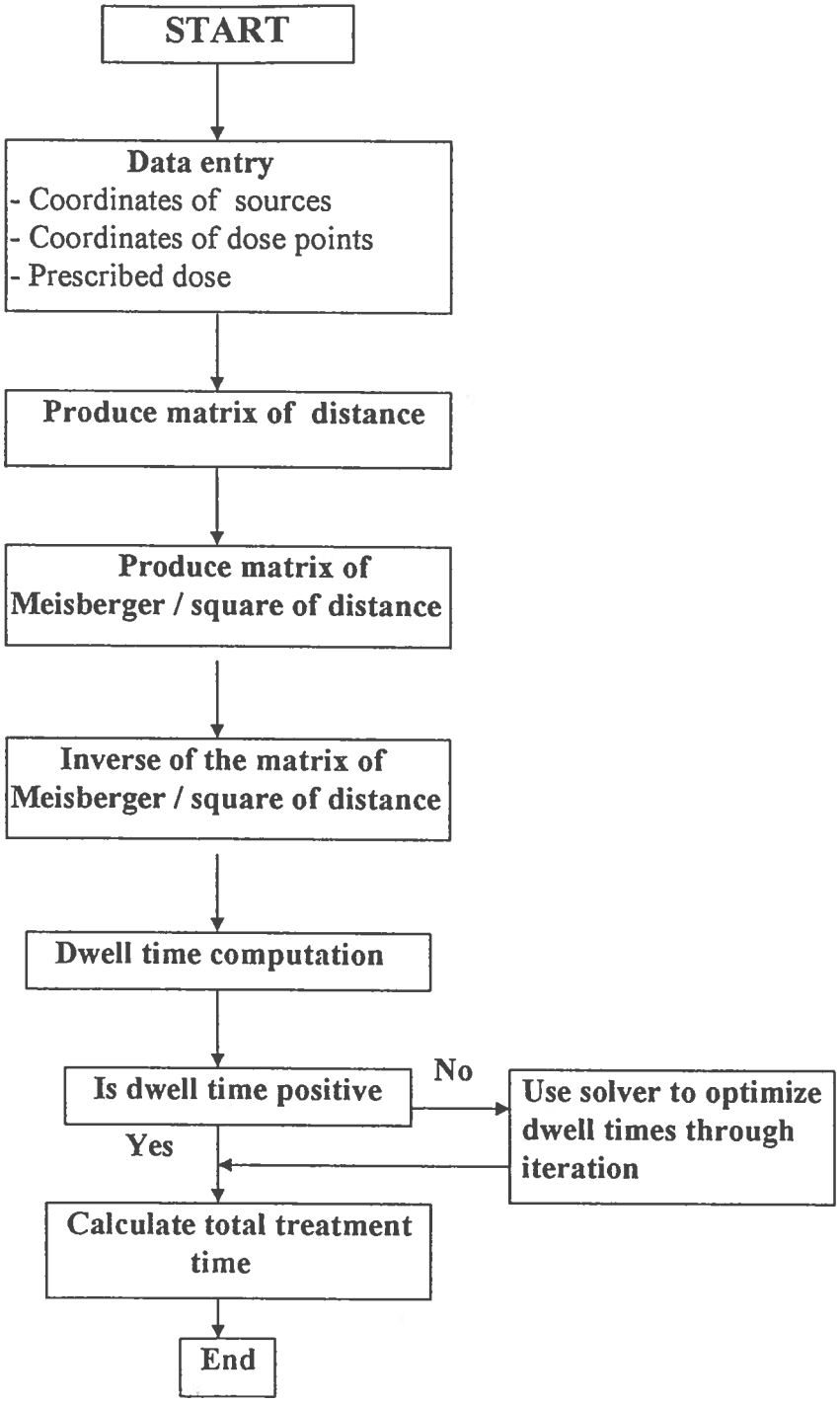


Figure 3.1: Flowchart of the Time program developed on personal computer

III) Matrix #2

The second matrix which is also a 50 by 50 spread sheet uses coordinates of the sources and dose points to calculate the Meisberger factor. It should be noted that, the Meisberger factor corrects for the absorption and scattering by the tissue. Excel uses equation 2.2.1 and matrix #1 to compute the "Matrix of the Meisberger / square of the distance".

IV) Matrix #3

The last 50 by 50 square spread sheet is the inverse of matrix #2. Since division is not defined for matrix algebra, Excel is used to compute the "Inverse Matrix" as a part of equation 3.2.6.

V) Matrix of time

Computed dwell times of an iridium source is shown in the program as a 50 by 1 (one column) matrix. Excel multiplies matrix#3 by the input prescribed dose and puts the result in the first worksheet. It also gives the total treatment time and compare it with the Nucletron treatment time. From the physics point of view, the appearance of negative dwell times in the result is not acceptable even though mathematically it is a correct answer. Therefore, when dwell times are calculated, a method should be used to convert negative dwell times to positive dwell times based on the same dose distributions. This method will be discussed later in this chapter.

3.4 Optimization methods

In high dose rate brachytherapy, optimization is used to optimize the dose distribution of implant by adjusting the dwell time of the stepping source in each dwell

position. In other words, optimized dwell times should produce an appropriate dose distribution. Depending on the circumstances of a particular case, this may mean a uniform dose, or greater dose in the center or any other desired shape. To optimize a stepping source implant, there are different approaches such as "optimization on distance" and "optimization on volume" [2]. When an isodose surface with a given dose is required at a given distance from the catheters, the optimization on distance approach is used. This approach is made in a single plane implant. On the other hand optimization on volume which is made in a multi-plane implant is searching for a homogeneous dose distribution in the volume between the catheters.

In the Time program developed on PC, optimization appears on the spreadsheet as a column of numbers which can be changed using solver through several iterations (see user manual, Appendix I). In the case of negative dwell times, with the help of the solver computer optimizes the dose until it satisfies the constraints and give us the positive times. The programming details about the solver is explained in the user manual in Appendix I.

3.5 A sample case

In this section, a sample case for an iridium source is solved by using the Time program. Also, isodose distributions are compared with the results obtained from other brachytherapy planning systems. Later in chapter 5, a similar comparison for a LDR brachytherapy in which a cesium source is used will be presented. Tables 3.5.2 and 3.5.3 show the comparison of the Nucletron microSelectron-HDR treatment planning, Capintec treatment planning, Theraplan treatment planning, and our Time

program developed on PC for the same case. This comparison is done for a two catheter endobronchial case with a prescription of 750 cGy at a 10mm distance from the catheters. Isodose distributions generated by using the time computed on a PC show an excellent agreement with the results obtained from the other brachytherapy planning systems. Based on the measurements presented in tables 3.5.2 and 3.5.3, PC results within 0-1 mm, fit very well with the other treatment planning systems. Table 3.5.1 represents a comparison of the dwell times calculated on a PC program with the times calculated by Nucletron for the sample case. It can be seen from this table that each computer calculated a different set of dwell times for this case. Comparison between isodose distributions generated by these different sets of dwell times reveals that there are in fact different combinations of dwell times that satisfy the same prescribed dose. For further comparison, isodose distributions generated with different treatment planning systems are presented in this section. It should be noted that, the magnification factor for all the distributions is not the same, but comparison between them were done in a life size scale.

Table 3.5.1: Comparison of the dwell times calculated by PC with the times calculated by Nucletron computer for the sample case.

Dose point #	Nucletron calculated dwell times	Personal Computer calculated dwell times
1	38.5 sec	43.1 sec
2	25.9 sec	26.5 sec
3	12.9 sec	14.4 sec
4	7.7 sec	1.0 sec
5	8.3 sec	7.2 sec
6	9.4 sec	26.5 sec
7	9.3 sec	1.0 sec
8	10.1 sec	1.0 sec
9	12.5 sec	26.5 sec
10	15.0 sec	1.0 sec
11	16.2 sec	26.4 sec
12	16.0 sec	1.0 sec
13	13.4 sec	26.5 sec
14	11.2 sec	3.1 sec
15	14.8 sec	21.2 sec
16	27.5 sec	26.5 sec
17	40.9 sec	44.8 sec
18	38.5 sec	42.2 sec
19	26.6 sec	26.5 sec
20	15.1 sec	21.8 sec
21	11.8 sec	1.0 sec
22	13.0 sec	14.5 sec
23	12.5 sec	26.5 sec
24	10.1 sec	1.0 sec
25	8.7 sec	19.0 sec
26	9.7 sec	1.0 sec
27	11.3 sec	26.5 sec
28	11.7 sec	1.6 sec
29	11.5 sec	25.3 sec
30	13.6 sec	7.9 sec
31	20.3 sec	26.5 sec
32	27.4 sec	26.5 sec

Total treatment time for Nucletron = 531.4 sec
Total treatment time for PC = 564.5 sec

Table 3.5.2: Comparison between different treatment planning systems along the positive axes for the sample case for Ir-192.

Dosimetry Planning System	750 cGy isodose along the X-axis	750 cGy isodose along the Y-axis	750 cGy isodose along the Z-axis
Nucletron	X_N= 16± (1 mm)	Y_N= 46± (1 mm)	Z_N= 14± (1 mm)
Capintec	X_C= 15± (1 mm)	Y_C= 47± (1 mm)	Z_C= 14± (1 mm)
Theraplan	X_T= 16± (1 mm)	Y_T= 46± (1 mm)	Z_T= 15± (1 mm)
PC	X_P= 16± (1 mm)	Y_P= 46± (1 mm)	Z_P= 14± (1 mm)

Table 3.5.3: Comparison between different treatment planning systems along the negative axes for the sample case for Ir-192.

Dosimetry Planning System	750 cGy isodose along the X-axis	750 cGy isodose along the Y-axis	750 cGy isodose along the Z-axis
Nucletron	X_N= 9± (1 mm)	Y_N= 41± (1 mm)	Z_N= 10± (1 mm)
Capintec	X_C= 9± (1 mm)	Y_C= 41± (1 mm)	Z_C= 10± (1 mm)
Theraplan	X_T= 10± (1 mm)	Y_T= 42± (1 mm)	Z_T= 10± (1 mm)
PC	X_P= 9± (1 mm)	Y_P= 41± (1 mm)	Z_P= 10± (1 mm)

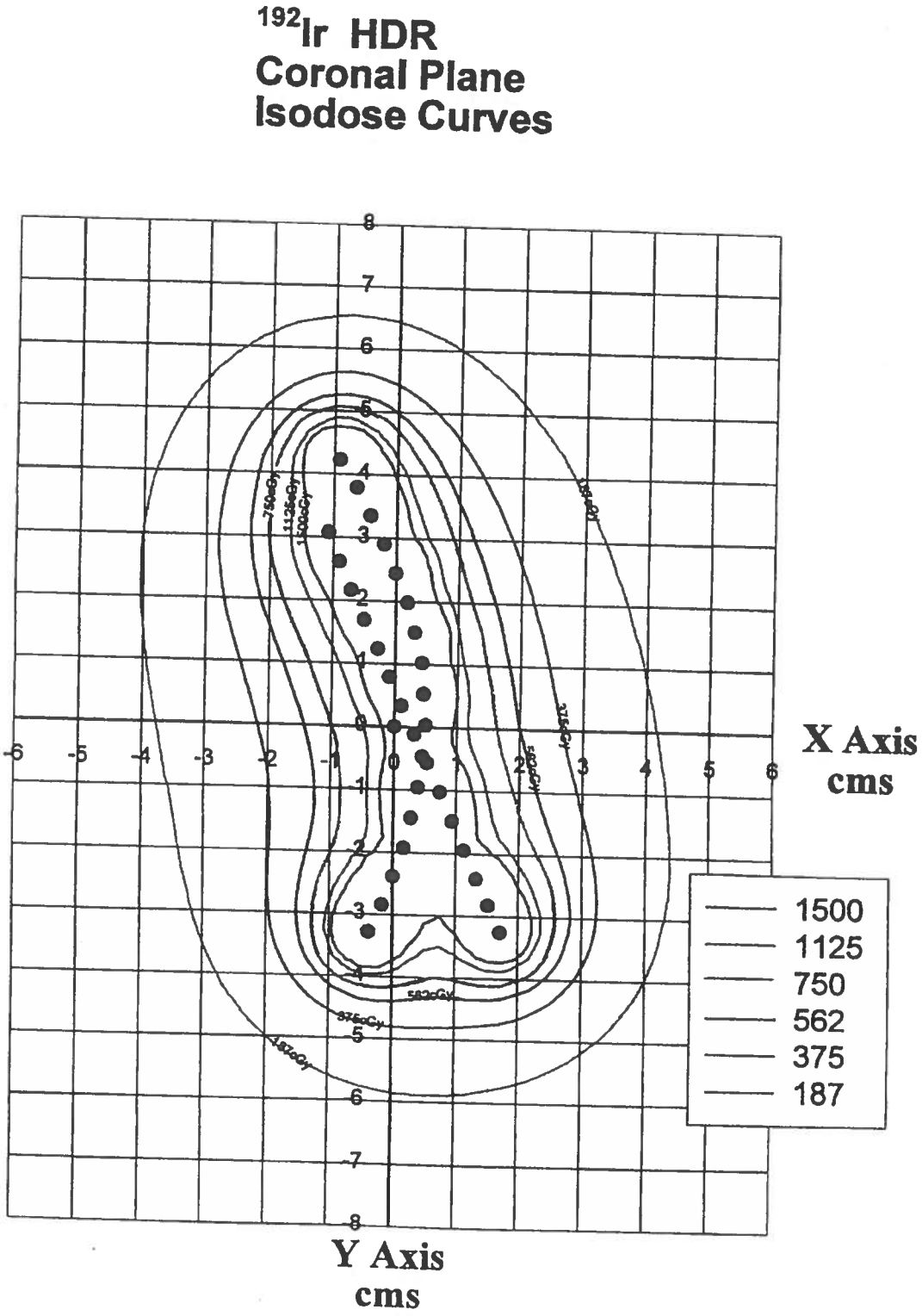


Fig 3.5.1: Coronal plane for the two catheter case (Ir-192), using personal computer

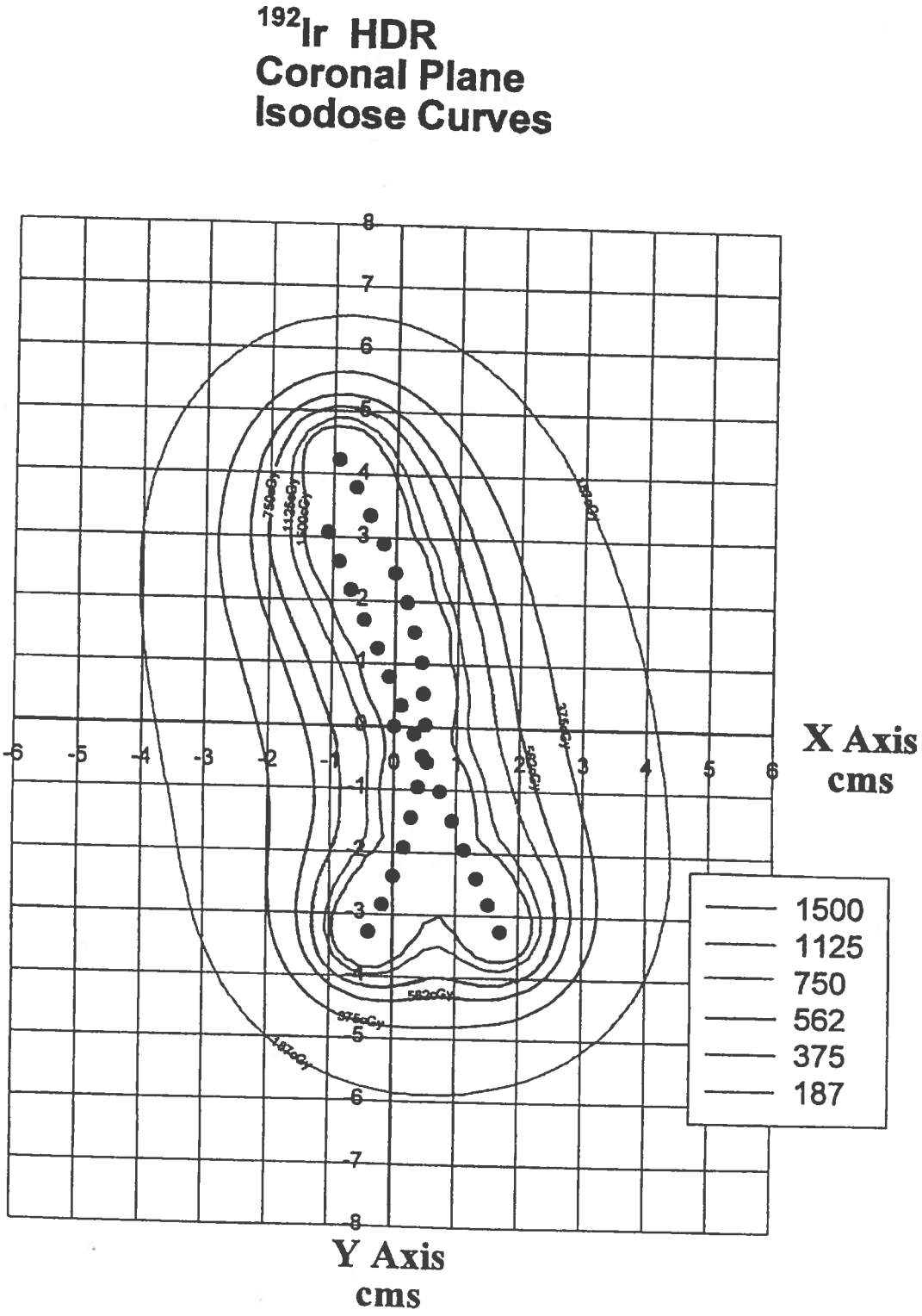


Fig 3.5.1: Coronal plane for the two catheter case (Ir-192), using personal computer

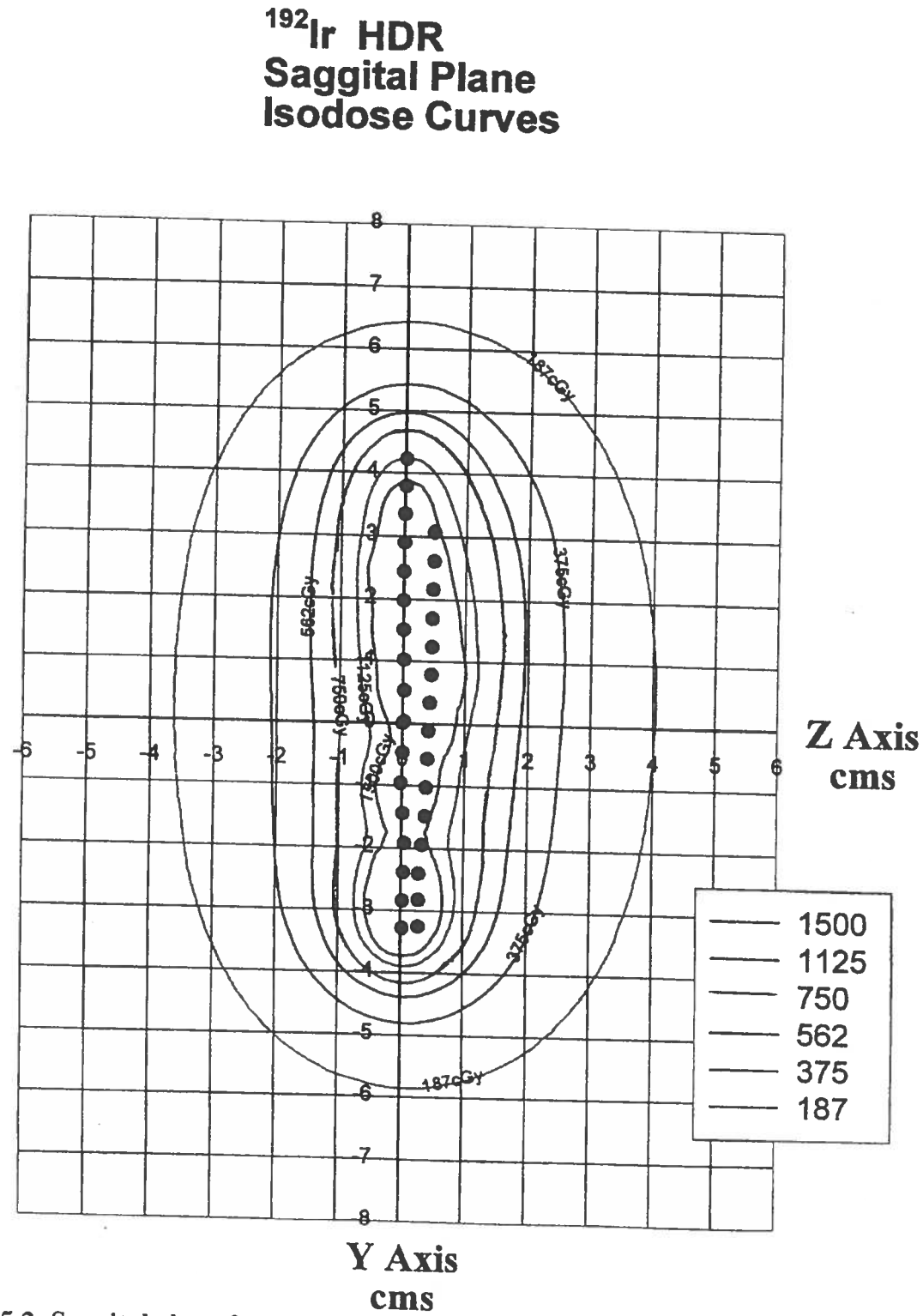


Fig 3.5.2: Saggital plane for the two catheter case (Ir-192), using personal computer

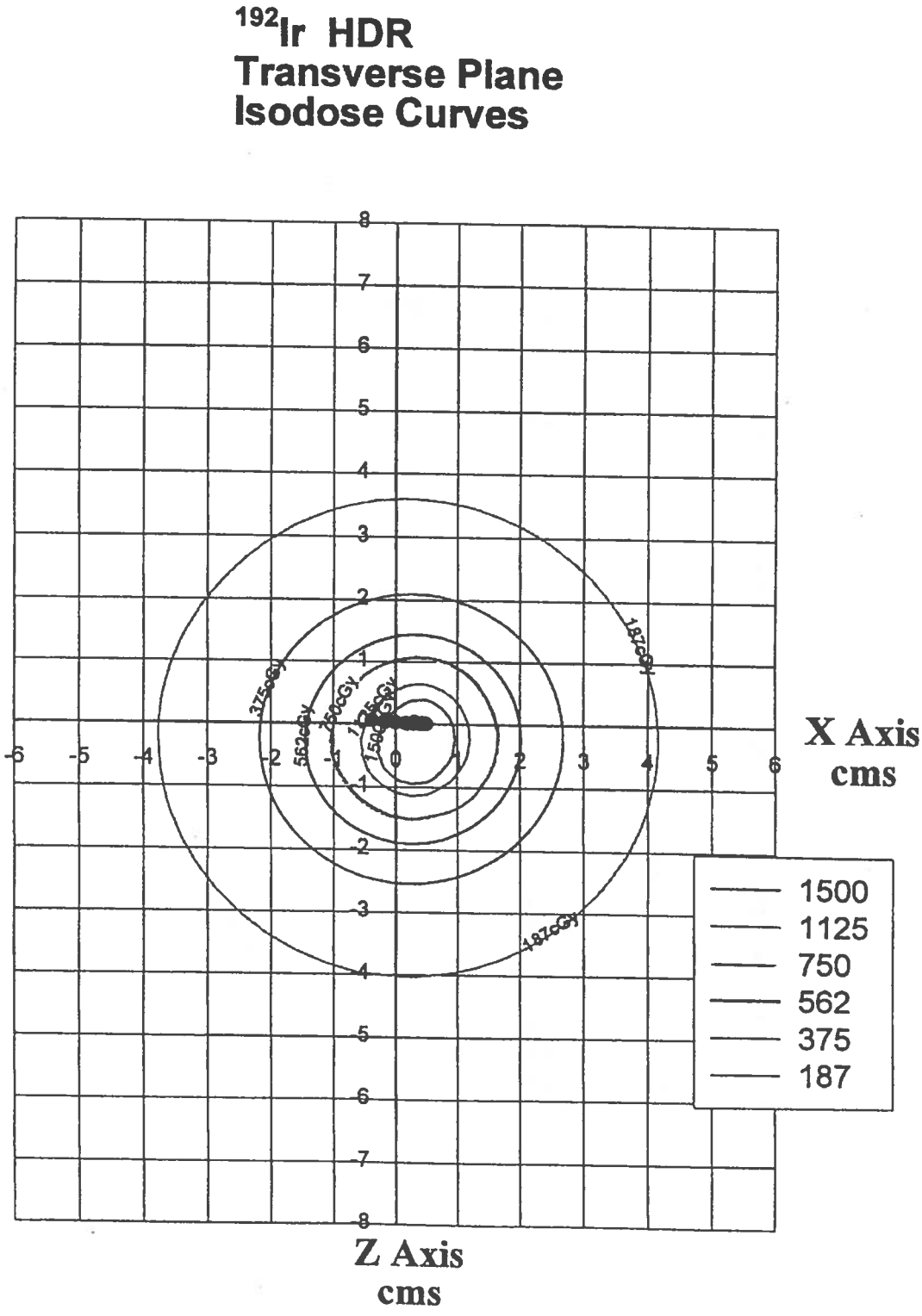


Fig 3.5.3: Transverse plane for the two catheter case (Ir-192), using personal computer

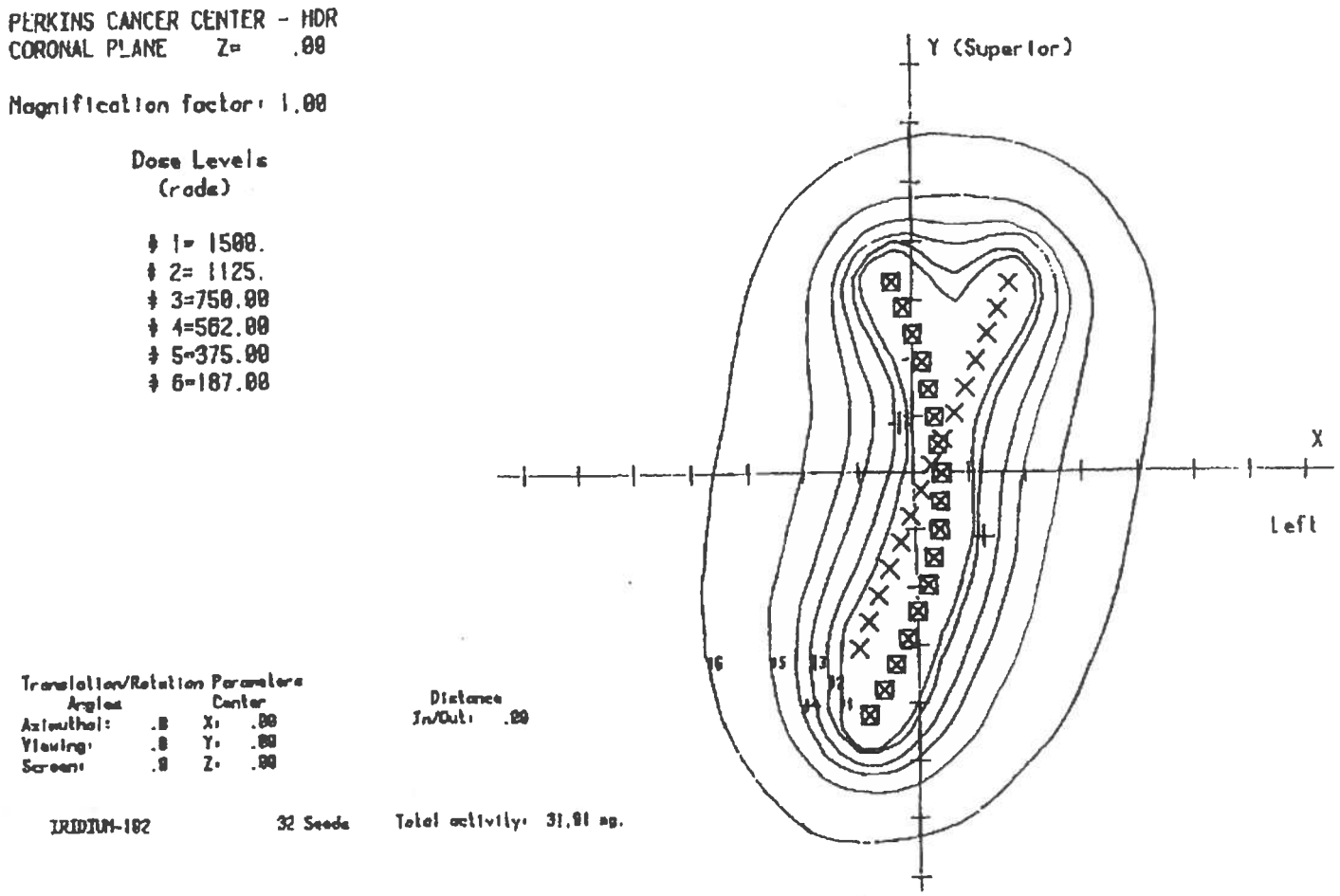


Fig 3.5.4: Coronal plane for the two catheter case (Ir-192), using Capintec computer

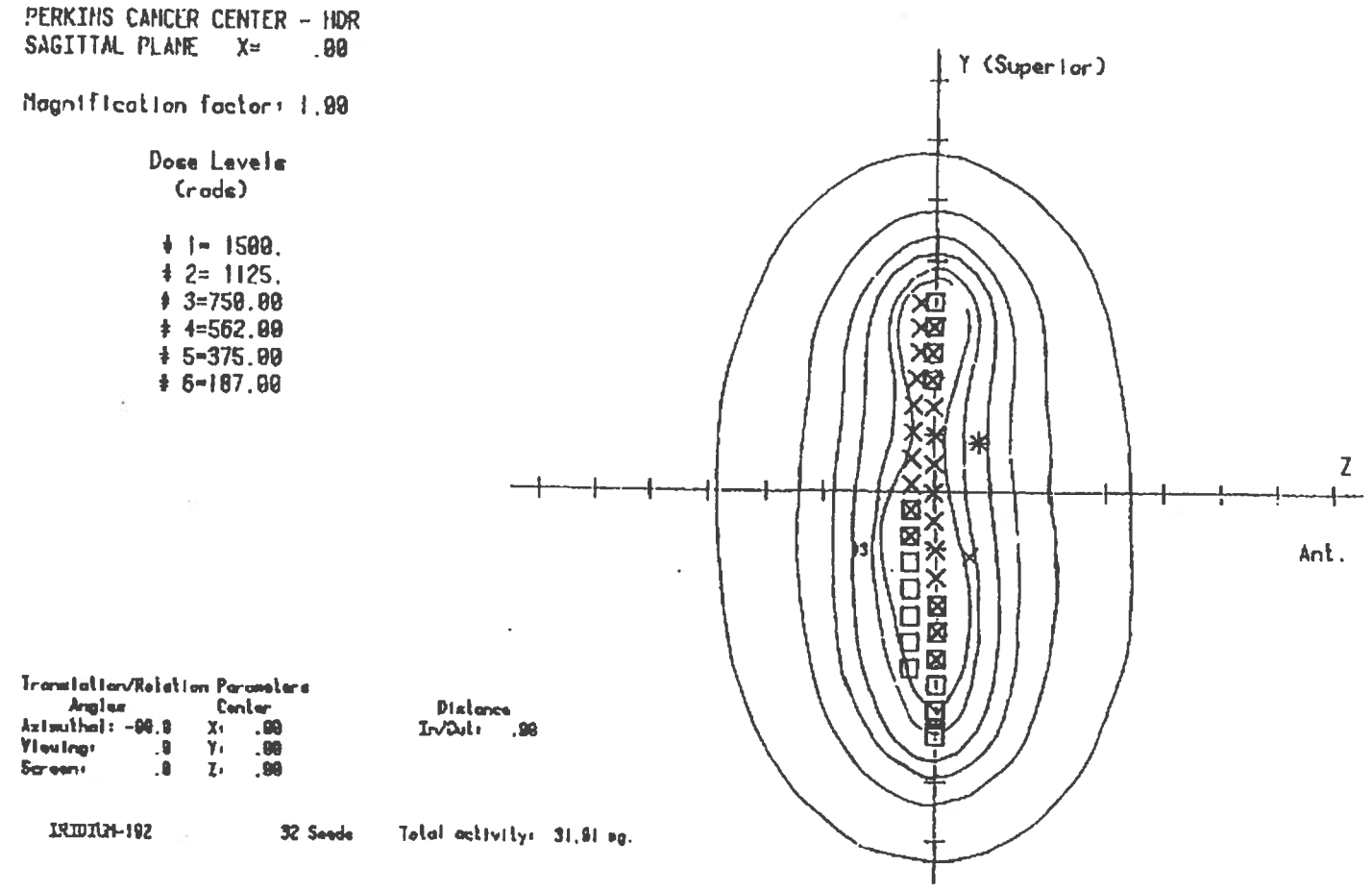


Fig 3.5.5: Saggital plane for the two catheter case (Ir-192), using Capintec computer

