COMMISSIONING AND EVALUATION OF THE PLATO - BRACHYTHERAPY PLANNING SYSTEM

A Thesis

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DEDICATION

As I reflect on the years of my life, one thing shines through. It is the love and support of my father and mother. My parents have been an inspiration in my life and in my achievements. They have given me the foundation I needed to be the person I am today. Through the struggles in my life, they have always been there walking beside me with words of continuous encouragement and commitment to my education.

Therefore, I would like to dedicate my research to the two most wonderful people I know, my father and mother. I have been truly blessed in life and would be honored to share my accomplishments with them as they have continued to be an instrument in my life and in my success.

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ABSTRACT

The objectives of this study were the commissioning and evaluation of the PLATO-Brachytherapy Planning System (PLATO) for use at Mary Bird Perkins Cancer Center (MBPCC). The brachytherapy planning system that is currently in use is the Nucletron Planning System (NPS) which has historically been difficult to utilize.

Direct assurance of the quality of a calculational algorithm and its implementation in a computer code is minimal. Tests of the output must therefore be performed. Verification of the calculational algorithm for PLATO involved calculation of dose at known distances from the source. The calculational method was found to be accurate; however, the ability to calculate dose within 5 mm from the source was not accurate. Human error in digitizing along with the sharp dose gradient present at short distances from the source were found to be the contributing factors to the inaccuracy. The required accuracy of hardware devices is 1 mm. Humans should not be expected to digitize better than 1 mm and with the sharp dose gradient, accurate calculation of dose within 5 mm from the source should not be expected. Consequently, dose should not be prescribed at distances less than 5 mm.

The complete treatment planning algorithm of PLATO was verified by performing tests of the output over a range of clinical conditions and comparing results with respect to spatial accuracy for equal isodose levels against those obtained with the NPS, Capintec Cap-Plan-RTP110, Theratronics Theraplan-V05B, and MBPCC spreadsheet programs. Although this process cannot test every possible parameter and situation, it gives the user confidence in the computer program as well as an understanding of its limitations and uncertainties.

PLATO is concluded to be an overall superior system and with training, should permit smooth entry of data. This should ultimately reduce treatment planning time, patient table time, and prolonged patient discomfort.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Cancer is a disease that is feared by people throughout the world. Cancer is not particular, it can strike anyone, at any age. Cancer cells are abnormal in structure and do not have specialized functions. They compete with normal cells for nutrients and ultimately kill normal tissues. Cancerous cells can remain localized or they can spread to other tissues or organs through the blood or lymphatic system, often resulting in death [1]. However, many cancers can be cured if they are detected early and treated promptly. Doctors and scientists together have been battling cancer for generations. Cancer is traditionally treated with surgery, chemotherapy, and radiation.

Management of any disease begins with the selection of a treatment methodology, of which all have benefits and risks. The choice of a particular method involves a joint venture between education and experience. No one method is clearly better than the others but through considering the benefits and risks, a method must be chosen that is believed to be the most beneficial to the patient.

1.2 Principles of Brachytherapy

The method of treatment for cancer that is discussed and analyzed in this research study is an irradiation method that involves the usage of small sealed radioactive sources that are used to deliver radiation at short distances from the tumor by interstitial, intracavitary, or surface application. This method is known as brachytherapy, meaning therapy at "short" distances. Brachytherapy sources can be administered as temporary or permanent implants to facilitate the local delivery of radiation to a tumor with rapid dose

fall-off in the surrounding normal tissue. This ability to localize the dose to the tumor volume gives brachytherapy a major physical advantage over conventional external beam therapy [2].

1.3 Principles of Commissioning and Quality Assurance

Brachytherapy is a complex process involving multiple steps beginning with patient diagnosis and continuing through treatment planning and ultimately the treatment of the patient. From the very first step, it is imperative that accurate and concise steps are performed with as little deviation as possible. With each step, building upon the previous, uncertainties in any one step can accumulate and drastically affect the outcome of the patient's treatment. This will have a great effect on cure rate as well as the possibility of radiation induced complications. Therefore, it is of vital importance to have and follow a comprehensive commissioning and continued quality assurance program for treatment planning computers to reduce the possibility of compounded errors throughout the brachytherapy treatment planning process.

Van Dyk et al. define quality assurance as "the systematic actions necessary to ensure that a product or process performs to specification" [3]. Quality assurance is the main emphasis involved in commissioning a brachytherapy treatment planning computer, as it is with any treatment planning computer. Once the commissioning is completed, the quality assurance measures take over and insure continued quality of the system. Quality assurance involves many aspects of brachytherapy including algorithm verification, software and hardware testing, as well as staff training. Quality assurance requires team work and is a continuous, never-ending process.

CHAPTER 2

LITERATURE REVIEW

2.1 Historical Overview

The history of brachytherapy began in the laboratory of Marie and Pierre Curie, on the slope of the Sainte Genevieve Hill in Paris in 1898, where the purification of radium was first performed [4]. Soon after the discovery of radium, followed the construction of platinum needles (tubes) to contain radium sulfate. However, due to the fact that platinum encased tubes are relatively soft, a radium tube can be bent or broken. The leakage of radon gas from a radium source represents a significant hazard if the source is broken. With a half-life of 1,620 years, a radium accident is a major safety problem [5].

As brachytherapy has progressed through the years, different isotopes and methods have been introduced. The introduction of artificial radionuclides such as Cs-137, Ir-192, Au-198 and I-125 has expanded brachytherapy extensively. The gamma ray energies, source flexibility, source size, and half-lives of the artificial nuclides have led to the development of various types of brachytherapy with a wide range of applications [6]. Applications of radionuclides can be accomplished by temporary or permanent implantation. When temporary implants are performed, Ir-192 and Cs-137 are often the radionuclides of choice. For permanent implants, short lived radionuclides are needed such as Au-198, Pd-103, and I-125 [7, 8].

Historically, physicians used radium implants for treatment of cervical cancer. Radium implants in the cervix were performed manually where protection of the fingers as well as the whole body from high energy gamma radiation was difficult, if not

impossible. The best protection that the physician had was speed and distance [9]. With the ability to better manage radiation protection concerns using artificial nuclides and due to the high radiation concerns involved with radium, radium is virtually no longer used. As concerns for more manageable radiation protection continued to grow, the development of afterloading applicators came into view in the 1950s. Afterloading allowed the applicator to be placed in the patient and repositioned as necessary to achieve the desired dose distribution before loading of active sources for treatment. As technology continued to advance, remote afterloading devices were developed in the 1960s that could be used to deliver controlled radiation exposure using small, high activity sources. With remote afterloading brachytherapy, the treatments could be started and stopped from outside the treatment room by remote control which allowed personnel and visitors to enter the treatment room safely when the source was retracted. There is a range of approaches to remote afterloading devices. Sources can be moved pneumatically or by mechanical linkage where manual as well as electrical power can be used. Some systems use multiple sources while others use single sources. The dose distributions can be varied by changing the arrangement of the sources (source train) or by step-movement. In a source train, a sequence of small sources, some active and some non-active, are arranged in a fixed and reproducible configuration. In some afterloading systems, a single source is moved in a continuous or stepwise fashion inside one or more catheters [6].

2.2 Contemporary Overview

Today, remote afterloading brachytherapy continues to be a very significant mode of radiation therapy for the treatment of cancer. It may be used alone or in conjunction

with external beam therapy. The results of improved patient care while sources are retracted as well as the elimination of unnecessary personnel exposure, have been a stimulus in the advancement of brachytherapy. It has been seen over and over throughout history that the fear of radiation prevails. Any hospital personnel who cares for brachytherapy patients is required to be trained about radiation safety issues. The hospital personnel are ensured that with routine patient care, they are not in danger from the radiation emitted. However, the fear of radiation among hospital personnel has persisted. Many times their fear leads to the refusal to care for conventional brachytherapy patients or to spend adequate time with them. With the ability of remote afterloading to reduce medical staff exposures to negligible amounts, remote afterloading has in turn helped reduce the fear that is inherent with the unseen. The Nuclear Regulatory Commission (NRC) requires that radiation levels be reduced to the lowest possible levels. With this standpoint, they termed the ALARA (as low as reasonably achievable) principle. "Since remote afterloading units have proven to reduce personnel exposure drastically; at some time in the future, regulations may make it mandatory that remote afterloading methods be applied" [10].

When a brachytherapy method is to be selected, the physician must face many questions and make decisions about how he plans to carry out his treatment method. The severity of the illness must be determined to choose a treatment protocol properly. In order for the physician to write his orders, he must consider all of the following: 1) the choice between permanent or temporary implant, 2) what source to use based on its characteristics, 3) the dose rate and number of fractions to implement, and 4) the radiobiological effects on the tumor as well as normal tissue tolerance [11]. Once the

physician has thoroughly reviewed all of the options and consequences, he must explicitly write the prescription that will be carried out by himself in conjunction with the physicists, dosimetrists, therapists, and nurses in order to give each patient the best possible care and highest probability of a cure. With early detection and prompt treatment, a "cure" is attainable for many patients.

2.3 Source Selection, Characterization, and Comparison

In order to choose a source for any brachytherapy treatment, the characteristics of the source must be known. Different sources are used for different treatment methods depending on whether the implant is permanent or temporary and depending on the location of application and type of cancer being treated.

Permanent interstitial implants involve encapsulated sources with relatively short half-lives that can be left in place permanently. This is an advantage to the patient because an operation to remove the implants is not necessary and the patient can go home with the implant in place. However, the expense is greater because the sources cannot be reused [12]. For permanent implants, short-lived sources are needed such as Au-198, Pd-103, and I-125. The main characteristics of these sources, commonly used in permanent interstitial brachytherapy, are listed in table 2.3.1.

Table 2.3.1: Main Characteristics of Sources Commonly Used in Permanent Interstitial Brachytherapy.

Isotope	Average Photon Energy	Half-Life	Half Value Layer (mm lead)
Au-198	412 keV	2.7 days	2.5
Pd-103	21 keV	17 days	0.008
I-125	28 keV	60.2 days	0.025

Temporary implants are commonly used in brachytherapy and the principle of afterloading is often employed. Intracavitary and intraluminal therapy are the most common temporary afterloading methods. They are used for treatments such as carcinoma of the cervix, nasopharynx, bladder, esophagus, and bronchus. With intracavitary therapy, applicators are placed within the cavity of interest with the tubes extending outside the body that are later used for afterloading with radioactive sources. Another temporary afterloading method involves interstitial therapy where hollow needles or plastic tubes are inserted into the tissue, with one or both ends brought through the skin. The radioactive sources are usually in another tube that are afterloaded for treatment. Interstitial therapy is the treatment choice for only 5 to 10 percent of patients whom the tumor is accessible for an implant [13].

The three radionuclides used most in temporary remote afterloading units include Co-60, Cs-137, and Ir-192. Their main characteristics are listed in table 2.3.2.

Table 2.3.2: Main Characteristics of Radionuclides Used Most in Temporary Remote Afterloading Units.

Isotope	Average Photon Energy	Half-Life	Half Value Layer (mm lead)	Specific Activity
Co-60	1.25 MeV	5.26 years	11.0	200 Ci/g
Cs-137	0.66 MeV	30 years	6.5	10 Ci/g
Ir-192	0.38 MeV	74.02 days	2.5	450 Ci/g

Co-60 was the first radionuclide used in remote afterloading units. The advantage of Co-60 is that it has a high specific activity of 200 Ci/g allowing it to be fabricated as a small source. However, the main disadvantage of Co-60 is the emission of high energy gamma rays at energies of 1.17 and 1.33 MeV with a half value layer of 11.0 mm of lead.

As one can see, this disadvantage primarily involves radiation protection concerns [14]. Another disadvantage of Co-60 was recognized in the fabrication process of Co-60 wires. It was found that there were problems involving the contamination of Co-60 dust. Therefore, whereas Co-60 has been used for brachytherapy in the past, it is seldom used today [6, 9].

Cs-137 has been widely used for intracavitary and interstitial brachytherapy. Cs-137 sources are similar in size and shape to radium sources, and have a similar output as radium. The same technique of application can therefore be applied and the clinical experience gained with radium can be correlated. The principal advantage of replacing radium with ^{137}Cs is to reduce the radiation exposure to the personnel. Cs-137 emits a single gamma ray with an energy of 0.66 MeV and has a half value layer of 6.5 mm of lead. This helps to reduce the shielding requirements in comparison to radium and Co-60. Cs-137 also has a long half-life of 30 years which decreases the expense of purchasing new sources and reduces the paperwork involved with source exchange procedures [6, 14].

In recent history, there has been a rapid replacement of Cs-137 with the radionuclide Ir-192. Ir-192 is the most common brachytherapy radioisotope in use today. It is supplied as an alloy of iridium and platinum. Ir-192 has a low average gamma ray energy of 0.38 MeV and has a smaller half value layer (2.5 mm of lead) than Cs-137, which therefore makes it relatively easier to shield. In addition, Ir-192 has a high specific activity of 450 Ci/g allowing it to be constructed as a small diameter (0.6 mm to 1.1 mm) source for use in intraluminal and interstitial treatments as well as intracavitary treatments. The other high dose rate sources, Co-60 and Cs-137, generally are larger in

diameter (2.5 mm to 4 mm) due to their lower specific activities of 200 Ci/g and 10.0 Ci/g respectively, which makes them less suitable for interstitial treatments. Ir-192 has a short half-life of 74.02 days, which is usually a disadvantage, however, its half-life is long compared to the average treatment time utilized. Overall, because Ir-192 is so much better from a radiation protection standpoint, it has become widely used throughout the United States as well as in many parts of the world [6, 14].

2.4 Radiobiology and Time-Dose-Fractionation

Most brachytherapy today involves the use of remote afterloading techniques which can be performed as low dose rate (LDR), high dose rate (HDR), medium dose rate (MDR), or pulsed dose rate (PDR). LDR involves a continuous course of brachytherapy irradiation extended over several days with a dose rate of 0.4 to 2 Gy/hr. HDR and MDR involve fractionated irradiation with dose rates of 12 Gy/hr or higher and 2 to 12 Gy/hr respectively [15]. PDR simulates LDR brachytherapy by administering a sequence of "mini" HDR fractions at hourly intervals [16].

"While either manual or mechanical afterloading techniques may be used for low dose rate applications, remote afterloading techniques are mandatory for medium, pulsed, and high dose rate applications in order to ensure proper radiation protection of the staff" [15]. Medium, pulsed, and high dose rate techniques require sources with elevated activity which makes it impossible to use manual afterloading techniques.

It has been found that the radiobiological effects of brachytherapy are related to the dose rate at which the treatment is performed. The relationship between dose rate and tissue response is a complex matter. When discussing radiation responses, the terms early (or acute) and late refer to the time of the development of injury. Acute reactions

can begin as soon as a few days after the first treatment and usually disappear within a few weeks of finishing treatment. Late reactions, however, may be delayed in appearance several months or more. The ultimate goal in brachytherapy is to maximize tumor control and at the same time, minimize normal late responding tissue damage [17, 18].

The genetic code is believed to be involved in radiation-induced cell killing. Evidence has shown that radiation causes DNA strand breaks and chromosome aberrations. Single strand breaks are more efficiently rejoined and repaired by the cells than are double stranded breaks. Double stranded breaks of DNA may be a precursor of chromosome aberrations which are thought to be related to cell death. The linear quadratic (α -β) model of cell survival has been useful for estimating the radiobiological effects of radiotherapy both on early and late responding tissues [18]. From the linear-quadratic model we see that the total number of double stranded breaks that occur per cell is equal to ($\alpha D + D\beta^2$) where α represents the linear coefficient, per unit dose that a double stranded break will be caused in a cell by a single ionizing event. β is the quadratic coefficient for the generation of double stranded breaks caused by two individual ionizing events. α/β values are assigned values depending on whether clinicians want to estimate early or late responding tissue effects and to what degree of response they are interested in observing [7, 8].

When a dose is split into fractions, separated by time a interval, more cells survive than for the same total dose given in a single fraction. This is due to sublethal damage repair. Continuous low dose rate (LDR) irradiation can be considered as an infinite number of small fractions (hyperfractionation) of radiation. With low dose rate brachytherapy treatment, radiation is delivered continuously over an extended period of

time which allows sublethal damage repair to take place during exposure. Late responding, normal tissues such as the bladder wall and rectal wall, have a greater ability for repair than tumor or early responding tissues. Therefore, giving cells time to repair will benefit the late responding, normal tissues more than the early responding tumor cells. Thus, we see that increasing the dose rate will cause more late complications for the same tumor control probability [5, 19].

The basis of knowledge and experience in brachytherapy stems from LDR treatment history. Therefore, when new or different methods are studied, the LDR pool of information becomes the starting point for comparison. The biological effective dose (BED) is a very useful concept in the radiobiology studies of brachytherapy. It helps to show the effect that changing dose rate will have on tumor cells and normal cells. The BED is "the dose which would be required to produce the same effect if it could be given at a very low dose rate, or with an infinite number of infinitely small fractions" [20]. The BED is used to compare different fractionation regimens. It is equal to the (Total Dose) * (Relative Effectiveness Factor), where the relative effectiveness factor is equal to 1 + (dose per fraction/(α/β)). When changing from continuous LDR treatments to fractionated HDR, the biological effectiveness of a given dose increases for both early and late responding tissues. However, the biological effectiveness increases more for the late responding tissues. Thus, the ratio of the biological effect to the tumor to the biological effect to the normal tissue, known as the therapeutic ratio, decreases when changing to fractionated HDR from continuous LDR. As the number of fractions increases, the therapeutic ratio moves toward that of LDR and a higher tumor dose becomes attainable without serious biological concerns of overdosing normal tissue [12].

From clinical and experimental data it has been determined that when the overall time is kept constant, it is the dose per fraction that affects acute and late responding tissues, not the number of fractions. These factors must be taken into consideration in order to obtain the goal of minimization of tumor repopulation and maximization of normal tissue cell repopulation, and ultimately the increase in cure and reduction of complications for the patient [12, 18].

Ling [7, 8] demonstrated the radiobiological effects of different radionuclides through an in depth study of three permanent interstitial implant sources. Due to the different time-dose patterns of isotopes, different prescribed doses were used to try to achieve equal biological effects. Ling used Au-198, Pd-103, and I-125 in his study with total doses administered of 60, 120, and 160 Gy delivered at dose rates of 0.64, 0.20 and 0.077 Gy/hr respectively. With these sources, he studied the radiobiological effects of varying BED and tumor doubling time on tumor surviving fractions.

Ling showed that the BED for these isotopes peaked at 14, 58, and 120 days for Au-198, Pd-103, and I-125 respectively. At times greater than these, the BED values decrease and the surviving fraction increases as tumor regrowth dominates over the effect of the radiation that is being delivered at a decreasing dose rate as the source decays.

Ling also demonstrated that when tumor doubling time is increased from 5 to 30 days for each of the isotopes, the surviving fraction changes were markedly different. Ling concluded from his data that when short-lived isotopes such as Au-198 (2.7 days) are implanted, a change in tumor doubling time has essentially no effect on the surviving fraction. The decrease in dose rate of Au-198 is so fast that the rate of tumor regrowth is less important. In the case of the tumor having a 5 day doubling time, Au-198 decreases

the surviving fraction more rapidly than Pd-103 and I-125. For treatment with long-lived isotopes such as Pd-103 and I-125, with slow decreases in dose rate, the surviving fractions are very sensitive to changes in tumor doubling time. It was observed that I-125 is the most sensitive to changes in tumor doubling time.