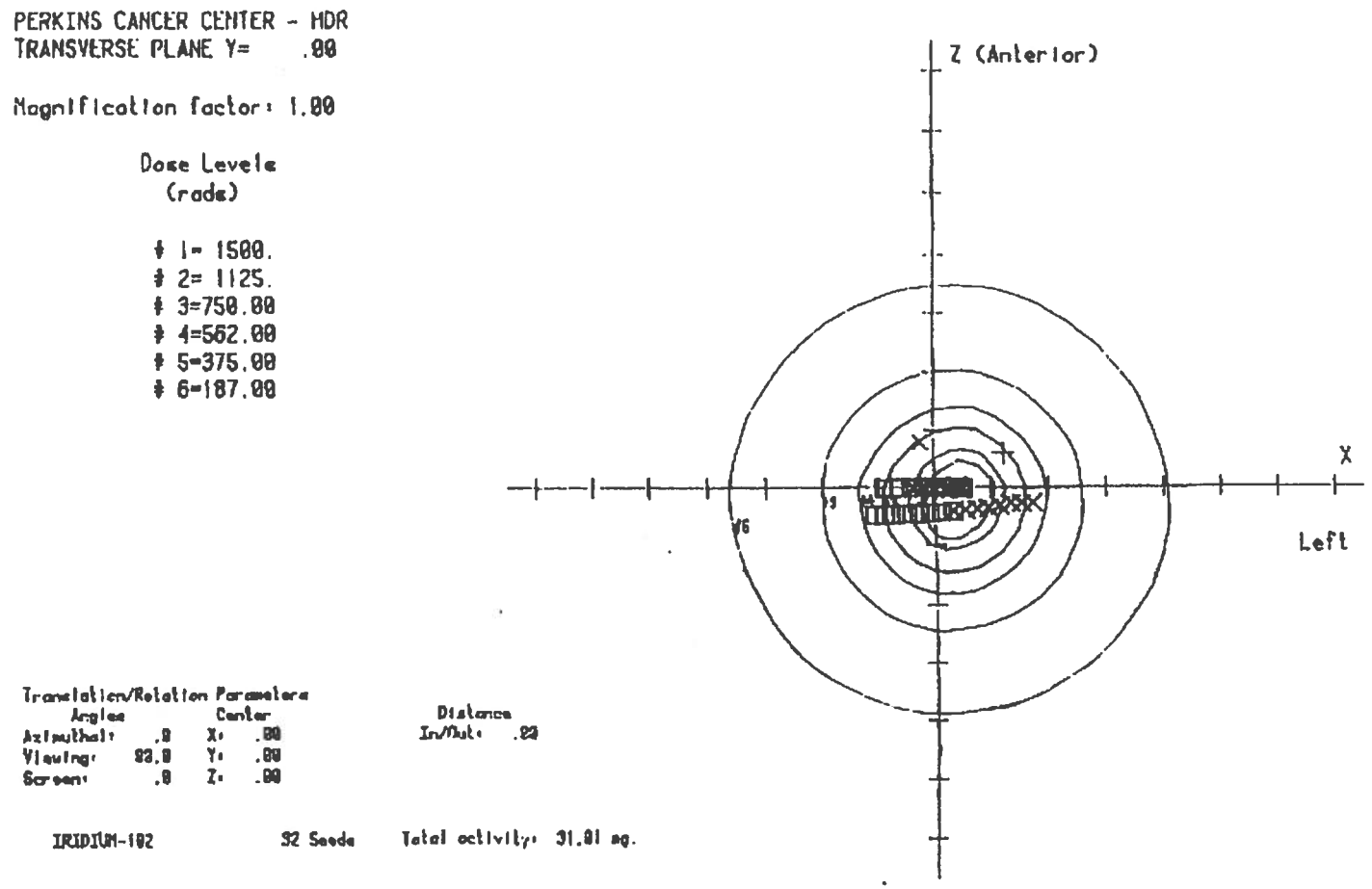


Fig 3.5.6: Transverse plane for the two catheter case (Ir-192), using Capintec computer

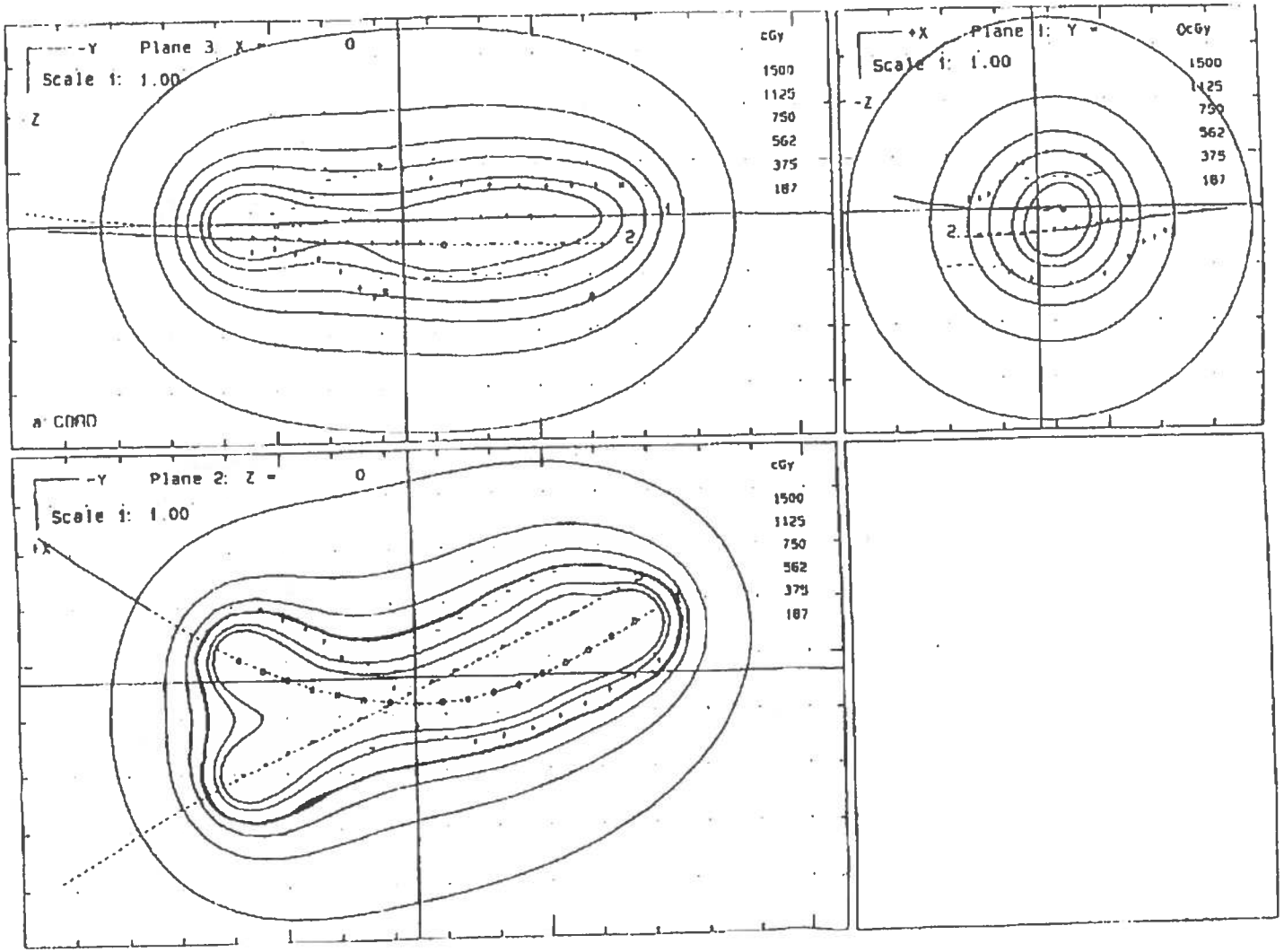


Fig 3.5.7: Isodose distributions for the two catheter case (Ir-192), using Nucletron computer

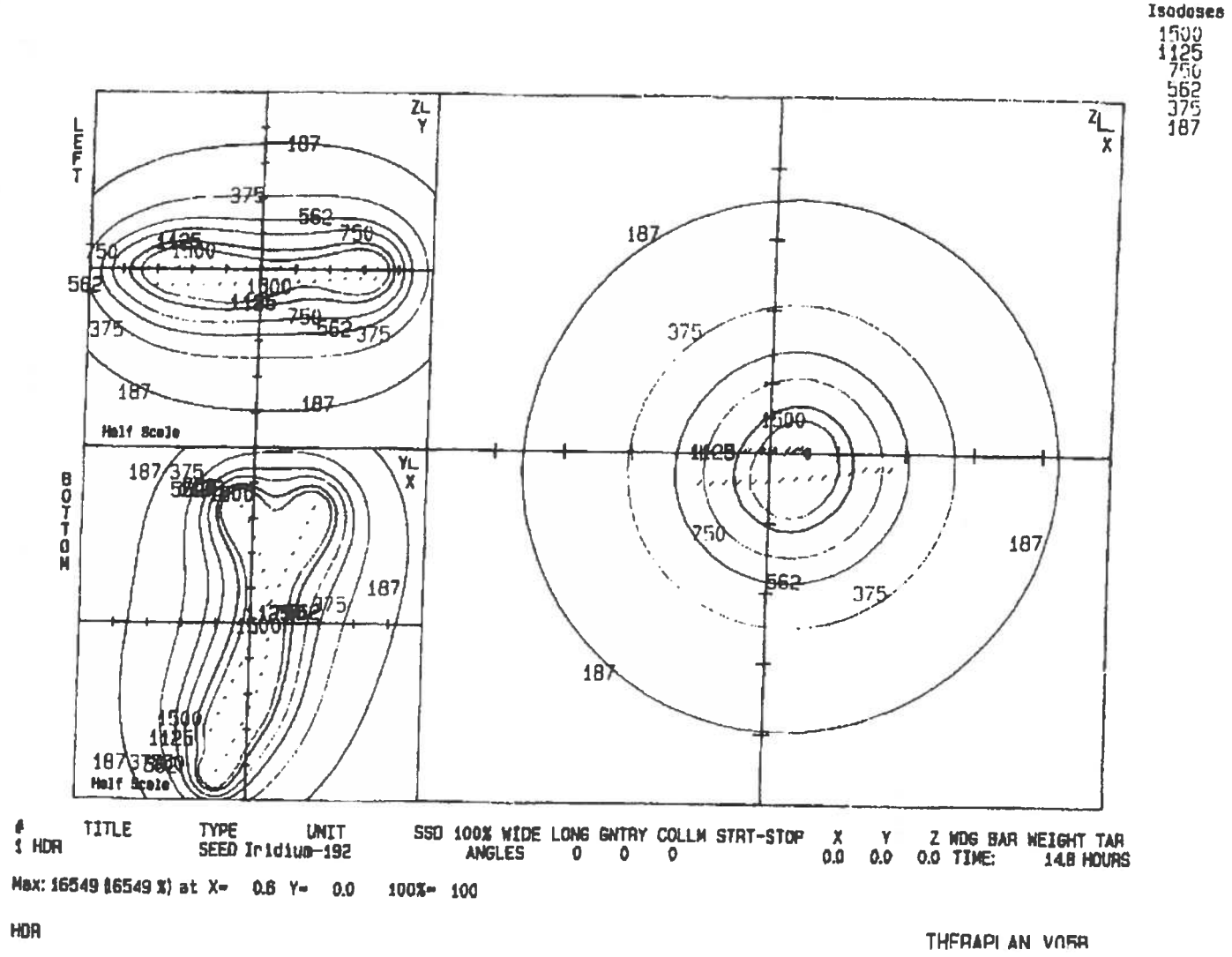


Fig 3.5.8: Isodose distribution for the two catheter case (Ir-192), using Theraplan computer

CHAPTER 4

PERSONAL COMPUTER GENERATED ISODOSE DISTRIBUTIONS FOR VAGINAL CYLINDERS

4.1 Introduction:

The most common malignancy arising in the female genital tract is Endometrial carcinoma[10]. Total abdominal hysterectomy with or without postoperative irradiation is usually considered as a primary treatment for stage I disease. Also, in patients determined to be at risk for locoregional recurrence, intracavitary vaginal cuff irradiation with or without external beam may be considered. Vaginal cylinders can be used for HDR brachytherapy as well as LDR brachytherapy to deliver cuff irradiation. The Mary Bird Perkins Cancer Center uses the HDR vaginal applicator set which is manufactured by Nucletron Corporation, Columbia, USA. The vaginal applicator set consists of solid sections (cylinder-shaped) each 2.5 cm in length. Each section, including the dome apical section, is marked with wires around the circumference. These sections are mounted on a stainless steel tube thru which the source travels and stops at dwell positions either 5 or 2.5 mm apart. The dwell position closest to the apex is approximately 6 mm from the apex[11]. This applicator is made of Derlin which is a polymerized formaldehyde plastic with a mass density of 1.43 g/cm^3.

In this chapter, "Time" computer program (explained in chapter3) will be used to calculate the dwell times of an HDR source, in order to generate the most common prescribed isodose distributions around the vaginal cylinders.

4.2 Method and materials

There are five HDR vaginal cylinders with diameters of 2.0, 2.5, 3.0, 3.5, and 4.0 centimeters each currently in use at Mary Bird Perkins Cancer Center. To get the input data for "Time" , radiographs of the vaginal cylinders are traced on regular graph paper. Then, by choosing an origin in the center of the cylinder, coordinates of the sources and the points where the dose was spesified can be obtained for input data. The dwell times of an HDR ^{192}Ir source and the isodose distributions are generated on a personal computer. Also, for the purpose of comparison, each case is done with the Nucletron treatment planning computer. In this chapter, some of the examples with tables of comparison will be presented.

4.2.1 Case #1

This example is done for the 3.5 cm diameter, 10.0 cm length vaginal cylinder. Using "Time", dwell times of the source are calculated to obtain 500 cGy at 5 mm distance from the cylinder and the dome surface. The total number of activated dwell positions in a real treatment procedure depend on the volume of the treated organ. Since this case and the following one are only examples, 20 dwell positions are considered for the calculations. Table 4.2.1.1 summarizes the information used in this case as well as coordinates and calculated dwell times on the personal computer. Also, this case is done with the Nucletron computer and table 4.2.1.2 presents more information about this example as well as calculated dwell times by this computer. It should be noted that each computer generated different dwell times for this case. This proves the fact that there are different combinations of dwell times to satisfy the

same dose. Even though Nucletron dwell times are more uniform than the PC ones, generated isodose distributions for PC results, shows the better agreement with the prescription. This can be seen from the shape of 500 cGy isodose, especially around the cylinder dome. Isodose distributions for the dwell times calculated by PC are shown in figures 4.2.1.1, 4.2.1.2, and, 4.2.1.3. Also, Nucletron generated isodose distributions for the same dwell times are shown in figure 4.2.1.4. Tables 4.2.1.3 and 4.2.1.4 are the results of comparison between isodose distributions generated by PC and Nucletron computer. This comparison, once again shows the acuracy of the Time program developed on PC. Also, isodose distributions for the Nucletron calculated dwell times are presented in figure 4.2.1.5. One way to evaluate both PC and Nucletron generated isodose distributions is to measure the variation of the dose from 500 cGy at 22.5 cm distance from the midline along Y axis and at the dome point. The result of the evaluation is presented in table 4.2.1.5 . Based on the presented evaluation PC generated isodose distributions have less variations from the prescribed dose. Also, at the dome surface, PC dwell times satisfy the dose better than Nucletron dwell times.

4.2.2 Case #2

This example is done for the 3.0 cm diameter, 10.0 cm length vaginal cylinder. Personal computer is used to calculate the dwell times of the source to obtain 500 cGy at 5 mm distance from the cylinder and dome surface. Table 4.2.2.1 summarizes the informations used in this case as well as coordinates and calculated dwell times on the personal computer. Also, this case is done with the Nucletron computer and its calculated dwell times are presented in table 4.2.2.2. As shown earlier in the other

case, each computer generated a different set of dwell times for 3.0 cm vaginal cylinder case. Figures 4.2.2.1, 4.2.2.2, and, 4.2.2.3 are presentations of isodose distributions generated with PC for the dwell times calculated by "Time'. Also, Nucletron generated isodose distributions for the same dwell times are shown in figure 4.2.2.4. Results of the comparison between isodose distributions generated by PC and Nucletron computer are presented in tables 4.2.2.3 and 4.2.2.4. These tables show an excellant agreement between distributions generated with PC and Nucletron distributions using PC dwell times for 3.0 vaginal cylinder. The result of the evaluation of the 500 cGy at 22.0 cm distance from the midline along Y axis is presented in table 4.2.2.5. the isodose distributions for the Nucletron calculated dwell times is presented in figure 4.2.2.5. The result of the comparison and evaluation of isodose distributions for this case reveals the same conclusions as the previous example (3.5 cm vag.cyl). That means, PC calculated dwell times are generated more uniform isodose distributions than Nucletron computer specially around the dome surface.

Table 4.2.1.1: Summary of information for Case#1, using PC to calculate the dwell times

NAME OF PATIENT:		case#1(3.5 cm vaginal cylinder)			
ACTIVITY OF THE SOURCE IN Ci TODAY:			10.00		
EXPOSURE CONST IN R-CM^2/SEC/Ci :			1.294		
POS. # OF SEED	SEED?		COORDINATE OF SEED		DWELL
	1. YES OR 0.NO		X (mm)	Y (mm)	Z (mm)	TIME (SEC)
1	1		0	45	0	3
2	1		0	40	0	9
3	1		0	35	0	92
4	1		0	30	0	57
5	1		0	25	0	1
6	1		0	20	0	1
7	1		0	15	0	6
8	1		0	10	0	6
9	1		0	5	0	6
10	1		0	0.1	0	1
11	1		0	-5	0	91
12	1		0	-10	0	1
13	1		0	-15	0	32
14	1		0	-20	0	1
15	1		0	-25	0	1
16	1		0	-30	0	6
17	1		0	-35	0	1
18	1		0	-40	0	1
19	1		0	-45	0	92
20	1		0	-50	0	64

Total treatment time = 472.0 sec

Table 4.2.1.2: Summary of information for case#1, using Nucletron to calculate the dwell times.

Pos.	Weight	Dwell times in sec.
1	0.42	16.6
2	0.64	25.1
3	0.73	28.9
4	0.75	29.5
5	0.71	28.0
6	0.64	25.2
7	0.56	21.9
8	0.48	18.7
9	0.40	15.8
10	0.35	13.7
11	0.32	12.5
12	0.31	12.3
13	0.34	13.3
14	0.39	15.4
15	0.47	18.6
16	0.58	22.7
17	0.69	27.3
18	0.82	32.1
19	0.92	36.3
20	1.00	39.3

Total treatment time = 453.2 sec

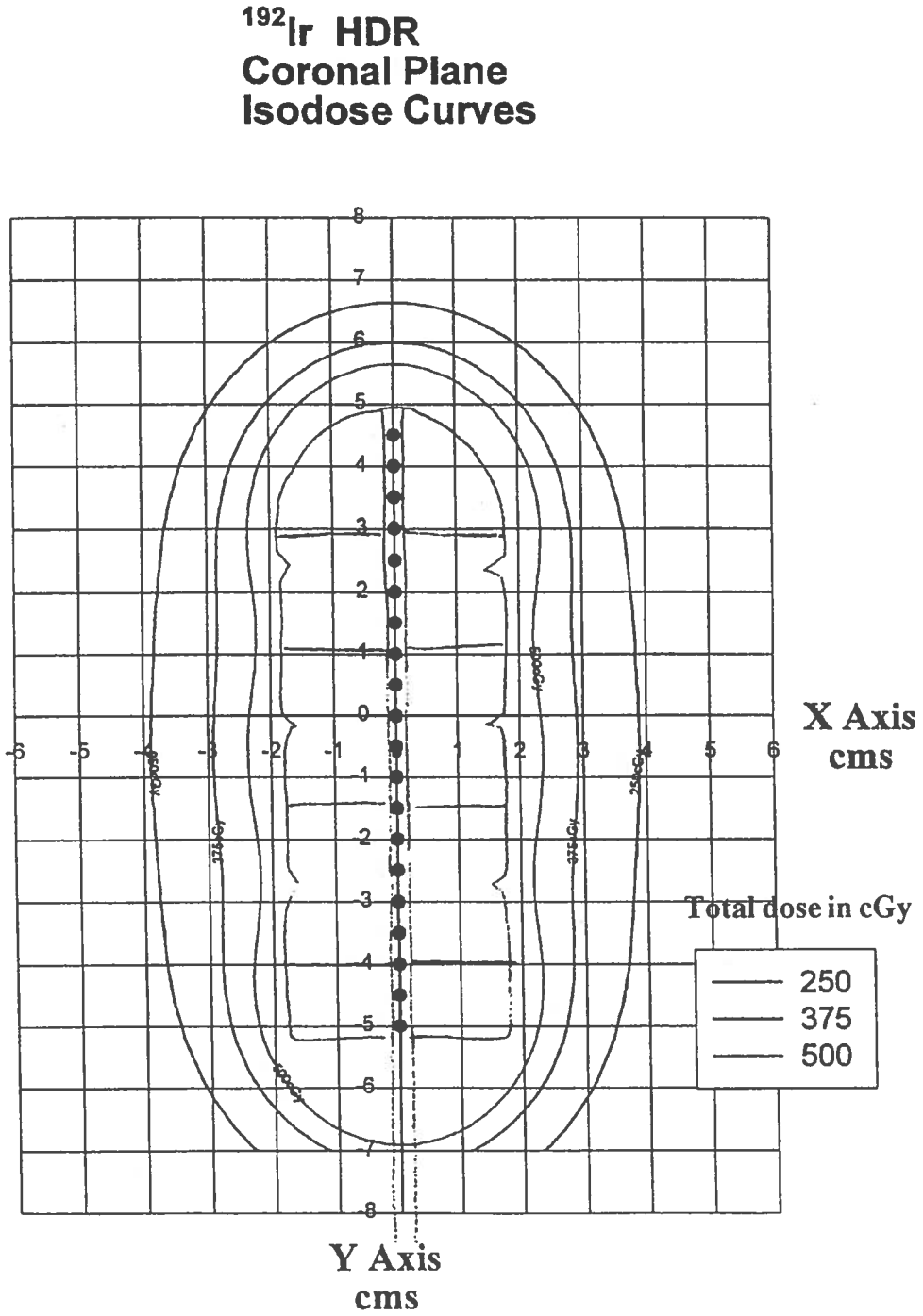


Fig 4.2.1.1: Isodose distributions generated with PC, using PC calculated time for case#1, to deliver 500 cGy at 5 mm from the cylinder.

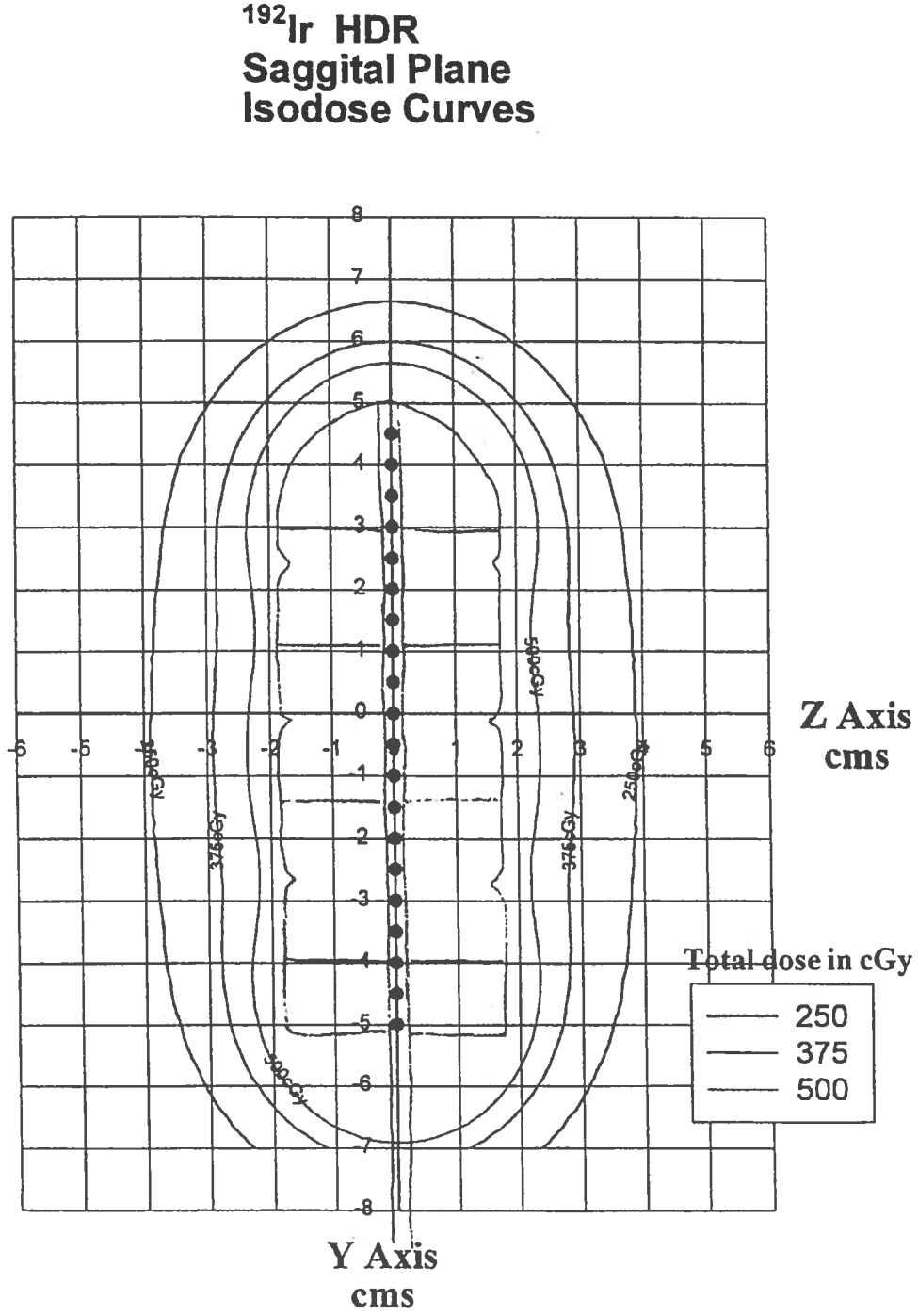


Fig 4.2.1.2: Isodose distributions generated with PC, using PC calculated time for case#1, to deliver 500 cGy at 5 mm from the cylinder.

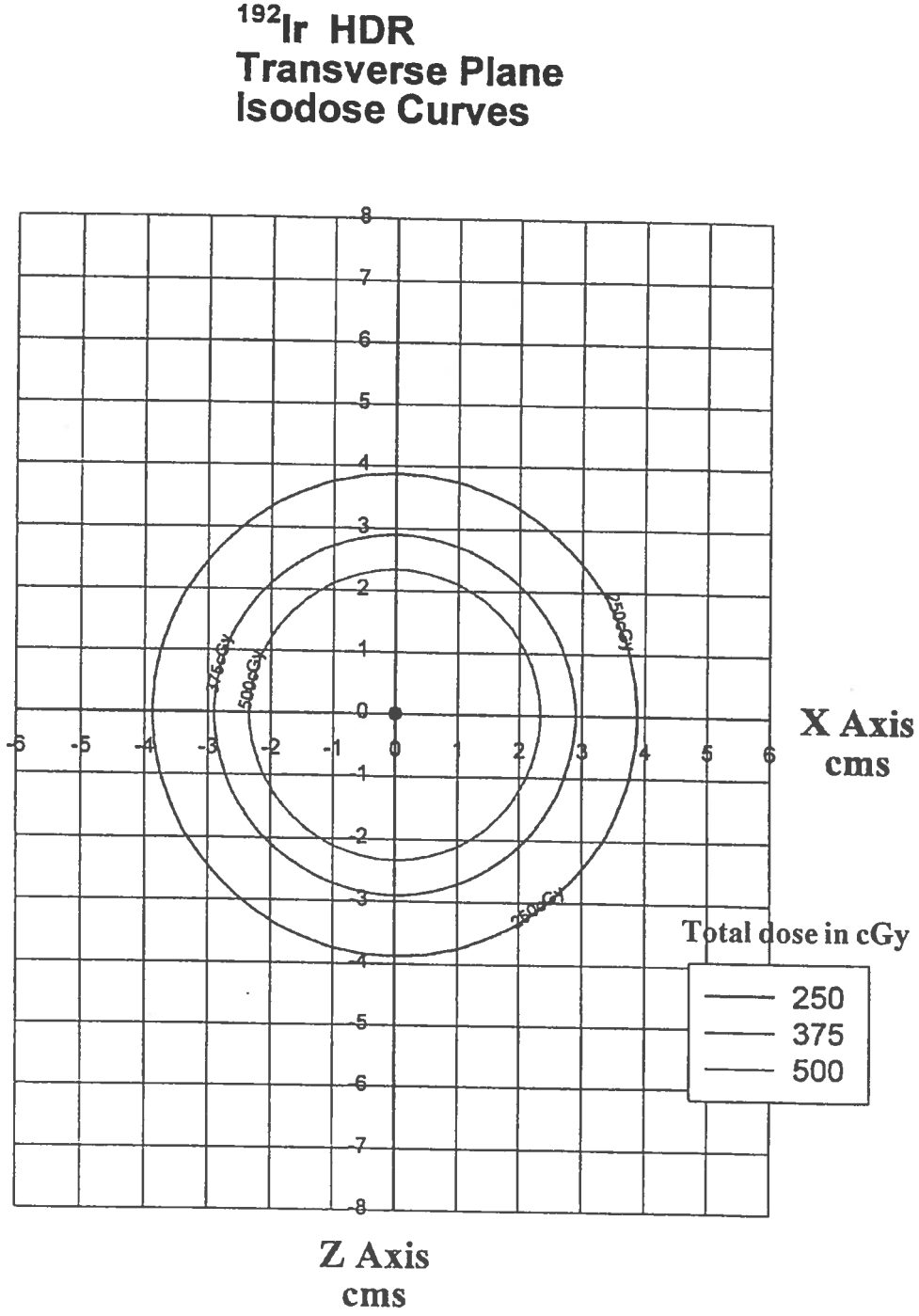


Fig 4.2.1.3: Isodose distributions generated with PC, using PC calculated time for case#1, to deliver 500 cGy at 5 mm from the cylinder.

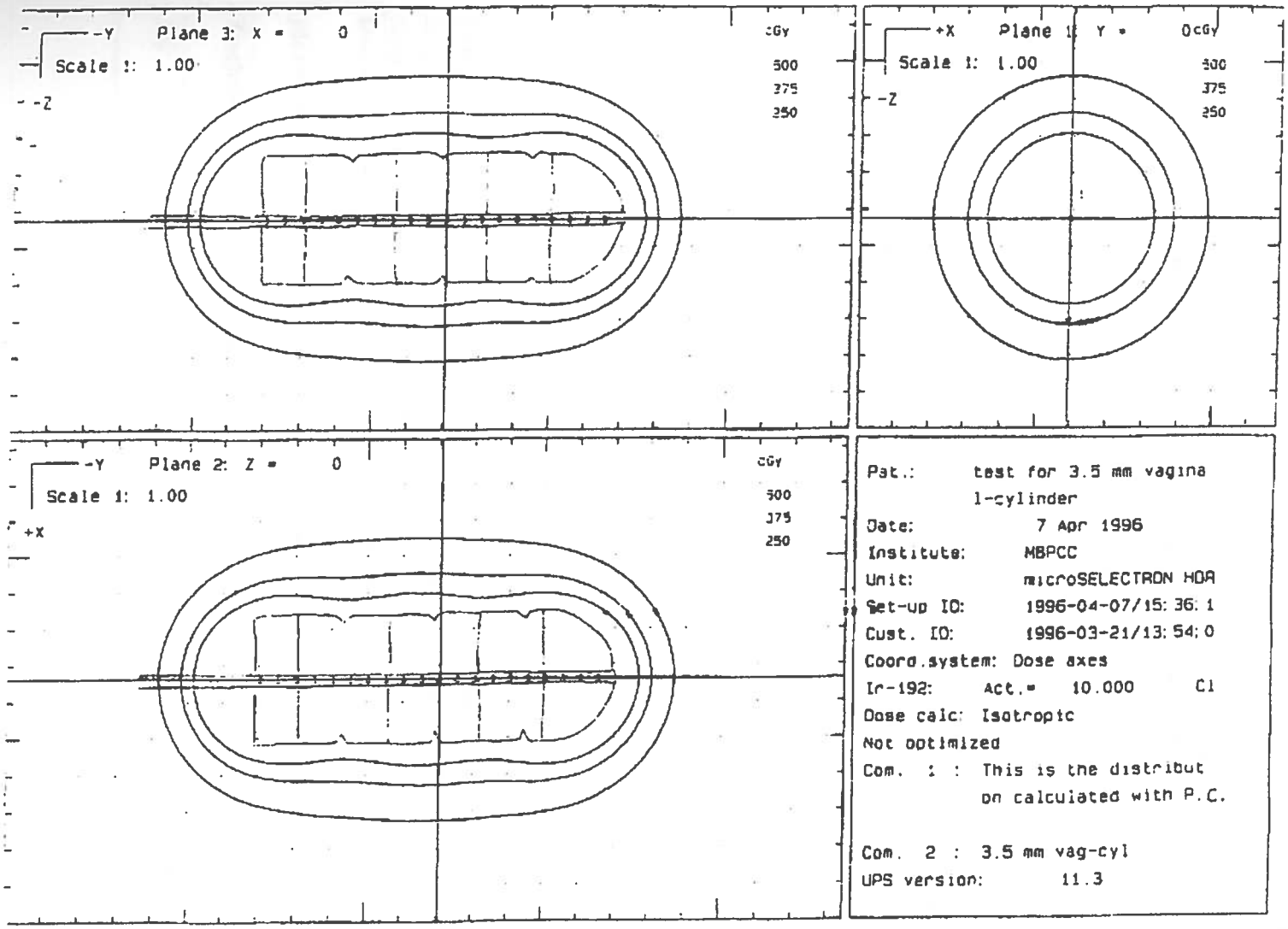


Fig 4.2.1.4: Isodose distributions generated with Nucletron computer, using PC calculated time for case#1

Table 4.2.1.3 Comparison between PC & Nucletron generated isodose distributions for vaginal cylinder (case #1) , using dwell times calculated with PC, along the positive axes.

Dosimetery planning system	500 cGy along the X-axis	500 cGy along the Y-axis	500 cGy along the Z-axis
Nucletron	X_N=23±1(mm)	Y_N=56±1(mm)	Z_N=23±1(mm)
PC	X_P=23±1(mm)	Y_P=56±1(mm)	Z_P=23±1(mm)

Table 4.2.1.4 Comparison between PC & Nucletron generated isodose distributions for vaginal cylinder (case #1) , using dwell times calculated with PC, along the negative axes.

Dosimetery planning system	500 cGy along the X-axis	500 cGy along the Y-axis	500 cGy along the Z-axis
Nucletron	X_N=23±1(mm)	Y_N=69±1(mm)	Z_N=23±1(mm)
PC	X_P=23±1(mm)	Y_P=69±1(mm)	Z_P=23±1(mm)

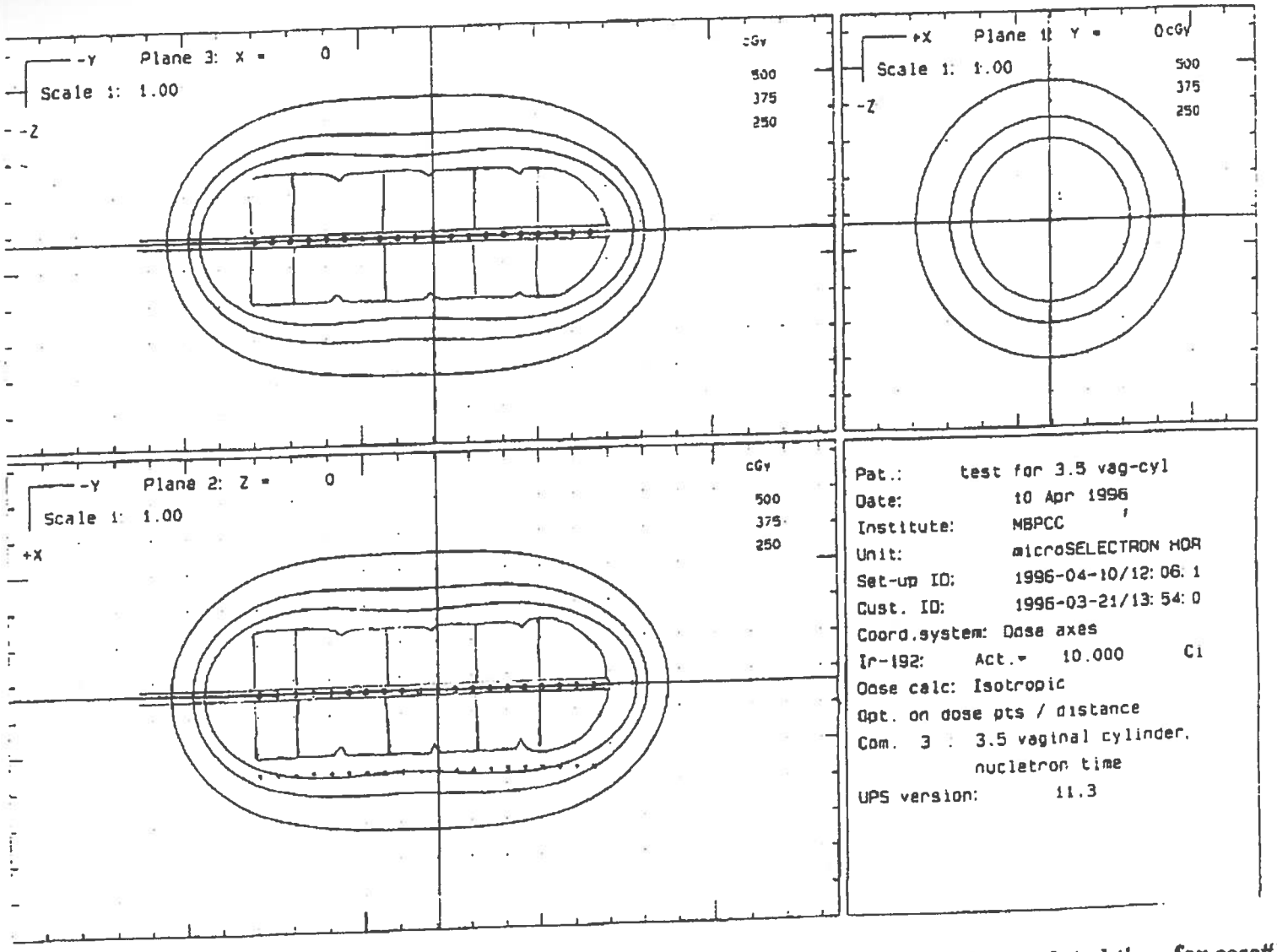


Fig 4.2.1.5: Isodose distributions generated with Nucletron computer, using Nucletron calculated time for case#1

Table 4.2.1.5: Evaluation of PC and Nucletron generated distributions for case#1 (3.5 cm vaginal cylinder).

Dose point	Coordinates of the point (X,Y,Z) in mm	Distance from 500 cGy Isodose for PC	Distance from 500 cGy Isodose for Nucletron
1	(22.5,4,0)	1mm	2mm
2	(22.5,3,0)	< 1mm	< 1mm
3	(22.5,2,0)	0mm	1mm
4	(22.5,1,0)	< 1mm	< 1mm
5	(22.5,0,0)	< 1mm	0mm
6	(22.5,-1,0)	0mm	0mm
7	(22.5,-2,0)	< 1mm	< 1mm
8	(22.5,-3,0)	1mm	1mm
9	(22.5,-4,0)	0mm	< 1mm
10	(22.5,-5,0)	< 1mm	2mm
dome point	(0,56.0,0)	< 1mm	1mm

Table 4.2.2.1: Summary of information for case#2, using PC to calculate the dwell times.

NAME OF PATIENT:		case#1(3.0 cm vaginal cylinder)			
ACTIVITY OF THE SOURCE IN Ci TODAY:			8.50		
EXPOSURE CONST IN R-CM^2/SEC/Ci :			1.294		
POS. # OF SEED	SEED?		COORDINATE OF SEED		DWELL
	1. YES OR 0.NO		X (mm)	Y (mm)	Z (mm)	TIME (SEC)
1	1		0	45	0	8
2	1		0	40	0	9
3	1		0	35	0	92
4	1		0	30	0	57
5	1		0	25	0	1
6	1		0	20	0	1
7	1		0	15	0	6
8	1		0	10	0	6
9	1		0	5	0	6
10	1		0	0.1	0	1
11	1		0	-5	0	91
12	1		0	-10	0	1
13	1		0	-15	0	32
14	1		0	-20	0	1
15	1		0	-25	0	1
16	1		0	-30	0	6
17	1		0	-35	0	1
18	1		0	-40	0	1
19	1		0	-45	0	92
20	1		0	-50	0	64

Total treatment time = 477 sec

Table 4.2.2.2: Summary of informations for case#2, using Nucletron to calculate the dwell times.

Pos.	Weight	Dwell times in sec.
1	0.57	23.1
2	0.74	29.9
3	0.75	30.4
4	0.69	27.9
5	0.61	24.6
6	0.53	21.5
7	0.47	19.1
8	0.43	17.5
9	0.41	16.4
10	0.39	15.7
11	0.38	15.2
12	0.37	14.9
13	0.37	15.1
14	0.39	15.8
15	0.44	17.6
16	0.51	20.8
17	0.63	25.3
18	0.77	30.9
19	0.91	36.6
20	1.00	40.4

Total treatment time = 458.7 sec

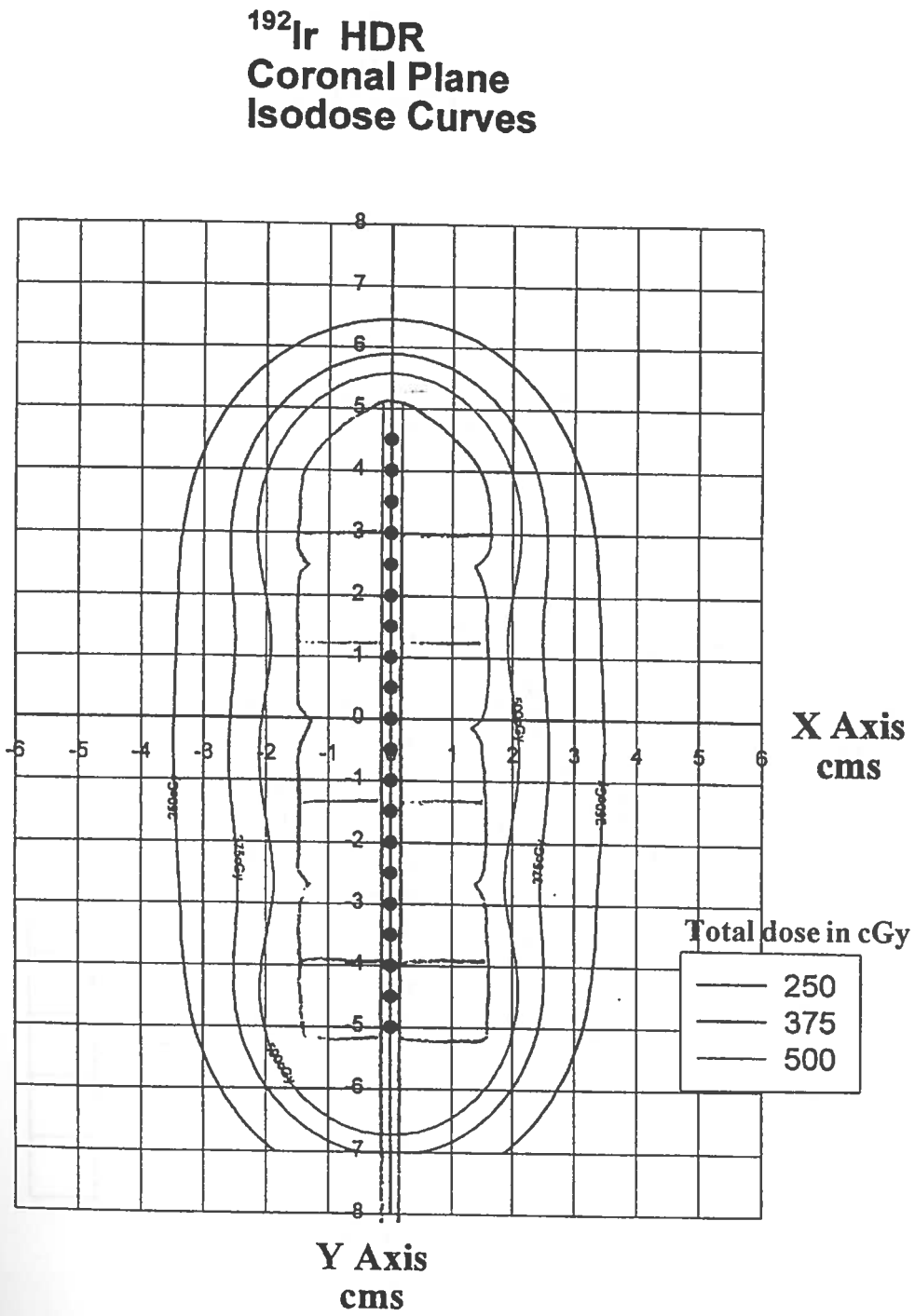


Fig 4.2.2.1: Isodose distributions generated with PC, using PC calculated time for case#2, to deliver 500 cGy at 5 mm from the cylinder.

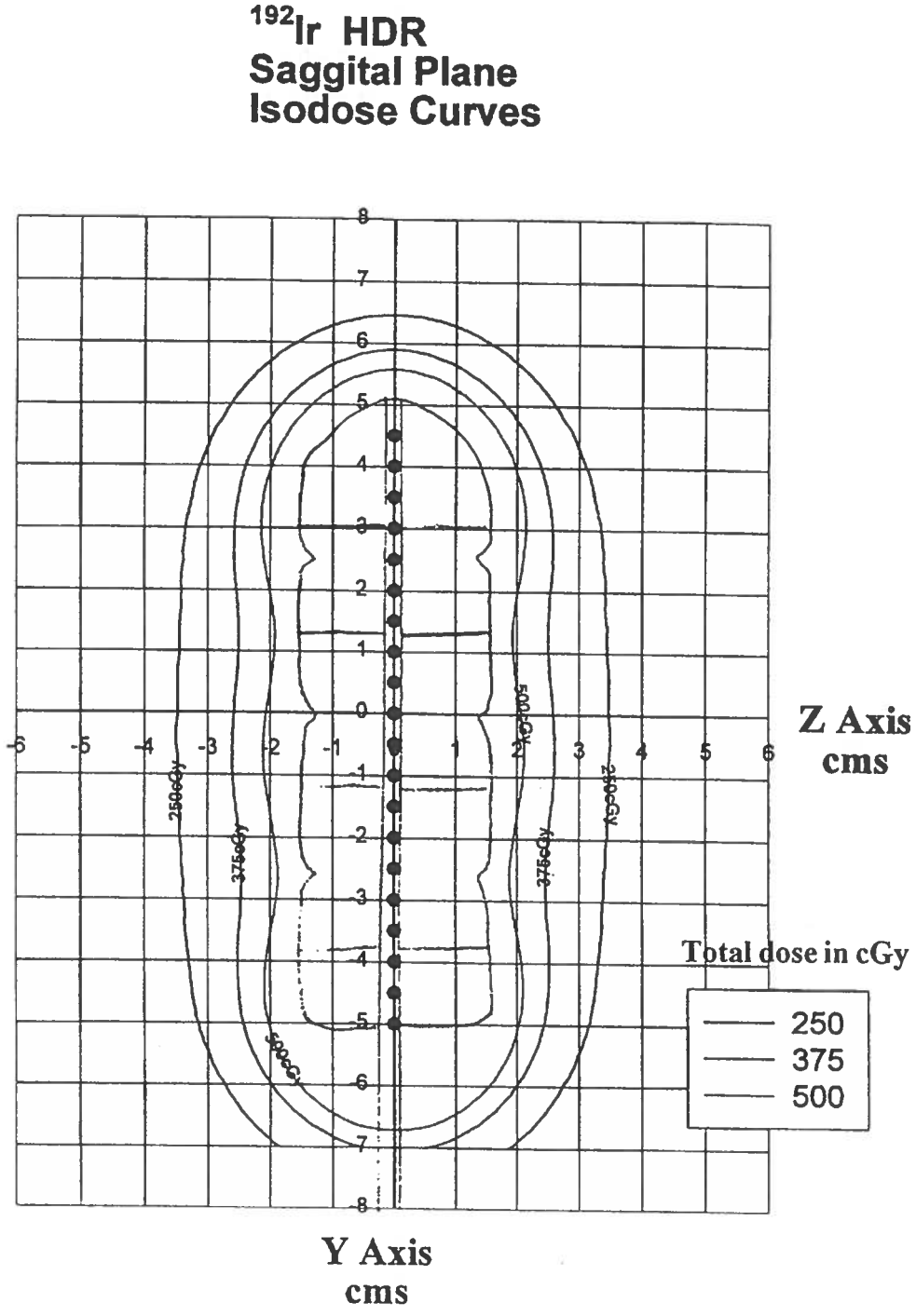


Fig 4.2.2.2: Isodose distributions generated with PC, using PC calculated time for case#2, to deliver 500 cGy at 5 mm from the cylinder.

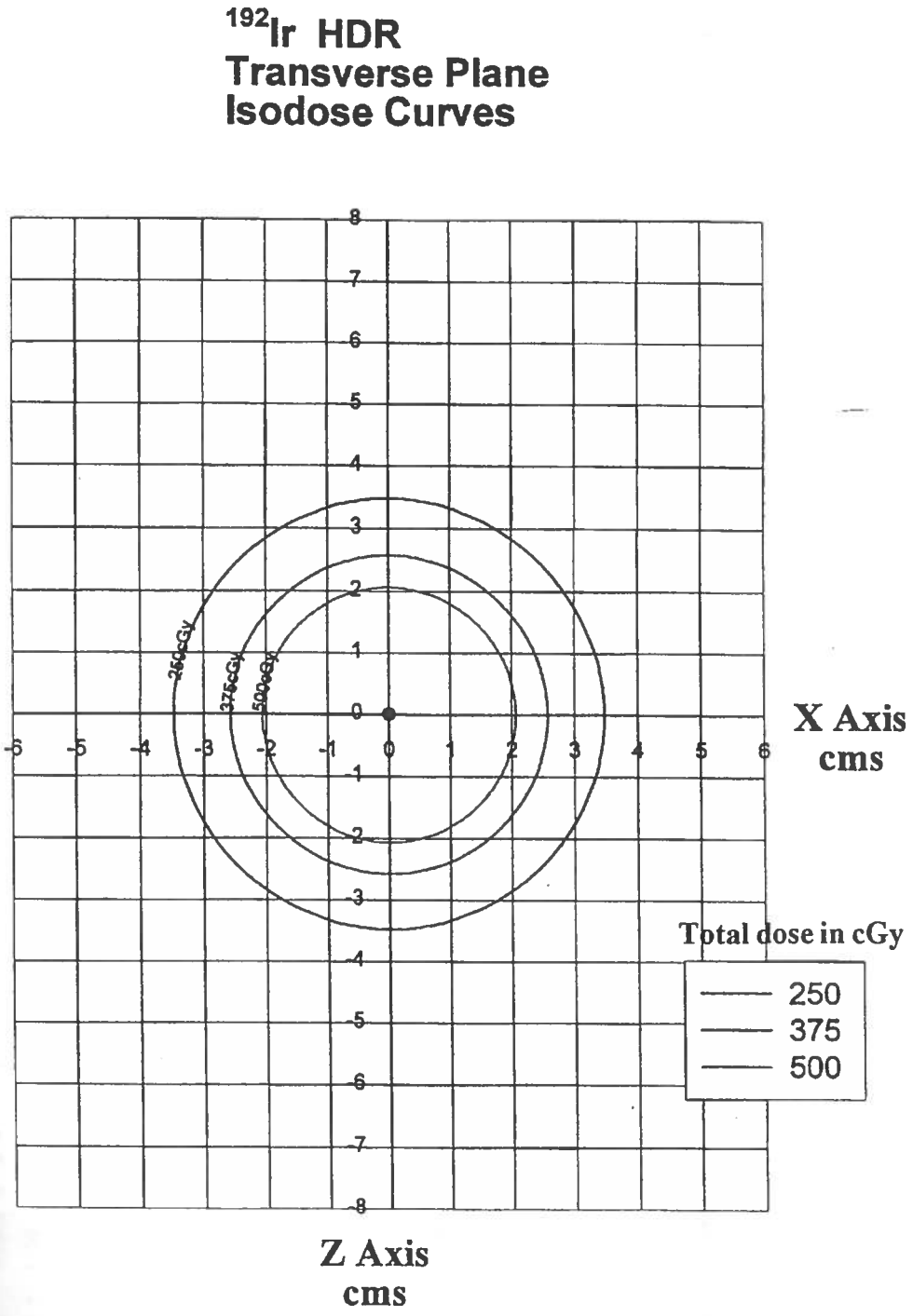


Fig 4.2.2.3: Isodose distributions generated with PC, using PC calculated time for case#2, to deliver 500 cGy at 5 mm from the cylinder.

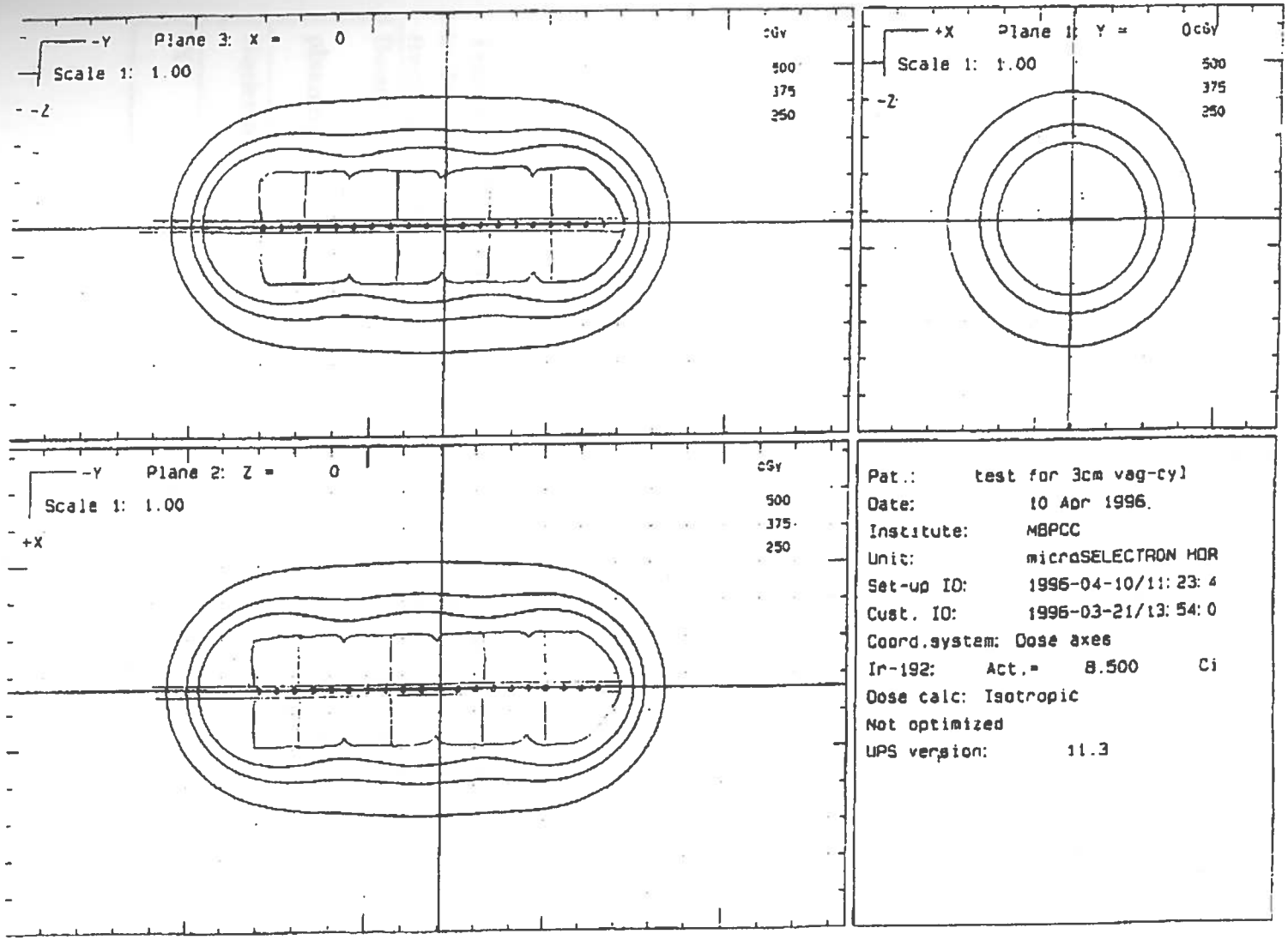


Fig 4.2.2.4: Isodose distributions generated with Nucletron computer, using PC calculated time for case#2

Table 4.2.2.3 Comparison between PC & Nucletron generated isodose distributions for vaginal cylinder (case #2) , using dwell times calcullated with PC, along the positive axes.

Dosimetery planning system	500 cGy along the X-axis	500 cGy along the Y-axis	500 cGy along the Z-axis
Nucletron	X_N=21±1(mm)	Y_N=55±1(mm)	Z_N=21±1(mm)
PC	X_P=21±1(mm)	Y_P=55±1(mm)	Z_P=21±1(mm)

Table 4.2.2.4 Comparison between PC & Nucletron generated isodose distributions for vaginal cylinder (case #2) , using dwell times calcullated with PC, along the negitive axes.

Dosimetery planning system	500 cGy along the X-axis	500 cGy along the Y-axis	500 cGy along the Z-axis
Nucletron	X_N=21±1(mm)	Y_N=67±1(mm)	Z_N=21±1(mm)
PC	X_P=21±1(mm)	Y_P=67±1(mm)	Z_P=21±1(mm)

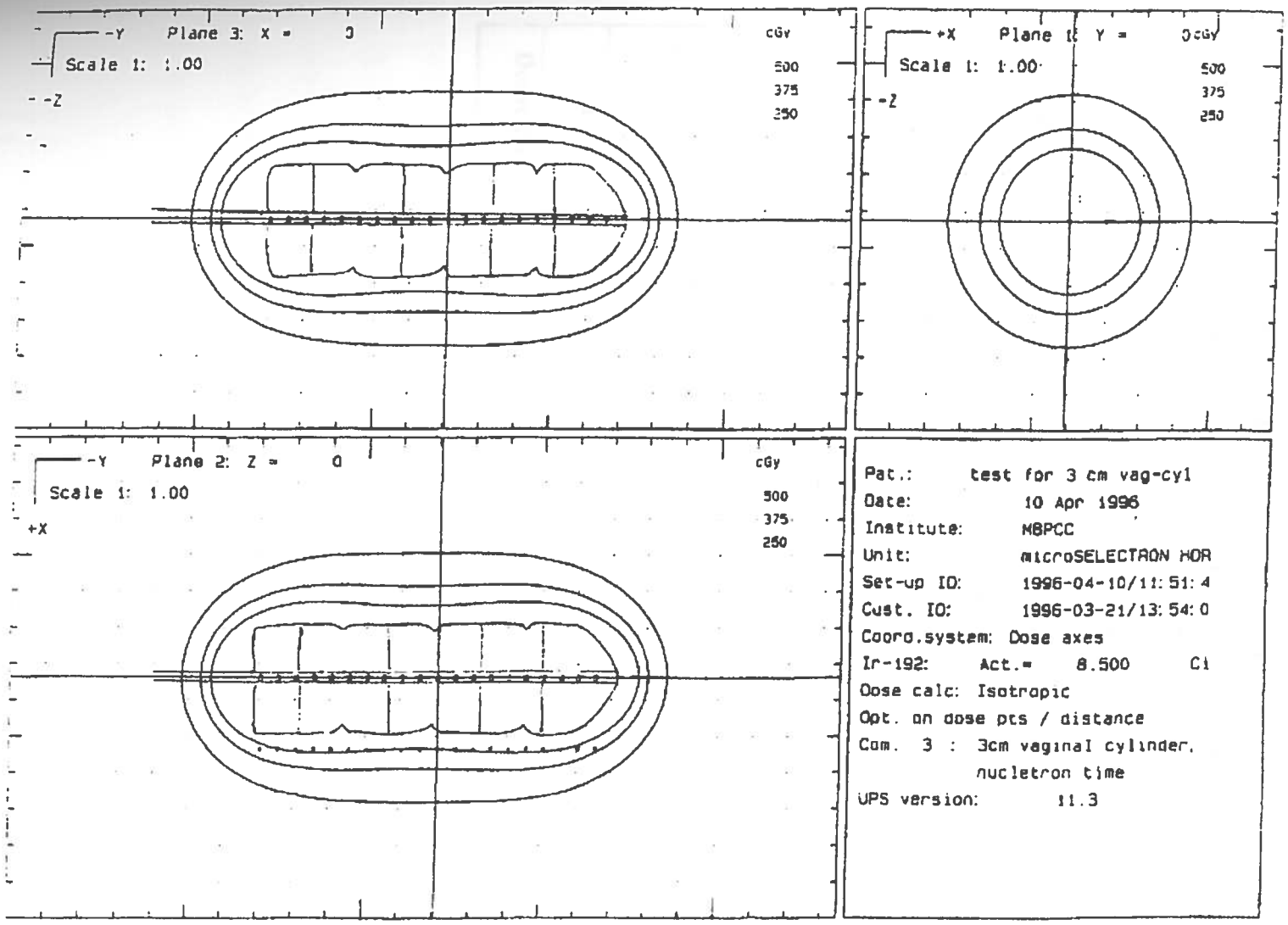


Fig 4.2.2.5: Isodose distributions generated with Nucletron computer, using Nucletron calculated time for case#2

Table 4.2.2.5: Evaluation of PC and Nucletron generated distributions for case#2 (3.0 cm vaginal cylinder).