In the past, iodine-125 has been a widely used isotope for permanent implants. Iodine-125 has a long half-life of 60.2 days. This equates to a low initial dose rate of about 7.7 cGy per hour for a prescribed target volume dose of 160 Gy in tissue. Ling suggests that at this low dose rate, the eradication of a fast growing tumor may require that a high dose be given in a brief time span. Therefore, if one wants to deliver a sufficiently high dose over the first week with I-125, to kill tumor cells before they regenerate, a large final dose will have to be administered which may cause severe late effects. However, a slow delivery of radiation to a large final dose using I-125 seeds can be very effective for very slow growing tumors such as in carcinoma of the prostate. The protraction of dose is radiobiologically preferred in order to spare the late responding tissues. Another advantage of I-125 is that it has a low energy emission of photons and a small HVL which simplifies the radiation protection problems because the isotope can be easily shielded [12].

Due to I-125's ineffectiveness in eradicating tumors with fast growth patterns, Pd-103 is being utilized more and more. Pd-103 has a similar low energy emission of photons as I-125 and therefore its radiation protection concerns are similar. Au-198 along with external beam therapy has the advantage of eradicating tumors that are aggressively growing. Pd-103 is advantageous in that it has more biological benefits in sparing normal late responding tissues than does Au-198. Pd-103 does not require

supplementation with external beam therapy and there is less chance that tumor regrowth could surpass cell kill as in the case of I-125 [7, 8].

2.4.1 Comparisons Between LDR, HDR, MDR, and PDR

Through the studies and evidence presented, it is apparent that LDR brachytherapy is the most radiobiologically beneficial method of treatment. However, even with the understanding of the radiobiological benefits of LDR, other modalities of brachytherapy treatment have been investigated. To an increasing extent, LDR brachytherapy is being replaced with HDR brachytherapy. "HDR is defined as a dose rate that is high enough so that the exposure is short when compared with repair of sublethal damage" [20]. Replacing continuous LDR with a few large dose fractions forfeits much of the radiobiological advantage of LDR concerning the sparing of normal tissues. Multiple fractions of HDR treatment would serve to improve the radiobiological disadvantages; however, practicality limits the total number of insertions that are possible to perform. When HDR applications are administered, decisions must be made concerning the time-dose-fractionation. The number of treatment sessions, the dose per fraction, and the schedule of treatment sessions must be carefully determined. Most HDR insertions are delivered in 3 to 12 fractions. They are performed weekly and are combined with external beam therapy by giving 4 fractions of external beam and 1 fraction of HDR treatment per week [5].

Both LDR and HDR remote afterloading systems can be used to improve dose distributions by use of multiple dwell positions that can be selectively loaded to achieve optimum tumor-dose distribution while limiting normal tissue exposure. However, low dose rate remote afterloading applicators are subject to the same degree of shifting in the

pelvis during the several days of treatment as are the non-remote afterloading LDR instruments. In HDR remote afterloading brachytherapy for gynecological treatments, the instruments are positioned and locked into place with possible packing or retraction to protect the vaginal wall, bladder, and rectum. The dose described by the isodose curves can then be accurately delivered over several minutes of treatment time [5].

The radiobiological disadvantages involved in HDR have been addressed in the treatment of carcinoma of the cervix. It has been seen that HDR brachytherapy can reduce the ability of normal tissues to recover between high dose fractions compared to LDR, which has historically been successful in the treatment of carcinoma of the cervix with minimal late reactions. However, for HDR treatments lasting only a few minutes, it has been shown that it is possible to use rectal retractors, vaginal speculums, Foley catheter balloons, and gauze packing to hold critical structures away from the source during the short treatment period. This will result in lower doses to the critical normal tissues than are possible with a LDR treatment that lasts 24 hours or more. Therefore, the resulting physical advantages of HDR offset the radiobiological disadvantages. Thus, the general principle that a few large fractions of HDR gives poorer results than LDR does not always apply [5, 12].

Orton, Seyedsasr, and Somnay [21] performed a study to evaluate and compare LDR and HDR brachytherapy using non-randomized clinical data. They began by surveying 56 institutions that treat cervix carcinoma patients with HDR remote afterloading. The survey revealed that the average fractionation regimen involved delivering 5 fractions of 7.5 Gy per fraction prescribed to point A (See Appendix A for explanation of point A). Historical controls were established using previous patients that

had been treated for the same condition with LDR by the same clinicians. Comparisons of the HDR to LDR historical controls, were made. The results showed that the 5 year survival for HDR treatments was significantly better and morbidity rates were lower than for the LDR treatments. They were able to show that there was a geometrical advantage with HDR intracavitary brachytherapy observable by a reduction in rectal and bladder doses. Orton, Seyedsasr, and Somnay concluded from their study that, " HDR brachytherapy for cervix carcinoma is at least as good as conventional LDR as far as survival is concerned and HDR brachytherapy is better than LDR with respect to radiation toxicity".

Fu and Phillips [22] also compared HDR and LDR intracavitary brachytherapy for cervical carcinoma. Their conclusions were similar to Orton, Seyedsasr, and Somnay in that survival, local control rates, and complications were similar using HDR intracavitary brachytherapy compared to historical LDR brachytherapy controls.

Stitt pointed out a negative side of HDR remote afterloading brachytherapy, stating that "HDR brachytherapy is more time consuming than LDR brachytherapy" [5]. For HDR applications, a staff of physicians, dosimetrists, technologists, and nurses is needed for an intense period of time for each insertion. The same personnel are required for LDR insertion, but there is less pressure and stress on the staff than with HDR. HDR requires more insertions and therefore more total professional time is required. Stitt points out that, along with the staffing pressures, changes in a treatment plan are difficult to make before completion of a HDR treatment due to the short treatment times [5].

Despite the obvious radiobiological and time consumption drawbacks of HDR brachytherapy, its popularity has grown immensely through the years and continues

today. However, the replacement of continuous low dose rate irradiation with fractionated high dose rate irradiation, should be done with careful evaluation. The importance of changes in time factors (dose rate) in determining the biological effect of ionizing radiation should not be underestimated. When time-dose patterns are drastically changed, the clinical experience accumulated with LDR techniques cannot be directly applied to the new irradiation conditions without careful consideration concerning normal tissue tolerance and effects on tumor control [15].

Medium Dose Rate (MDR) and Pulsed Dose Rate (PDR) brachytherapy are not popular treatment methods used today. MDR, also known as intermediate dose rate brachytherapy, involves dose rates that are about three times higher than traditional radium dose rates. Medium dose rates are generally in the area of 2.0 Gy/hr [16]. Medium dose rate brachytherapy is very uncommon in the United States. The advantages of MDR (Cs-137) over HDR (Ir-192) is that source exchange is not required as often. For clinics with limited funds, this will save money because sources will not need to be purchased as often due to the fact that the half-life of Cs-137 is 30 years whereas that of Ir-192 is 74.02 days. One of the disadvantages of MDR is that more shielding and radiation protection concerns are seen with Cs-137 which has a HVL of 6.5 mm of lead than with Ir-192 which has a HVL of 2.5 mm of lead. MDR brachytherapy also requires more extended treatment times encompassing hours versus treatment times of only a few minutes with HDR. Therefore MDR brachytherapy involves prolonged patient discomfort compared to HDR treatment times. The longer period of time for treatment may also allow shifting of the applicators over this time period similar to what can happen in LDR. Therefore, inaccuracies in dose distributions may occur.

Pulsed Dose Rate (PDR) remote afterloading combines many of the physical advantages of the single-stepping source design with the radiobiological advantages of conventional LDR inpatient brachytherapy. PDR simulates LDR brachytherapy by administering a sequence of "mini" HDR fractions at hourly intervals. Between "pulses" the source remains in the safe and medical personnel can attend to the patient's needs. During each pulse, a single high activity source is stepped through all the catheters of the implant using computer controlled dwell times. Brenner and Hall performed a study to find what combination of radiation pulses with a HDR remote afterloader would be equivalent to a continuous LDR irradiation and what impact on late effects the pulsed regimen would produce. From their research, Brenner and Hall, concluded that a 10 minute pulse repeated hourly (for 60 hours) would produce a biological effect that was equal to continuous irradiation of 30 Gy in 60 hours at 0.5 Gy/hr for both early and late effects [23].

The advantages of PDR brachytherapy include the use of a single high activity source welded to the end of a transfer cable which can be administered in a manner in which the treatment time and average dose rate are maintained as the activity of the source decays by increasing the pulse length. PDR is beneficial in that it only requires one source which decreases the expensive and complexity of housing multiple sources; however, like LDR brachytherapy, PDR applicators cannot be as securely immobilized as in short duration HDR treatments. The patient hospitalization requirement, complexity of treatment planning and patient procedures, and quality assurance measures required for this type of brachytherapy are definite disadvantages. These disadvantages clearly contribute to the low participation of PDR brachytherapy [16].

2.4.2 Principles of HDR Remote Afterloading

With the studies performed and data analyzed, many clinicians have chosen HDR remote afterloading as their primary method of brachytherapy. HDR remote afterloading unit treatments are required to be performed in fully shielded rooms. Existing accelerator and cobalt rooms have been utilized in many facilities to house the HDR units. The standard features of remote afterloading units include: a safe for storage of the radioactive source, the radioactive source, a remote operating console (microprocessor), a source control/drive mechanism to transport the source between a shielded container and the patient for specific times, the source transfer guide tubes, applicators to hold sources, and a treatment planning computer to determine the isodose patterns arising from the source configuration selected [14].

Nucletron microSelectron HDR remote afterloading implants involve a single 3.5 mm long, high activity (10 Ci) Ir-192 source that is welded to the end of a flexible stainless steel cable that is capable of moving through a number of channels. The cable travels inside an applicator or catheter that has been inserted inside a patient. The source can be programmed to move precisely to any position along the applicator or catheter by programming the dwell position and dwell time to obtain the desired isodose distributions. A well designed system can permit the optimization of dose distributions better than what has been achieved with manual afterloading methods. The goal is to generate plans accurately and quickly with minimal input from the user, due to the fact that planning must be done after the placement of the catheters are in the patient and before the actual treatment can begin. It has been seen that HDR remote afterloading treatments can be fractionated with high consistency and reproducibility of source and

applicator positions. The most advantageous aspect of HDR remote afterloading is the convenience of the system. Patients can be treated on an outpatient basis with no general anesthesia or long immobilization times, reducing the otherwise prolonged hospitalization and decreasing the complications common in administration of a general anesthetic which is often used for LDR brachytherapy [5, 22, 24].

CHAPTER 3

THEORETICAL BACKGROUND

3.1 Source Localization

Source localization is a crucial step in brachytherapy treatment planning. It involves accurately determining the source coordinate positions of an implant. Once the applicator position is determined with fluoroscopy, localization films are taken. The most common method of source reconstruction starts with taking a set of orthogonal radiographs. One anterior-to-posterior (AP) and one lateral film are taken to pinpoint the locations of the source positions in order to perform dose distribution calculations.

A coordinate system is conventionally established with x axis from the right to left of the patient, the y axis from inferior to superior, and the z axis from posterior to anterior [6]. The AP film represents a view of the implant image projected onto the x-y plane while the lateral film presents the image projected on the y-z plane. The origin of the coordinate system is chosen to be the same on both films such as one end of a source. The sources can be identified by comparing the y coordinates of both films. After all the source positions have been identified, they are digitized into the computer. The computer compares the y coordinates and the physical lengths of the sources and determines if errors have been made in source localization. After the sources have been entered into the computer, it is up to the dosimetrist or physicist to manipulate the available options of the software to optimize the dose distribution for the treatment of each individual patient.

3.2 Dose Calculation

Calculations of dose distributions in brachytherapy are based on point dose calculations. The calculation of absorbed dose to a particular point begins at the level of

the exposure rate distribution of a source. Exposure is the measure of the ionization produced in air by photons. The SI unit for exposure is coulomb per kilogram (C/kg) but the special unit is roentgen (R) where $1R = 2.58 \times 10^{-4}$ C/kg of air [25]. Exposure in air (X_{air}) is calculated using the following equation:

$$\mathbf{X_{air}\ (R) = A * \Gamma * T / d^2}$$

where; A = activity of source (Ci), Γ = gamma factor or exposure rate constant ($Rcm^2/Ci\text{-}sec$), T = time of exposure or dwell time (sec), and d = distance from the source (cm).

Absorbed dose is a measure of the quantity of energy imparted by ionizing radiation to a specified mass of material. The SI unit for absorbed dose is the gray (Gy) which is equal to 1 J/kg or 100 rads ($1 \text{ rad} = 10^{-2}$ J/kg). The absorbed dose to air (D_{air}) is calculated using the following equation:

$$\mathbf{D_{air}\ (J/kg) = X_{air}\ (R) * k * \frac{\overline{W}}{e}}$$

where; $k = 2.58 \times 10^{-4}$ (C/kg) and the average energy absorbed per unit charge of ionization $\left(\frac{\overline{W}}{e}\right) = 33.97$ J/C. Therefore, the absorbed dose to air in J/kg is calculated using the following equation:

$$\mathbf{D_{air}\ (J/kg) = X_{air}\ (R) * 0.876 \times 10^{-2}\ (J/kg/R)}$$

and the absorbed dose to air in rads is calculated using the following equation:

$$\mathbf{D_{air}\ (rad) = X_{air}\ (R) * 0.876\ (rad/R)}.$$

3.2.1 Attenuation and Scatter Correction

When a source is implanted in tissue, attenuation and scattering in the surrounding tissue must be addressed. Several researchers have attempted to experimentally

determine the ratio of exposure in water to exposure in air as a function of distance for different isotopes. Due to large differences in the data reported, in 1968, Meisberger et al. published a paper where they reported the effective absorption in water of the gamma rays of the isotopes Au-198, Ir-192, Cs-137, Ra-226, and Co-60.

The energy absorption buildup factor (B) is defined as the ratio of the total absorbed energy due to the primary and scattered gamma rays to the absorbed energy due to the primary gamma rays alone. This ratio is approximated by the equation:

$$\frac{\textbf{Exposure in water}}{\textbf{Exposure in air}} = B\, e^{-\mu r}$$

where μ is the attenuation coefficient for water and r is the distance from the point source. Meisberger et al. performed calculations of the ratio of the diffusion of gamma rays in water and air for each of the sources listed above at distances varying from 1 cm to 10 cm. Meisberger et al. compared their calculated values to the experimental values determined by several investigators and formulated a third order polynomial to fit the average of the experimental and calculated data available. The equation to calculate the attenuation in water for gamma rays from a point source is:

$$\frac{\textbf{Exposure in water}}{\textbf{Exposure in air}} = A + Br + Cr^2 + Dr^3$$

where r is the distance (up to 10 cm) from the source to the dose point and A, B, C, and D are the coefficients determined by Meisberger et al. [26]. The coefficients for Ir-192 are listed in Table 3.2.1. The Meisberger factor (M), is therefore defined as:

$$M = A + Br + Cr^2 + Dr^3.$$

Table 3.2.1: Meisberger Factor Coefficients for Ir-192.

Isotope	A	B	C	D
Ir-192	1.0128×10^{00}	5.019×10^{-03}	-1.178×10^{-03}	-2.008×10^{-05}

The Nucletron treatment planning computer systems use a different fitting equation for tissue absorption and scatter corrections. Van Kleffens and Star approximated the ratio of the dose rate in tissue to the dose rate in air as a function of the distance by the formula:

$$\varphi(r) = \frac{1 + \alpha r^2}{1 + \beta r^2}$$

where r is the distance of the source center to the dose point and α and β are constants determined from experimental data. This relationship was preferred to that of Meisberger since it required shorter calculation times [27]. The Van Kleffens and Star formula, however does not predict values greater than 1 which can produce discrepancies up to 2% when compared with Meisberger results. Nucletron made a modification of the formula to overcome this problem. They introduced a constant (δ) as a normalization factor to get better agreement with the Meisberger polynomial:

$$\varphi(r) = \delta \frac{1 + \alpha r^2}{1 + \beta r^2}$$

The values for the alpha (α), beta (β), and delta (δ) coefficients of Nucletron's modification of the Van Kleffens and Star relationship for tissue absorption and the scatter correction for Ir-192 appear in Table 3.2.2 [28].

Table 3.2.2: Values for the α, β, and δ Coefficients of Nucletron's Modification of the Van Kleffens and Star Relationship for Tissue Absorption and the Scatter Correction for Ir-192.

Isotope	α (cm^{-2})	β (cm^{-2})	δ
Ir-192	0.1×10^{-29}	6.00×10^{-06}	1.018×10^{00}

The absorbed dose in tissue can then be calculated using the following equation:

$$\mathbf{D_{tissue}\,(rad) = D_{air}\,(rad) * M * \left(\frac{\mu}{\rho}\right)^{tissue}_{water}}$$

where; $\left(\frac{\mu}{\rho}\right)^{tissue}_{water}$ is the ratio of mean mass energy absorption coefficients. The accepted value of the ratio of mean mass energy absorption coefficients by Nucletron is 1.11. When combining each step, we now see that the absorbed dose in tissue (D_{tissue}) is calculated by the following equation:

$$\mathbf{D_{tissue}\,(rad) = \left[\left(A * \Gamma * T / d^2\right) * M * k * \frac{\overline{W}}{e} * \left(\frac{\mu}{\rho}\right)^{tissue}_{water}\right]} .$$

The f factor (F) is used to simplify the equation. It is sometimes called the roentgen to rad conversion factor. It is calculated as follows:

$$\mathbf{f\ factor = k * \frac{\overline{W}}{e} * \left(\frac{\mu}{\rho}\right)^{tissue}_{water} = 0.876\ (rad / R) * \left(\frac{\mu}{\rho}\right)^{tissue}_{water}} .$$

Dose calculations to a particular point in brachytherapy are calculated by summing the contribution to a point from each dwell position of the source. For only one dwell position, the dose to a particular point (D_p) is calculated by:

$$\mathbf{D_p\,(rad) = A * \Gamma * T / d^2 * M * F} .$$

For multiple dwell positions, the dose to a particular point is calculated by:

$$\text{Total } D_p \text{ (rad)} = \left(A * \Gamma * F\right) * \sum_{i=1}^{n} \left(M_{pi} / d_{pi}^2\right) * T$$

where n is the total number of dwell positions and i denotes one dwell position. Once the absorbed dose is calculated to a matrix of points around a source, curves can be generated in any arbitrary plane. Isodose curves are constructed by connecting points receiving the same dose. This is a very time consuming and tedious process. With the advancement of computers, this task has been accelerated [6].

3.3 Modern Computer Dosimetry

Modern computer dosimetry involves the repeated calculations of dose at a point for each of the implant source positions. The total dose at a given point is the result of summing up the individual source position contributions. The main objectives of treatment planning are to determine the optimum dose distribution with the source(s) available and to provide a uniform dose distribution within the targeted volume. Fortunately, today, brachytherapy planning software systems can perform sophisticated treatment planning manipulations involving multiple sources as well as three-dimensional distributions at a high rate of speed and accuracy [6].

With manual methods of calculation, the absorption and scatter corrections are usually ignored, but many computer methods which have become available include the corrections. However, some brachytherapy treatment planning computers do not calculate the dose distribution around an Ir-192 source by calculating the primary and scattered dose components at a point in tissue. The dose distribution calculation has been

simplified for radionuclides, such as Ir-192, by assuming the attenuation of the primary gamma ray is canceled out by the scattered radiation.