Dose point	Coordinates of the point (X,Y,Z) in mm	Distance from 500 cGy Isodose for PC	Distance from 500 cGy Isodose for Nucletron
1	(22.5,4,0)	0mm	1mm
2	(22.5,3,0)	1mm	1mm
3	(22.5,2,0)	0 mm	1mm
4	(22.5,1,0)	< 1mm	< 1mm
5	(22.5,0,0)	< 1mm	0mm
6	(22.5,-1,0)	< 1mm	0mm
7	(22.5,-2,0)	< 1mm	0mm
8	(22.5,-3,0)	1mm	1mm
9	(22.5,-4,0)	< 1mm	< 1mm
10	(22.5,-5,0)	0mm	2mm
Dome point	(0,56.0,0)	< 1mm	1mm

CHAPTER 5

COMPARISON BETWEEN LDR AND HDR LOADING FOR TANDEM AND OVOIDS APPLICATORS

5.1 Introduction

Low Dose Rate brachyteraphy is used for treatment of malignancies arising in the female genital tract since the earliest years of radiation therapy. The Fletcher applicators were developed in the early 1950's in an attempt to provide a colpostat for standard tubes that would insert easily and maintain a steady position in the lateral fornices[12]. The first "afterloadable" Fletcher colpostat which was used with radium tubes was developed in 1958[13]. An afterloadable applicator allowed the insertion and packing of the ovoids and tandem to be a separate and independent procedure from placing the source in the applicators. This procedure eliminated radiation exposure to operating room, anesthesiology, recovery room, diagnostic X-ray, and transportation personnel[13],[14]. By 1964, ^{137}Cs was becoming popular as a source for gynecological applications. This radioisotope with 0.662 Mev gamma rays and a long half-life of about 30 years can be used clinically for many years without replacement. One of the objectives of this study is to generate different proportions (loadings) for an HDR ^{192}Ir source comparable with loadings which were suggested by Fletcher[15] for tandem and ovoids applicators in LDR Brachytherapy. Isodose distributions for HDR and LDR ovoid and tandem applicators for different loadings will be presented in this chapter.

5.2 Description of the sources

^{137}Cs is used in temporary interstitial and intracavitary Low Dose Rate brachytherapy. Due to its long half-life, this source may be used clinically for about 7 years without replacement. The ^{137}Cs sources available in the inventory at the Mary Bird Perkins Cancer Center are the 6500 series manufactured by 3M. They are made of two stainless steel capsules with an inner core and an outer casing. The inner stainless steel casing is loaded with ceramic microspheres embedded with cesium-137. Each source has the following dimensions: 2.0 cm physical length by 0.31 cm diameter with a 1.4 cm active length, and a 0.093 cm stainless steel wall casing. On the other hand, the micro-selectron HDR remote afterloader uses a single solid cylindrical ^{192}Ir source. The source has an active diameter of 0.6 mm and an active length of 3.5 mm, and it is encapsulated by stainless steel. The outer dimensions are 4.5 mm in length by 1.1 mm outer diameter or 5.0 mm in length with welded top. The source comes with an nominal activity of 370 Gbq (10Ci) and can be programmed to any one of 48 dwell positions within an applicator for a total active treatment length of 24 cm with a spacing of 5.0 mm between positions. There are varieties of applicators to be used with an ^{192}Ir source.

5.3 Method and Materials

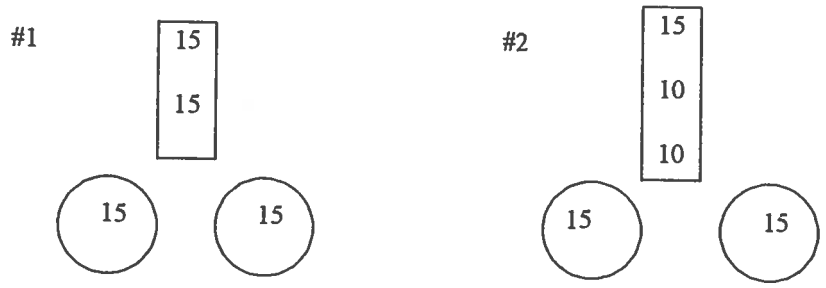
The standard Fletcher style applicator set is one of the applicators currently in use at the Mary Bird Perkins Cancer Center with the HDR unit, for treatment of patients with gynecological malignancies. In this chapter, isodose distributions generated by an equivalent loading of ^{192}Ir and ^{137}Cs will be compared. It should be

noted that, for each case the most common cesium loadings recommended by Fletcher are used [15]. Figure 5.3.1 shows all of the loadings used in this study for the comparison between isodose distributions of a ^{137}Cs and an ^{192}Ir source. In this study each ^{137}Cs source with active length of 1.4 cm is substituted by four ^{192}Ir dwell positions with 0.5cm separation. Due to the existence of shielding material in the shielded applicator set (Fletcher style), only three dwell positions can be used practically in the ovoids. Thus, for each loading, two sets of isodose distributions are generated, one with four dwell positions in the ovoid and one with only three dwell positions in the ovoid. In order to compare isodose distributions, several spreadsheet based programs are used such as "HDR checking program"[16] and "Cesium Brachytherapy program"[17] . To verify the accuracy of these programs some of the results are compared with the generated isodose distributions for a ^{137}Cs and an ^{192}Ir implant using Capintec treatment planning computer.

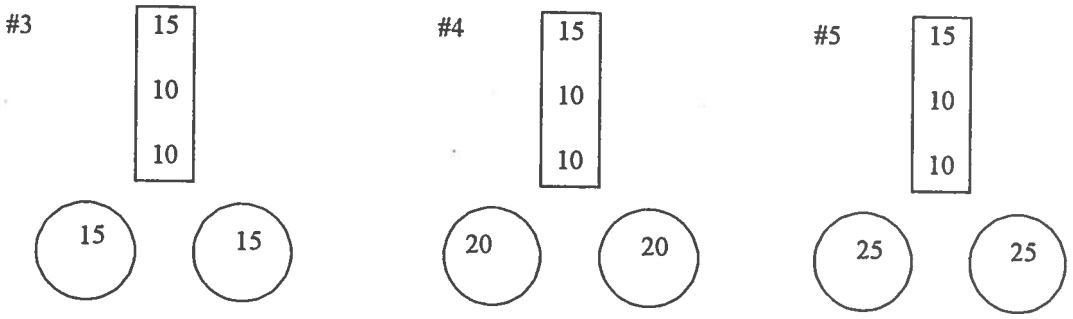
5.4 Isodose distributions

To get the source coordinates for each set of loadings, graph paper is used. As an example AP and LT planes are drawn on the graph paper and a proper origin is used. Then the coordinates of each individual source, and points of interest such as points A and B (which are gotten from the graph paper) are used as input data. Seven types of cesium loadings in three categories of small, medium, and large ovoids are shown in figure 5.3.1. Later in this chapter, one example from each category will be presented. Also , for one of the cases, verification plans using the Capintec treatment planning system will be presented.

Small ovoids with diameter of 20mm



Medium ovoids with diameter of 25 mm



Large ovoids with diameter of 30 mm

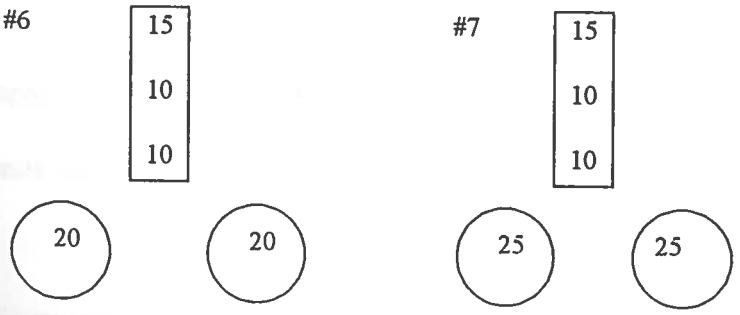


Fig 5.3.1: Different loadings used in this study for a tandem and ovoids applicator. The loading refers to the proportion or weighting of mg of Ra equivalent in each section of the tandem and ovoids to give a desired dose in space, in an optimum length of time.

5.4.1 Case #1

This example is for loading #1 in figure 5.3.1. Figures 5.4.1.1, 5.4.1.2, and 5.4.1.3 are isodose distributions in three different planes generated with personal computer for an HDR ^{192}Ir source. In these figures each ^{137}Cs source is substituted with four ^{192}Ir dwell positions. Also, figures 5.4.1.4, 5.4.1.5, and 5.4.1.6 represent the same isodose distributions for a LDR ^{137}Cs source . Based on the loading #1, four cesium sources with the same amount of activity (15 mgRaEq) are emulated. It should be noted that the isodose distributions for ^{192}Ir with the same proportions (loading) as cesium, fit very well with the distribution given by cesium. The results for the 600 cGy isodose (prescribed dose to point A) are presented in tables 5.4.1.1 and 5.4.1.2. Based on the measurements presented on those tables, an HDR ^{192}Ir source can give us the same isodose distributions as a LDR ^{137}Cs source , when the same loading proportions are used.

5.4.1.1 The concept of Time Factor

In this section, the method used in generating isodose distributions for ^{192}Ir examples will be discussed. As it is shown in equation 5.4.1.1, dose at any point depends on two variables, activity and time.

$$\text{Dose} = k * \text{Activity} * \text{Time} \qquad 5.4.1.1$$

In this equation, k is a positive constant. It can be seen that when variable is fixed, the other one will play the major role in defining the dose. For example, in HDR brachytherapy procedure, activity of the source at the time of implant is fixed. Therefore, time is the only variable which effects the total dose. In this chapter,

primary isodose distributions for iridium examples were generated by using a 10 Ci source (as the starting activity) when the dwell times were kept fixed proportions. Then, the activity was changed until 600 cGy isodose line at the point A was satisfied. For most examples, the final activity was not a practical one (e.g.15 Ci), therefore an adjusting factor, called Time Factor (TF) was defined to modify the activity. The Time Factor per unit time, is defined as a ratio of the final activity of the source which generated the ideal isodose distributions to a practical amount of activity (e.g.8 Ci) for the ^{192}Ir source. The TF factor as an adjusting parameter can be calculated for any amount of activity. In this chapter, Time Factor for a 8 Ci ^{192}Ir source is shown in each plane. The proportion, shown next to each source, will give the dwell time in seconds when multiplied by the Time Factor for that particular ^{192}Ir source. To adjust the dwell times for radioactive decay of the source, the Time Factor should be adjusted using the following equation.

Adjusted Time Factor = (Time factor) * [8(Ci) / Current Activity(Ci)] 5.4.1.2

In Figures 5.4.1.7, 5.4.1.8, and 5.4.1.9 each cesium-137 in the ovoids is substituted with three ^{192}Ir sources. Therefore, in this distribution the Time Factor for ovoids is different than the one for the tandem. Tables 5.4.1.3 and 5.4.1.4 compare isodose distributions with four dwell positions in each ovoid with the distributions using only three dwell positions in each ovoid. The results of the comparison show an excellent agreement between those sets of distributions. Therefore, by using a different time factor, four dwell positions in each ovoid can be simply substituted by three dwell positions.

5.4.2 Case #2

This example is for loading #3 in figure 5.3.1. Figures 5.4.2.1, 5.4.2.2, and 5.4.2.3 are distributions generated with personal computer for an HDR ^{192}Ir source emulating the cesium loading. Similarly, figures 5.4.2.4, 5.4.2.5, and 5.4.2.6 represent the same isodose distributions with cesium using a personal computer. Figures 5.4.2.7, 5.4.2.8, and 5.4.2.9 represent the same isodose distributions when only three dwell positions with the ^{192}Ir source is considered in each ovoid. The results of comparison for the 600 cGy isodose (prescribed dose to point A) is presented in tables 5.4.2.1 and 5.4.2.2. . Those tables reveal an excellent agreement between the isodose distributions for ^{192}Ir with the same proportions (loading) as cesium for this case. Therefore, like case #1, an HDR ^{192}Ir source gave us the same isodose distributions as a LDR ^{137}Cs source , when the same loading proportions were used.

As mentioned earlier in this chapter, for verification purposes, isodose distributions for both ^{192}Ir and ^{137}Cs implants are generated using Capintec treatment planning computer. Figures 5.4.2.10, 5.4.2.11, and 5.4.2.12 are isodose distributions generated for an HDR^{192}Ir source using the Capintec treatment planning computer. The result of comparison between these distributions and the same ones generated with personal computer is presented in tables 5.4.2.3 and 5.4.2.4. Also the same comparison is done for the ^{137}Cs implant and the result of the comparison between figures 5.4.2.13, 5.4.2.14, and 5.4.2.15 and the same ones generated with personal computer is presented in tables 5.4.2.5 and 5.4.2.6. Based on the measurements presented in these tables, isodose distributions generated with PC for both HDR and

LDR brachytherapy within 0-1 mm fit very well with the Capintec treatment planning distributions.

5.4.3 Case #3

This example is for loading #6 in figure 5.3.1. Figures 5.4.3.1, 5.4.3.2, and 5.4.3.3 are distributions generated with personal computer for an HDR ^{192}Ir source. Similarly, figures 5.4.3.4, 5.4.3.5, and 5.4.3.6 represent the same isodose distributions for a cesium case using a personal computer. Figures 5.4.3.7, 5.4.3.8, and 5.4.3.9 represent the same isodose distributions when only three dwell positions for the ^{192}Ir source is considered in each ovoid. Tables 5.4.3.1 and 5.4.3.2 in this chapter present results for the 600 cGy isodose (prescribed dose to point A). Based on the measurements it can be seen that the isodose distributions for ^{192}Ir with the same proportions (loading) as cesium, fit very well with the distribution given by cesium.

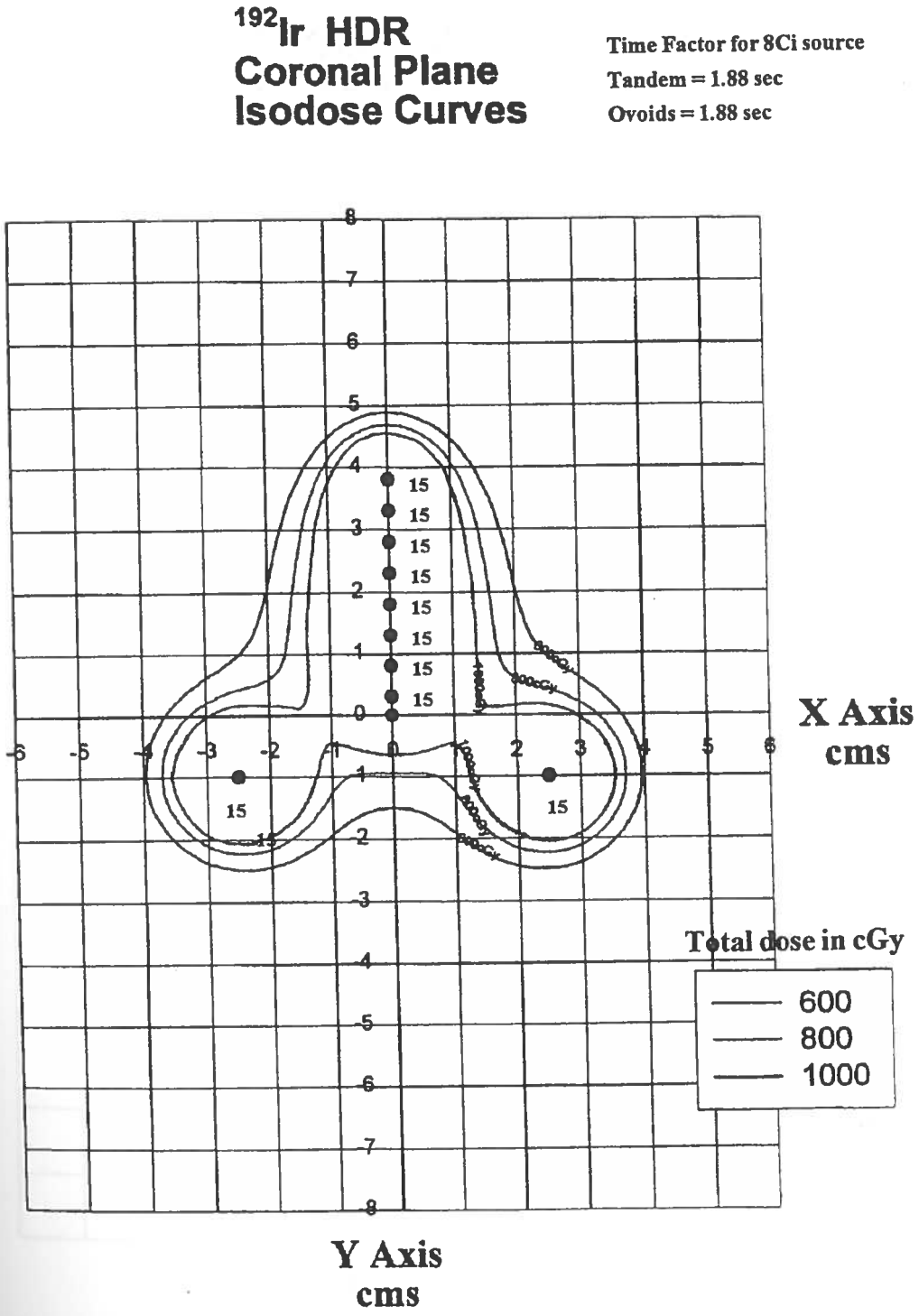


Fig 5.4.1.1: Isodose distributions generated with PC for Ir-192 (case#1) with four dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

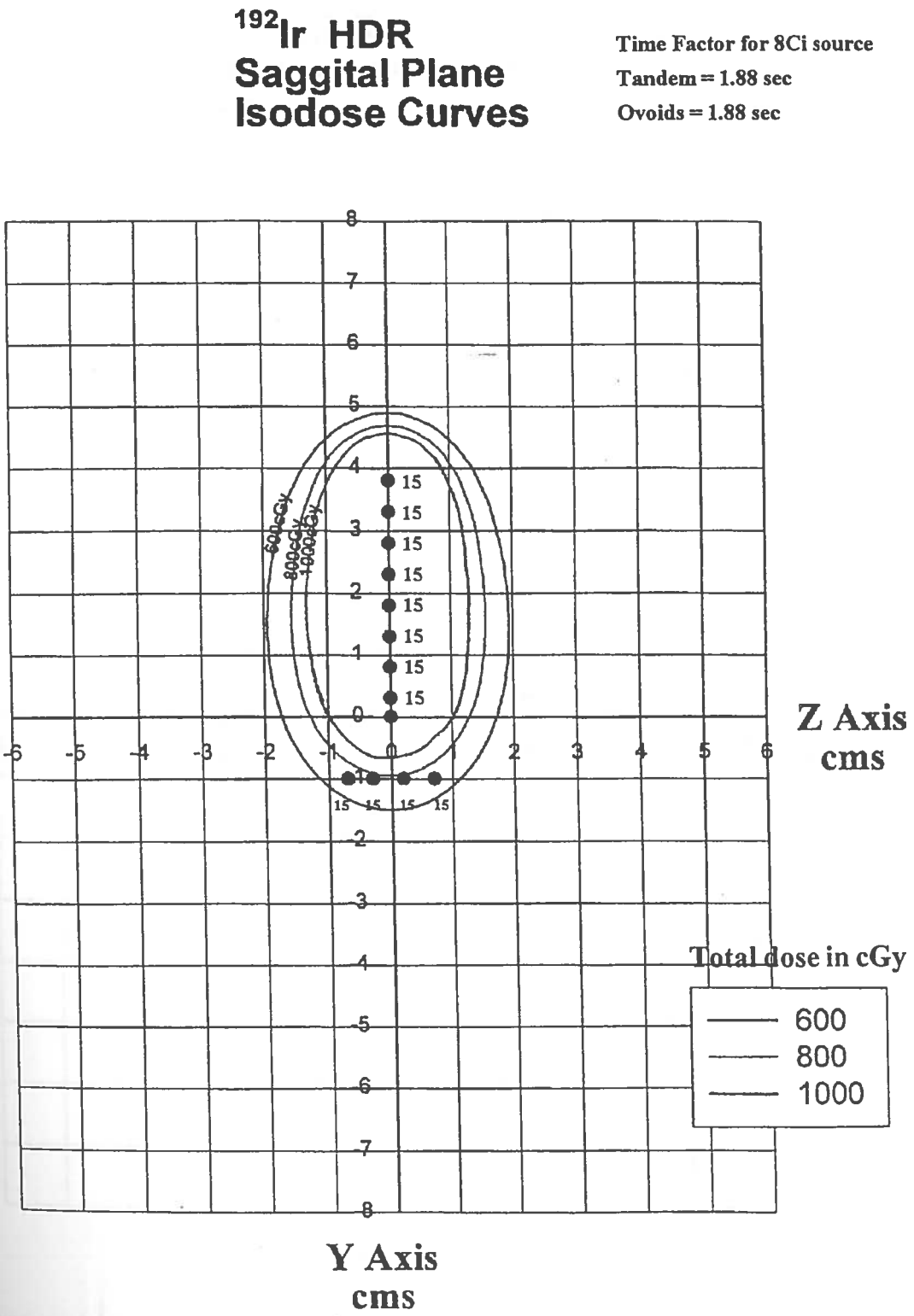


Fig 5.4.1.2: Isodose distributions generated with PC for Ir-192 (case#1) with four dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

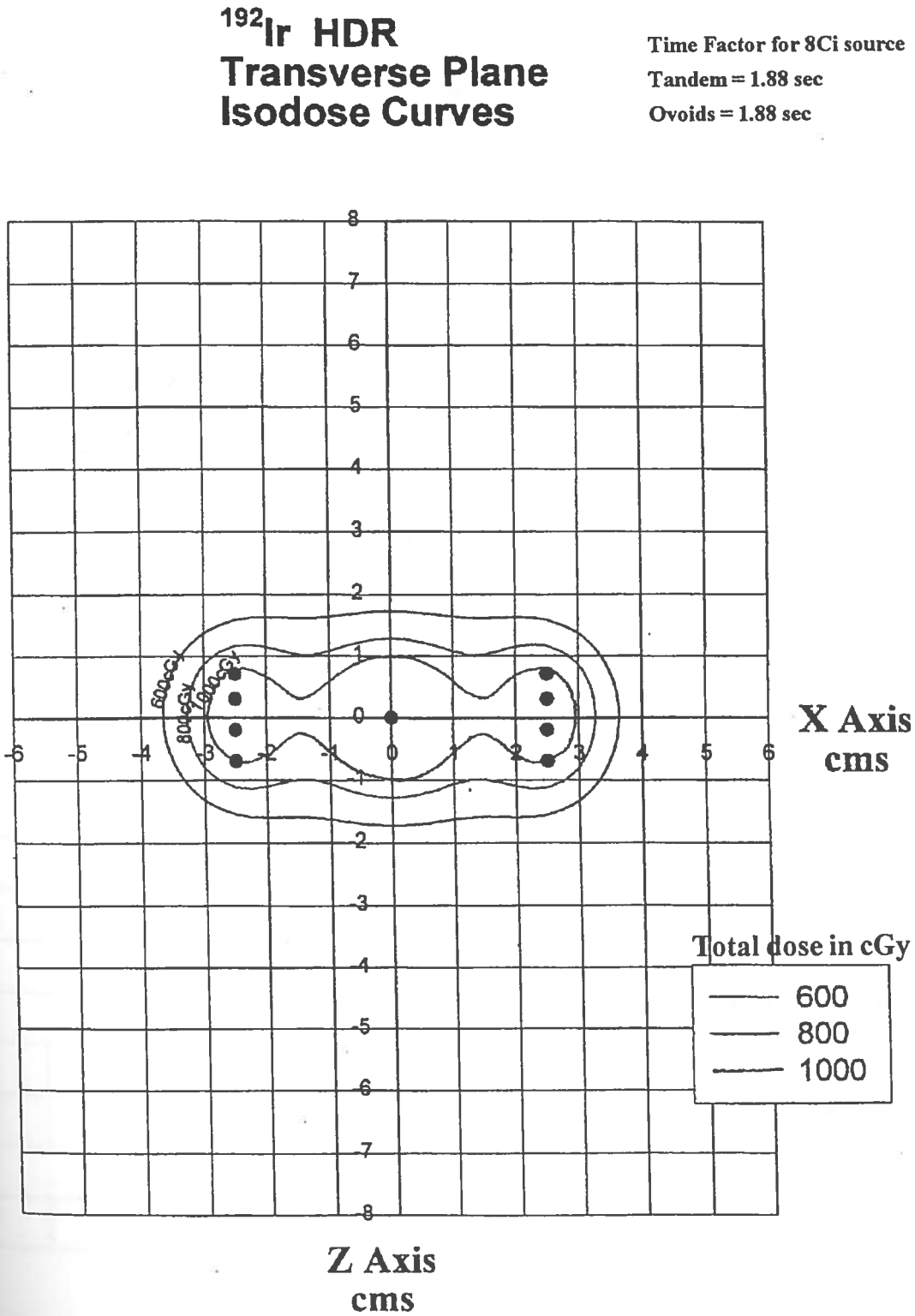


Fig 5.4.1.3: Isodose distributions generated with PC for Ir-192 (case#1) with four dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

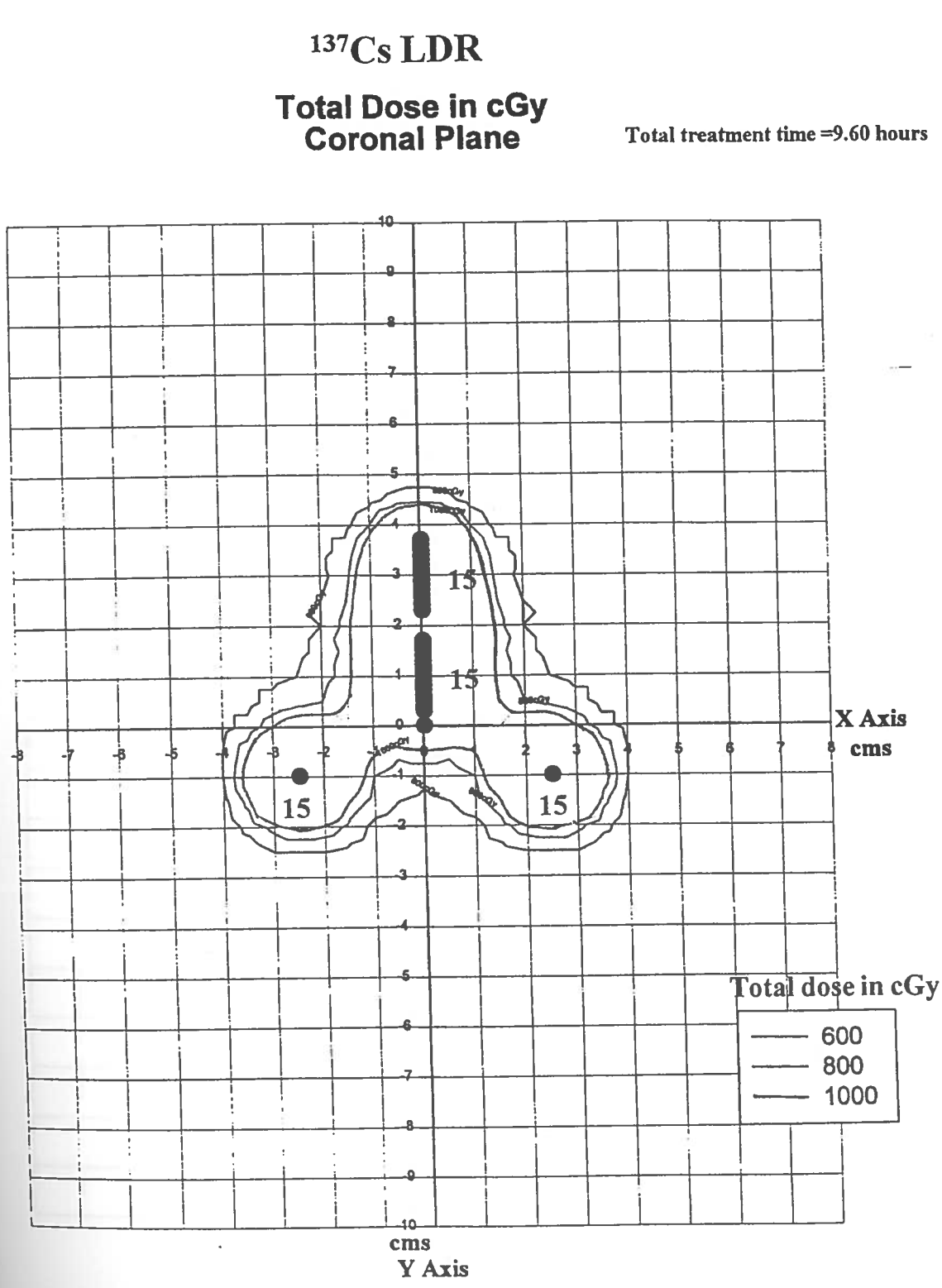


Fig 5.4.1.4: Isodose distributions generated with PC for Cs-137 (case#1). The numbers represent the activity of the source in mg Ra equivalent, as well as proportions or weighting.

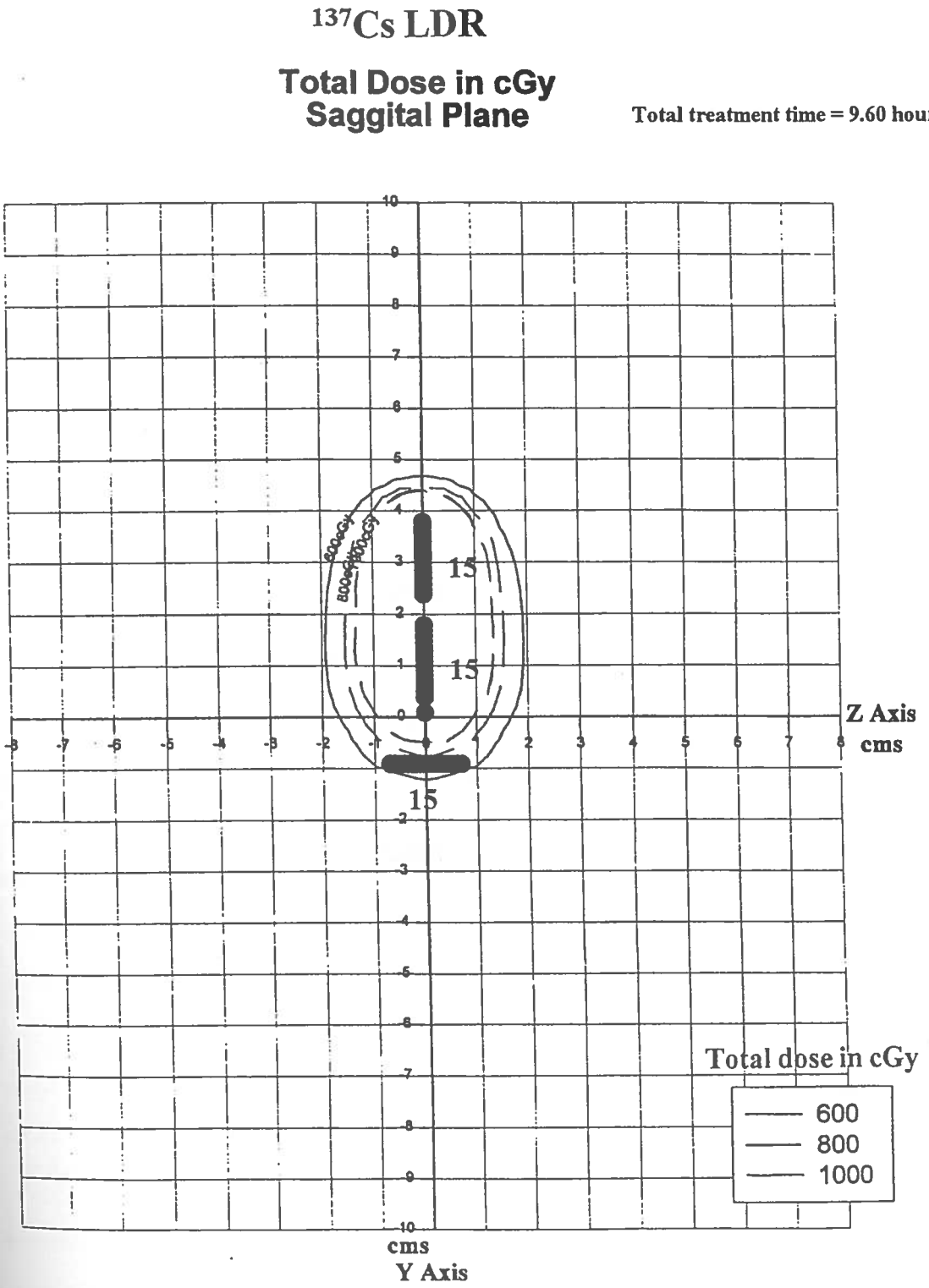


Fig 5.4.1.5: Isodose distributions generated with PC for Cs-137 (case#1). The numbers represent the activity of the source in mg Ra equivalent, as well as proportions or weighting.

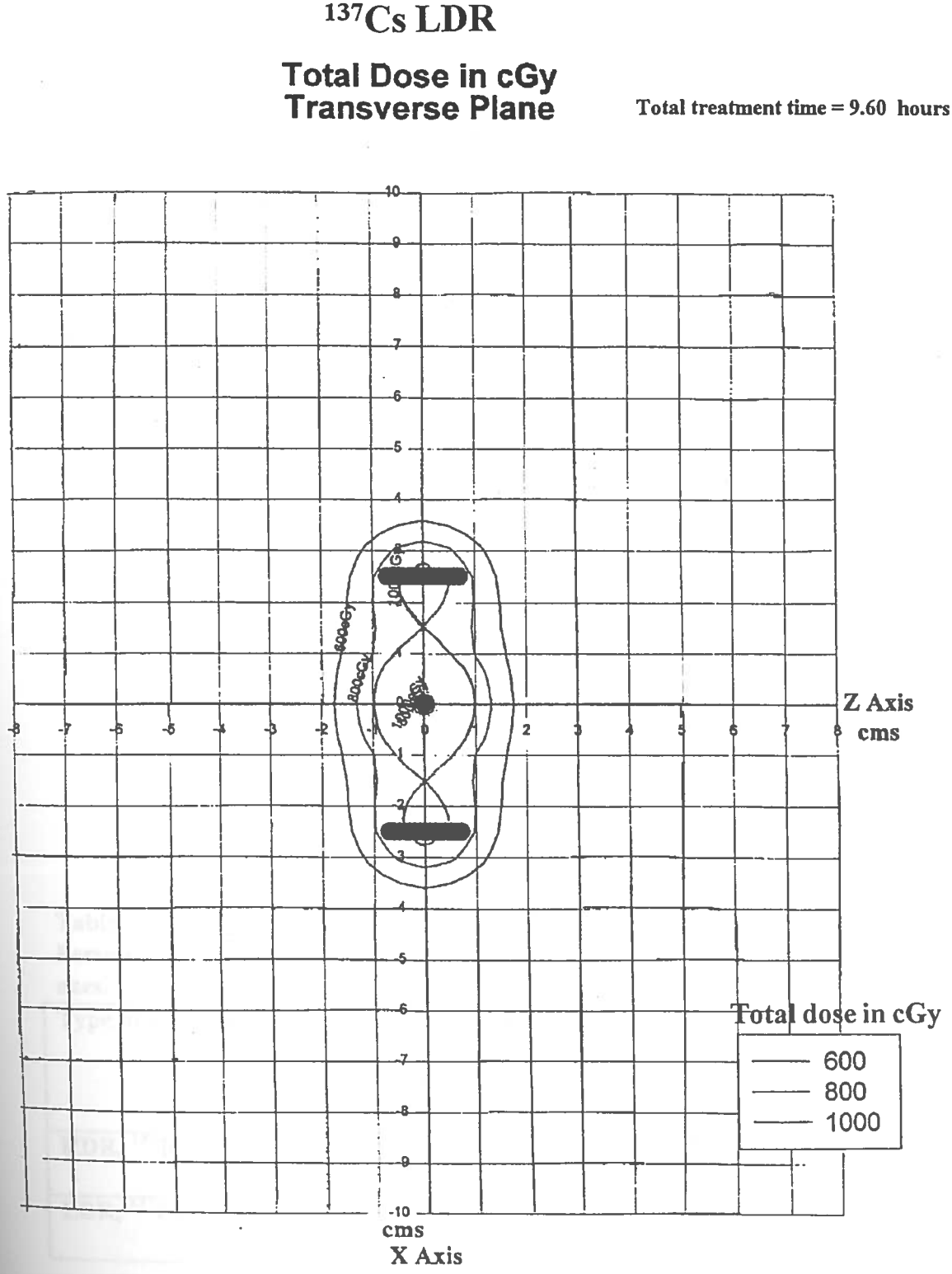


Fig 5.4.1.6: Isodose distributions generated with PC for Cs-137 (case#1). The numbers represent the activity of the source in mg Ra equivalent, as well as proportions or weighting.

Table 5.4.1.1: Comparison between HDR and LDR brachytherapy done with Personal computer for case #1 (4 dwell positions in the ovoids) along the positive axes.

Type of implant	600 cGy isodose along the X-axis	600 cGy isodose along the Y-axis	600 cGy isodose along the Z-axis
HDR, ^{192}Ir	$X_{(HDR)}$=37±1(mm)	$Y_{(HDR)}$=49±1(mm)	$Z_{(HDR)}$=17±1(mm)
LDR, ^{137}Cs	$X_{(LDR)}$=38±1(mm)	$Y_{(LDR)}$=48±1(mm)	$Z_{(LDR)}$=16±1(mm)

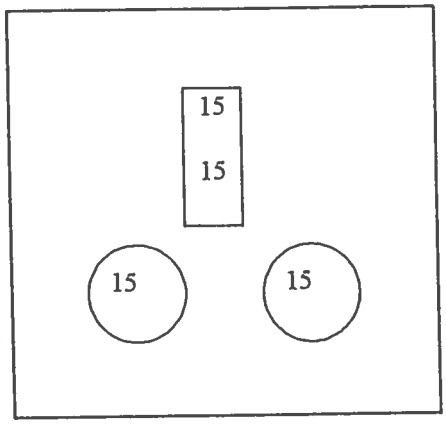


Table 5.4.1.2: Comparison between HDR and LDR brachytherapy done with Personal computer for case #1 (4 dwell positions in the ovoids) along the negative axes.

Type of implant	600 cGy isodose along the X-axis	600 cGy isodose along the Z-axis
HDR, ^{192}Ir	$X_{(HDR)}$=37±1(mm)	$Z_{(HDR)}$=17±1(mm)
LDR, ^{137}Cs	$X_{(LDR)}$=38±1(mm)	$Z_{(LDR)}$=16±1(mm)

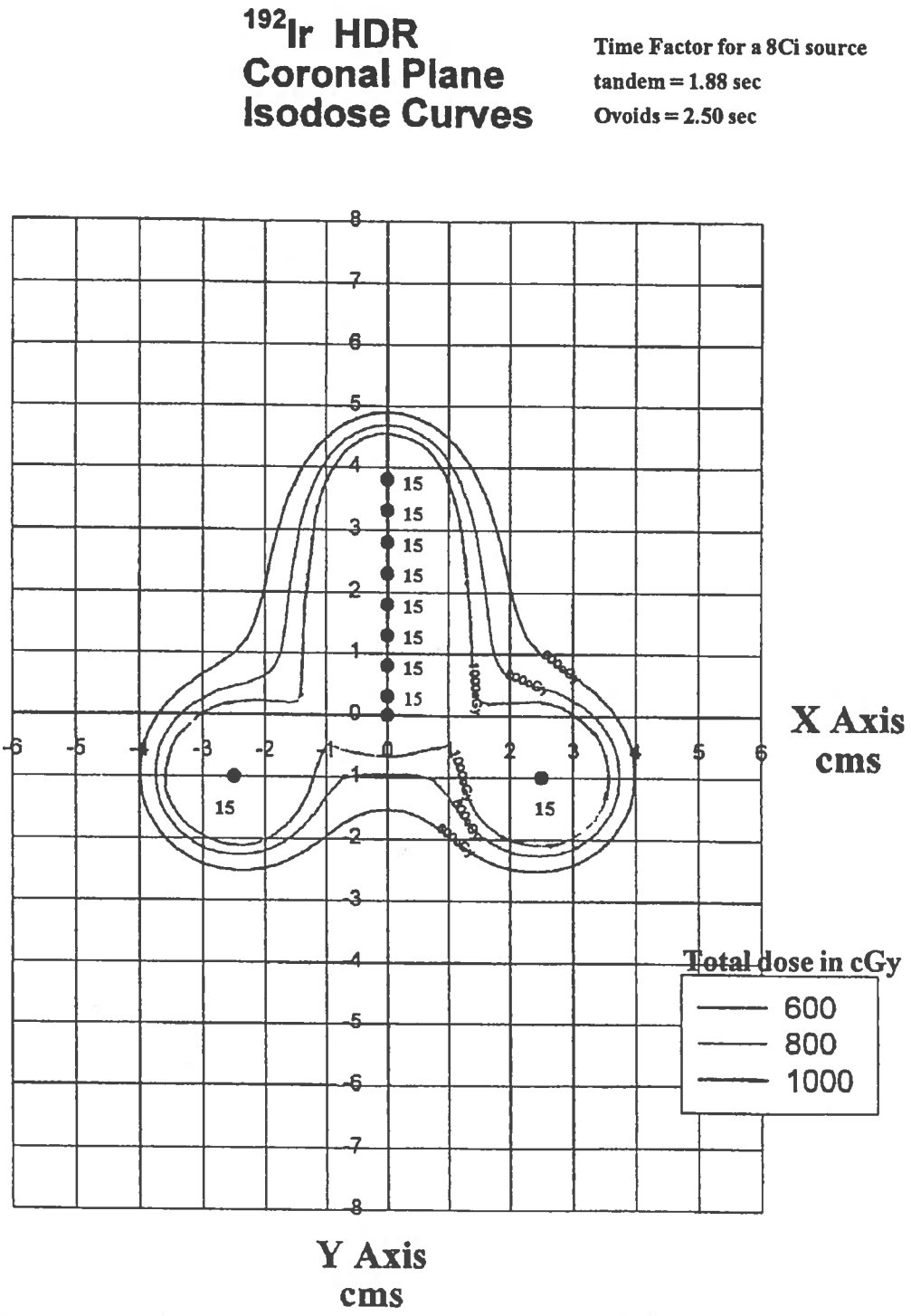


Fig 5.4.1.7: Isodose distributions for case#1 with three dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

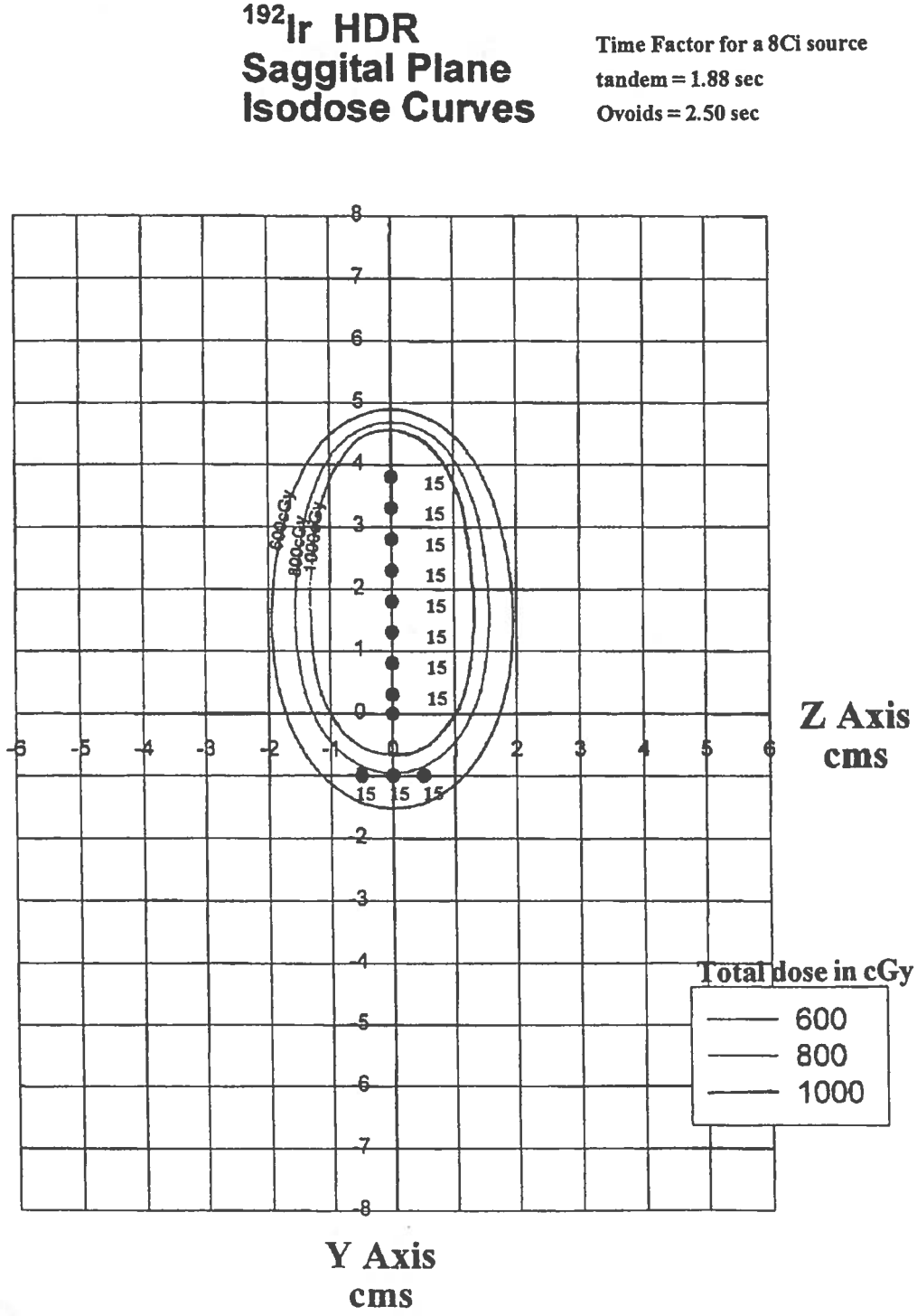


Fig 5.4.1.8: Isodose distributions for case#1 with three dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

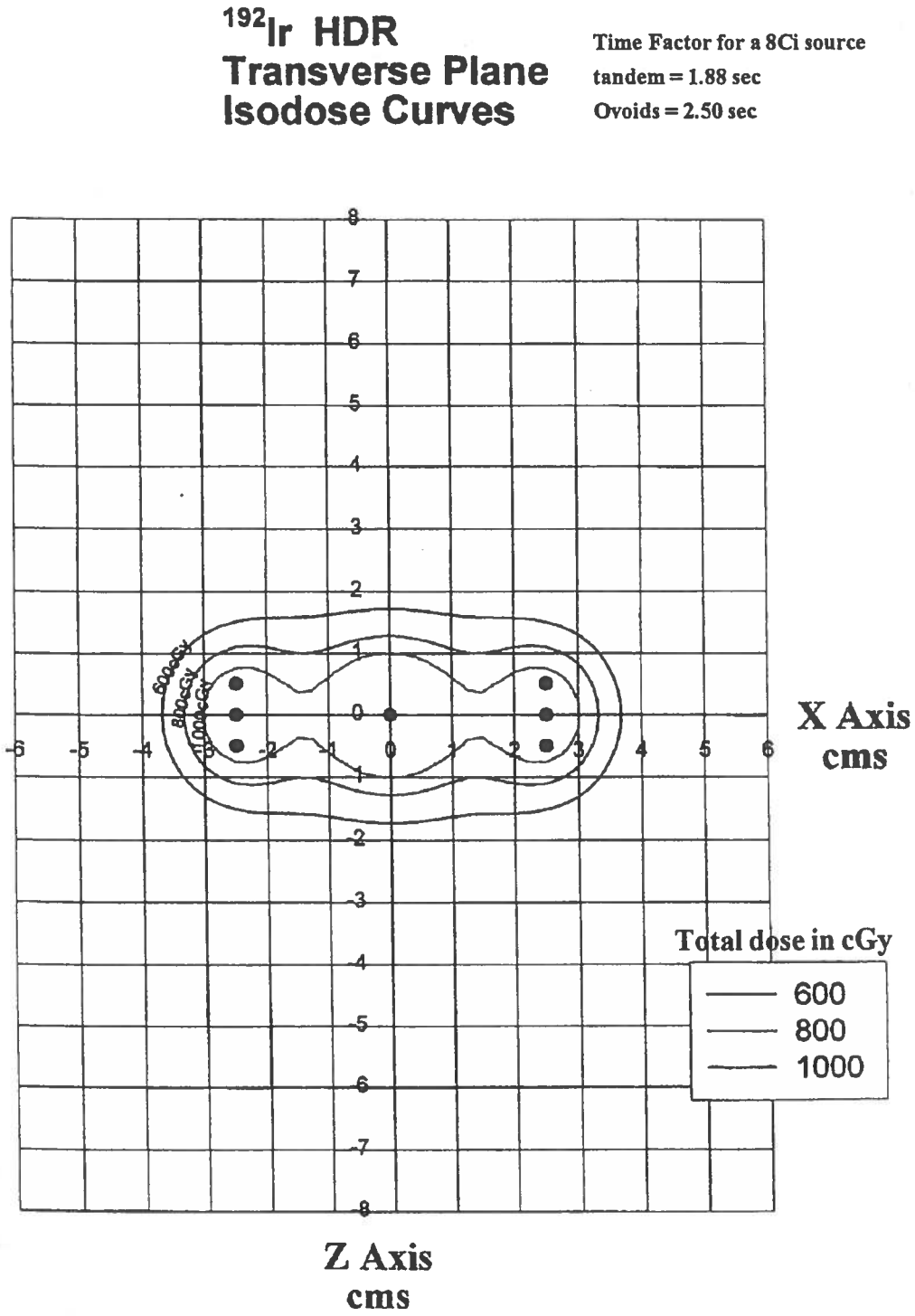


Fig 5.4.1.9: Isodose distributions for case#1 with three dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

Table 5.4.1.3: Comparison along the positive axes between four dwell positions and three dwell positions in ovoids for HDR brachytherapy (case #1), done with Personal computer.

Number of dwell positions in ovoids	600 cGy isodose along the X-axis	600 cGy isodose along the Y-axis	600 cGy isodose along the Z-axis
4	X =37±1(mm)	Y = 49±1(mm)	Z = 17±1(mm)
3	X = 37±1(mm)	Y = 49±1(mm)	Z = 17±1(mm)

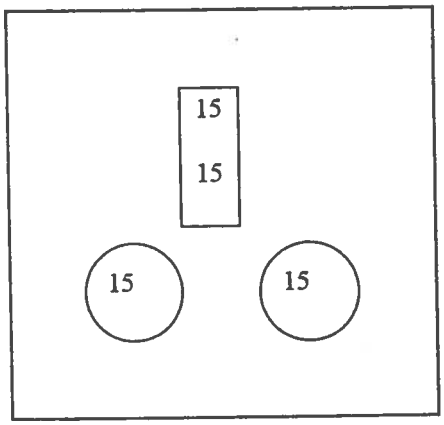


Table 5.4.1.4: Comparison along the negative axes between four dwell positions and three dwell positions in ovoids for HDR brachytherapy (case #1), done with Personal computer.

Number of dwell positions in ovoids	600 cGy isodose along the X-axis	600 cGy isodose along the Z-axis
4	X = 37±1(mm)	Z = 17±1(mm)
3	X = 37±1(mm)	Z = 17±1(mm)

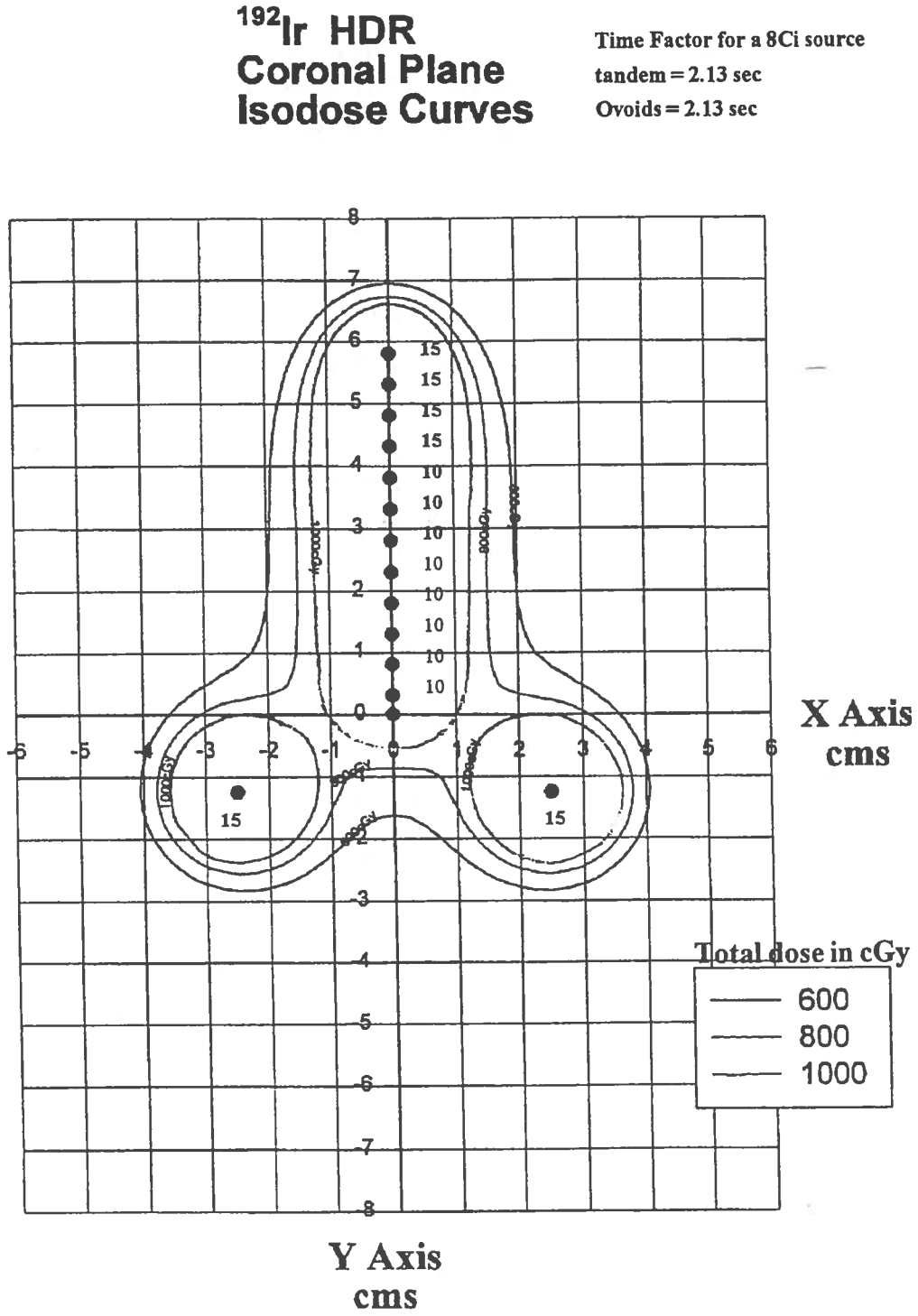


Fig 5.4.2.1: Isodose distributions for case#2 with four dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

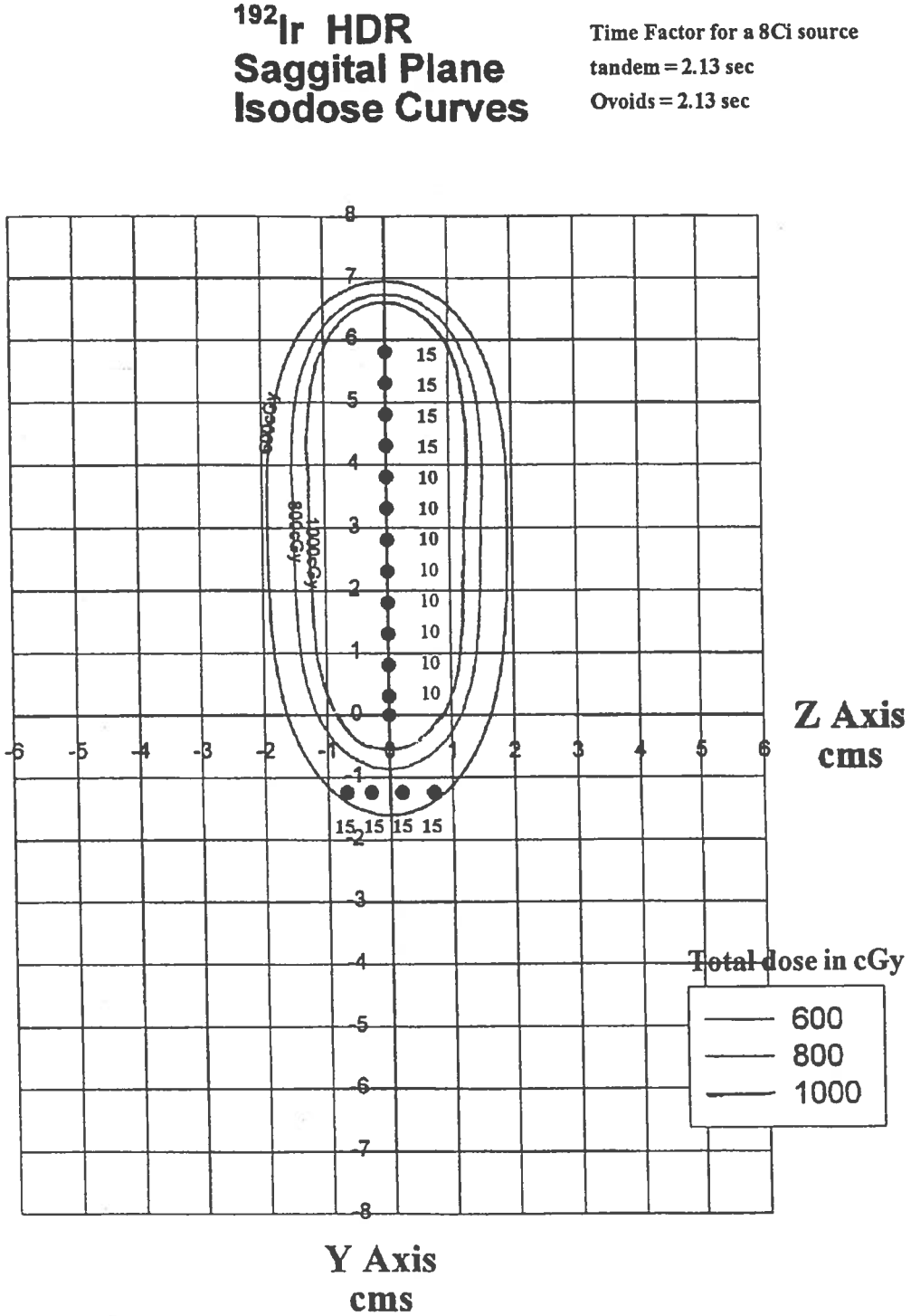


Fig 5.4.2.2: Isodose distributions for case#2 with four dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

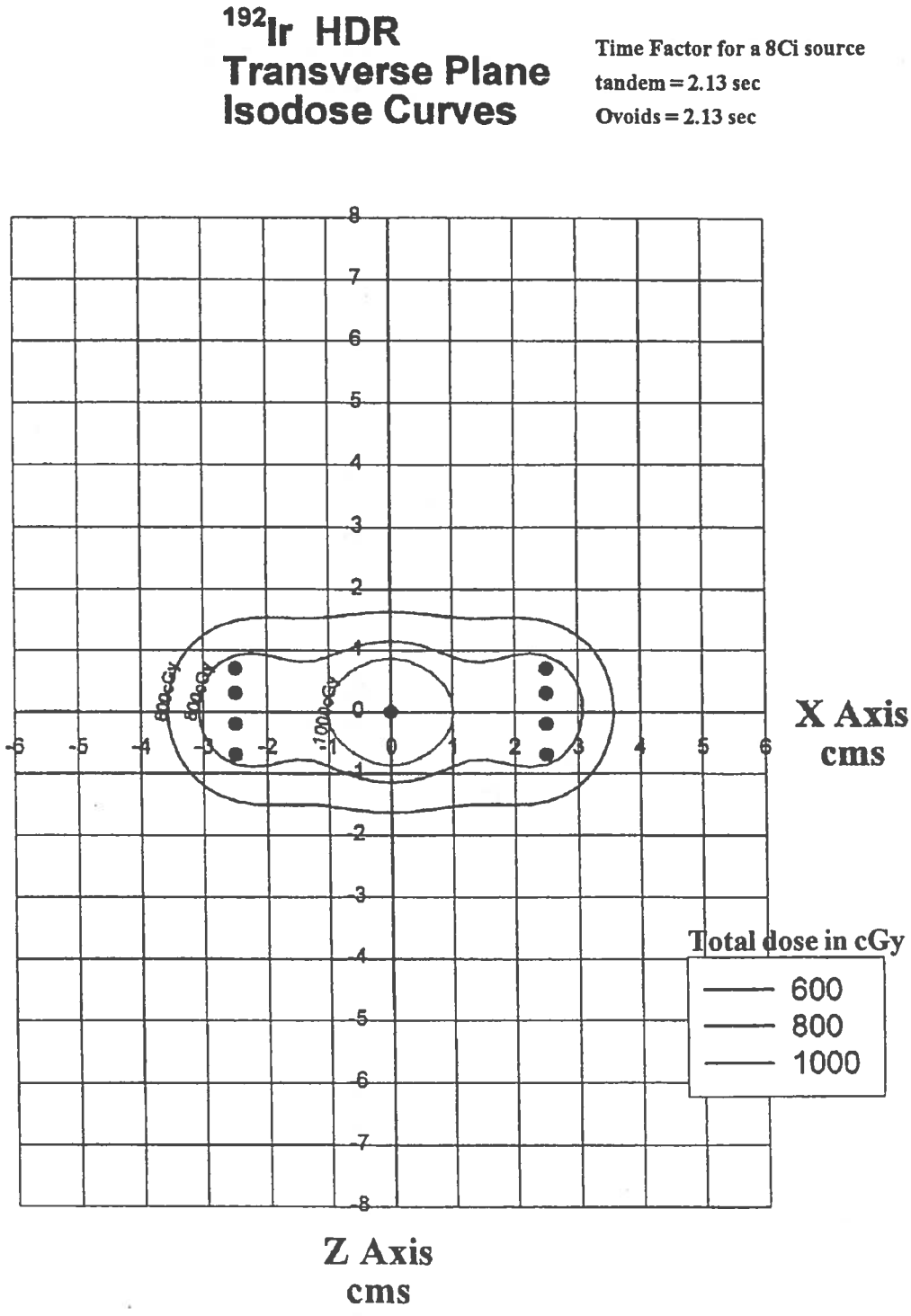


Fig 5.4.2.3: Isodose distributions for case#2 with four dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

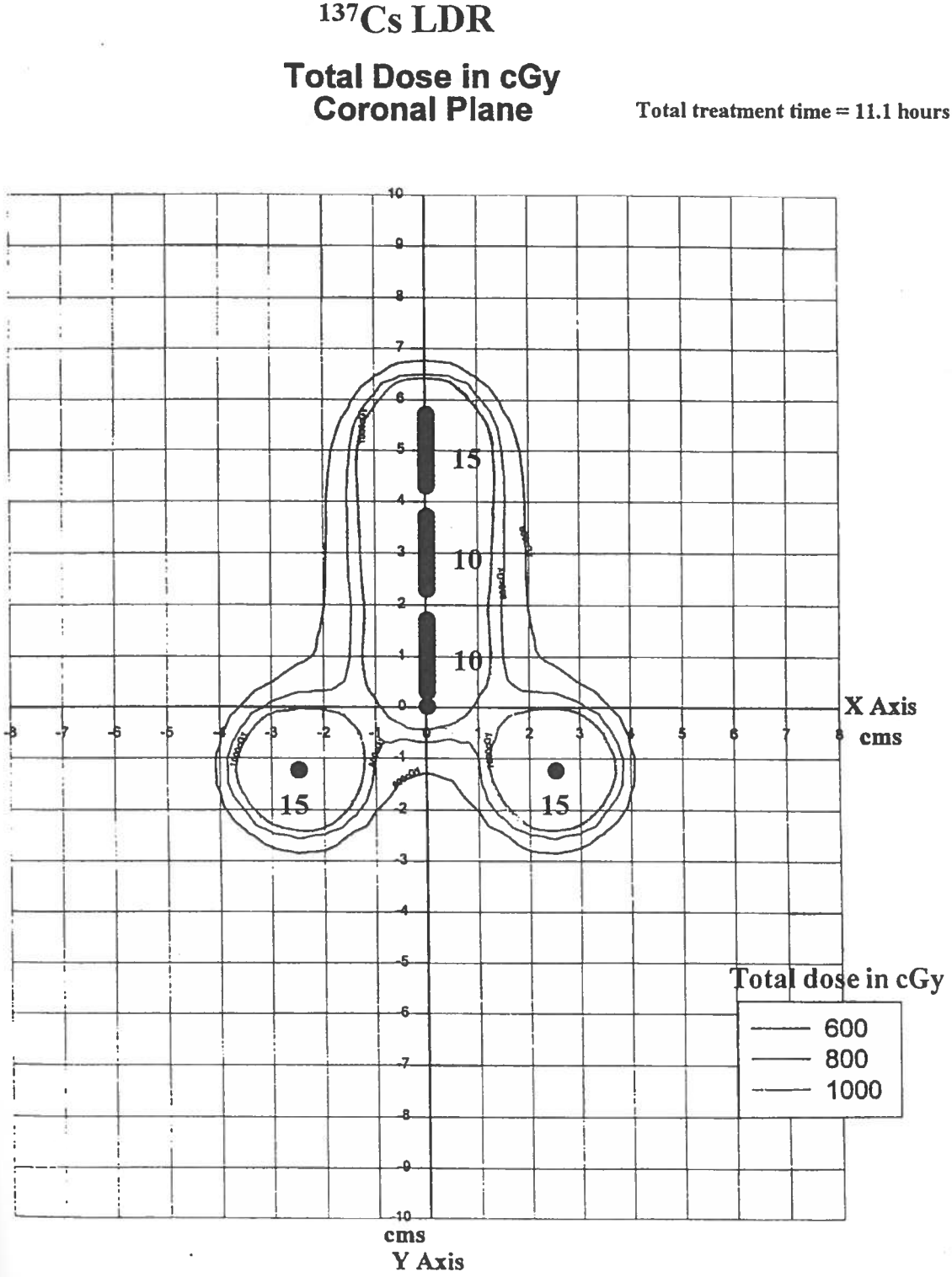


Fig 5.4.2.4: Isodose distributions generated with PC for Cs-137 (case#2). The numbers represent the activity of the source in mg Ra equivalent, as well as proportions or weighting.