Hale studied the use of radium dose rate tables for estimating dose from isotopes other than radium. He noted that traditional radium exposure dose rate tables neglected these absorption and scatter correction factors. Hale addressed in his research this issue of neglecting the corrections for absorption and scatter in reference to isotopes other than radium. In order to estimate the dose from isotopes other than radium, Hale multiplied the table value of radium dose rate by the ratio of the specific gamma-ray emission of the isotope of interest (Γ_I) to the gamma-ray emission of radium (Γ_{Ra}). Now $D_{water,\,I} = (\Gamma_I / \Gamma_{Ra}) * D_{air,Ra} * AB$ where Γ_I is a measured or calculated value, $\Gamma_{Ra} = 8.4$ R/mg-hr at 1 cm with 0.5 mm platinum filtration, and $D_{air,Ra}$ is obtained from the radium dose rate table. The correction factor (AB) was calculated by Hale as a function of gamma-ray energy and distance. The results of Hale's research indicate that the absorption factor (A) and scatter factor (B) come very close to canceling each other over a wide range of gamma-ray energies and distances that occur often in clinical practice. Hale concluded that the correction factors A and B "can probably be neglected for practical purposes" [29].

The results obtained by both Hale and Meisberger are only valid in a homogeneous medium. The scatter-to-primary ratio for Ir-192 increases with distance from the source where the scatter-to-primary ratio is 1 at approximately 6 cm from the source. The scattered radiation component is a significant portion of the dose and therefore anything that reduces the scatter will drastically affect the dose.

Waterman and Holcomb addressed the idea that if the scattered component is reduced significantly by the insertion of a shield in a vaginal cylinder, causing an inhomogeneity effect. A reduction in the distribution of dose in the unshielded region of the vagina may occur due to the decrease in scatter from the shielded volume which would not be predicted by the brachytherapy treatment planning program. This may result in the algorithm overestimating the dose delivered to the tumor volume.

Waterman and Holcomb used a 2.5 cm diameter vaginal cylinder for their study. They took measurements with the cylinder unshielded and with 0.8 cm thick 90°, 180°, and 270° tungsten shields in place. The dose distributions were calculated for the shielded and unshielded vaginal cylinder with a Nucletron microSelectron HDR brachytherapy planning system which assumes an extended homogeneous scattering medium. This system assumes that the attenuation of primary gamma rays is compensated for by scattered radiation.

The results of the study by Waterman and Holcomb showed that the scattered radiation to the unshielded side of the cylinder is reduced and therefore the dose to the tumor is overestimated. This reduction in dose increases with distance from the source and with the increase in shielding angle. However, this reduction is only 1 to 2 percent within 1 cm of the cylinder where the tumor dose is usually prescribed, regardless of the shield that is used. The results therefore show that the assumption that attenuation of the primary gamma rays cancels out with the scattered radiation is acceptable and that the inhomogeneity effect of the shield is negligible [30].

CHAPTER 4

COMMISSIONING AND EVALUATION MATERIALS

4.1 Introduction

There are many aspects to the commissioning and evaluation of a high dose rate (HDR) brachytherapy treatment planning system and therefore a variety of components working together are required. Since remote afterloading techniques are mandatory for HDR applications in order to ensure proper radiation protection of the staff, the foundation of any HDR brachytherapy treatment planning system is the remote afterloading unit (RAU). The treatment planning computer used in conjunction with the RAU must be compatible, precisely tailored to its specifications, and work cooperatively with it. The microprocessor control unit is the physical link between the treatment planning computer and the RAU.

The basic requirements for a brachytherapy treatment planning system involves not only the central processing unit with the appropriate software, but the peripherals as well. A Silicon Graphics Iris INDIGO 133 megahertz dedicated computer is utilized for HDR brachytherapy treatment planning at Mary Bird Perkins Cancer Center (MBPCC) in Baton Rouge, Louisiana. It contains 64 megabytes of main memory and is loaded with the Nucletron Planning System (NPS) - Brachytherapy Planning System Version 11.4.1 software that is currently in use. The input and output peripherals include a program card writer, Kontron Elektronik digitizer tablet, Hewlett Packard Laser Jet IIIp printer, and Hewlett Packard pen plotter. Each of these components performs a specific function and participate in the overall definition of a treatment planning "system".

4.2 Description of Remote Afterloading Unit

Clinicians at MBPCC perform HDR brachytherapy with a Nucletron microSelectron HDR RAU. The Nucletron microSelectron HDR RAU is an 18 channel unit that uses a single iridium (Ir) - 192 source. The source pellet is 0.6 mm in diameter and is 4 mm long. The source capsule has a 1.1 mm outside diameter and is 5 mm in length. The capsule is laser welded to one end of a flexible stainless steel drive cable. The source capsule is moved to the required dwell positions by a cable drive system. The maximum extension of the source is 1500 mm. The microSelectron HDR RAU has a second drive system which controls the positioning of a "check cable". The check cable serves the purpose of checking the path that the source will traverse. The check cable will extend 5 mm beyond the most distal programmed dwell position of each channel before the source goes out. This checks the construction and friction in the channels as a safety measure. The source is then moved in a step forward manner through an applicator that can be up to 1500 mm in length. There is a maximum of 48 possible dwell positions per channel where dwell position 1 is the most distal position and dwell position 48 is the most proximal dwell position. Treatment in a channel starts at the proximal programmed dwell position and continues to dwell in each consecutive position for the programmed dwell time until it completes the distal dwell position. Then the next channel is started and so on.

The Nucletron microSelectron HDR RAU has visible indicators of radiation, backup batteries, and an emergency hand crank for emergency source retraction. The microprocessor control unit is separate from the isodose planning computer and is used to signal the afterloader where to dwell, the position, and for how long. The treatment unit

is designed to deliver dose distributions based on treatment data which is either directly programmed at the control unit or is transferred from a program card containing the data originating from the treatment planning computer.

4.3 Brachytherapy Treatment Planning Systems

There are two treatment planning software packages available through the Nucletron Corporation that are designed to facilitate treatment planning for the Nucletron microSelectron HDR RAU. They are the Nucletron Planning System (NPS) and PLATO Brachytherapy Planning Systems. The NPS - Brachytherapy Planning System is written in FORTRAN and compiled with the Microsoft FORTRAN77 compiler. It is a two-dimensional software package which has historically been difficult to utilize. Correcting small errors in data entry has required plans to be aborted and re-entered in the past, causing problems for the treatment planning staff which ultimately affects the patients.

The PLATO - Brachytherapy Planning System is the Nucletron Corporation's most recent development in HDR brachytherapy treatment planning software. PLATO is an acronym for "Planning and Treatment Optimization". The PLATO - Brachytherapy Planning System is a more "user friendly" system than NPS - Brachytherapy Planning System. It uses X Windows in a UNIX environment to facilitate treatment planning which allows the user to alter patient data and make corrections very quickly and simply. The PLATO - Brachytherapy Planning System has enhanced graphics capabilities and allows three-dimensional viewing of the applicators with surface doses, which can be rotated or laterally moved and viewed from any position with the click of the mouse. The PLATO - Brachytherapy Planning System currently does not have the full functionality of NPS - Brachytherapy Planning System, however; it will be available in the near future.

Commissioning of a HDR brachytherapy treatment planning system requires making comparisons with independent systems. The comparisons made between two HDR brachytherapy treatment planning systems are an excellent source of data. Low dose rate (LDR) brachytherapy treatment planning computers can also be used for comparisons in commissioning a HDR brachytherapy treatment planning system. With a small amount of data manipulation with respect to activity and time, calculations between HDR and LDR brachytherapy treatment planning systems for a particular source, can be compared directly. The Capintec Cap-Plan RTP110 and Theratronics Theraplan 500 V05B are two independent treatment planning computers housed at MBPCC in Baton Rouge, Louisiana. They are primarily used for external beam calculations but have the capabilities of LDR brachytherapy calculations with Ir-192. The use of a program developed at MBPCC using a spreadsheet for computational purposes also makes for a good independent comparison.

4.4 Summary

Treatment plan calculational comparisons between HDR brachytherapy treatment planning systems as well as additional comparisons with LDR and spreadsheet based programs gives greater confidence in the HDR brachytherapy treatment planning system under investigation. With multiple intercomparisons, more principles can be tested and evaluated for their quality, accuracy, and consistency.

CHAPTER 5

COMMISSIONING AND EVALUATION METHODOLOGY

5.1 Introduction

Brachytherapy is a complex process involving multiple steps beginning with patient diagnosis and continuing through treatment planning and ultimately the treatment of the patient. From the very first step, it is imperative that accurate and concise steps be performed with as little deviation as possible. With each step, building upon the previous, uncertainties in any one step can accumulate and drastically effect the outcome of the patient's treatment. This will have a great effect on the cure rate as well as the possibility of radiation induced complications. Therefore, it is of vital importance to have and follow a comprehensive commissioning and continued quality assurance program for treatment planning computers to reduce the possibility of compounded errors throughout the brachytherapy treatment planning process.

Van Dyk et al. define quality assurance as "the systematic actions necessary to ensure that a product or process performs to specification" [3]. Quality assurance is the main emphasis involved in commissioning a brachytherapy treatment planning computer. Once the commissioning is completed, the quality assurance measures take over and ensure the continued quality of the system. Commissioning of a brachytherapy treatment planning system involves many aspects, including familiarization with the system documentation, hardware and software testing, machine and source customization, as well as staff training before any software algorithm tests can be performed.

5.2 System Documentation

The first stage in commissioning a treatment planning software system starts at the basics. The user should be informed, through the manufacturer provided User's Guide documentation, about how the hardware and software carry out the planning procedures. The user must make an effort to familiarize himself with the basic understanding of the system, its calculation procedures, normalization procedures, capabilities, limitations, as well as how to use the data entry and output devices. The user must fully understand how to use the system properly. The ability to enter the correct information is the foundation of accurate brachytherapy treatment planning. The algorithms may be accurate but if the user enters the wrong machine, source, or patient data, the resulting calculations may be in error. Therefore, it is vital that the user be well informed about the software's capabilities and limitations with respect to the proper use of data entry and output devices as well as the calculational procedures that are carried out by the system.

5.3 Hardware and Software Testing

There are multiple types of errors that can occur in the brachytherapy treatment planning process. Some examples include hardware errors, computer algorithm errors, as well as human errors. An accurate treatment planning system requires properly functioning and properly utilized hardware. Inaccuracies in the input and output hardware may cause treatment planning errors. Therefore, prior to performing treatment planning tests of the software algorithm, hardware tests must be performed to verify the proper functioning of the graphical data input and output devices. Van Dyk et al. state that "the inherent accuracy of all input and output devices should be better than 1 mm"

[3]. The verification of the input and output devices used for high dose rate brachytherapy treatment planning at MBPCC is presented in Chapter 6 - Reproducibility Testing and Verification of the Calculational Method of the PLATO - Brachytherapy Planning System.

5.4 Machine and Source Customization

Once the hardware has been tested and determined to be functioning properly, the PLATO - Brachytherapy Planning System Version 13.2 software is installed into the Silicon Graphics Iris INDIGO dedicated brachytherapy treatment planning computer. At this point, the machine and source data must be customized. Customization requires providing the PLATO - Brachytherapy Planning System with details of the afterloader, the radioactive source to be used, as well as the specific reconstruction parameters. The afterloader data requirements include the serial number, default step-size, and data transfer method specification. The PLATO - Brachytherapy Planning System requires the specifications of the isotope including; half-life, calibration date, calibrated source strength, gamma factor for the isotope, the ratio of mean mass absorption coefficients in tissue and air, as well as the parameters for tissue attenuation and scatter. These values and their significance are discussed in Chapter 3 - Theoretical Background. The reference for the afterloader is the invoice supplied with it. For source data, the reference is the Certificate of Sealed Sources supplied with the source.

The reconstruction box utilized must be customized in the PLATO - Brachytherapy Planning System. The Nucletron reconstruction box is intended for use with the semi-orthogonal reconstruction method. The size of the box and the film to box distances must be specified. Incorrect box parameters will lead to serious reconstruction

errors. The reconstruction box parameters for the system at MBPCC are listed in Table 5.4.1.

Table 5.4.1: Reconstruction Box Parameters entered in the PLATO - Brachytherapy Planning System Version 13.2

Feature	Measurement (mm)
Half cross wire dimension	50.0
Bottom cross to top cross	400.0
Left side cross to right side cross	650.0
Bottom cross to upper-side cross	200.0
Top cross to lower-side cross	300.0

5.5 Staff Training and Independent Checks

Staff training plays an important role in commissioning and continued quality assurance. All treatment planning staff should be appropriately trained to ensure that they understand how to utilize the treatment planning system accurately. To ensure that each patient's treatment plan is accurate, it is best that an independent check be performed. The independent check should be done by a physicist, not present during the dosimetric procedure, and should be performed without the use of the treatment planning system. The physicist should verify the prescribed dose, applicator type, and dose specification points along with dwell time and accurate source decay [5]. These steps need to be accomplished as rapidly as possible to maintain patient comfort. It is impossible for a complex treatment planning system or user to be completely error free 100 percent of the time. Therefore, the initial testing during commissioning and routine testing should not eliminate the careful examination of each individual patient's treatment plan to ensure that each patient is given the best possible care and the best chance for cure without unnecessary complications.

5.6 Suggested Criteria of Acceptability

There are a number of authors who have made recommendations on the levels of accuracy that should be achievable with external beam treatment planning computers. The amount of information for brachytherapy dose calculations is significantly less. Uncertainty estimates for brachytherapy calculations are more difficult to estimate due to the sharp dose gradients present which can give large uncertainties. The International Commission of Radiation Units and Measurements (ICRU) recommends that for brachytherapy, the aim should be ± 3% accuracy in dose at distances of 0.5 cm or more at any point for any radiation source. Van Dyk et al. state that the criterion of acceptability for brachytherapy calculations for a single point source, at distances of 0.5 cm to 5.0 cm, should be ± 5% accuracy" [3]. The criteria which is followed at MBPCC and used in the commissioning of the PLATO - Brachytherapy Planning System are ± 3.0 mm spatial accuracy for equal isodose levels and ± 5% dose accuracy for calculational points at distances of 0.5 cm or more.

5.7 Summary

Commissioning and continued quality assurance requires team work and is a continuous, never-ending process. The goal in brachytherapy treatment planning is to generate plans accurately and quickly since planning must be done after the placement of the catheters in the patient and before the treatment can begin. With the proper foundation, brachytherapy programs can be an excellent tool in radiation therapy.

CHAPTER 6

REPRODUCIBILITY TESTING AND VERIFICATION OF THE CALCULATIONAL METHOD OF THE PLATO - BRACHYTHERAPY PLANNING SYSTEM

6.1 Introduction

The purpose of performing commissioning and quality assurance tests on a brachytherapy treatment planning system is to verify that the software is performing according to its standards. The ability of the user to directly assure the quality of the calculational algorithm or its implementation in the computer code of treatment planning systems today is minimal. Therefore, the user must verify the algorithm by performing tests of the output both with respect to the calculational method as well as the implementation of the complete treatment planning algorithm.

6.2 Verification of Input and Output Devices

Before any tests of the software can be performed, all input and output devices must be tested and verified for accuracy. The components of the hardware that are crucial to accurate treatment planning are the digitizers used for entering graphical data and the plotting devices used to produce isodose curves as well as the display screen, keyboard, and printer. The system documentation advises the user how to perform hardware tests and readjustments for each of these hardware components. The system has built-in diagnostic programs for self-tests of the hardware; however, it is advantageous for the user to perform independent tests. Hardware devices can be independently tested by entering known dimensions and outputting the results for comparison and analysis.

6.2.1 Reproducibility Testing

The reproducibility of the digitizer is a very important function due to the fact that digitizing errors can drastically affect treatment planning results. The two main factors that contribute to digitizing errors are digitizer malfunctioning and human error.

A procedure was set up to test the reproducibility of the Kontron Elektronik digitizer at MBPCC for use with the PLATO - Brachytherapy Planning System. The test involves marking dose points on 1 mm increment graph paper at known distances ranging from 2 mm to 50 mm away from a single point source. The treatment planning algorithm requires a minimum of two views (radiographs) of an implant in order to reconstruct source and dose point positions. Therefore, two pieces of graph paper are used for the reproducibility testing. One represents the anterior-to-posterior (AP) view and one represents the lateral view. The graph paper is verified for accuracy with a Staedtler Mars 98719-S1 metric ruler.

The source position is digitized at the origin of the radiograph (center of graph paper) and dose points are digitized at known distances from the source position. The treatment planning system assigns coordinates (x, y, and z) to the source and each dose point position. The coordinates are listed in the treatment planning output print-out. The distances between the source and each dose point are then calculated with a spreadsheet program using the coordinates. The equation used in the spreadsheet program to calculate the distance is:

$$\textbf{Calculated Distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

where x, y, and z represent the coordinates of the source and digitized points.

Two separate techniques are followed for the entry of the dose point positions into the PLATO - Brachytherapy Planning System. The first technique involves digitizing the points in a slow, relaxed manner in order to be as accurate as possible. The second technique involves digitizing the same points in a fast, stressed manner in order to simulate the environment that is most commonly seen during an actual brachytherapy treatment planning procedure. Stress builds during brachytherapy treatment planning procedures due to the fact that there is generally a patient on the table with applicators in place, the patient is uncomfortable, the nurses are anxious, the doctor is waiting for the plan to be completed, and the physicist is waiting to check the plan before the patient can be treated.

The distances calculated with the spreadsheet for techniques one and two are listed in Tables 6.2.1.1 and 6.2.1.3 respectively. The calculated distances are compared amongst each other for the same known distance digitized through seven trials. The averages and standard deviations are then compared to the known distances.

The dose to each dose point through the seven trials is calculated by the PLATO - Brachytherapy Planning System. A comparison of the dose is made amongst the points digitized at the same distance. The average, standard deviation, and percent error in dose for technique one and two are listed in tables 6.2.1.2 and 6.2.1.4 respectively. The percent error in dose is calculated using the equation:

$$\textbf{\% Error in Dose} = \frac{\textbf{Standard Deviation in Dose}}{\textbf{Average Dose}}.$$

Reproducibility of dose is an important issue in high dose rate brachytherapy treatment planning systems. The objective is to be able to prescribe dose to a small volume with a

sharp dose fall off in the immediate surrounding healthy tissue. Most brachytherapy patients receive multiple fractions of radiation that are administered at weekly intervals. It is important for the doctors to be able to prescribe a dose accurately at a specified distance.

The results of the digitizer reproducibility test show that the distances calculated using the reconstructed coordinates vary from the known distances. The results also show that there is variability in the calculated distances amongst points digitized at the same known distance. The average standard deviation for points repeatedly digitized at the same known distances through seven trials using a slow, relaxed technique was found to be ± 0.2 mm. However, when the same points were digitized quickly and under stress, the average standard deviation escalated to ± 0.5 mm. Digitizing is a sensitive process in which stress affects the outcome as seen by the increase in variability when points are digitized quickly under stressed conditions.

The results also show that variability in digitizing greatly affects the reproducibility of dose to points at very short distances from the source. This is due to the high dose gradient that is present around the source. Figure 6.2.1.1 shows a curve depicting the nature of the dose gradient within 10 mm around an Ir-192 source. A spreadsheet is used to calculate the dose in 1 mm increments for known distances ranging from 2 mm to 10 mm.

The curve shows that the dose falls off sharply between points located at 2 mm and 3 mm distances from the source with a gradient of 484.1 cGy/mm. It is also shown that at points located at greater distances from the source, the gradient begins to decrease as shown between 3 mm and 4 mm distances where the gradient is 169.5 cGy/mm. The

Table 6.2.1.1 Digitizer Reproducibility Test Results Using a Slow, Relaxed Technique

Trial #	Calculated Distances (mm) for Points Digitized at Known Distances							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	2.4	5.1	9.9	15.0	20.3	29.9	40.2	50.1
2	2.5	4.9	10.2	15.1	20.3	30.3	40.2	50.3
3	2.1	5.0	10.1	15.2	20.0	30.1	39.9	50.3
4	2.1	5.0	9.8	15.0	19.9	30.1	40.0	50.4
5	2.0	4.9	9.8	14.9	20.1	29.9	39.8	49.9
6	2.1	4.7	10.3	15.0	20.4	29.8	40.3	50.0
7	2.2	4.9	9.7	14.7	20.1	30.0	40.3	50.0
Average	2.2	4.9	10.0	15.0	20.2	30.0	40.1	50.1
Standard Deviation	± 0.2	± 0.1	± 0.2	± 0.2	± 0.2	± 0.2	± 0.2	± 0.2
*Δ	+ 0.2	- 0.1	0	0	+ 0.2	0	+ 0.1	+0.1
Average Standard Deviation = ± 0.2 mm								

* Note: Δ = Average Calculated Distance - Known Distance

Table 6.2.1.2 Reproducibility of Dose Point Calculations in cGy Using a Slow, Relaxed Technique

Trial #	Dose to Point (cGy) Digitized at Varying Distances from Source							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	606.5	134.6	35.7	15.5	8.5	3.9	2.1	1.4
2	559.8	145.7	33.6	15.3	8.5	3.8	2.1	1.4
3	791.6	140.0	34.3	15.1	8.7	3.8	2.2	1.4
4	786.3	139.7	36.4	15.5	8.8	3.8	2.2	1.4
5	856.1	145.2	36.4	15.7	8.6	3.9	2.2	1.4
6	784.0	158.2	32.9	15.5	8.4	3.9	2.1	1.4
7	714.8	145.7	37.2	16.2	8.6	3.9	2.1	1.4
Average	728.4	144.2	35.2	15.5	8.6	3.9	2.1	1.4
Standard Deviation	± 108.2	± 7.4	± 1.6	± 0.3	± 0.1	± 0.1	± 0.1	0
% Error in Dose	14.9	5.1	4.5	1.9	1.2	2.6	4.8	0

Table 6.2.1.3 Digitizer Reproducibility Test Results Using a Fast, Stressed Technique

Trial #	Calculated Distances (mm) for Points Digitized at Known Distances							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	2.4	5.2	9.7	15.4	20.2	30.3	40.1	50.7
2	2.9	5.6	10.3	15.6	20.6	30.5	40.3	50.3
3	1.2	4.6	9.3	14.6	19.5	29.5	39.6	49.6
4	2.2	4.7	9.7	14.4	19.7	29.4	40.0	50.0
5	2.5	5.5	10.0	15.2	20.1	30.0	40.5	50.0
6	2.7	5.6	10.7	15.4	20.3	30.3	40.3	50.5
7	1.9	4.6	9.7	14.7	19.3	29.7	39.2	49.6
Average	2.3	5.1	9.9	15.0	20.0	30.0	40.0	50.1
Standard Deviation.	± 0.6	± 0.5	± 0.5	± 0.5	± 0.5	± 0.4	± 0.5	± 0.4
*Δ	+ 0.3	+ 0.1	- 0.1	0	0	0	0	+ 0.1
Average Standard Deviation = ± 0.5 mm								

* Note: Δ = Average Calculated Distance - Known Distance

Table 6.2.1.4 Reproducibility of Dose Point Calculations in cGy Using a Fast, Stressed Technique

Trial #	Dose to Point (cGy) Digitized at Varying Distances from Source							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	856.2	145.1	39.5	15.3	8.8	3.9	2.2	1.4
2	606.3	131.7	36.4	15.2	8.6	3.8	2.2	1.4
3	1216.2	133.7	37.1	15.5	8.8	3.9	2.2	1.4
4	607.8	145.6	35.0	16.2	8.7	3.9	2.1	1.4
5	771.8	128.9	37.1	15.7	8.9	3.9	2.1	1.4
6	707.3	134.3	33.6	15.6	8.9	3.9	2.2	1.4
7	625.2	137.0	34.3	15.1	8.9	3.8	2.2	1.4
Average	770.1	136.6	36.1	15.5	8.8	3.9	2.2	1.4
Standard Deviation	± 217.8	± 6.5	± 2.0	± 0.4	± 0.1	0	0	0
% Error in Dose	28.3	4.8	5.5	2.6	1.1	0	0	0

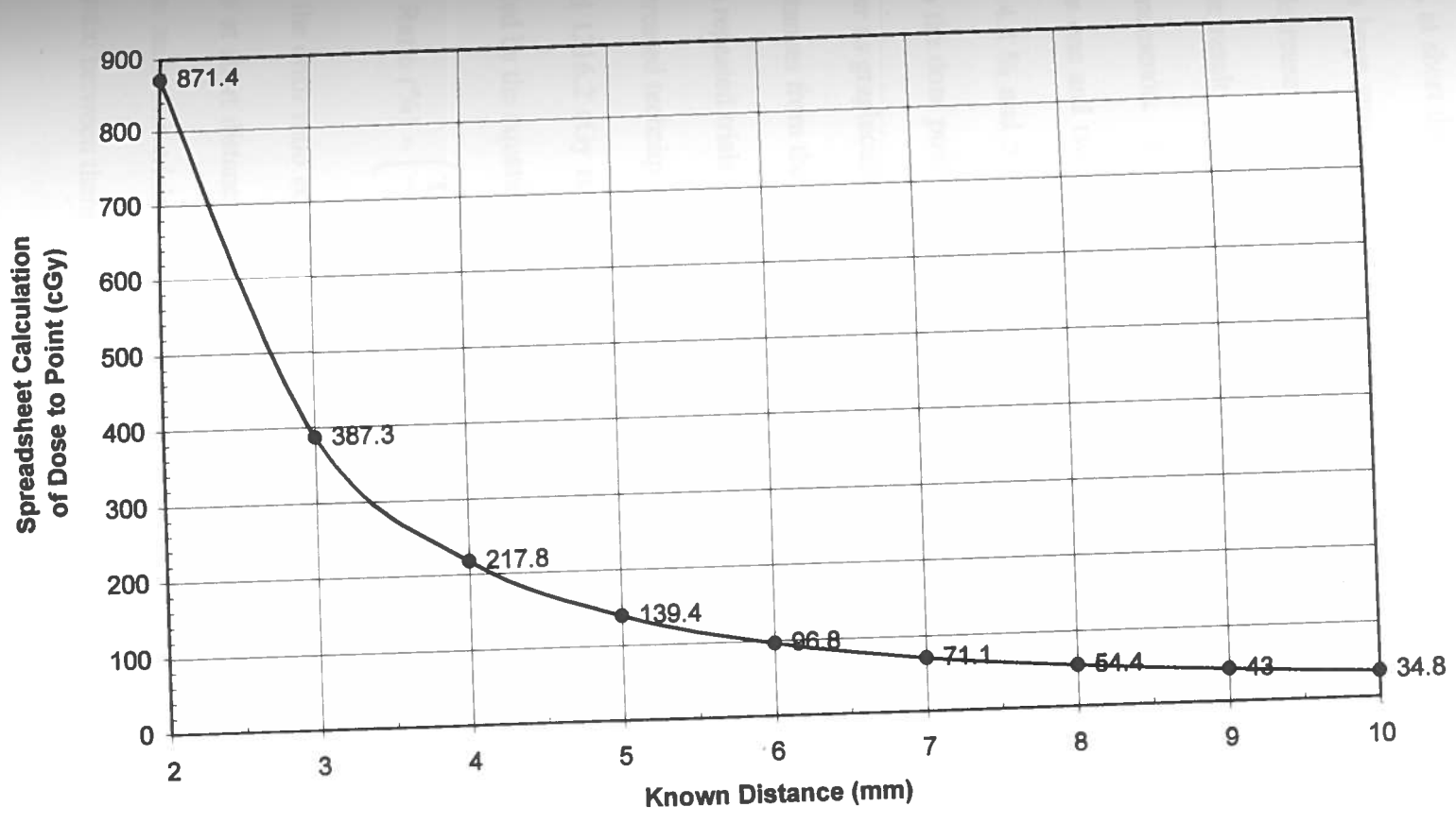


Figure 6.2.1.1 Dose Gradient Curve

gradient begins to level off at a distance of approximately 7 mm from the source where the gradient between 7 mm and 8 mm distances is 16.7 cGy/mm. It can therefore be stated that, at short distances from the source, any small amount of deviation in digitizing results in a large amount of error. However, as the distance from the source increases, the error decreases.

The results of the dose point calculations in the reproducibility test follow this same phenomenon. The percent error in dose at 2 mm was 14.9 % and 28.3 % for techniques one and two respectively. Consequently, at 5 mm, the percent error in dose drops to 4.8 % and 5.1 % respectively. The data show that as the distance from the source to the dose point increases, the dose curves for each trial begin to converge upon each other as graphically shown in Figures 6.2.1.2 and 6.2.1.3. The curves show that at short distances from the source, there is more variability in dose. The greatest difference between repeated trials was between Trial # 2 and Trial # 3 at a distance of 2.0 mm using a fast, stressed technique. At this distance, the doses for Trial # 2 and Trial # 3 are 606.3 cGy and 1216.2 cGy respectively. The resulting error ratio between these two tests is calculated by the equation:

$$\textbf{Error Ratio (\%)} = \left(\frac{\textbf{Trial \#3 Calculation of } D_p \textbf{ – Trial \#2 Calculation of } D_p}{\textbf{Trial \#2 Calculation of } D_p} \right) * 100$$

where the error ratio equals 100.6 %. This is evidence of the high dose gradient that is present at short distances around the source in high dose rate brachytherapy treatments. For the same two trials (Trial # 2 and Trial # 3) at a digitized distance of 5.0 mm, the error ratio between them drops to 1.5 % as expected.

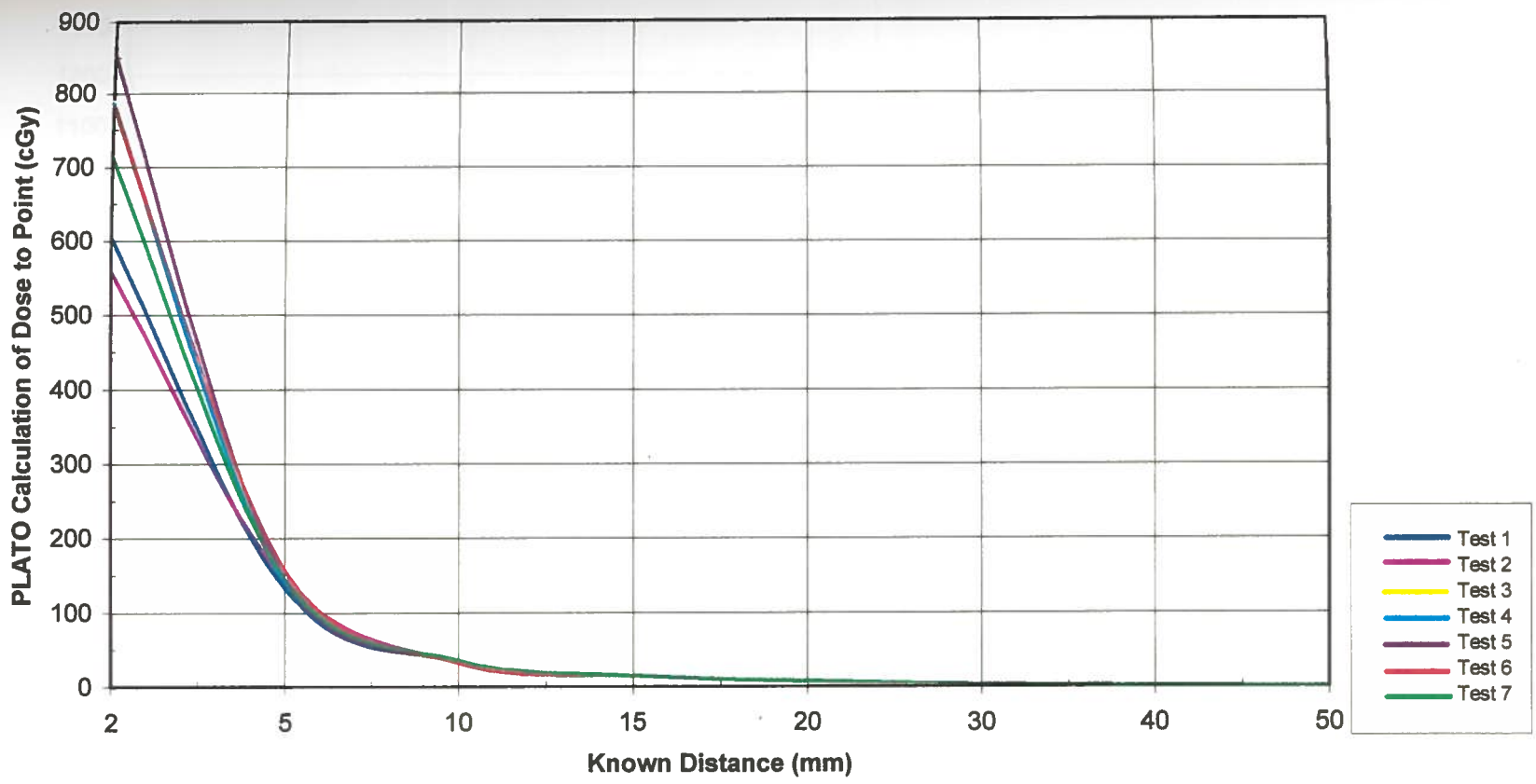


Figure 6.2.1.2 Dose Curve of Digitizer Reproducibility Test Results Using a Slow, Relaxed Technique

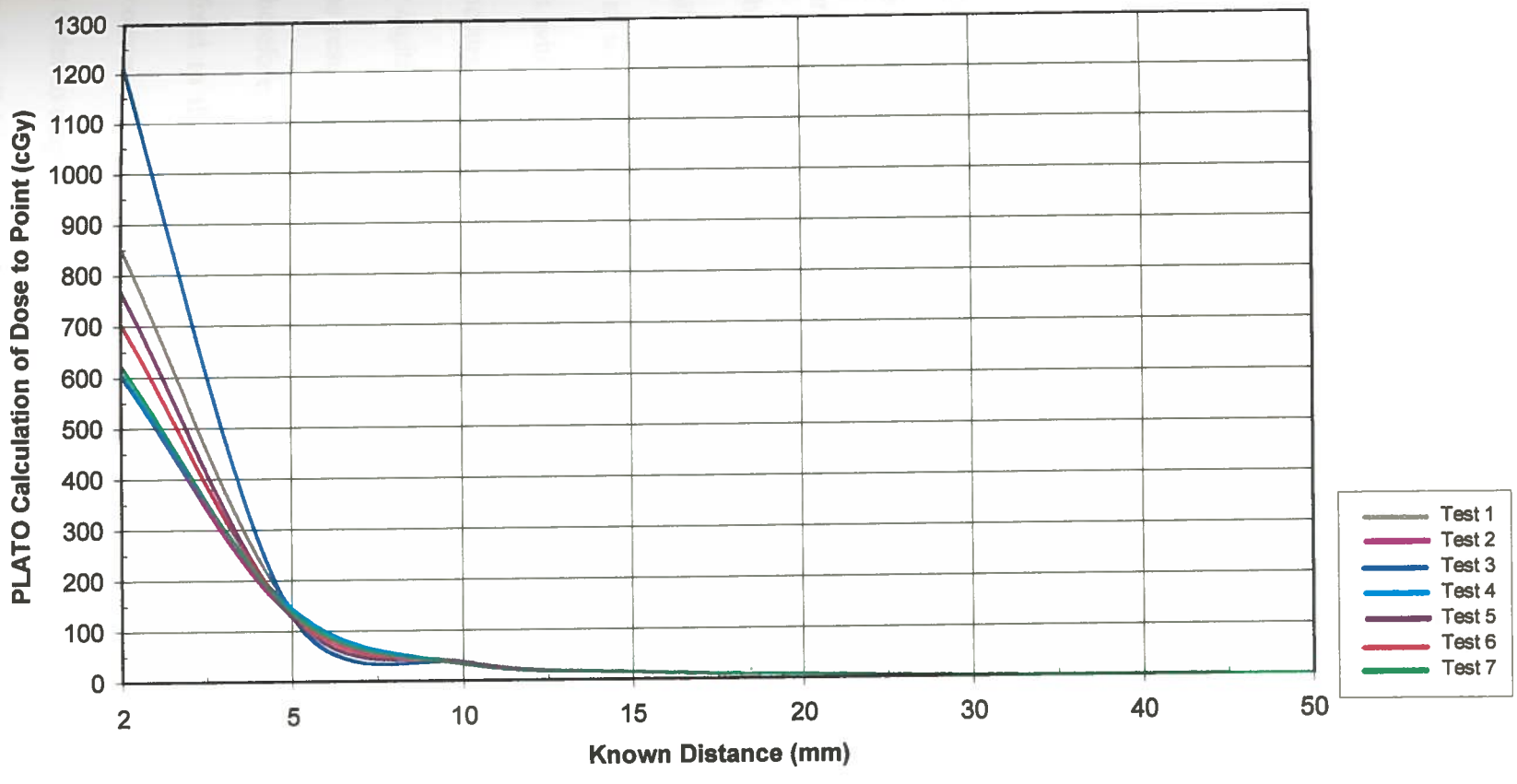


Figure 6.2.1.3 Dose Curve of Digitizer Reproducibility Test Results Using a Fast, Stressed Technique

The analysis of the results shows that the standard deviation in dose for points repeatedly digitized through seven trials at 2 mm using a slow, relaxed technique is ± 108.2 cGy. When the points are digitized quickly and under stress, the standard deviation in dose at 2 mm escalates to ± 217.8 cGy. However, as the distances increases to 5 mm, the standard deviations drop to ± 7.4 cGy and ± 6.5 cGy respectively. Once you get to 10 mm away from the source, the standard deviation falls to ± 2 cGy or less for both techniques. This re-emphasizes the nature of the sharp dose gradient that is present at short distances from the source. Any small fluctuation in digitizing can therefore cause a large uncertainty in the resulting doses at short distances.

The variability in the distances calculated in the digitizer reproducibility test may be due to malfunctioning of the digitizer or to human error. In order to ensure that the variability between trials is not due to digitizer malfunctioning, the digitizer is tested for reproducibility of repeated point entries. This procedure involves taping the digitizer to the tablet at selected points on the digitizing tablet and repeatedly digitizing the exact same point without moving the digitizer in order to determine if any variability in the digitizer occurs. The resulting coordinates assigned by the PLATO-BPS for each repeatedly digitized point are shown in Appendix B, Tables B.1 through B.7.

The results of the taped digitizer test show standard deviations of zero for all points. Therefore, since no variability in the repeated digitizing of the same point with the digitizer fixed to the tablet was found, it is concluded that human error is the reason variability occurred in the calculated distances of the digitizer reproducibility test.

In order to emphasize the effects of human error, four volunteer users were asked to perform the digitizer reproducibility test. The four volunteer users were given the

same two pieces of graph paper with points marked on it at known distances ranging between 2 mm and 50 mm. The users were each instructed to digitize the points through seven trials using the technique that they use for actual brachytherapy treatment planning procedures. The calculated distances and corresponding dose results are shown in Tables 6.2.1.5 through 6.2.1.12.