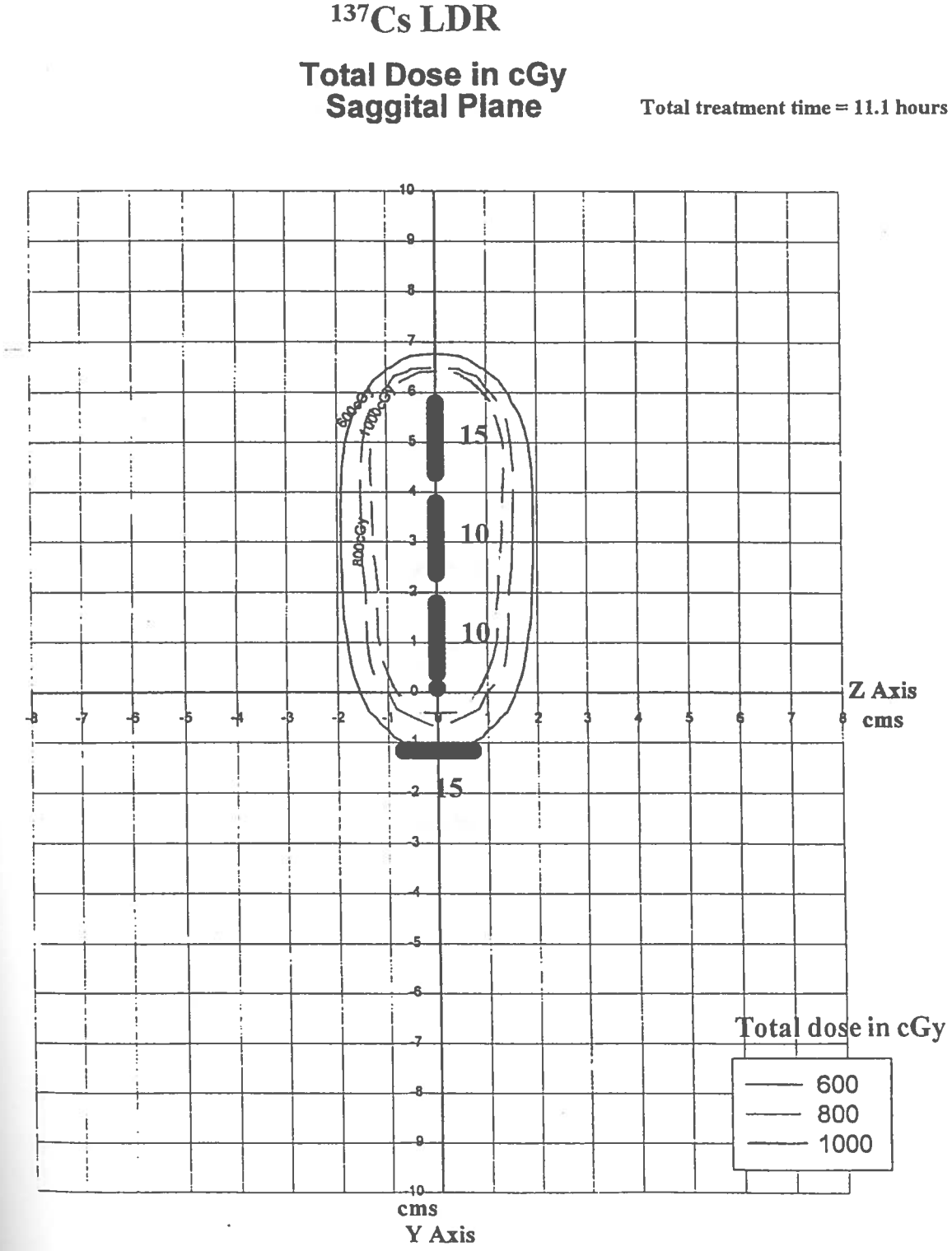


Fig 5.4.2.5: Isodose distributions generated with PC for Cs-137 (case#2). The numbers represent the activity of the source in mg Ra equivalent, as well as proportions or weighting.

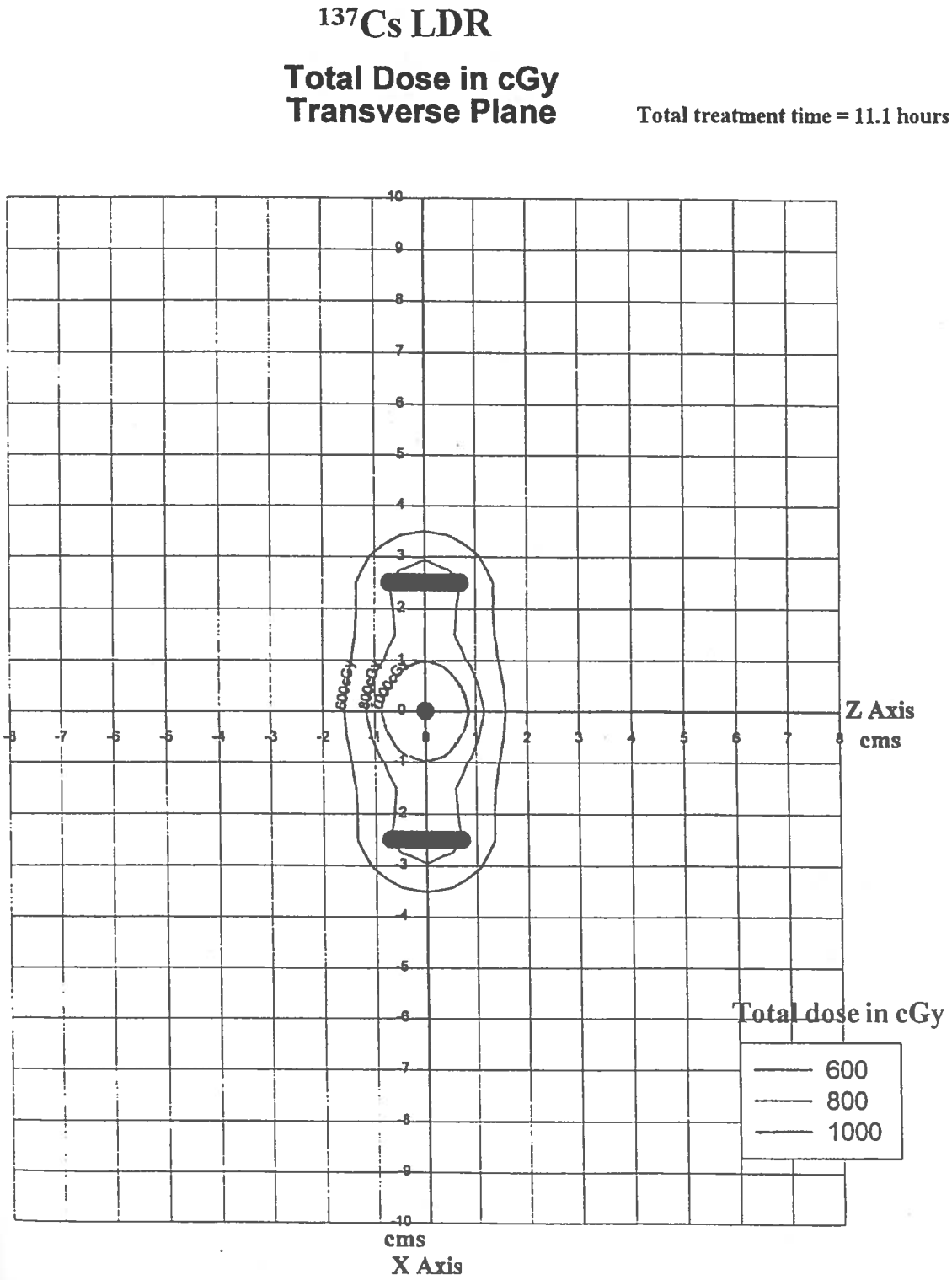


Fig 5.4.2. 6: Isodose distributions generated with PC for Cs-137 (case#2). The numbers represent the activity of the source in mg Ra equivalent, as well as proportions or weighting.

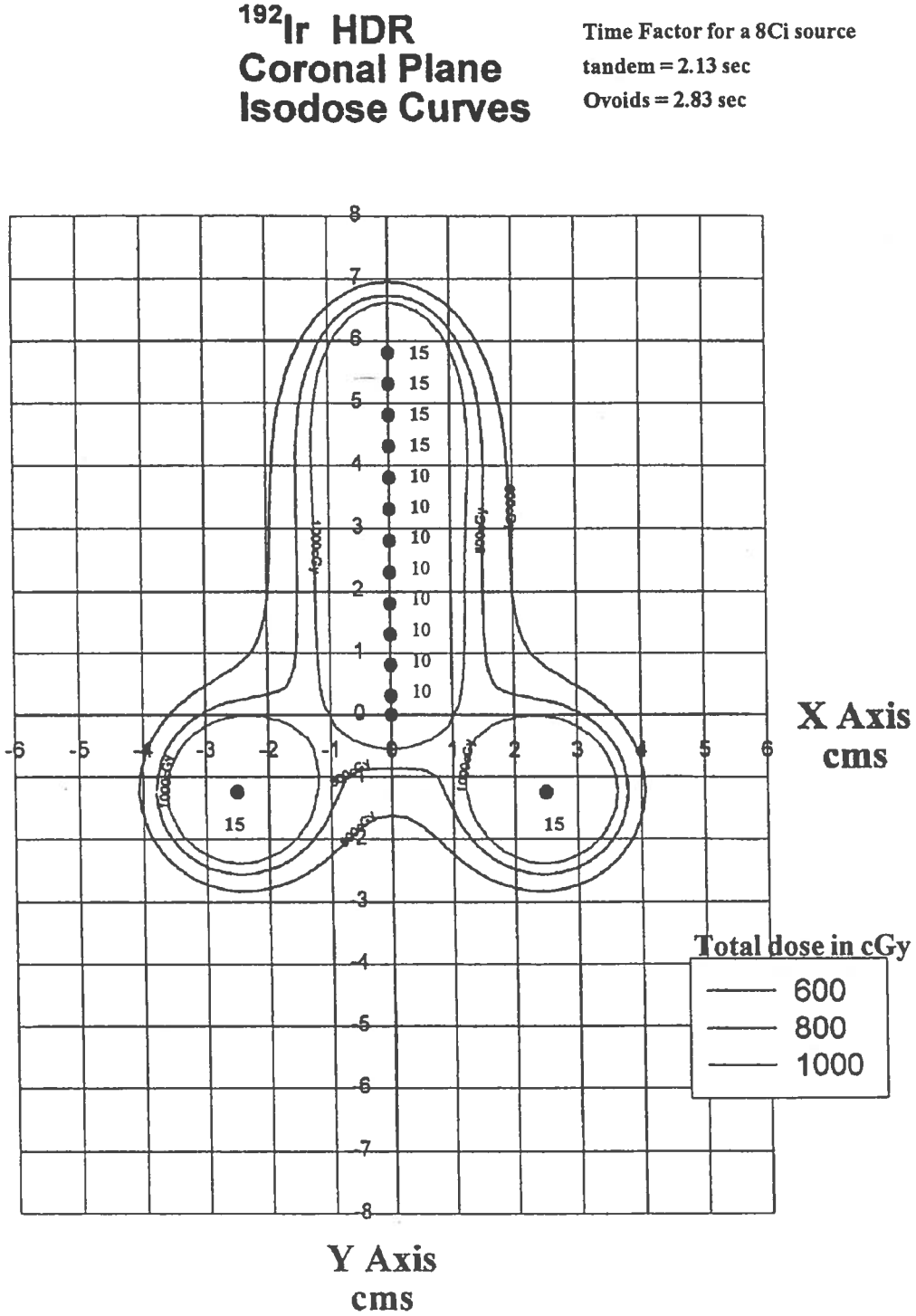


Fig 5.4.2.7: Isodose distributions for case#2 with three dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

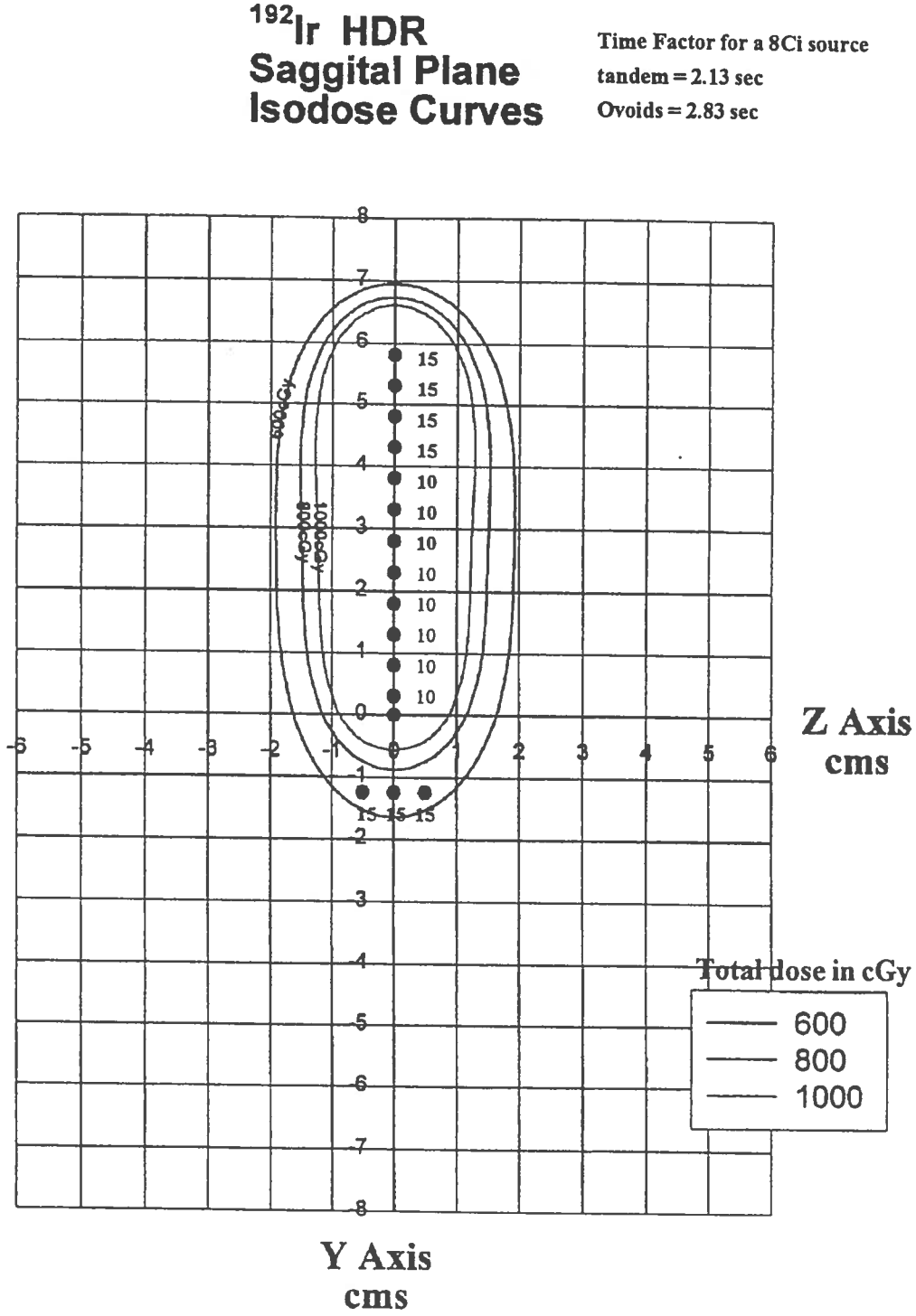


Fig 5.4.2.8: Isodose distributions for case#2 with three dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

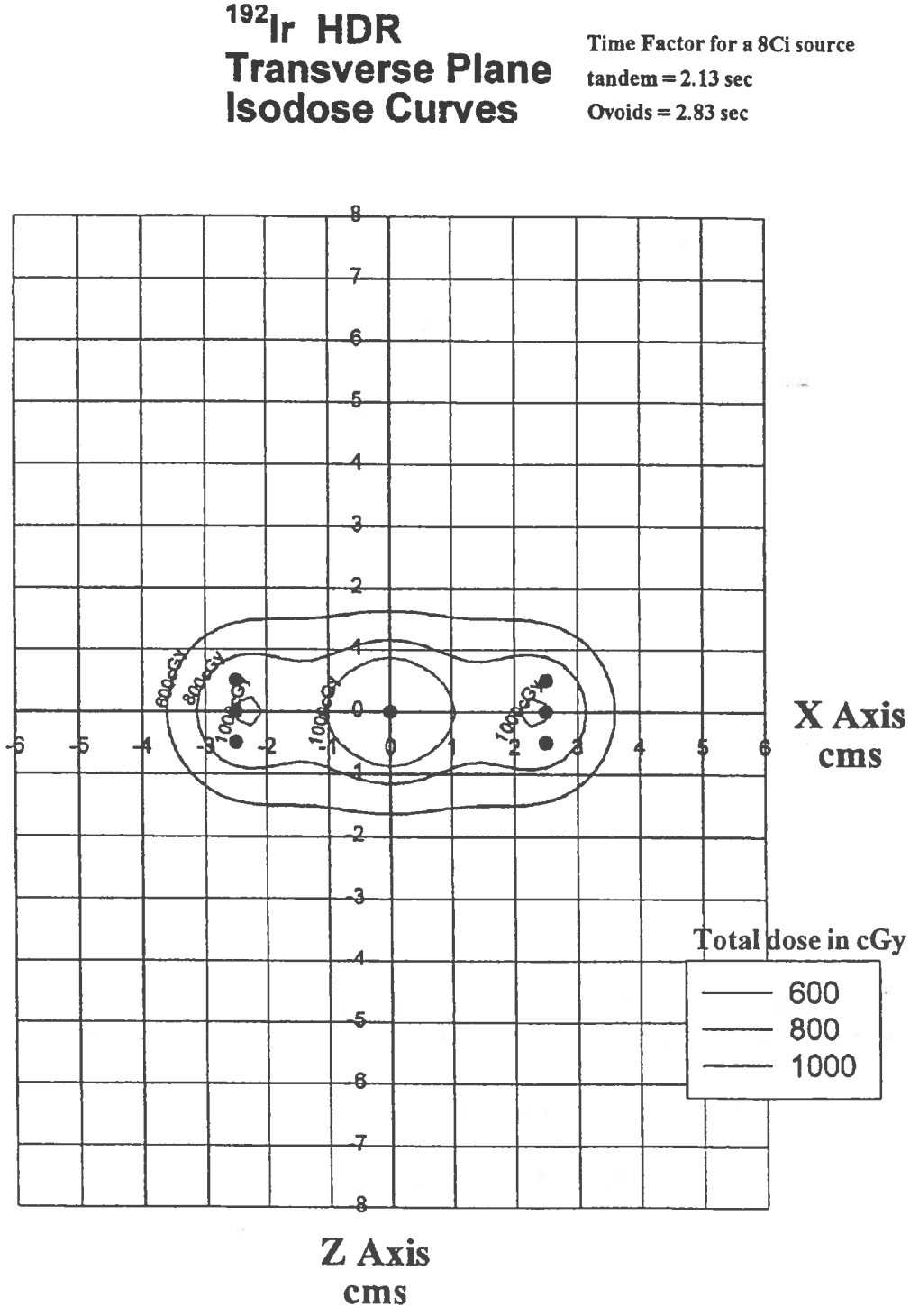


Fig 5.4.2.9: Isodose distributions for case#2 with three dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

Table 5.4.2.1: Comparison between HDR and LDR brachytherapy done with Personal computer for case #2 (4 dwell positions in the ovoids) along the positive axes.

Type of implant	600 cGy isodose along the X-axis	600 cGy isodose along the Y-axis	600 cGy isodose along the Z-axis
HDR, ^{192}Ir	$X_{(HDR)}$=36±1(mm)	$Y_{(HDR)}$=69±1(mm)	$Z_{(HDR)}$=16±1(mm)
LDR, ^{137}Cs	$X_{(LDR)}$=36±1(mm)	$Y_{(LDR)}$=68±1(mm)	$Z_{(LDR)}$=15±1(mm)

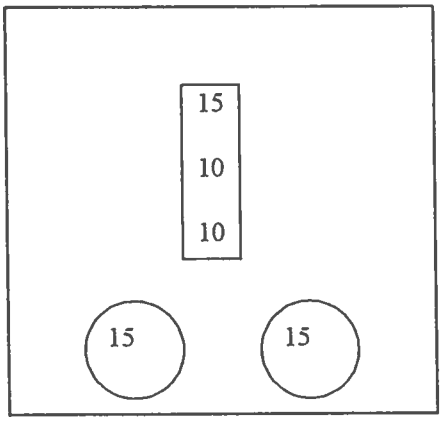


Table 5.4.2.2: Comparison between HDR and LDR brachytherapy done with Personal computer for case #2 (4 dwell positions in the ovoids) along the negative axes.

Type of implant	600 cGy isodose along the X-axis	600 cGy isodose along the Z-axis
HDR, ^{192}Ir	$X_{(HDR)}$=36±1(mm)	$Z_{(HDR)}$=16±1(mm)
LDR, ^{137}Cs	$X_{(LDR)}$=36±1(mm)	$Z_{(LDR)}$=15±1(mm)