The results of the digitizer reproducibility test involving four volunteer users also show variability between known distances and calculated distances as well as amongst the calculated distances for the same known distances. The average standard deviations in distance for volunteer users 1 through 4 are ± 0.6, ± 0.7, ± 0.5, and ± 0.5 mm respectively. The standard deviations in dose at 2 mm for volunteer users 1 through 4 are ± 236.3, ± 346.6, ± 117.8, and ± 378.8 cGy respectively. The standard deviations in dose drop off quickly at 5 mm with values of ± 9.6, ± 17.9, ± 15.3, and ± 14.6 cGy respectively. The percent error in dose at 2 mm are 27.3 %, 35.5 %, 13.0 %, and 36.3 % for volunteer users 1 through 4 respectively. Consequently, at 5 mm, the percent error in dose drops to 7.2 %, 14.1 %, 10.6 % and 11.1 % respectively.

It can therefore be concluded that the human error contribution to digitizing error is not just present with one user but it is present to some degree in all users. Van Dyk et al. state that the inherent accuracy of all input and output devices should be better than ± 1 mm [3]. If this is the guideline for hardware devices, then no human should be expected to digitize better than 1 mm. Due to the fact that a sharp dose gradient exists at short distances from the source and since humans cannot digitize without error, one cannot expect to calculate dose accurately within the first 5 mm from the source. The dose therefore should not be prescribed at distances less than 5 mm.

Table 6.2.1.5 Digitizer Reproducibility Test Results for Volunteer User # 1

Trial #	Calculated Distances (mm) for Points Digitized at Known Distances							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	1.6	5.1	9.7	14.2	19.5	29.4	39.0	49.6
2	2.7	5.2	10.2	15.7	20.5	30.9	40.4	50.4
3	2	4.9	9.9	15	19.7	29.6	39.6	49.4
4	2.5	5.6	10.4	15.1	20.8	30.6	40.4	50.7
5	1.3	4.5	9.5	14.3	19.5	29.4	39.3	49.6
6	2.7	5.7	10.7	15.7	20.8	30.6	40.6	50.7
7	1.7	4.5	9.4	14.2	19.2	29.4	39.5	49.4
Average	2.1	5.1	10.0	14.9	20.0	30.0	39.8	50.0
Standard Deviation	± 0.6	± 0.5	± 0.5	± 0.7	± 0.7	± 0.7	± 0.6	± 0.6
*Δ	+ 0.1	+ 0.1	0	- 0.1	0	0	- 0.2	0
Average Standard Deviation = ± 0.6 mm								

* Note: Δ = Average Calculated Distance - Known Distance

Table 6.2.1.6 Reproducibility of Dose Point Calculations Results in cGy for Volunteer User # 1

Trial #	Dose to Point (cGy) Digitized at Varying Distances from Source							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	1123.0	123.6	34.9	16.6	8.9	3.9	2.2	1.4
2	633.7	145.2	35.7	14.7	8.6	3.7	2.2	1.4
3	760.0	133.7	33.6	14.9	8.7	3.9	2.2	1.4
4	772.2	124.0	34.3	15.9	8.3	3.8	2.2	1.4
5	1271.8	145.1	35.3	16.1	8.8	3.9	2.2	1.4
6	709.5	127.0	33.3	15.0	8.4	3.8	2.1	1.4
7	789.8	141.1	36.3	16.3	9.0	3.9	2.2	1.4
Average	865.7	134.2	34.8	15.6	8.7	3.8	2.2	1.4
Standard Deviation	± 236.3	± 9.6	± 1.1	± 0.8	± 0.3	± 0.1	0	0
% Error in Dose	27.3	7.2	3.2	5.1	3.4	2.6	0	0

Table 6.2.1.7 Digitizer Reproducibility Test Results for Volunteer User # 2

Trial #	Calculated Distances (mm) for Points Digitized at Known Distances							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	2.1	5.9	9.9	15.4	20.1	30.5	40.1	50.3
2	1.3	4.6	9.5	14.5	19.9	29.6	40.0	50.1
3	2.9	5.7	10.7	15.6	21.0	30.5	40.7	50.6
4	1.1	4.3	9.2	14.3	19.0	28.8	38.9	48.8
5	2.4	6.1	10.0	15.3	20.5	30.5	40.8	49.9
6	1.8	5.1	9.6	14.9	19.6	30.1	39.2	49.6
7	2.8	5.7	11.1	15.7	20.8	30.5	40.7	50.1
Average	2.1	5.3	10.0	15.1	20.1	30.1	40.1	49.9
Standard Deviation	± 0.7	± 0.7	± 0.7	± 0.5	± 0.7	± 0.7	± 0.8	± 0.6
*Δ	+ 0.1	+ 0.3	0	+ 0.1	+ 0.1	+ 0.1	+ 0.1	- 0.1
Average Standard Deviation = ± 0.7 mm								

* Note: Δ = Average Calculated Distance - Known Distance

Table 6.2.1.8 Reproducibility of Dose Point Calculations Results in cGy for Volunteer User # 2

Trial #	Dose to Point (cGy) Digitized at Varying Distances from Source							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	1071.1	111.5	38.0	15.3	8.9	3.8	2.2	1.4
2	1514.6	145.3	36.4	15.9	8.5	3.9	2.1	1.4
3	581.7	127.4	33.6	15.2	8.3	3.8	2.1	1.4
4	1316.8	154.7	36.9	16.1	9.2	4.1	2.2	1.4
5	864.4	104.0	37.2	15.5	8.6	3.8	2.1	1.4
6	861.2	119.7	35.6	15.1	8.8	3.8	2.2	1.4
7	623.3	124.5	30.5	15.1	8.4	3.8	2.1	1.4
Average	976.2	126.7	35.5	15.5	8.7	3.9	2.1	1.4
Standard Deviation	± 346.6	± 17.9	± 2.6	± 0.4	± 0.3	± 0.1	± 0.1	0
% Error in Dose	35.5	14.1	7.3	2.6	3.4	2.6	4.8	0

Table 6.2.1.9 Digitizer Reproducibility Test Results for Volunteer User # 3

Trial #	Calculated Distances (mm) for Points Digitized at Known Distances							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	2.0	4.7	9.6	14.4	20.0	29.6	39.8	49.9
2	2.3	5.2	10.3	14.8	20.3	30.4	39.7	50.1
3	2.0	5.3	10.3	14.7	19.8	30.0	39.7	49.9
4	2.3	5.1	9.7	15.2	20.0	30.2	40.3	50.1
5	1.5	4.4	9.3	14.3	19.4	29.2	39.0	49.4
6	2.6	5.8	10.7	15.8	20.5	30.7	40.7	50.7
7	1.4	4.4	9.6	14.6	19.2	29.3	39.2	49.0
Average	2.0	5.0	9.9	14.8	19.9	29.9	39.8	49.9
Standard Deviation	± 0.4	± 0.5	± 0.5	± 0.5	± 0.6	± 0.6	± 0.6	± 0.5
*Δ	0	0	- 0.1	- 0.2	- 0.1	- 0.1	- 0.2	- 0.1
Average Standard Deviation = ± 0.5 mm								

* Note: Δ = Average Calculated Distance - Known Distance

Table 6.2.1.10 Reproducibility of Dose Point Calculations Results in cGy for Volunteer User # 3

Trial #	Dose to Point (cGy) Digitized at Varying Distances from Source							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	828.8	144.1	35.7	16.2	8.5	3.9	2.2	1.4
2	1042.3	151.1	34.9	16.6	8.7	3.8	2.2	1.4
3	837.1	115.0	31.7	15.5	8.6	3.8	2.2	1.4
4	1078.2	156.9	39.6	15.7	9.0	3.9	2.2	1.4
5	910.5	147.4	36.3	16.0	8.9	4.0	2.2	1.4
6	750.2	124.3	33.5	14.8	8.7	3.8	2.2	1.4
7	905.2	147.6	34.6	15.3	9.1	3.9	2.1	1.4
Average	907.5	140.9	35.2	15.7	8.8	3.9	2.2	1.4
Standard Deviation	± 117.8	± 15.3	± 2.5	± 0.6	± 0.2	± 0.1	0	0
% Error in Dose	13.0	10.6	7.1	3.8	2.3	2.6	0	0

Table 6.2.1.11 Digitizer Reproducibility Test Results for Volunteer User # 4

Trial #	Calculated Distances (mm) for Points Digitized at Known Distances							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	2.1	4.7	10.0	14.9	19.8	29.5	39.7	49.7
2	2.2	5.7	9.9	14.8	20.3	30.1	40.0	50.2
3	1.2	4.7	9.5	14.2	19.7	29.2	39.2	49.4
4	2.6	5.8	10.6	15.4	20.9	30.5	40.6	50.7
5	1.7	4.9	9.9	14.8	19.9	29.9	39.8	49.9
6	1.9	6.0	9.7	15.3	19.8	30.4	39.7	50.2
7	1.4	4.2	9.8	14.2	19.3	29.3	39.5	49.3
Average	1.9	5.1	9.9	14.8	20.0	29.8	39.8	49.9
Standard Deviation	± 0.5	± 0.7	± 0.3	± 0.5	± 0.5	± 0.5	± 0.4	± 0.5
*Δ	- 0.1	+ 0.1	- 0.1	- 0.2	0	- 0.2	- 0.2	- 0.1
Average Standard Deviation = ± 0.5 mm								

* Note: Δ = Average Calculated Distance - Known Distance

Table 6.2.1.12 Reproducibility of Dose Point Calculations Results in cGy for Volunteer User # 4

Trial #	Dose to Point (cGy) Digitized at Varying Distances from Source							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	663.3	140.7	33.3	15.1	8.6	3.9	2.2	1.4
2	976.6	121.7	37.7	16.5	8.7	3.9	2.2	1.4
3	1189.3	131.1	34.9	16.3	8.6	4.0	2.2	1.4
4	740.8	123.9	33.9	15.6	8.3	3.9	2.2	1.4
5	1034.6	132.8	33.6	15.3	8.6	3.8	2.2	1.4
6	1804.4	110.9	39.6	15.5	9.2	3.8	2.2	1.4
7	902.9	156.2	33.6	16.1	9.0	3.9	2.2	1.4
Average	1044.6	131.0	35.2	15.8	8.7	3.9	2.2	1.4
Standard Deviation	± 378.8	± 14.6	± 2.5	± 0.5	± 0.3	± 0.1	0	0
% Error in Dose	36.3	11.1	7.1	3.2	3.4	2.6	0	0

Once the digitizer is determined to be functioning properly, hardware testing continues. The plotter must be tested for accuracy in output. The test procedure used for the plotter involves digitizing a test square with 100 mm length sides through seven trials. The corners of the square are digitized and the square is plotted and measured with a Staedtler Mars 98719-S1 metric ruler. The resulting measured lengths are shown in Table 6.2.1.13. The lengths of all four sides were found to be within 100 ± 1 mm which meets the criterion of acceptability stated by Van Dyk et al. [3].

Table 6.2.1.13 Plotter Test Results for 100 mm Test Square

Trial #	Length of Side of Square (mm)			
	Side A	Side B	Side C	Side D
1	100	100	99	100
2	100	100	99	100
3	100	100	100	100
4	100	99	100	100
5	99	100	100	100
6	100	100	100	100
7	100	99	99	100
Average	100	100	100	100
Standard Deviation	± 0.4	± 0.5	± 0.5	0

The video display, keyboard, and printer are also tested to determine if they are consistent with respect to accurate input and output. Independent tests other than the hardware self-test procedures for these devices are not necessary due to the fact that these devices are utilized throughout the entire process of commissioning the PLATO - Brachytherapy Planning System. The positions of points on the screen, keyboard data

entry, and printed data results are all observed for consistency and accuracy throughout each step of the research.

6.3 Verification of the Calculational Method

The calculational method of the PLATO - Brachytherapy Planning System is verified by analyzing the data from the computer printouts of each of the seven trials performed using the slow and relaxed digitizing technique of the digitizer reproducibility test. The data needed to perform the analysis of the calculational method include the dose point coordinates, source coordinates, and PLATO calculated doses to each of the points. Using the distances calculated from the source to each of the dose points listed in Table 6.2.1.1, a manual calculation of the dose to each point can be performed by the method discussed in Chapter 3 - Theoretical Background, where the tissue absorption and scatter corrections are considered using the Nucletron modified Van Kleffens and Star equation. Once the manual calculations are performed, a comparison can be made between the dose calculated by the PLATO - Brachytherapy Planning System, listed in Table 6.2.1.2, and the manually calculated results to determine if the PLATO calculational method is accurate. The method of comparison involves the calculation of an error ratio from the following equation:

$$\textbf{Error Ratio (\%)} = \left(\frac{\textbf{PLATO Calculation of } D_p - \textbf{Manual Calculation of } D_p}{\textbf{Manual Calculation of } D_p} \right) * 100$$

The results of the comparisons for the seven trials of repeated point doses for verification of the calculational method of the PLATO - Brachytherapy Planning System are presented in Tables 6.3.1 through 6.3.7.

Table 6.3.1: Trial # 1 - Comparison of Dose Point (D_p) Calculations: Manual Dose Point Calculations versus Calculations with the PLATO - Brachytherapy Planning System

Calculated Distance From Source to Dose Point (mm)	PLATO Calculation of D_p (cGy)	Manual Calculation of D_p (cGy)	Error Ratio (%)
2.4	606.5	603.1	0.6
5.1	134.6	133.9	0.5
9.9	35.7	35.5	0.5
15.0	15.5	15.5	0
20.3	8.5	8.4	0.7
29.9	3.9	3.9	0
40.2	2.1	2.1	0
50.1	1.4	1.4	0

Table 6.3.2: Trial # 2 - Comparison of Dose Point (D_p) Calculations: Manual Dose Point Calculations versus Calculations with the PLATO - Brachytherapy Planning System

Calculated Distance From Source to Dose Point (mm)	PLATO Calculation of D_p (cGy)	Manual Calculation of D_p (cGy)	Error Ratio (%)
2.5	559.8	556.8	0.5
4.9	145.7	145.1	0.4
10.2	33.6	33.5	0.4
15.1	15.3	15.3	0
20.3	8.5	8.4	0.7
30.3	3.8	3.8	0
40.2	2.1	2.1	0
50.3	1.4	1.4	0

Table 6.3.3: Trial # 3 - Comparison of Dose Point (D_p) Calculations: Manual Dose Point Calculations versus Calculations with the PLATO - Brachytherapy Planning System

Calculated Distance From Source to Dose Point (mm)	PLATO Calculation of D_p (cGy)	Manual Calculation of D_p (cGy)	Error Ratio (%)
2.1	791.6	788.6	0.4
5.0	140.0	139.4	0.5
10.1	34.3	34.2	0.4
15.2	15.1	15.1	0
20.0	8.7	8.7	0
30.1	3.8	3.8	0
39.9	2.2	2.2	0
50.3	1.4	1.4	0

Table 6.3.4: Trial # 4 - Comparison of Dose Point (D_p) Calculations: Manual Dose Point Calculations versus Calculations with the PLATO - Brachytherapy Planning System

Calculated Distance From Source to Dose Point (mm)	PLATO Calculation of D_p (cGy)	Manual Calculation of D_p (cGy)	Error Ratio (%)
2.1	786.3	781.6	0.6
5.0	139.7	139.1	0.4
9.8	36.4	36.2	0.4
15.0	15.5	15.5	0
19.9	8.8	8.8	0
30.1	3.8	3.8	0
40.0	2.2	2.2	0
50.4	1.4	1.4	0

Table 6.3.5: Trial # 5 - Comparison of Dose Point (D_p) Calculations: Manual Dose Point Calculations versus Calculations with the PLATO - Brachytherapy Planning System

Calculated Distance From Source to Dose Point (mm)	PLATO Calculation of D_p (cGy)	Manual Calculation of D_p (cGy)	Error Ratio (%)
2.0	856.1	852.3	0.4
4.9	145.2	144.6	0.4
9.8	36.4	36.2	0.4
14.9	15.7	15.7	0
20.1	8.6	8.6	0
29.9	3.9	3.9	0
39.8	2.2	2.2	0
49.9	1.4	1.4	0

Table 6.3.6: Trial # 6 - Comparison of Dose Point (D_p) Calculations: Manual Dose Point Calculations versus Calculations with the PLATO - Brachytherapy Planning System

Calculated Distance From Source to Dose Point (mm)	PLATO Calculation of D_p (cGy)	Manual Calculation of D_p (cGy)	Error Ratio (%)
2.1	784.0	781.6	0.3
4.7	158.2	157.6	0.4
10.3	32.9	32.8	0.2
15.0	15.5	15.5	0
20.4	8.4	8.4	0
29.8	3.9	3.9	0
40.3	2.1	2.1	0
50.0	1.4	1.4	0

Table 6.3.7: Trial # 7 - Comparison of Dose Point (D_p) Calculations: Manual Dose Point Calculations versus Calculations with the PLATO - Brachytherapy Planning System

Calculated Distance From Source to Dose Point (mm)	PLATO Calculation of D_p (cGy)	Manual Calculation of D_p (cGy)	Error Ratio (%)
2.2	714.8	714.3	0.1
4.9	145.7	145.1	0.4
9.7	37.2	37.0	0.5
14.7	16.2	16.1	0.6
20.1	8.6	8.6	0
30.0	3.9	3.9	0
40.3	2.1	2.1	0
50.0	1.4	1.4	0

The criterion followed for comparison between computer and manual calculations is ± 5 % accuracy for dose points at distances of 0.5 cm or greater from the source. Tables 6.3.1 through 6.3.7 show that for the calculation of dose to points, placed at distances ranging from 2 mm to 50 mm from the source, the results calculated by the PLATO - Brachytherapy Planning System show an excellent agreement with the results of the manual method. Based on the calculations presented, the results of Trial 1 through Trial 7 are all within the criterion of acceptability of ± 5.0 % dose accuracy for calculational points. Therefore, from the results of the comparisons between the PLATO - Brachytherapy Planning System and the manual method, it can be determined that the calculational method of the PLATO - Brachytherapy Planning System is accurate and therefore verified. With the calculational algorithm verified, the next step is to verify the implementation of the algorithm through clinical trials.

6.4 Summary

It has been shown that the commissioning of a brachytherapy treatment planning system involves multiple steps including user familiarization with the system, hardware testing, machine and source customization, and staff training. Since errors can occur in each step of the brachytherapy treatment planning process, it is important to identify them at each step in order to decrease their frequency and compounding effects.

The results of the digitizer reproducibility tests showed variability in distance due to human error which in turn caused variation in the dose from one trial to another for points that were digitized at the same known distances. The calculational method of the PLATO - Brachytherapy Planning System was found to be accurate in the data shown in this chapter; however, the ability to calculate dose within the first 5 mm from the source is not accurate. Due to the fact that a high dose gradient exists close to the source, small digitizing errors greatly affect dose calculations at short distances whereas at longer distances, small errors are not as evident. Therefore, since humans cannot digitize error free, you cannot expect to calculate dose accurately within the first 5 mm from the source and the dose therefore should not be prescribed at distances less than 5 mm.

CHAPTER 7

VERIFICATION OF THE TREATMENT PLANNING ALGORITHM OF THE PLATO - BRACHYTHERAPY PLANNING SYSTEM

7.1 Introduction

The calculational method must be tested prior to investigating the implementation of the algorithm. Once the calculational method is verified, the implementation of the algorithm must be verified by performing tests of the output over a range of clinical conditions from very simple cases to rare and unusual circumstances. The output can then be evaluated for its quality and accuracy. Although this process cannot test every possible parameter and possible situation that may arise, it should give the user a certain degree of confidence in the computer program as well as an understanding of its limitations and uncertainties.

The basis of any brachytherapy treatment plan includes two radiographs with the implant in place. The position of the applicator and any identifying patient points have to be transferred to the system. This is performed by the use of a digitizer tablet and a minimum of two radiographs. Depending on the area to be treated and the applicator used, four radiographs may be required for reconstruction, two to identify the implant and two to identify the patient's structures.

Decisions on the dose to be delivered and the area to be treated are made prior to starting a treatment plan. The International Commission on Radiation Units and Measurements (ICRU) recommends certain criteria be followed for specifying the application and calculating the dose rate at specified points for brachytherapy treatments such as the treatment of cervix carcinoma. ICRU Report #38 directly refers to

intracavitary treatment of cervix carcinoma, although, the concepts developed in the report are designed to be applicable to other intracavitary applications as well. However, years after ICRU Report #38 was published, there is still no consensus on dose specification and dose prescription [15].

Different brachytherapy systems have been recognized throughout the years. The first system, the Paris System, arose in the early years of radiotherapy. It prescribed a fixed number of milligram-hours, the product of the total activity and implant duration, for a given tumor volume. Recognizing that the Paris System did not address anatomical targets or tolerance of organs in its dose prescription, the Manchester System was developed expanding on the principles laid down by the Paris System. The Manchester System set the central target to be the cervix, the uterus, the vaginal vault, and the parametrium. The Manchester System was designed to deliver a constant dose rate for all patients to defined points near the cervix, independent of size and shape of the uterus and vagina. Application of the Manchester System involved dose specification in roentgens delivered to four points; point A, point B, a bladder point, and a rectal point. Tod and Meredith originally defined point A as 2 cm superior to the lateral vaginal fornix and 2 cm lateral to the cervical canal. In 1953 point A was redefined by Tod and Meredith as 2 cm superior to the external cervical os , and 2 cm lateral to the cervical canal. Point B was defined as 5 cm lateral to the midline [31].

The dosage at point A is representative of the dose throughout a considerable zone of tissue containing tumor. This zone contains the vital paracervical tissues that are often the site of early invasion by cancer. Typically point A designated the location where the uterine vessel crosses the ureter. This location is believed to be the limiting

factor in the irradiation of the uterine cervix and therefore would be predictive of late radiation complications. The dose prescription and duration of the implant, is based on the dose rate calculated at point A [1].

In clinical practice (MBPCC included), dose calculations are made from a minimum of two radiographs. Right A (RtA) and left A (LtA) are taken 2 cm up from the flange of the intrauterine source and 2 cm laterally from the tandem. Right B (RtB) and left B (LtB) are also taken 2 cm up from the flange of the intrauterine source but 5 cm laterally from the midline of the patient [15].

The ICRU also recommends determining and specifying the absorbed dose to organs at risk or bony structures. Organs at risk are those organs in or near the target volume which could influence treatment planning or prescription of dose. Knowing the absorbed dose at organs such as the bladder and rectum for intracavitary treatment of gynecological cases is beneficial for determining normal tissue tolerance limits. Reference points related to bony structures are recommended to be located through use of Fletcher's lymphatic trapezoid method. The trapezoid is constructed in order to estimate the dose rate to the middle external iliac, lower para-aortic, and lower common iliac lymph nodes. The evaluation of the absorbed dose at reference points, related to well-defined bony structures and lymph node areas, is particularly useful when intracavitary therapy is combined with other modalities of treatment [15, 32]. A diagram and detailed descriptions of how to locate and enter points for organs at risk, point As and Bs, and the lymphatic trapezoid are located in Appendix A.

Once decisions on dose are made, the task then is to obtain a suitable dose distribution with the brachytherapy planning system. This is achieved by determining the

positions to be occupied by the source and the length of time that the positions are to be occupied. This is the job of the treatment planning system. The user's part is to generalize to the brachytherapy planning system, how the required dose distribution might be obtained. The brachytherapy planning system then shows the user graphically what is achieved, leaving the user free to instruct it in optimizing the dose.

It is not always necessary to optimize the dose to acquire the desired dose distribution. For some treatment plans, it might be sufficient to simply normalize the dose and prescribe it. For normalization of the dose, it is required that at least one point be specified where you want to normalize the relative dose calculation. Multiple points can be selected, in which case the mean value is used for the normalization. The dose can be normalized to any applicator, patient, or dose point which is defined in the treatment plan. Dose points can be placed oriented to the catheter, oriented to the axis, or specified by coordinates. With the dose point optimization method, the brachytherapy planning system is able to program the relative dwell times to such an extent that the dose uniformity at the defined dose points is optimized. The ultimate goal is to obtain a homogeneous dose distribution with sharp fall-off immediately outside the treatment area.

7.2 Materials and Methods

A variety of applicators have been designed to hold the sources in a fixed configuration for afterloading. Brachytherapy sources can be afterloaded by different methods such as intraluminal, interstitial, and intracavitary depending on the size and location of the tumor. Intraluminal therapy is utilized for esophageal and endobronchial treatments. Intraluminal applicators are flexible, hollow plastic catheters which allow sources to be inserted after positioning. An endoscope is often used to guide and place

the catheter(s) in the proper position. An endoscope is an instrument which consists of a lighted tube attached to a viewing device or miniature television camera to explore areas such as the bronchi of the lungs, the esophagus, or the colon. For interstitial therapy, hollow needles or plastic tubes are inserted into the tissue with one or both ends brought through the skin. The radioactive sources utilized in interstitial therapy are fabricated as needles, wires, or seeds which can be directly afterloaded into the applicator(s) in the tumor. Interstitial therapy is used when the tumor is well localized such as in a breast. Intracavitary therapy is used when applicators containing radioactive sources can be placed into body cavities. Intracavitary therapy is primarily used for cancers of the uterine cervix, uterine body, and vagina.

There are a variety of applicators utilized for gynecological brachytherapy treatments. The applicators come in different designs depending on the area under treatment. Applicators are designed to work specifically with a particular afterloading unit. The Nucletron gynecological applicators used in the Commissioning and Evaluation of the PLATO - Brachytherapy Planning System are shown in Figures 7.2.1 through 7.2.4. Figure 7.2.1 shows a Nucletron ring and tandem applicator set that is utilized for treatment of cervical and endometrial cancer. It consists of a central tube, called a tandem, which is inserted into the uterus, and a ring with a cap that rests against the cervix. The rings and tandems are designed with various angles (i.e. 45° and 60°). The rings are angled to match the tandems and fit perpendicular together as an assembly. The rings come in various diameters (i.e. 26, 30 and 34 mm) in order for the physician to find the best fit assembly for each patient's anatomy. Figure 7.2.2 shows a Nucletron Houdek applicator set that is utilized for treatment of cervical and vaginal cancer. The Houdek

applicator consists of a tandem and a 90° ring. The tandem ends in the middle of the ring and is not extended through the ring into the uterus. Figure 7.2.3 shows a Nucletron cylinder and tandem applicator set that is utilized for treatment of cervical, endometrial, and vaginal cancer. The tandem is inserted through the cervical canal and the cylinder holds the wall of the vagina away from the tandem. The cylinder actually consists of multiple segments that fit together. The diameter and number of the segments utilized depends on the patient's anatomy. Figure 7.2.4 shows a Nucletron tandem and ovoids applicator. It consists of a tandem and two lateral capsules or ovoids for treatment of cervical and endometrial cancer.

Thirteen treatment plan cases are presented in this chapter for the commissioning and evaluation of the PLATO - Brachytherapy Planning System. The types of cases incorporated involve a variety of treatment sites, applicator types, reconstruction methods, and optimization methods and are listed in Table 7.2.1. The plans are divided into two groups; 1) clinical cases previously performed at Mary Bird Perkins Cancer Center (MBPCC) and 2) cases provided by the Nucletron Corporation in the instruction manuals. The use of the Nucletron-provided cases increases the variety of testing parameters that can be investigated for cases that are not often found at MBPCC.

The cases listed in Table 7.2.1 are calculated with different treatment planning systems for verification of the PLATO - Brachytherapy Planning System algorithm. The PLATO and Nucletron Planning System (NPS) Brachytherapy Planning Systems are used for calculation of isodose distributions for all thirteen treatment plan cases. For Case # 1 and Case # 2, the PLATO and NPS Brachytherapy Planning Systems as well as three additional treatment planning systems are used for calculation of isodose distributions.

The additional treatment planning systems used for comparison include two treatment planning systems used at MBPCC; the Capintec Cap-Plan RTP110 (Capintec) and Theratronics Theraplan 500 V05B (Theraplan). The Capintec and Theraplan treatment planning computers are primarily used for external beam treatment planning; however, they have the capability of performing low dose rate (LDR) treatment planning procedures. With minimal manipulations of the plan input data with respect to activity and time, these computers make good comparisons of the results obtained with the PLATO - Brachytherapy Planning System. The final treatment planning comparison involves calculations with a program developed at MBPCC using a spreadsheet for computational purposes to calculate dose distributions for comparison against the PLATO - Brachytherapy Planning System results. The results of each of the treatment plans are compared with respect to spatial accuracy for equal isodose levels. Comparisons of treatment plan results between treatment planning systems of each case are done by overlaying the isodose distributions as well as physically measuring the distance from the origin of the dose distribution axes to the point at which the prescribed isodose levels cross each axis (± X, ± Y, and ± Z). Physical measurements of the distances are performed with a Staedtler Mars 98719-S1 metric ruler with ± 1 mm accuracy. The criterion of acceptability is ± 3.0 mm spatial accuracy for equal isodose levels. The results of each case, including isodose distributions and measured distances, are presented in the figures and tables respectively in each section. It should be noted that the magnification factor for all the isodose distributions are not the same, but comparisons between them were done in a life size scale.

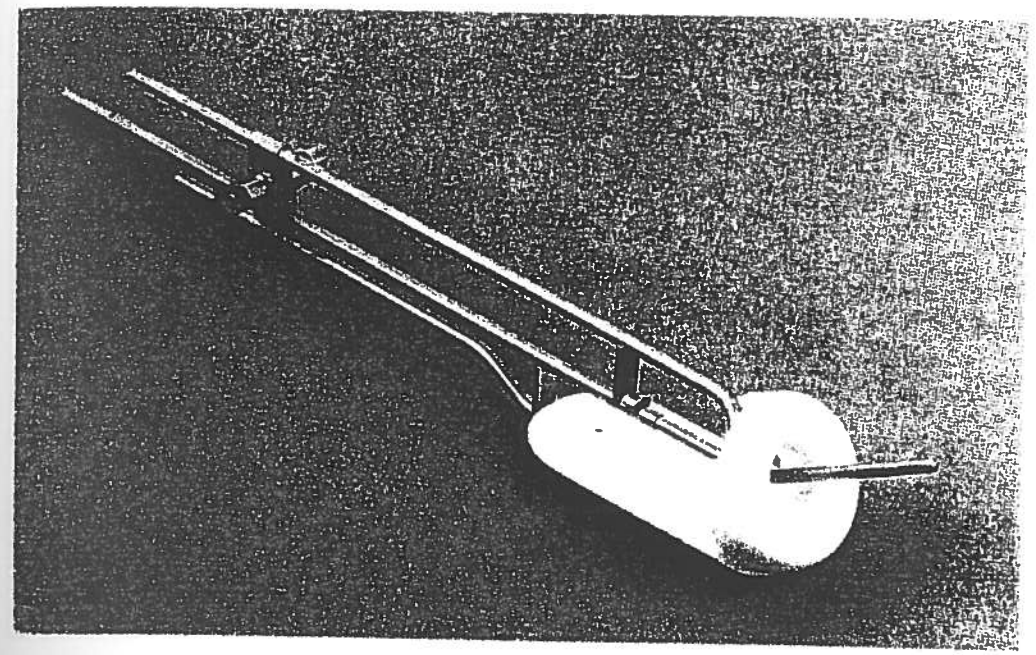


Figure 7.2.1 Nucletron Ring and Tandem Applicator Set

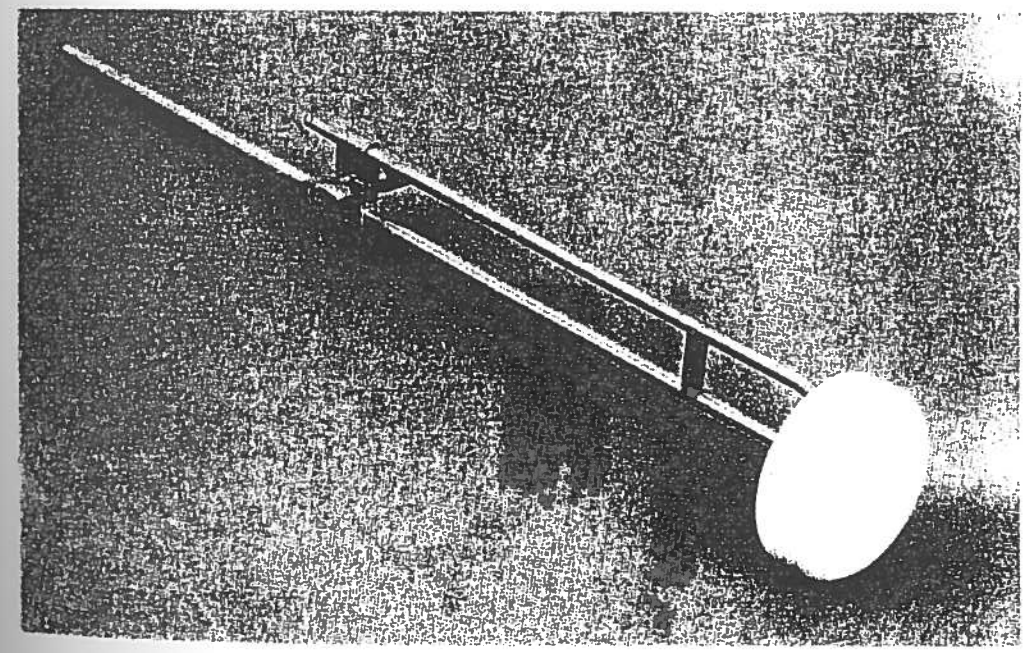


Figure 7.2.2 Nucletron Houdek Applicator Set

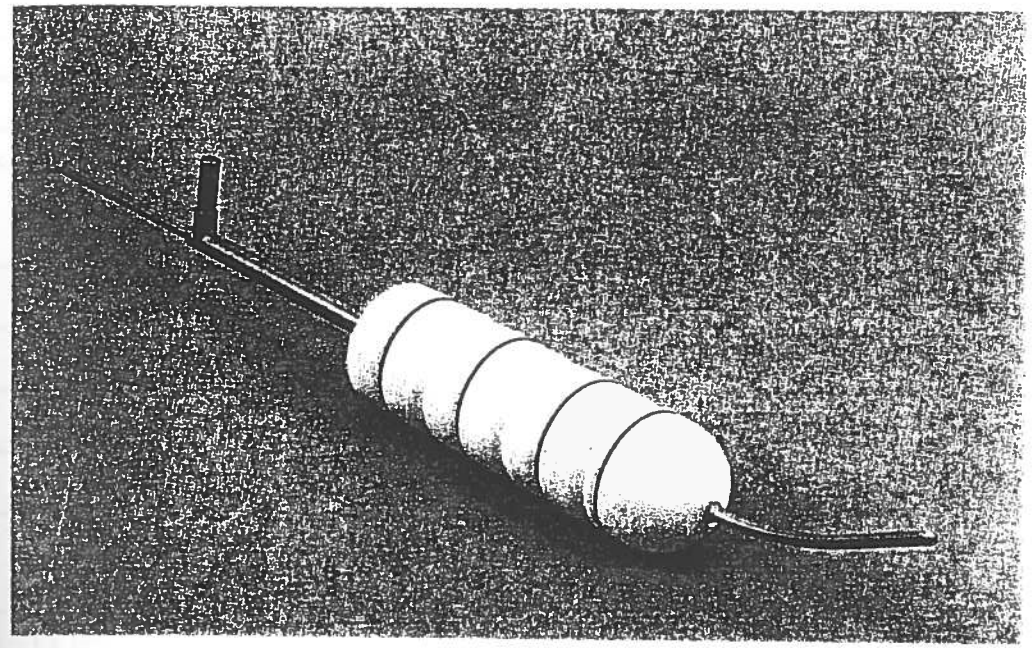


Figure 7.2.3 Nucletron Cylinder and Tandem Applicator Set

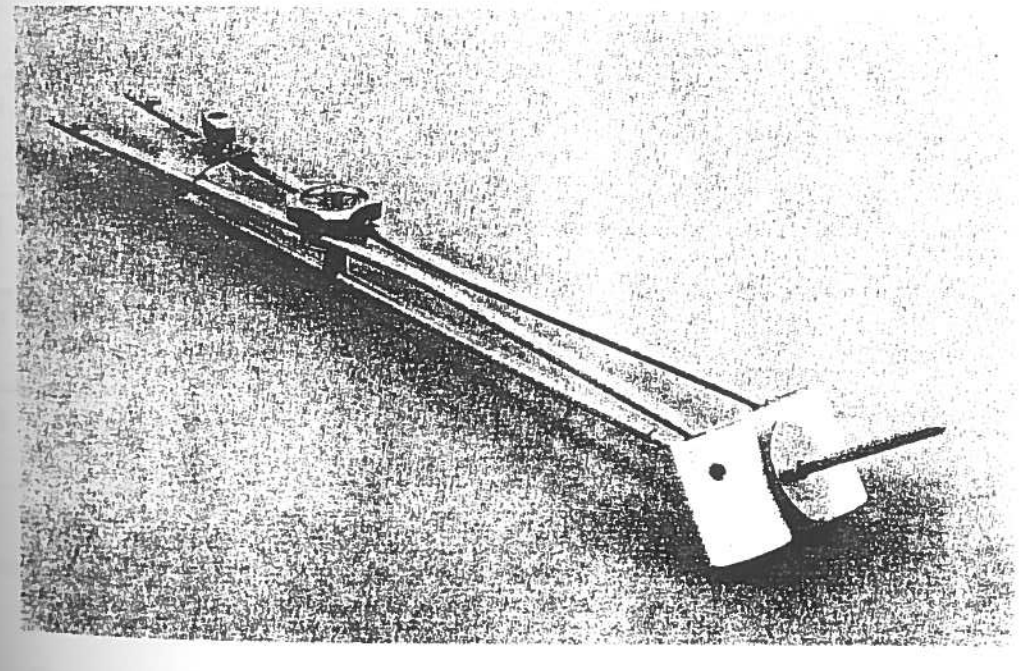


Figure 7.2.4 Nucletron Tandem and Ovoids Applicator Set

Table 7.2.1: Treatment Plans Incorporated in the Commissioning and Evaluation of the PLATO - Brachytherapy Planning System

Case #	Treatment Site	Clinical (C) or Nucletron (N) Provided	Applicator Type	Reconstruction Method	Optimization Method
1	* Axes Test	N/A	2 Catheters	Orthogonal	None
2	* Cervix	C	Houdek	Orthogonal	Distance
3	Esophagus	C	1 Catheter	Orthogonal	Distance
4	Bronchus	C	1 Catheter	Orthogonal	Distance
5	Cervix / Endometrium	C	Ring and Tandem	Orthogonal and Variable Angle	None
6	Cervix / Vaginal Wall	C	Cylinder and Tandem	Semi-Orthogonal	Distance
7	Esophagus	N	1 Catheter	Semi-Orthogonal	Distance
8	Bronchi	N	2 Catheter	Variable Angle	Distance
9	Bronchi	N	2 Catheters	Semi-Orthogonal	Distance
10	Cervix / Endometrium	N	Ring and Tandem	Variable Angle	None (wt 0.6 to 1.0)
11	Cervix / Endometrium	N	Tandem and Ovoids	Orthogonal	None
12	Cervix / Vaginal Wall	N	Cylinder and Tandem	Semi-Orthogonal	Distance
13	Breast	N	5 Catheters (Needles)	Variable Angle	Volume

Note: All cases are calculated with the Nucletron (PLATO and NPS) Brachytherapy Planning Systems.