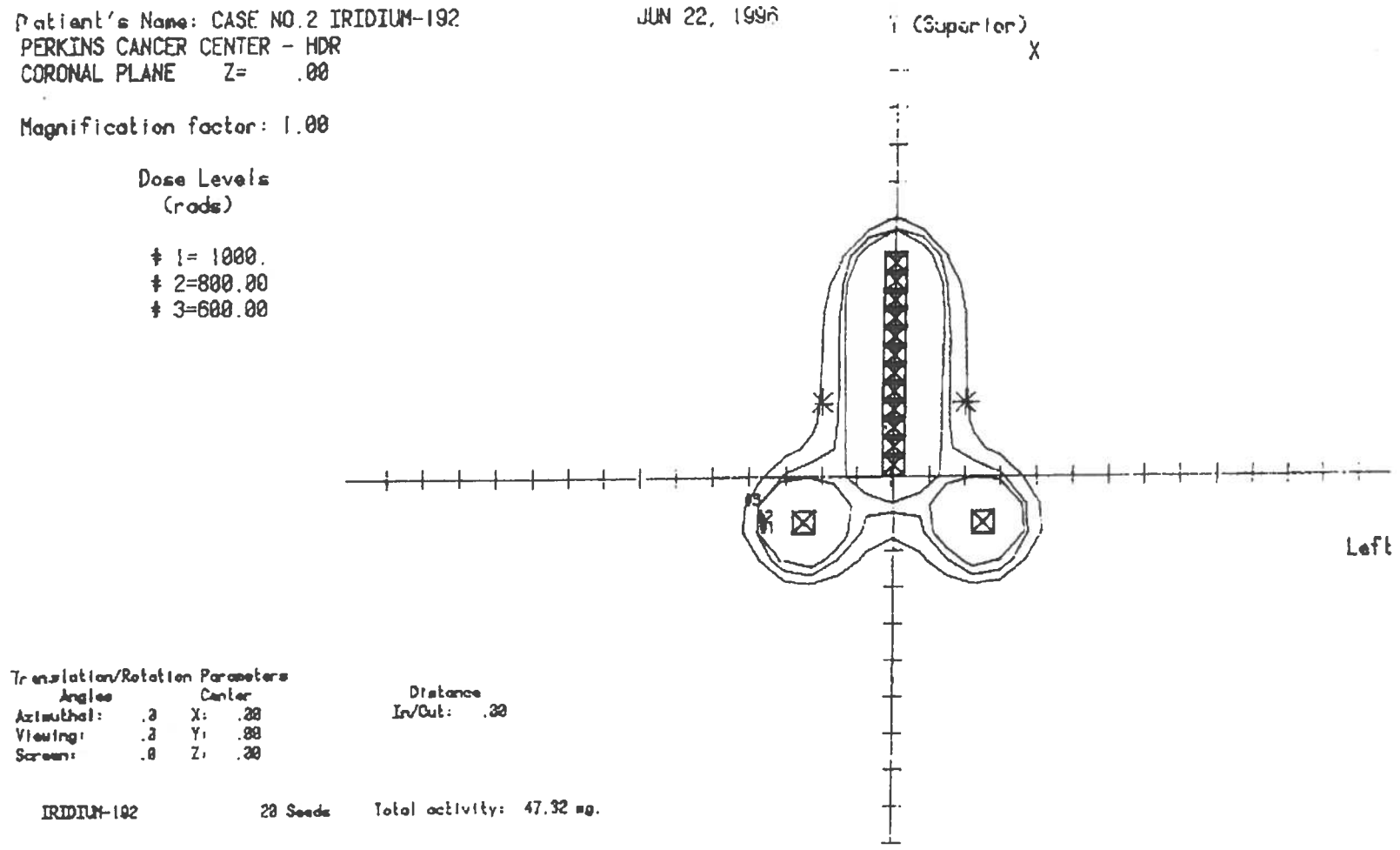


Fig5 .4.2.10: Isodose distributions for Ir-192 (case#2) generated with Capintec

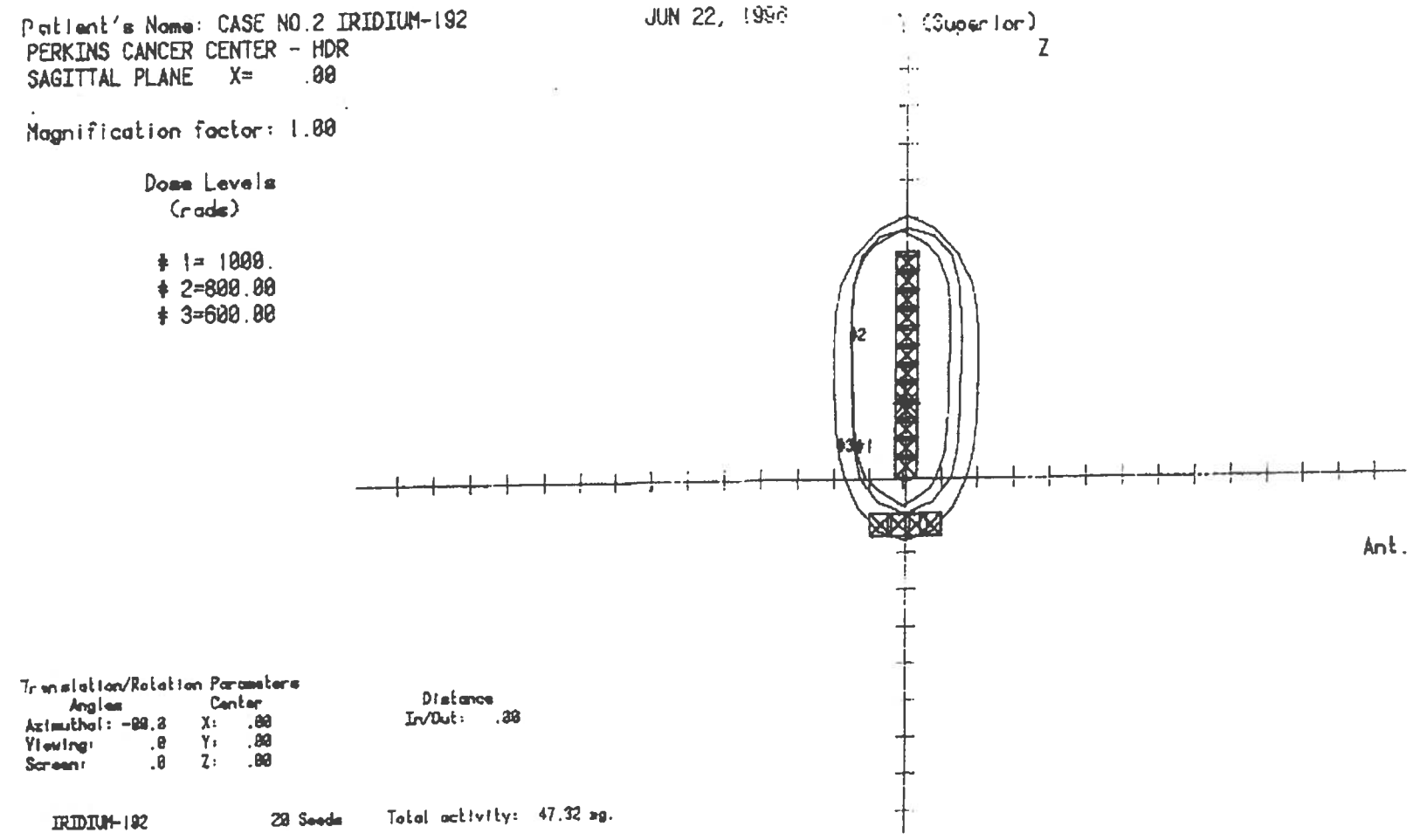


Fig 5.4.2.11: Isodose distributions for Ir-192 (case#2) generated with Capintec

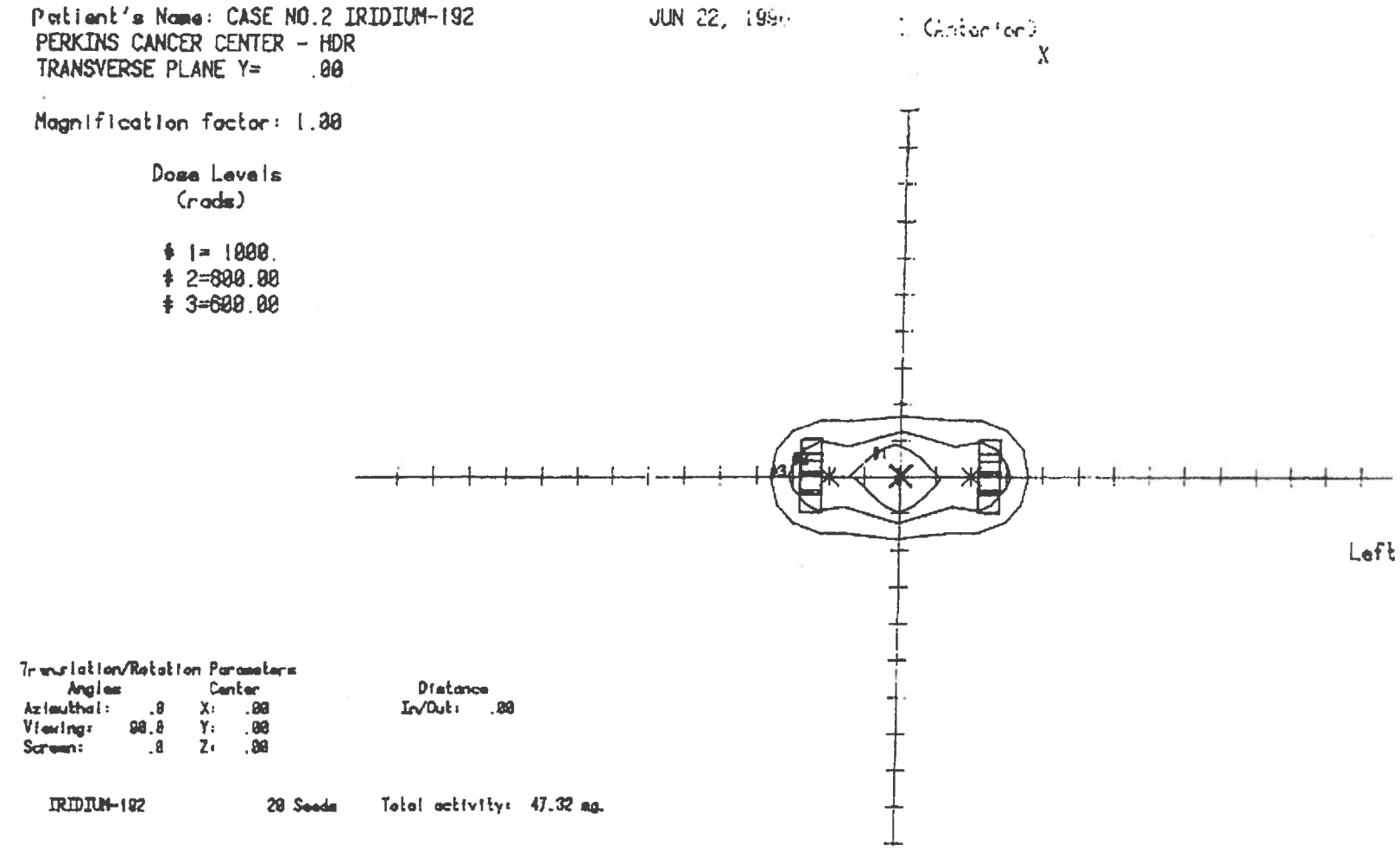


Fig 5.4.2.12: Isodose distributions for Ir-192 (case#2) generated with Capintec

Table 5.4.2.3 Comparison between generated isodose distributions for ^{192}Ir (case #2, 4 dwell positions in ovoids) , using Capintec computer and Personal computer, along the positive axes

Dosimetery planning system	600 cGy isodose along the X-axis	600 cGy isodose along the Y-axis	600 cGy isodose along the Z-axis
Capintec	X_C=36±1(mm)	Y_C=70±1(mm)	Z_C=17±1(mm)
PC	X_P=36±1(mm)	Y_P=69±1(mm)	Z_P=16±1(mm)

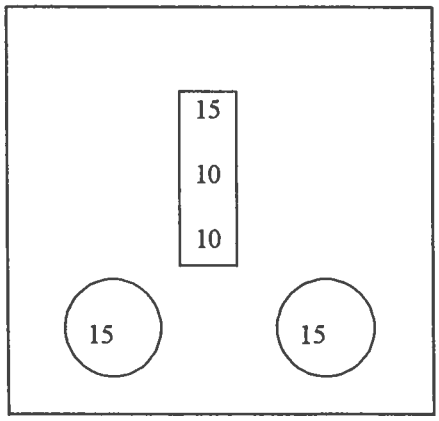


Table 5.4.2.4 Comparison between generated isodose distributions for ^{192}Ir (case #2, 4 dwell positions in ovoids) , using Capintec computer and Personal computer, along the negative axes

Dosimetery planning system	600 cGy isodose along the X-axis	600 cGy isodose along the Y-axis	600 cGy isodose along the Z-axis
Capintec	X_C=36±1(mm)	Y_C=17±1(mm)	Z_C=17±1(mm)
PC	X_P=36±1(mm)	Y_P=16±1(mm)	Z_P=16±1(mm)

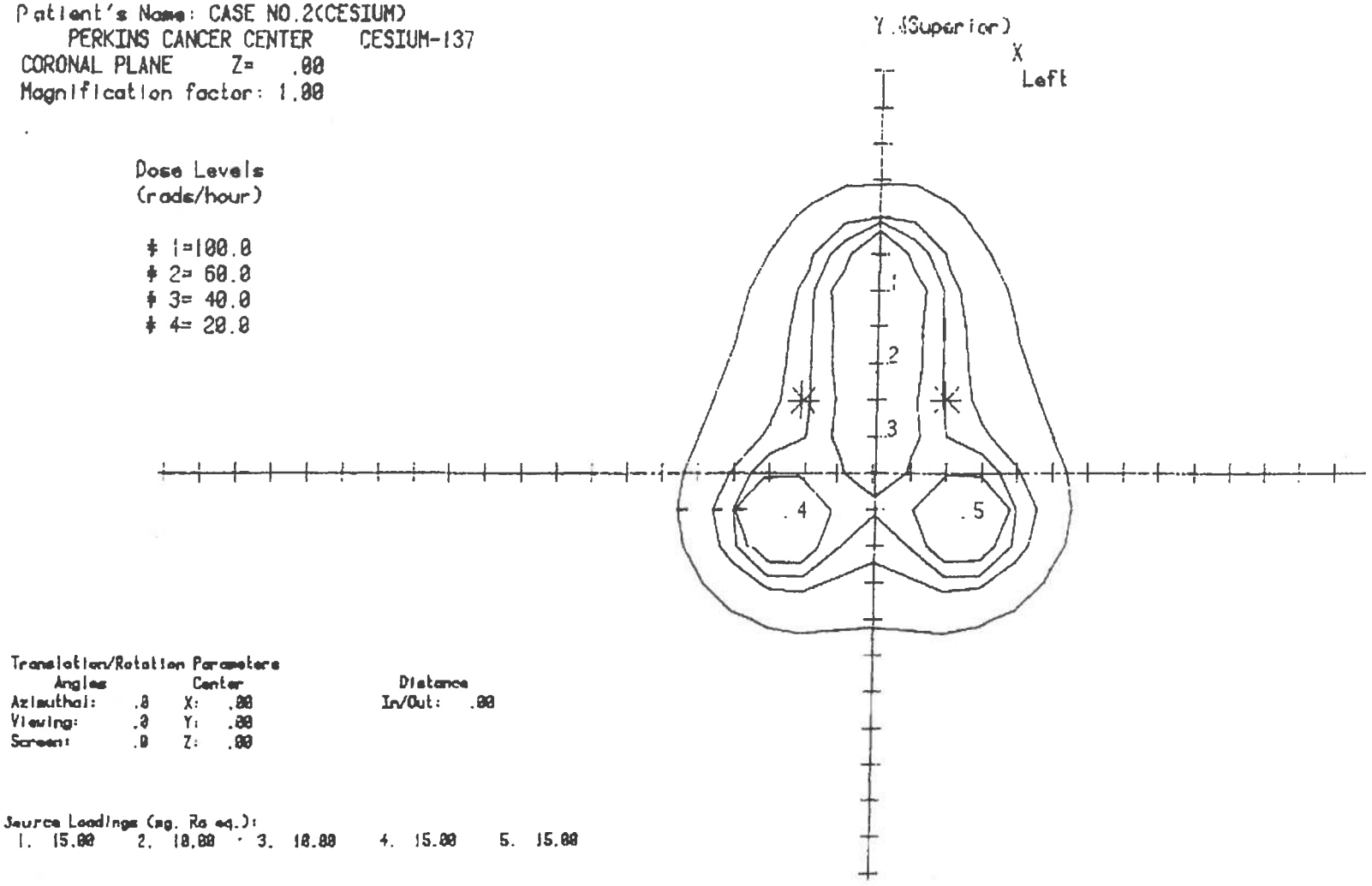


Fig 5.4.2.13: Isodose distributions for Cs-137(case#2) generated with Capintec

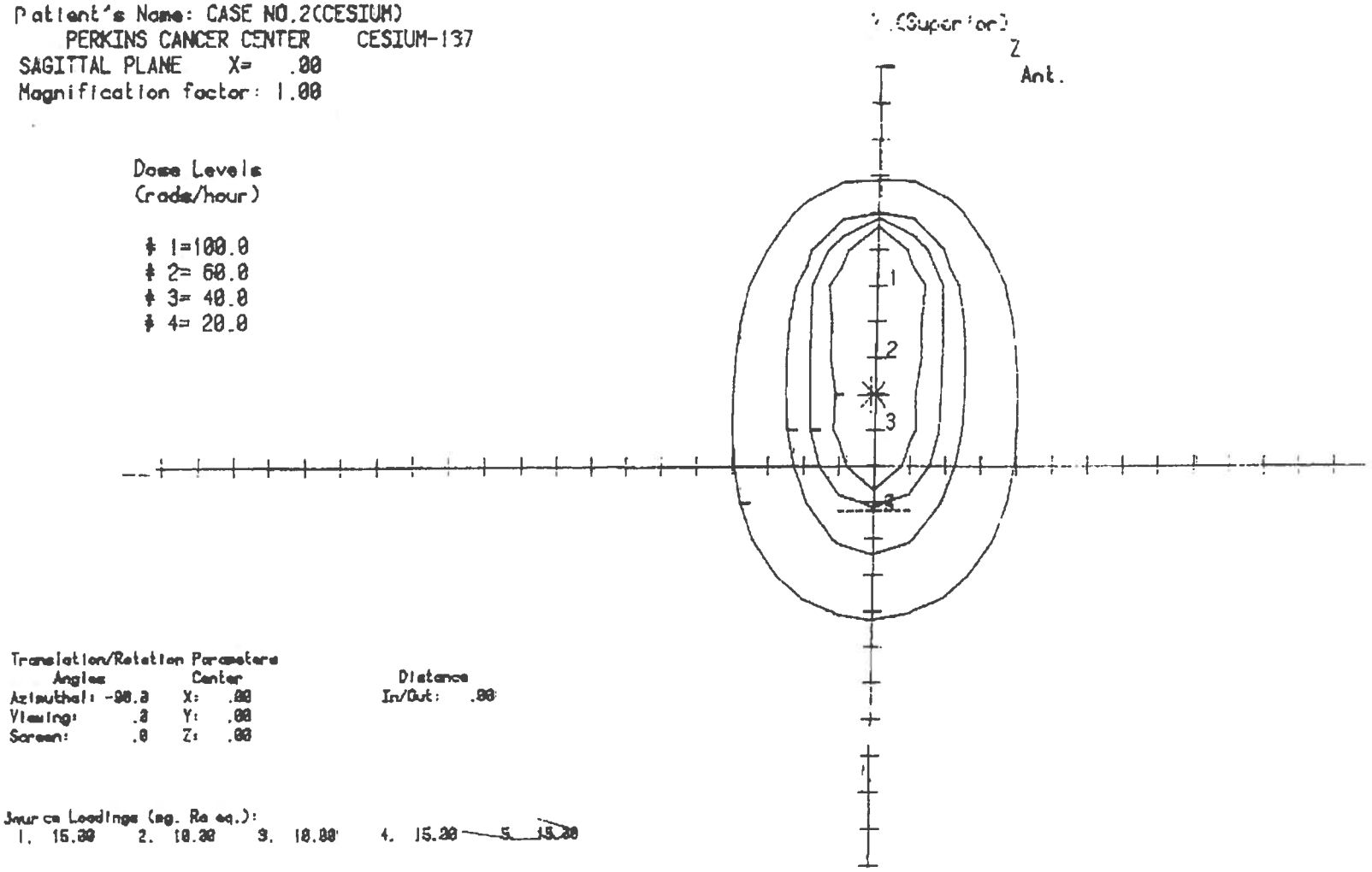


Fig 5.4.2.14: Isodose distributions for Cs-137(case#2) generated with Capintec

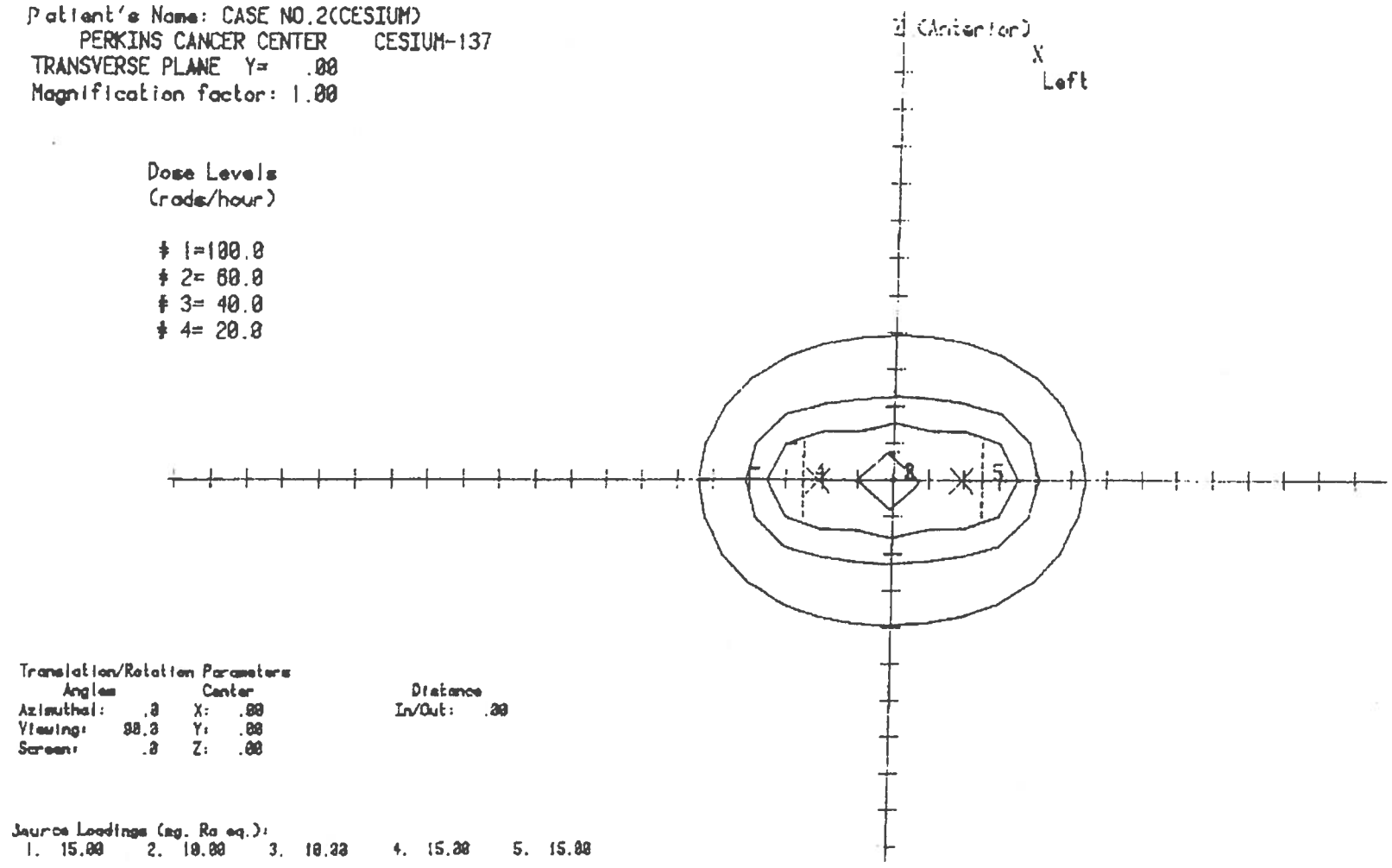


Fig 5.4.2.15: Isodose distributions for Cs-137(case#2) generated with Capintec

Table 5.4.2.5 Comparison between generated isodose distributions for ^{137}Cs (case #2) , using Capintec computer and Personal computer, along the positive axes

Dosimetery planning system	60 (cGy/hour) along the X-axis	60 (cGy/hour) along the Y-axis	60 (cGy/hour) along the Z-axis
Capintec	X_C=35±1(mm)	Y_C=69±1(mm)	Z_C=15±1(mm)
PC	X_P=35±1(mm)	Y_P=68±1(mm)	Z_P=14±1(mm)

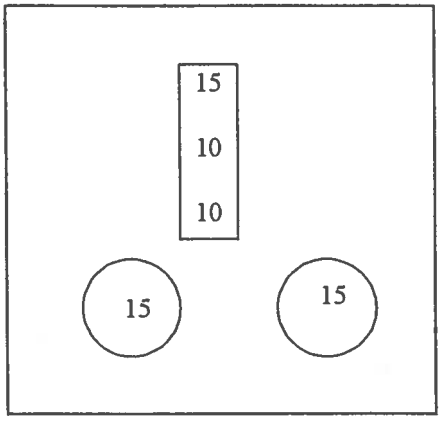


Table 5.4.2.6 Comparison between generated isodose distributions for ^{137}Cs (case #2) , using Capintec computer and Personal computer, along the negative axes

Dosimetery planning system	60 (cGy/hour) along the X-axis	60 (cGy/hour) along the Y-axis	60 (cGy/hour) along the Z-axis
Capintec	X_C=35±1(mm)	Y_C=12±1(mm)	Z_C=15±1(mm)
PC	X_P=35±1(mm)	Y_P=10±1(mm)	Z_P=14±1(mm)

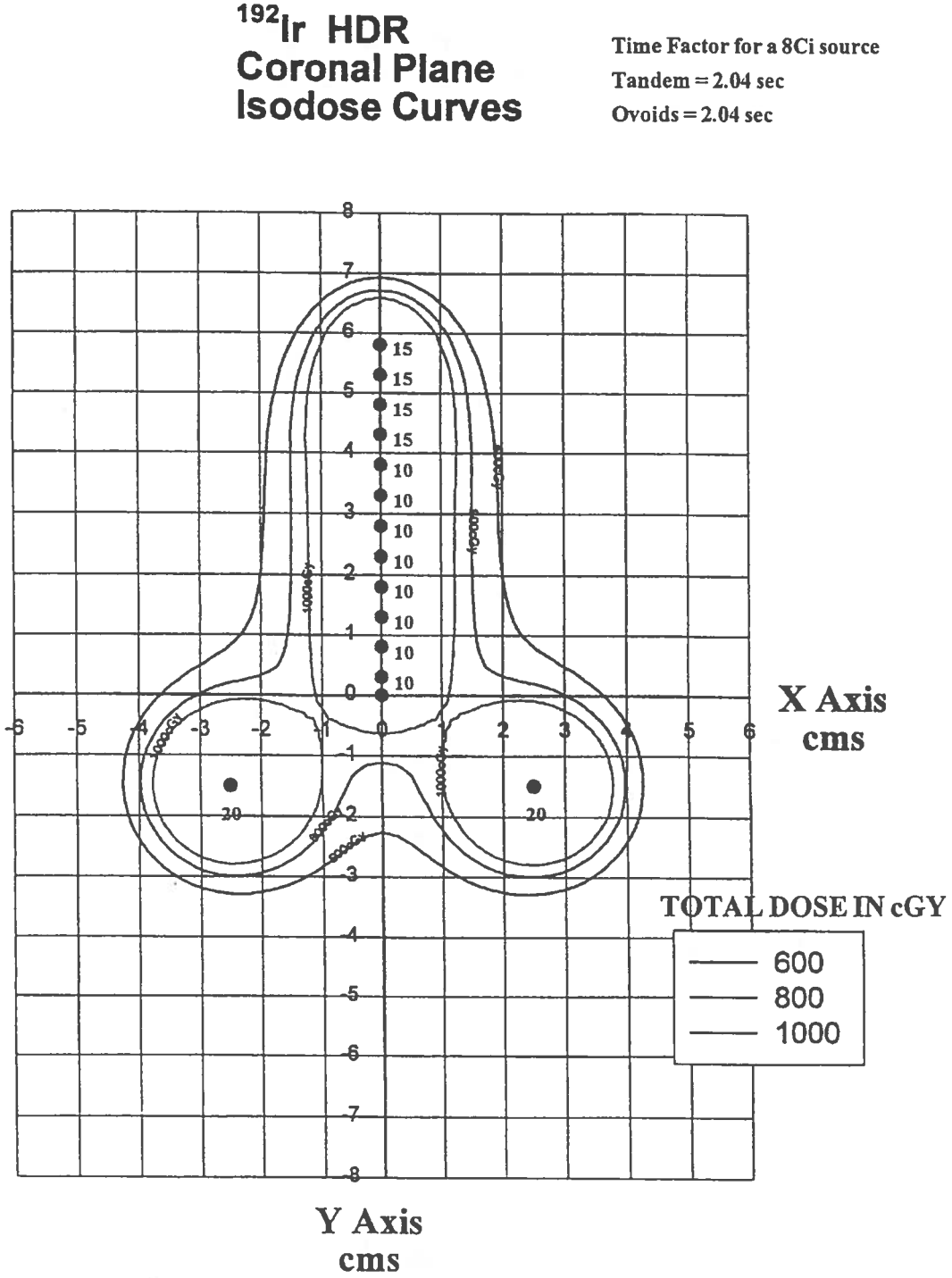


Fig5.4.3.1: Isodose distributions generated with PC for Ir-192 (case#3) with four dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

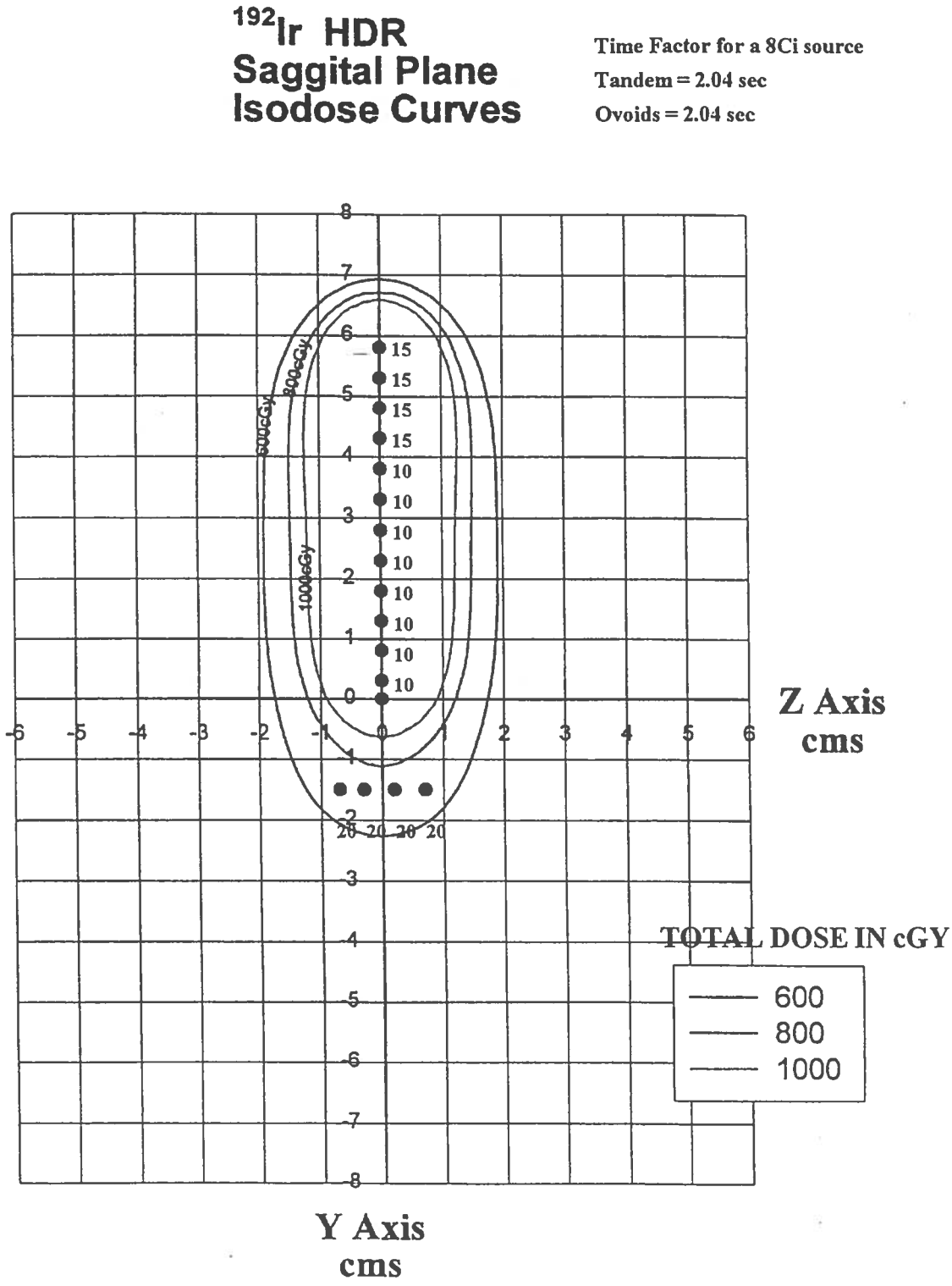


Fig5.4.3.2: Isodose distributions generated with PC for Ir-192 (case#3) with four dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

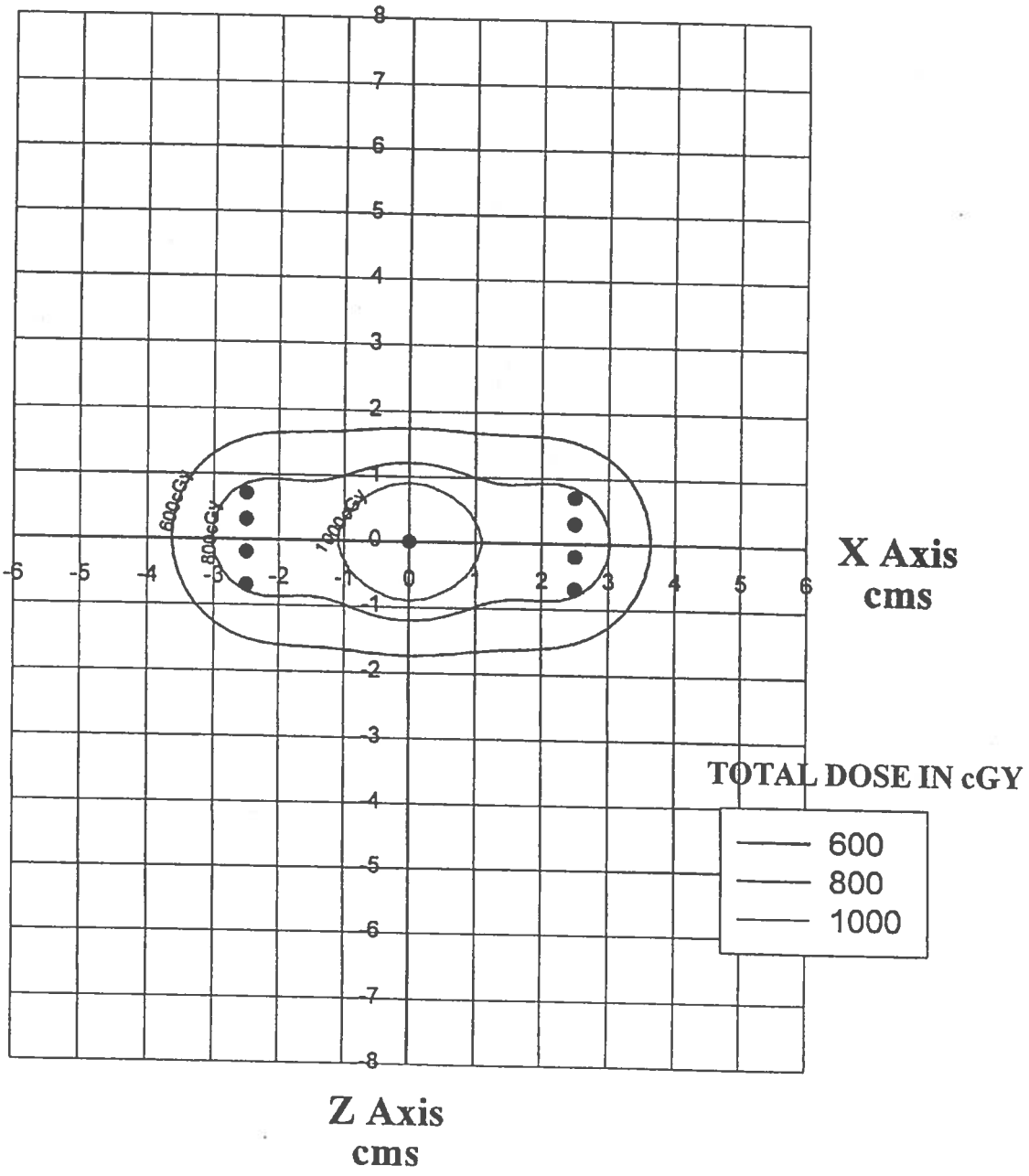


Fig5.4.3.3: Isodose distributions generated with PC for Ir-192 (case#3) with four dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

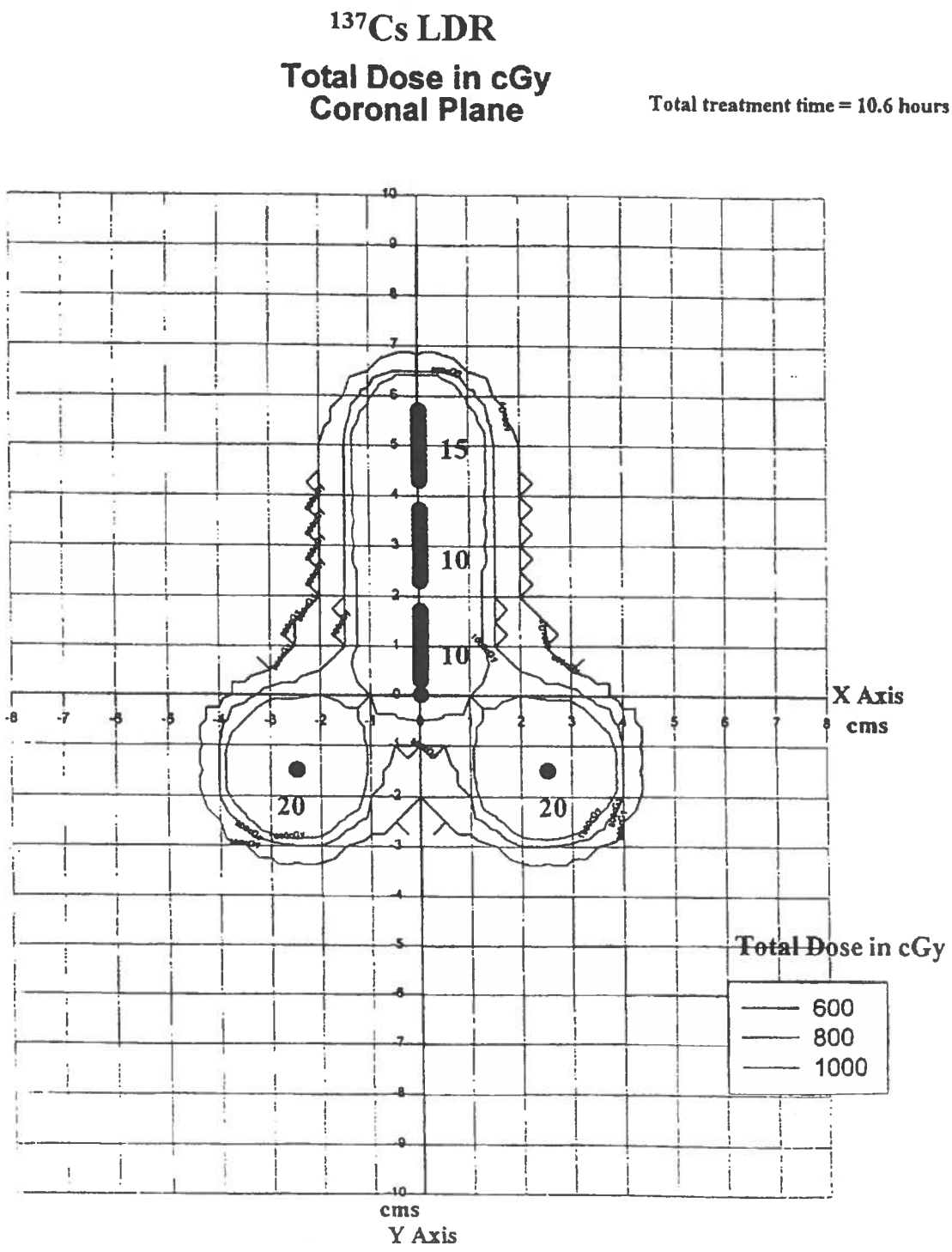


Fig 5.4.3.4: Isodose distributions generated with PC for Cs-137 (case#3). The numbers represent the activity of the source in mg Ra equivalent, as well as proportions or weighting.