* Cases are calculated with three additional treatment planning systems including the Capintec Cap-Plan RTP110, Theratronics Theraplan 500 V05B, and a MBPCC spreadsheet program.

7.3 Intercomparison of Brachytherapy Treatment Plans Performed with the Nucletron (PLATO and NPS), Capintec, Theraplan, and MBPCC Spreadsheet Treatment Planning Systems

The Axes Test Case and Houdek Applicator Case, are presented in sections 7.3.1 and 7.3.2 respectively. These cases are calculated with five treatment planning systems for verification of the PLATO - Brachytherapy Planning System. The PLATO and NPS Brachytherapy Planning Systems as well as the Capintec, Theraplan, and MBPCC spreadsheet program are utilized to calculate dose distributions for comparison.

7.3.1 Case # 1 - Axes Test Case

Case # 1 represents the initial testing of the PLATO - Brachytherapy Planning System. This case is designed with two catheters perpendicular to each other with active positions on each catheter giving a non-symmetrical isodose distribution for analysis of the algorithm. This case is performed with orthogonal reconstruction. The resulting isodose distributions generated with each treatment planning system are presented in Figures 7.3.1.1 through 7.3.1.9. Tables 7.3.1.1 and 7.3.1.2 represent the comparison of the isodose distributions for case # 1.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System, Nucletron Planning System, Capintec, Theraplan, and MBPCC spreadsheet treatment planning systems for Case # 1 (Axes Test Case) show an excellent agreement between all five treatment planning systems. When each isodose distribution was overlaid with the PLATO - Brachytherapy Planning System, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.3.1.1

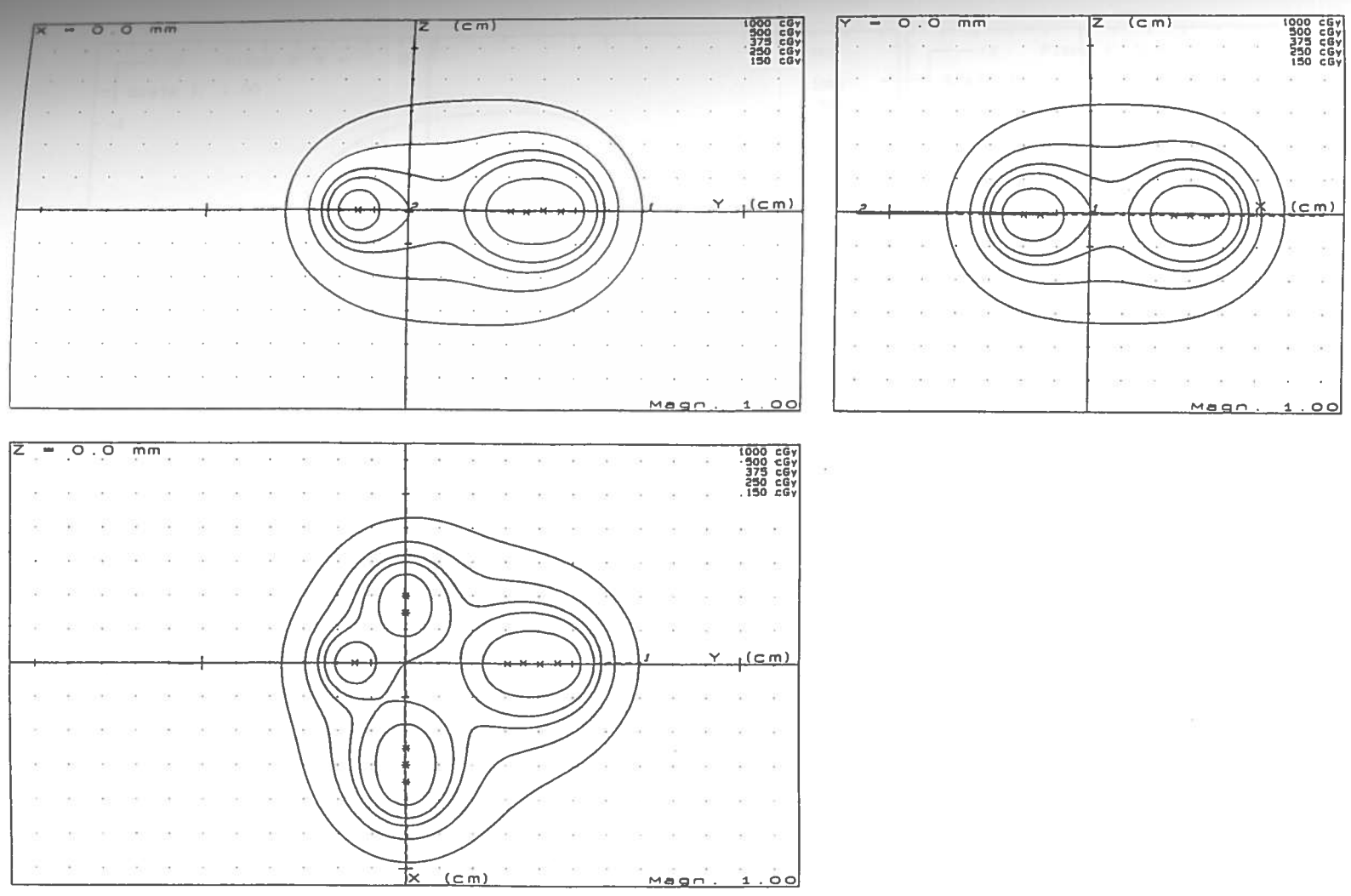


Figure 7.3.1.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 1 - Sagittal, Transverse, and Coronal Planes (Axes Test)

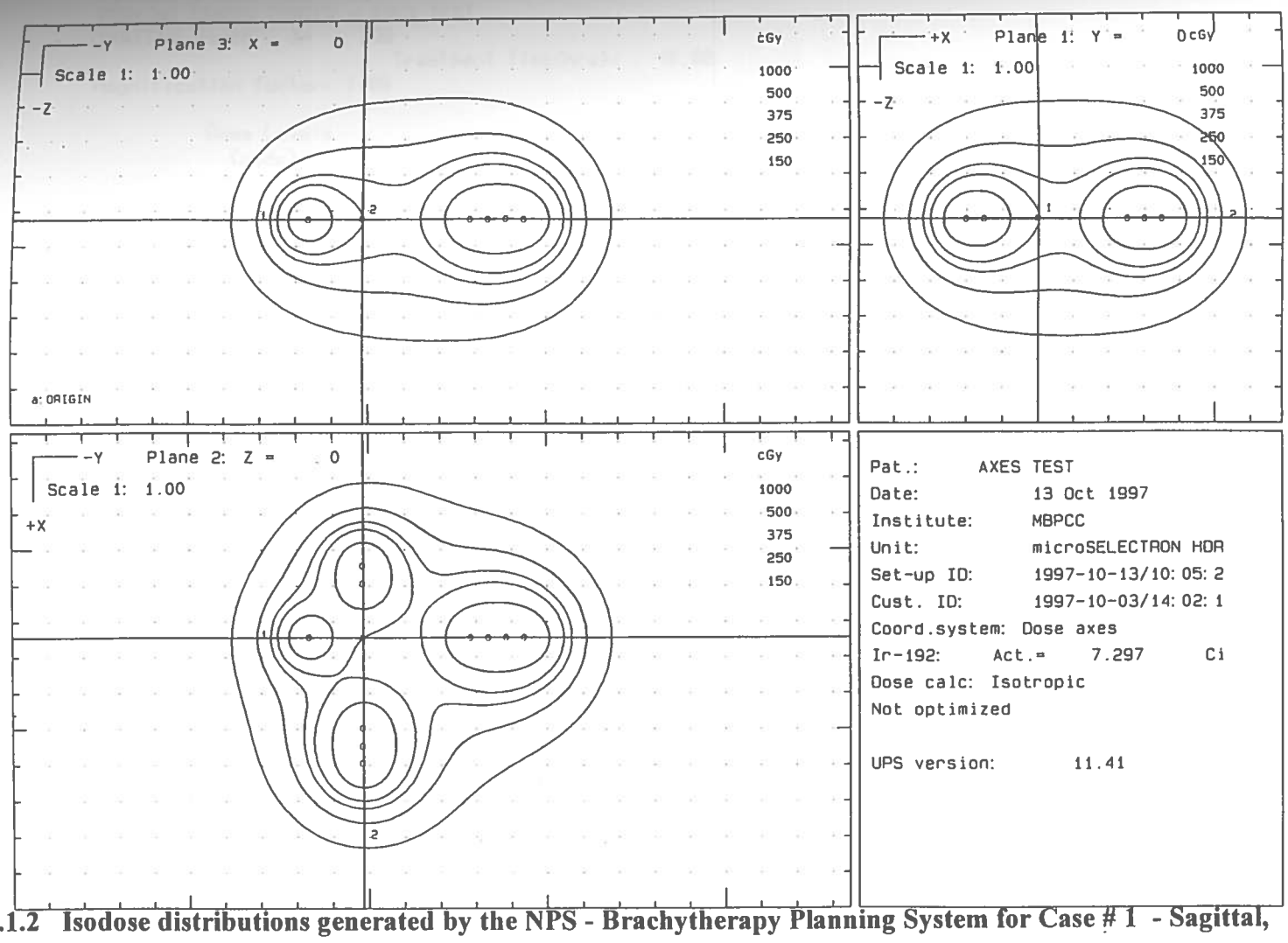


Figure 7.3.1.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 1 - Sagittal, Transverse, and Coronal Planes (Axes Test)

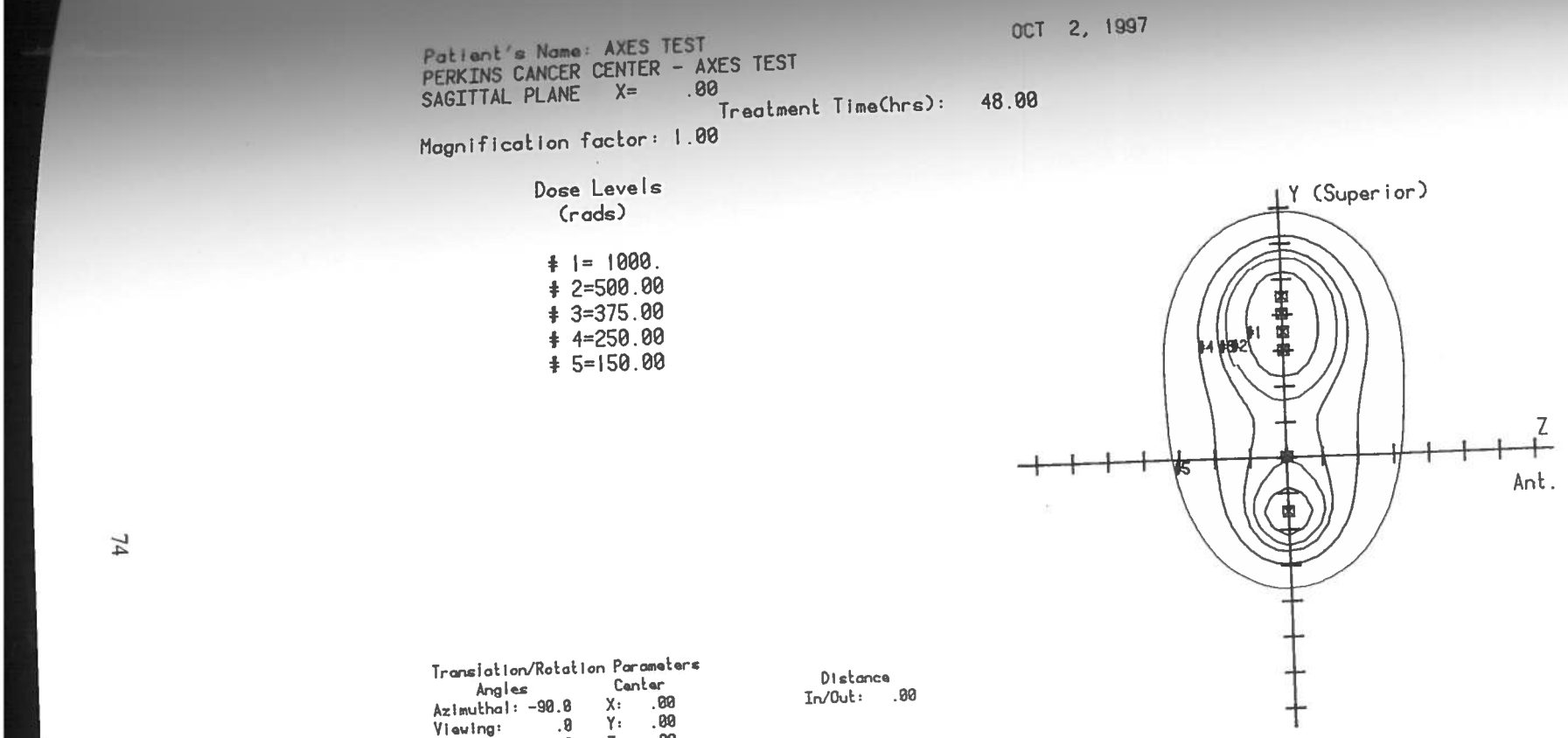


Figure 7.3.1.3 Isodose distributions generated by the Capintec Treatment Planning System for Case # 1 - Sagittal Plane (Axes Test)

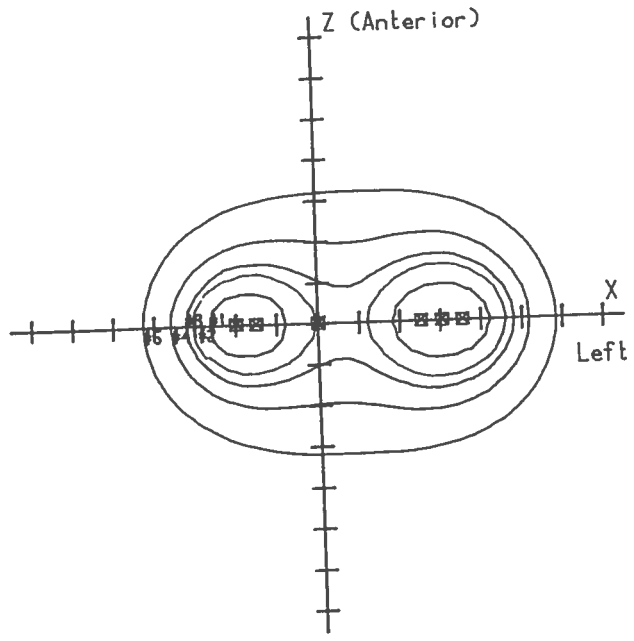
OCT 2, 1997

Patient's Name: AXES TEST
PERKINS CANCER CENTER - AXES TEST
TRANSVERSE PLANE Y= .00
Treatment Time(hrs): 48.00

Magnification factor: 1.00

Dose Levels
(rads)

1= 1000.
2=500.00
3=375.00
4=250.00
5=150.00



Translation/Rotation Parameters

Angles		Center	
Azimuthal:	.0	X:	.00
Viewing:	90.0	Y:	.00
Screen:	.0	Z:	.00

Distance In/Out: .00

IRIDIUM-192 10 Seeds Total activity: 7.08 mg.

Figure 7.3.1.4 Isodose distributions generated by the Capintec Treatment Planning System for Case # 1 - Transverse Plane (Axes Test)

Patient's Name: AXES TEST OCT 2, 1997
PERKINS CANCER CENTER - AXES TEST
CORONAL PLANE Z= .00
Treatment Time(hrs): 48.00
Magnification factor: 1.00

Dose Levels
(rads)

1= 1000.
2=500.00
3=375.00
4=250.00
5=150.00

Translation/Rotation Parameters

Angles		Center		Distance
Azimuthal:	.0	X:	.00	In/Out: .00
Viewing:	.0	Y:	.00	
Screen:	.0	Z:	.00	

IRIDIUM-192 10 Seeds Total activity: 7.08 mg.

Figure 7.3.1.5 Isodose distributions generated by the Capintec Treatment Planning System for Case # 1 - Coronal Plane (Axes Test)

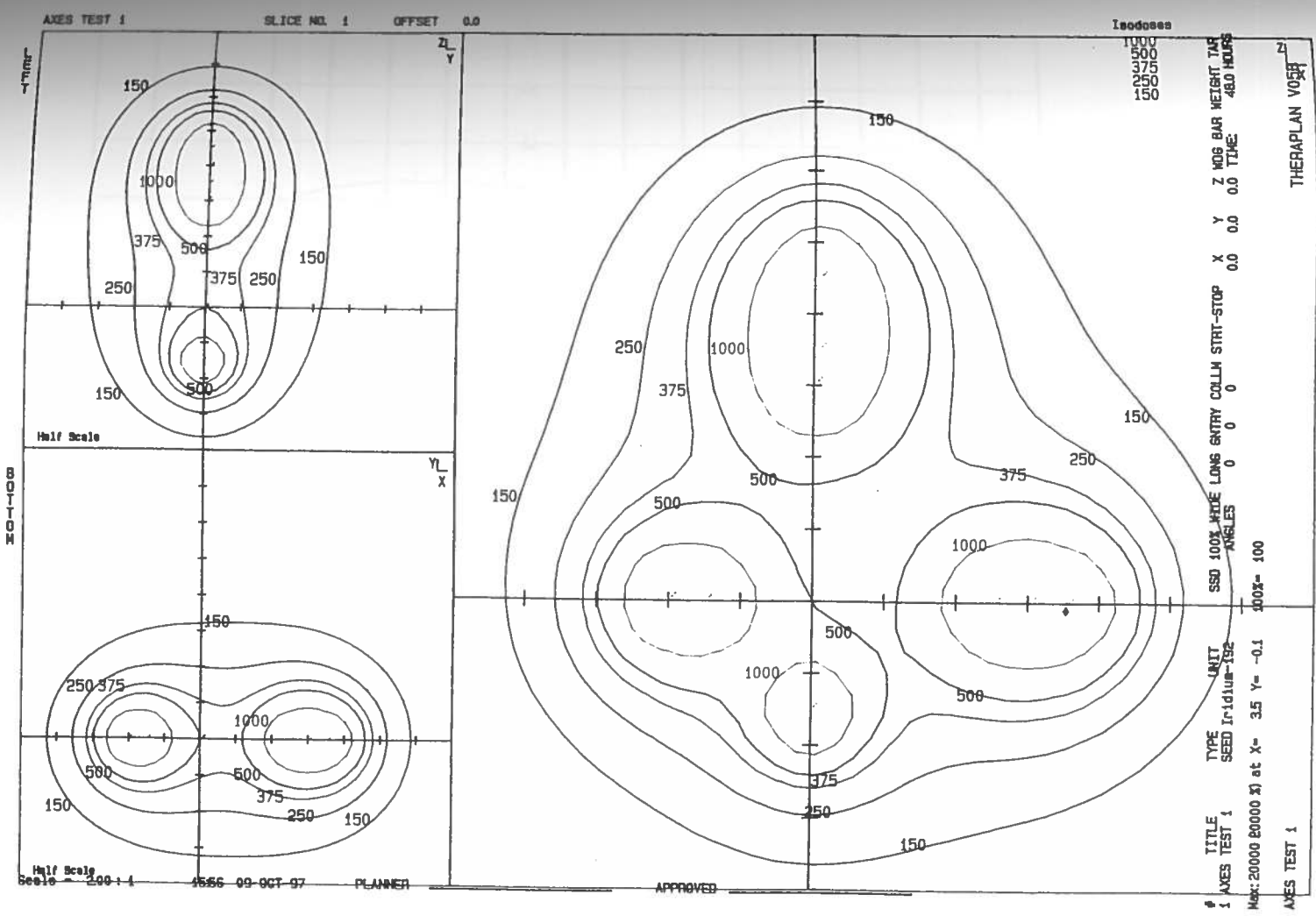


Figure 7.3.1.6 Isodose distributions generated by the Theraplan Treatment Planning System for Case # 1 - Sagittal, Transverse, and Coronal Planes (Axes Test)