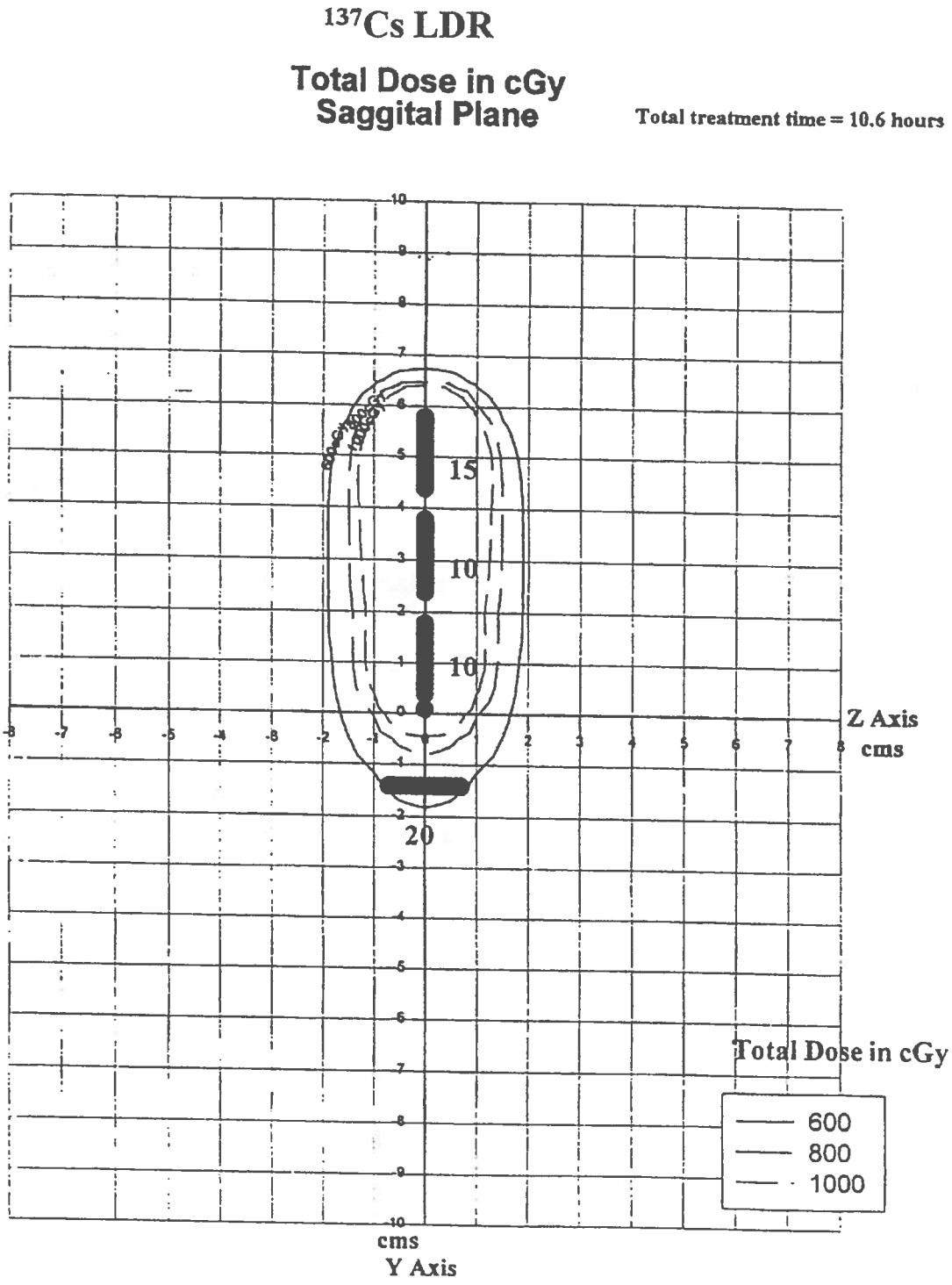


Fig 5.4.3.5: Isodose distributions generated with PC for Cs-137 (case#3). The numbers represent the activity of the source in mg Ra equivalent, as well as proportions or weighting.

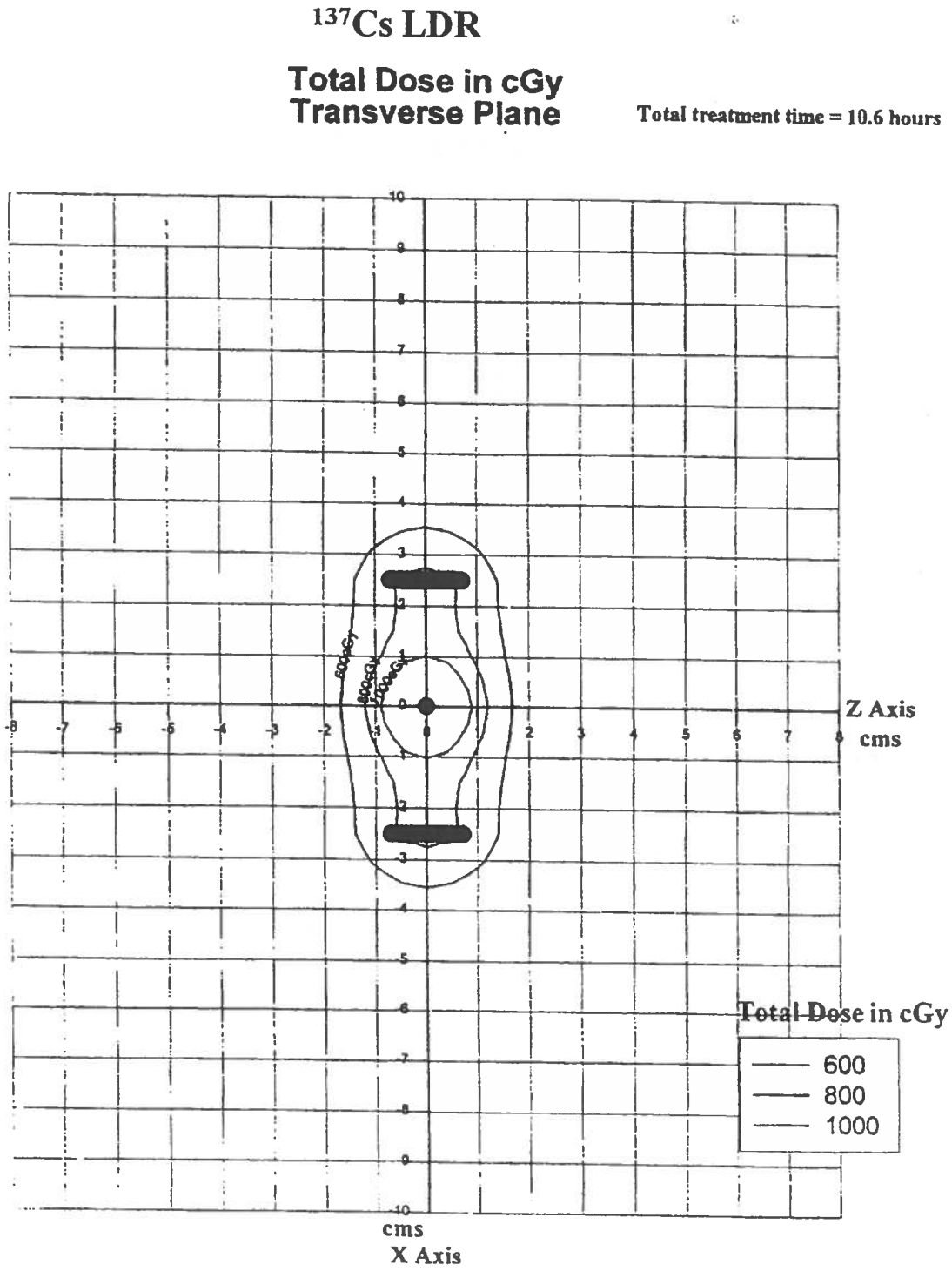


Fig 5.4.3.6: Isodose distributions generated with PC for Cs-137 (case#3). The numbers represent the activity of the source in mg Ra equivalent, as well as proportions or weighting.

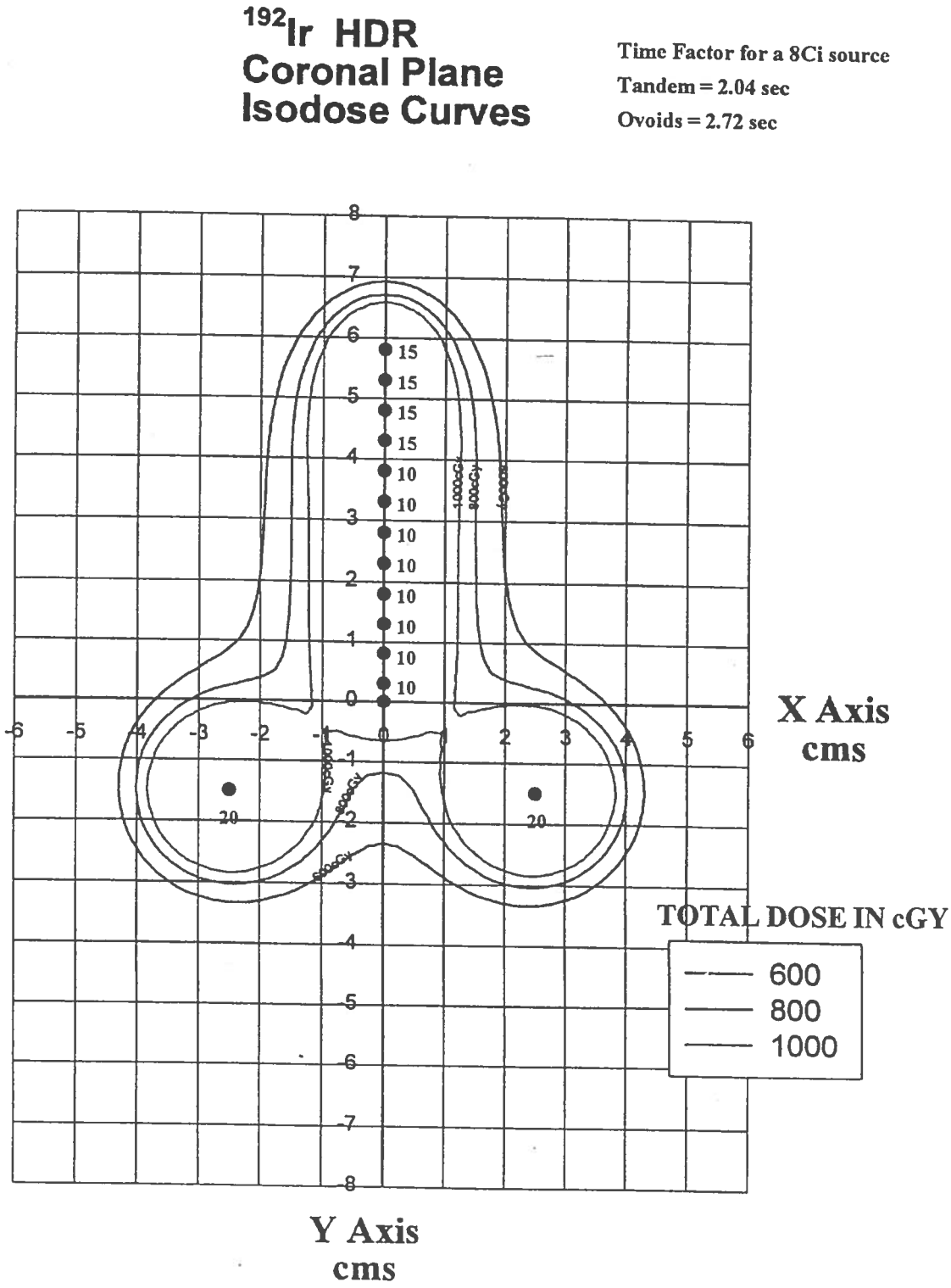
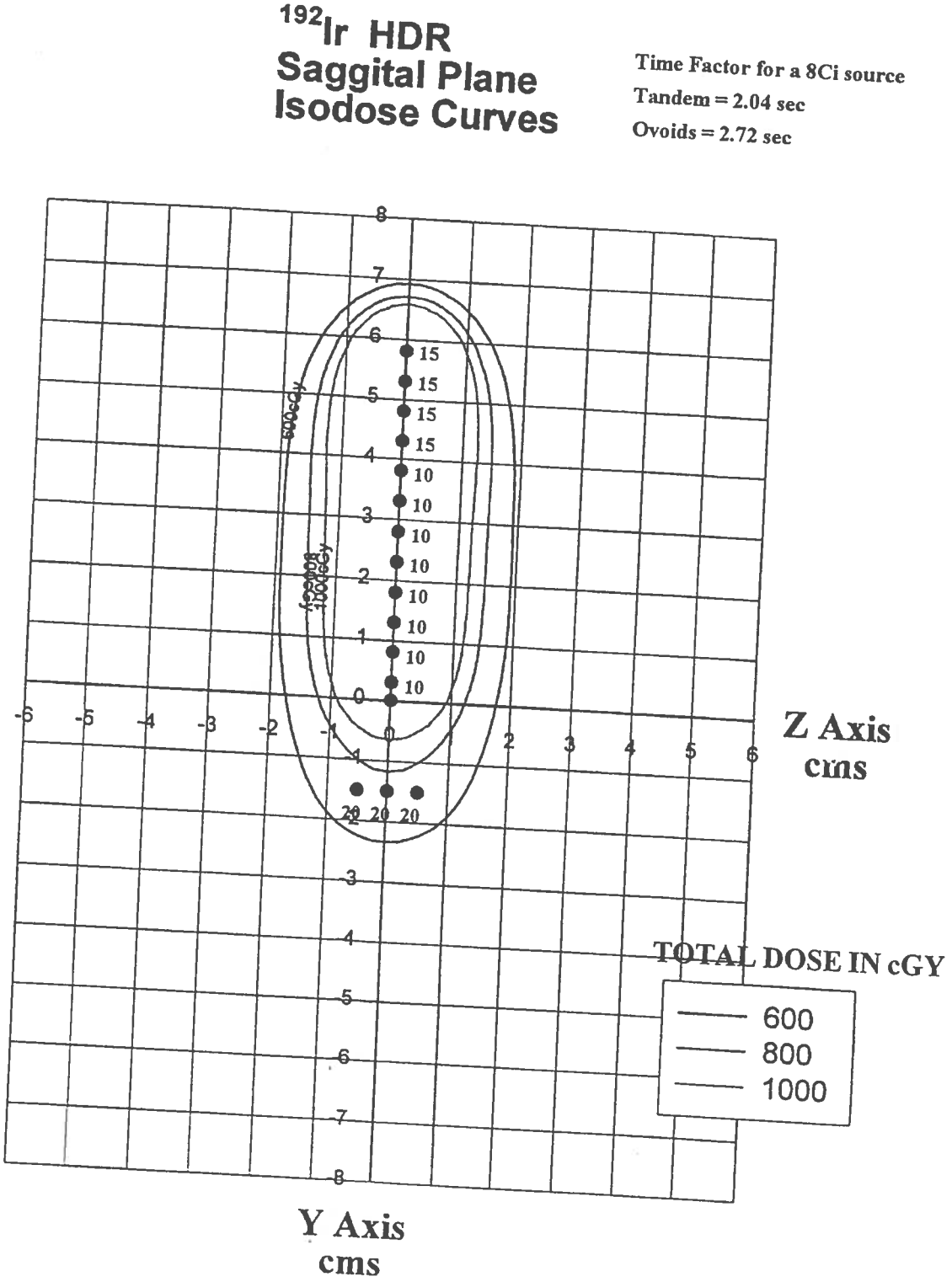


Fig5.4.3.7: Isodose distributions for case#3 with three dwell positions in each ovoid. The numbers in this case represent proportions or weighting.



g5.4.3. 8: Isodose distributions for case#3 with three dwell positions in each ovoid.
ıc numbers in this case represent proportions or weighting.

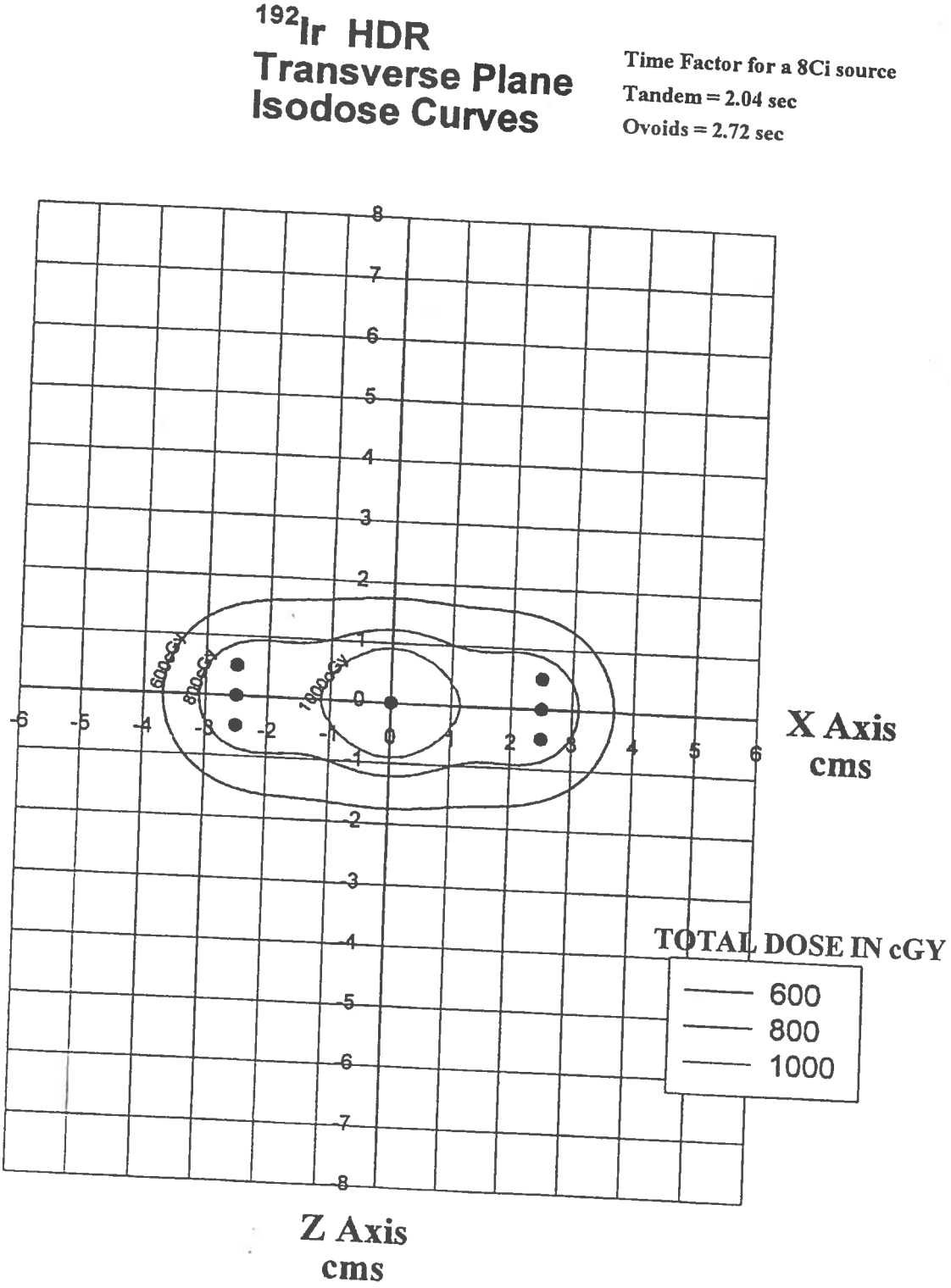


Fig5.4.3.9: Isodose distributions for case#3 with three dwell positions in each ovoid. The numbers in this case represent proportions or weighting.

Table 5.4.3.1 Comparison between HDR and LDR brachytherapy done with Personal computer for case #3 (4 dwell positions in the ovoids) along the positive axes.

Type of implant	600 cGy isodose along the X-axis	600 cGy isodose along the Y-axis	600 cGy isodose along the Z-axis
HDR, ^{192}Ir	$X_{(HDR)}$=37±1(mm)	$Y_{(HDR)}$=68±1(mm)	$Z_{(HDR)}$=16±1(mm)
LDR, ^{137}Cs	$X_{(LDR)}$=36±1(mm)	$Y_{(LDR)}$=69±1(mm)	$Z_{(LDR)}$=17±1(mm)

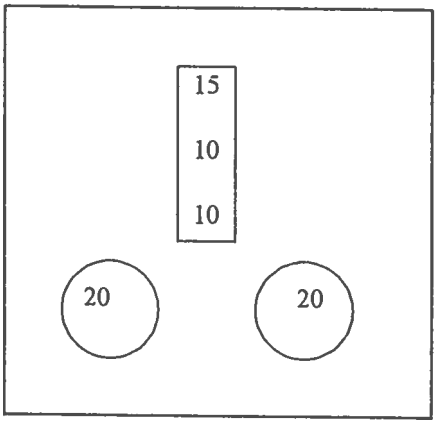


Table 5.4.3.2Comparison between HDR and LDR brachytherapy done with Personal computer for case #3 (4 dwell positions in the ovoids) along the negative axes.

Type of implant	600 cGy isodose along the X-axis	600 cGy isodose along the Z-axis
HDR, ^{192}Ir	$X_{(HDR)}$=37±1(mm)	$Z_{(HDR)}$=16±1(mm)
LDR, ^{137}Cs	$X_{(LDR)}$=36±1(mm)	$Z_{(LDR)}$=17±1(mm)

CHAPTER 6

SUMMARY AND CONCLUSION

Convenience and speed of modern personal computers have made them a powerful tool in solving complex problems in radiation therapy treatment, especially brachytherapy. In this study, we took advantage of these capabilities to generate isodose distributions, compare different loadings, and evaluate different computer planning systems' generated distributions.

In this study, a program called Time has been developed to compute dwell times of a high activity ^{192}Ir source. In this spreadsheet-based code, matrix calculations are used to solve the dose equation and generate the dwell times of an ^{192}Ir source. The developed code was tested for several example problems. The result of the comparison between different treatment planning systems for a sample case is presented in chapter 3. It can be seen that, there is a good agreement between isodose distributions generated with PC calculated dwell times and other distributions using Nucletron, Capintec, and Theraplan treatment planning systems. In another word, PC results compare very well within ±1mm with the treatment planning systems used in this study.

Other PC-based codes have been used in this study to generate isodose distributions around the HDR and LDR ovoid and tandem applicators, using Fletcher recommended loadings. The results of the comparison between HDR and LDR loadings are presented in different tables at the end of chapter 5. It can be concluded from those comparisons that HDR brachytherapy gives us the same isodose distributions as LDR brachytherapy when the same loading proportions are used. Also, the comparison

between isodose distributions for 4 dwell positions in ovoids versus 3 dwell positions in ovoids reveals an excellent agreement between these distributions. Thus with a simple modification, 4 dwell positions in each ovoid can simply be substituted by 3 dwell positions.

Also, in this study two sets of configurations which produce an improved dose distributions for vaginal cylinders are presented. Based on the evaluations presented at the end of chapter 4, PC calculated dwell times satisfy the prescribed dose points along the vaginal cylinder and the dome. Also, the result of the evaluation tables (tables 4.2.1.5 & 4.2.2.5) reveals that PC calculated dwell times generate more uniform isodose distributions than Nucletron computer especially around the dome surface.

One of the most important highlights of this study was to find the ability of the PC based spreadsheets to offer a new, friendly, and affordable treatment planning system. In this study, only one software program and a particular approach are used to solve equation 3.2.1, however, other software as well as a different method can be used to solve this equation as well.

As it was mentioned in chapter 3, "Time" and other spreadsheet based codes developed at the Mary Bird Perkins Cancer Center get their input data (such as source and dose point coordinates) either from other treatment planning computer-digitized data or manually traced graphs from radiographs. To improve this procedure a code can be developed to link a digitizer to a personal computer. Thus, the input data will automatically be transferred to the code. This will significantly simplify the procedure in running the codes.

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APPENDIX

TIME PROGRAM
EXCEL SPREAD SHEET BASED

USER MANUAL

I) Introduction:

The Time program is developed on a personal computer at the Mary Bird Perkins Cancer Center. Suggested requirements to run this program is a 386 or higher personal computer, 4MB RAM, 3MB HDD, Windows ver.3.1 or higher and Microsoft Excel ver.5.0 or later.

II) Instructions:

- First start Microsoft Excel, then in the toolbar menu go to the File.

- Click on open and type ," time.xls" then Enter.

-Since this program is password protected, a message will appear on the screen. Type the password and Enter.

A) General Data

-Type the patient's name and chart number.

-Type the activity of the Ir-192 source at the time of HDR procedure.

-Type the Nucletron calculated time (optional).

B) Coordinates of the sources and dose points

-Input the coordinates of each dwell position in mm.

-Input the coordinates of each dose point in mm (number of sources should be the same as dose points).

Input the prescribed dose to the each dose point in cGy.

:) Results

Excel calculates the dwell times as soon as you input the data and displays them on the :esult column.

If there is any negative dwell time in the result, go to the tools and click on solver)ption.

Solver will be displayed as a window on top of the spread sheet. This tool can be used o tune the time and dose through iterations until the constrains satisfied.

Input "V10" cell as a target cell.

Cells in the optimization column, starting from cell #8 through the last one which :orresponds to the last dose point, should be inputted for changing cells (For example k8 : k39).

In order to apply the constraints in the program, click on Add button and type a :onstraint, then click on O.K.

-Constraints should define our time arrow or optimization column. As an example P8 : P39>0 put a constraint on the dwell times to be positive. It should be noted :hat constraints must be related to the target cell. Another important constraint which allows solver to tune the isodose distributions within a reasonable criteria is a :onstraint on the optimization (For example following constraints defined the dose within %4 of the prescribed dose, K8 : K39 ≤ 1.04 and K8 : k39 ≥ 0.96).

-After inputting all the constraints, click on options.

-Enter Maximum time for the iteration process(For example 100 seconds).

Enter the number of iterations desired to solve the problem(For example 100 erations).

Click on OK, then click on "solve".

Solver will try to satisfy all the constraints and solve the problem. A message will be lisplayed on the screen to notify the user about the status of the results. If the message ells you " all the constraints were satisfied and solver found the feasible answer "save he results by clicking on O.K. If solver could not satisfy all the constraints you go oack to the solver and after modifying the constraints run it again.

-By clicking on " print " button in the first page you can have a hardcopy of the data and results.

VITA

Sharareh Nikbakht was born on April 29, 1962, in Tehran, Iran. She attended Nezam Vafa high school in Ahwaz and graduated in June 1980. She obtained her Bachelor in Physics in August 1987 from Shahid Chamran University in Ahwaz, Iran. She entered graduate school and received a graduate assistantship in the Nuclear Science Center at Louisiana State University in January 1993. She is currently a candidate for a Master of Science and Engineering Degree in Nuclear Science, Medical Physics Option, Which will be awarded in May of 1997.

MASTER'S EXAMINATION AND THESIS REPORT

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Major Field: Nuclear Science and Engineering

Title of Thesis: Performing Brachytherapy Dosimetry on Personal Computers

Approved:

Oscar Hidalgo S.
Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

October 16, 1996