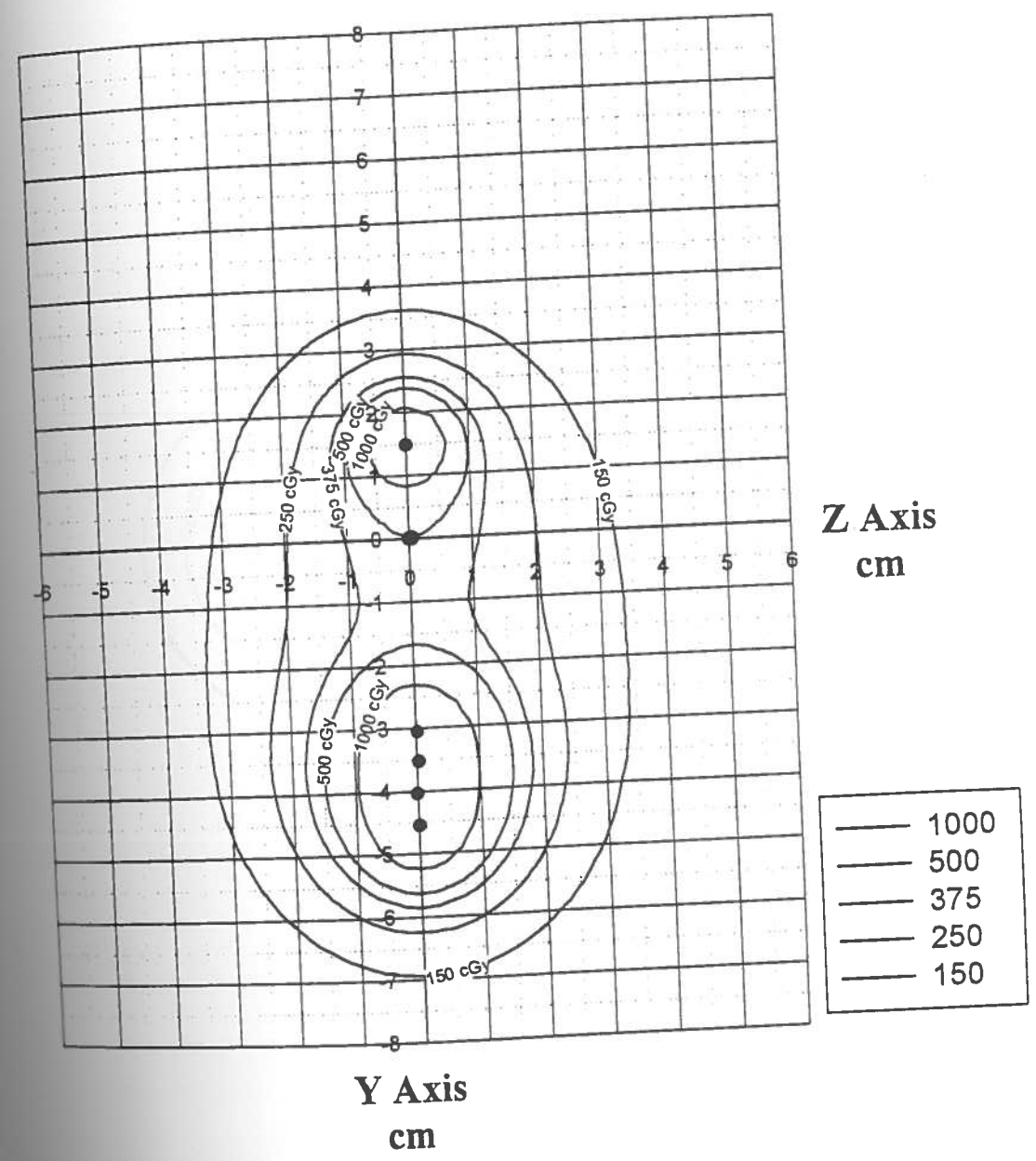


Figure 7.3.1.7 Isodose distributions generated by the MBPCC Spreadsheet Program for Case # 1 - Sagittal Plane (Axes Test)

Ir-192 HDR
Transverse Plane
Isodose Curves

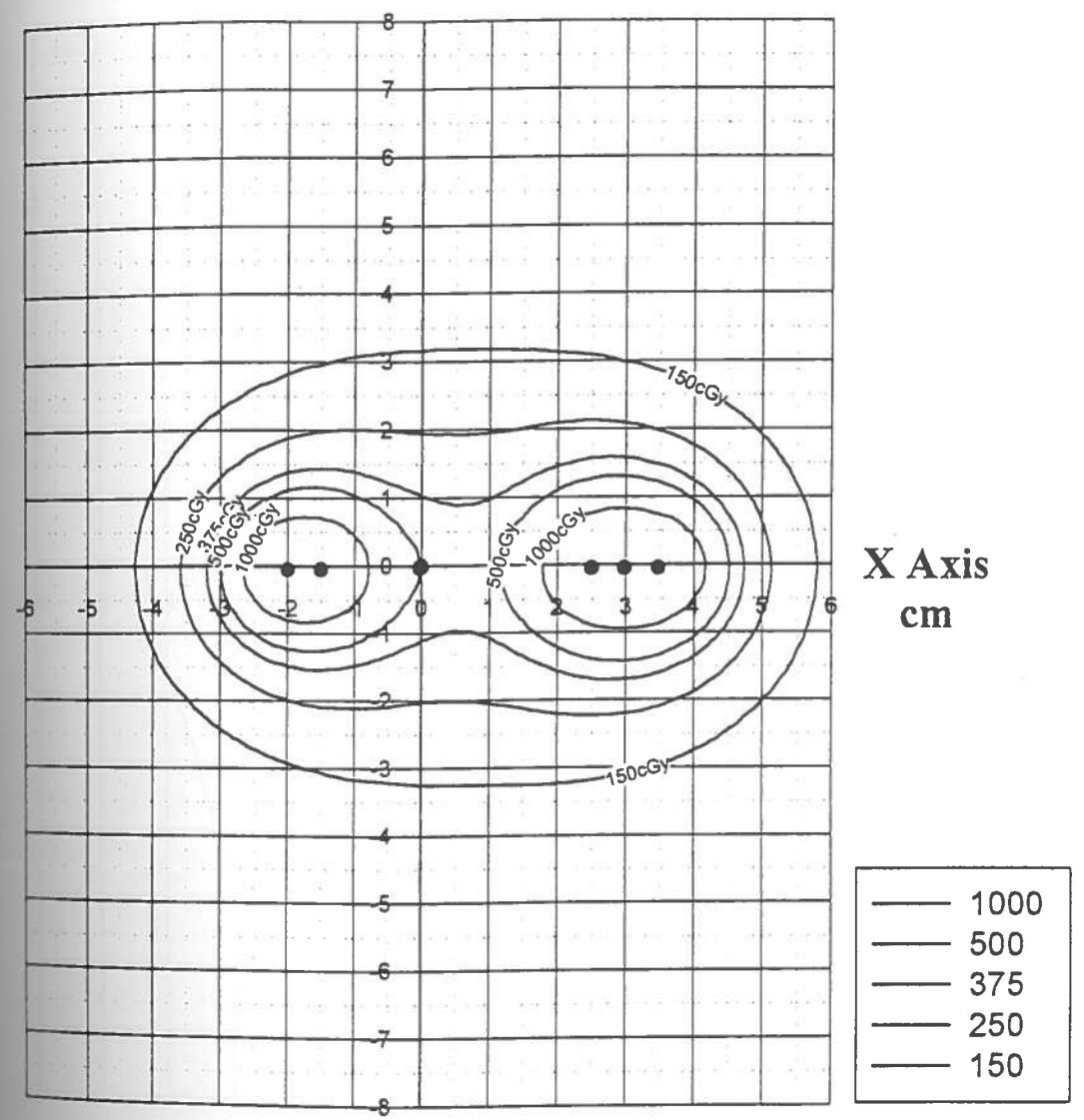


Figure 7.3.1.8 Isodose distributions generated by the MBPCC Spreadsheet Program for Case # 1 - Transverse Plane (Axes Test)

Ir-192 HDR
Coronal Plane
Isodose Curves

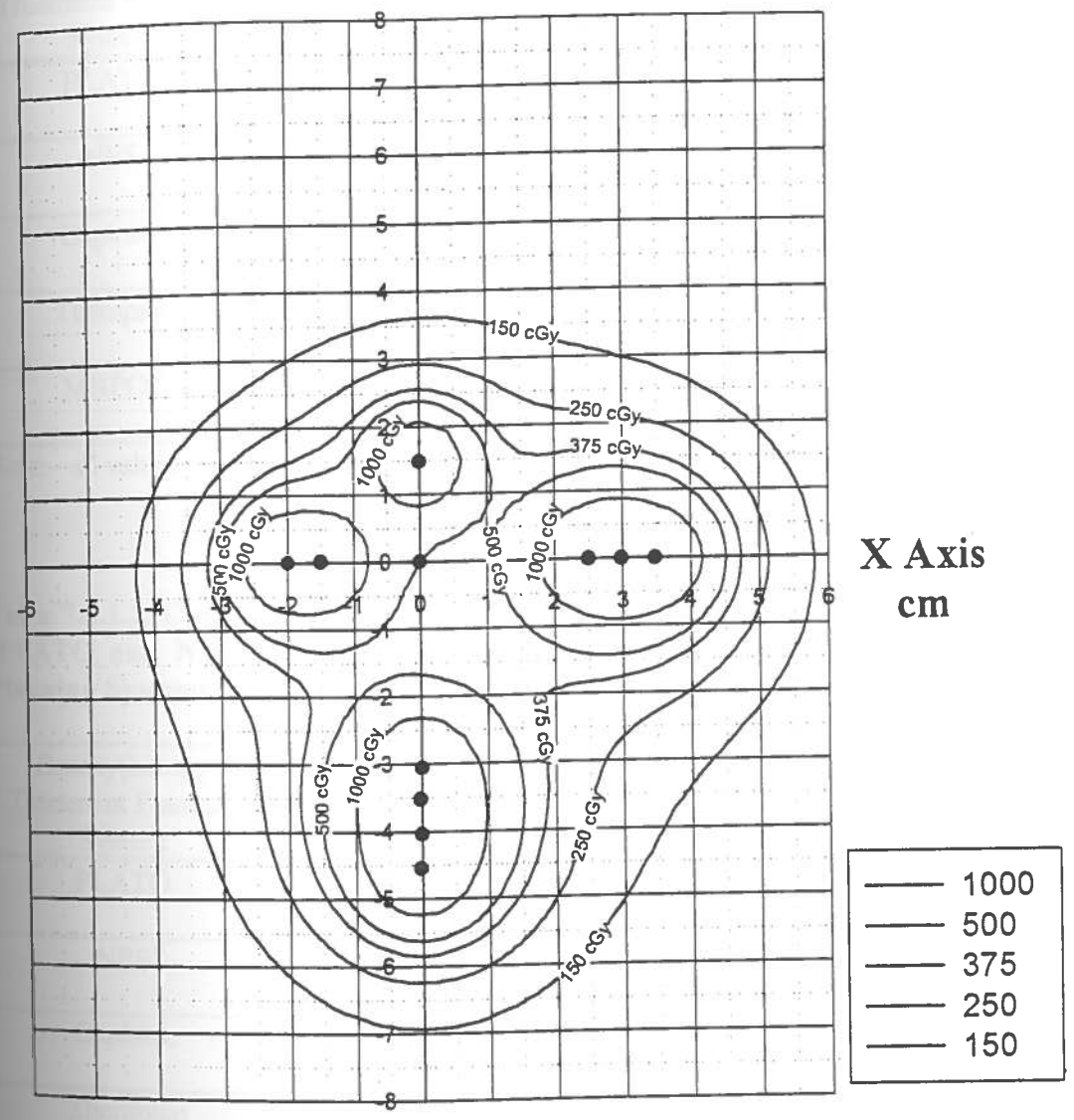


Figure 7.3.1.9 Isodose distributions generated by the MBPCC Spreadsheet Program for Case # 1 - Coronal Plane (Axes Test)

Table 7.3.1.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS), Capintec, Theraplan, and MBPCC Spreadsheet Treatment Planning Systems for Case # 1 (Axes Test Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_{P1} = 12$ $X_{P2} = 46$	$Y_{P1} = 16$ $Y_{P2} = 56$	$Z_P = 0$
NPS	$X_{N1} = 11$ $X_{N2} = 45$	$Y_{N1} = 16$ $Y_{N2} = 56$	$Z_N = 0$
Capintec	$X_{C1} = 12$ $X_{C2} = 46$	$Y_{C1} = 16$ $Y_{C2} = 56$	$Z_C = 0$
Theraplan	$X_{T1} = 12$ $X_{T2} = 46$	$Y_{T1} = 16$ $Y_{T2} = 56$	$Z_T = 0$
MBPCC	$X_{E1} = 11$ $X_{E2} = 45$	$Y_{E1} = 16$ $Y_{E2} = 56$	$Z_E = 0$

Note: all values (± 1 mm)

Table 7.3.1.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS), Capintec, Theraplan, and MBPCC Spreadsheet Treatment Planning Systems for Case # 1 (Axes Test Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_{P1} = 0$ $X_{P2} = 30$	$Y_{P1} = 0$ $Y_{P2} = 24$	$Z_P = 0$
NPS	$X_{N1} = 0$ $X_{N2} = 30$	$Y_{N1} = 0$ $Y_{N2} = 24$	$Z_N = 0$
Capintec	$X_{C1} = 0$ $X_{C2} = 30$	$Y_{C1} = 0$ $Y_{C2} = 24$	$Z_C = 0$
Theraplan	$X_{T1} = 0$ $X_{T2} = 30$	$Y_{T1} = 0$ $Y_{T2} = 24$	$Z_T = 0$
MBPCC	$X_{E1} = 0$ $X_{E2} = 30$	$Y_{E1} = 0$ $Y_{E2} = 24$	$Z_E = 0$

Note: all values (± 1 mm)

and 7.3.1.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.3.2 Case # 2 - Houdek Applicator Case

Case # 2 represents a two catheter case for treatment of the cervix. The Houdek applicator is utilized with a dose prescription of 500 cGy at 5.0 mm distance into tissue. Orthogonal films are utilized for patient and applicator reconstruction. The distance from dwell position one in the tandem to the surface of the cap is 10.0 mm and the distance from the ring dwell positions to the surface of the cap is 8.0 mm. In order to prescribe to 5.0 mm into the tissue of the cervix, dose points are placed at a distance of 15.0 mm from dwell position one in the tandem and 13.0 mm from the ring dwell positions. The dose is normalized on dose points oriented to the catheter and the dose is optimized on distance on these points. The resulting isodose distributions generated with each treatment planning system are presented in Figures 7.3.2.1 through 7.3.2.9. Tables 7.3.2.1 and 7.3.2.2 represent the comparison of the isodose distributions for case # 2.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System, Nucletron Planning System, Capintec, Theraplan, and MBPCC spreadsheet treatment planning systems for Case # 2 (Houdek Applicator Case) show an excellent agreement between all five treatment planning systems. When each isodose distribution was overlaid with the PLATO - Brachytherapy Planning System, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.3.2.1

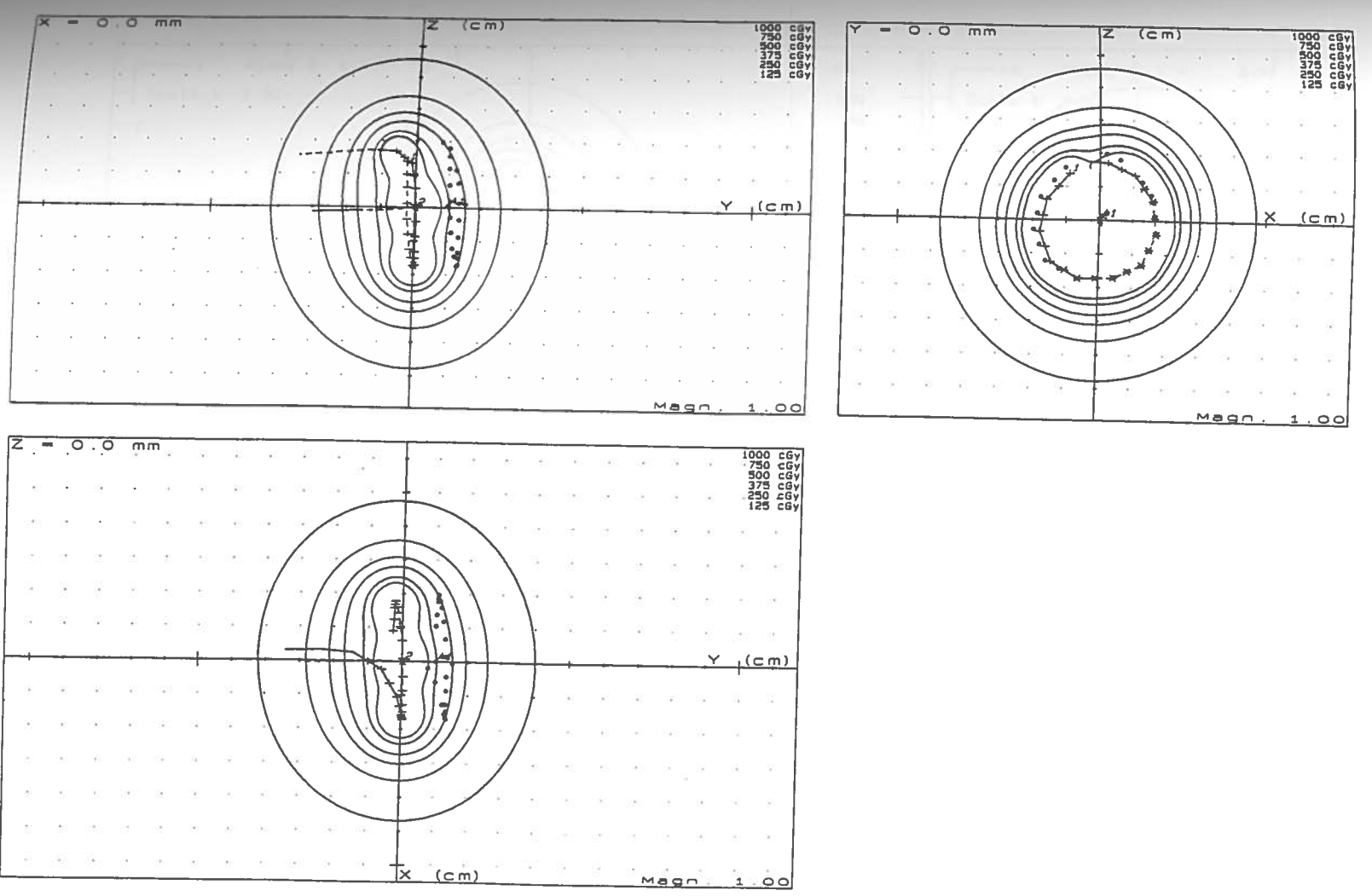


Figure 7.3.2.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 2- Sagittal, Transverse, and Coronal Planes (Houdek Applicator Case)

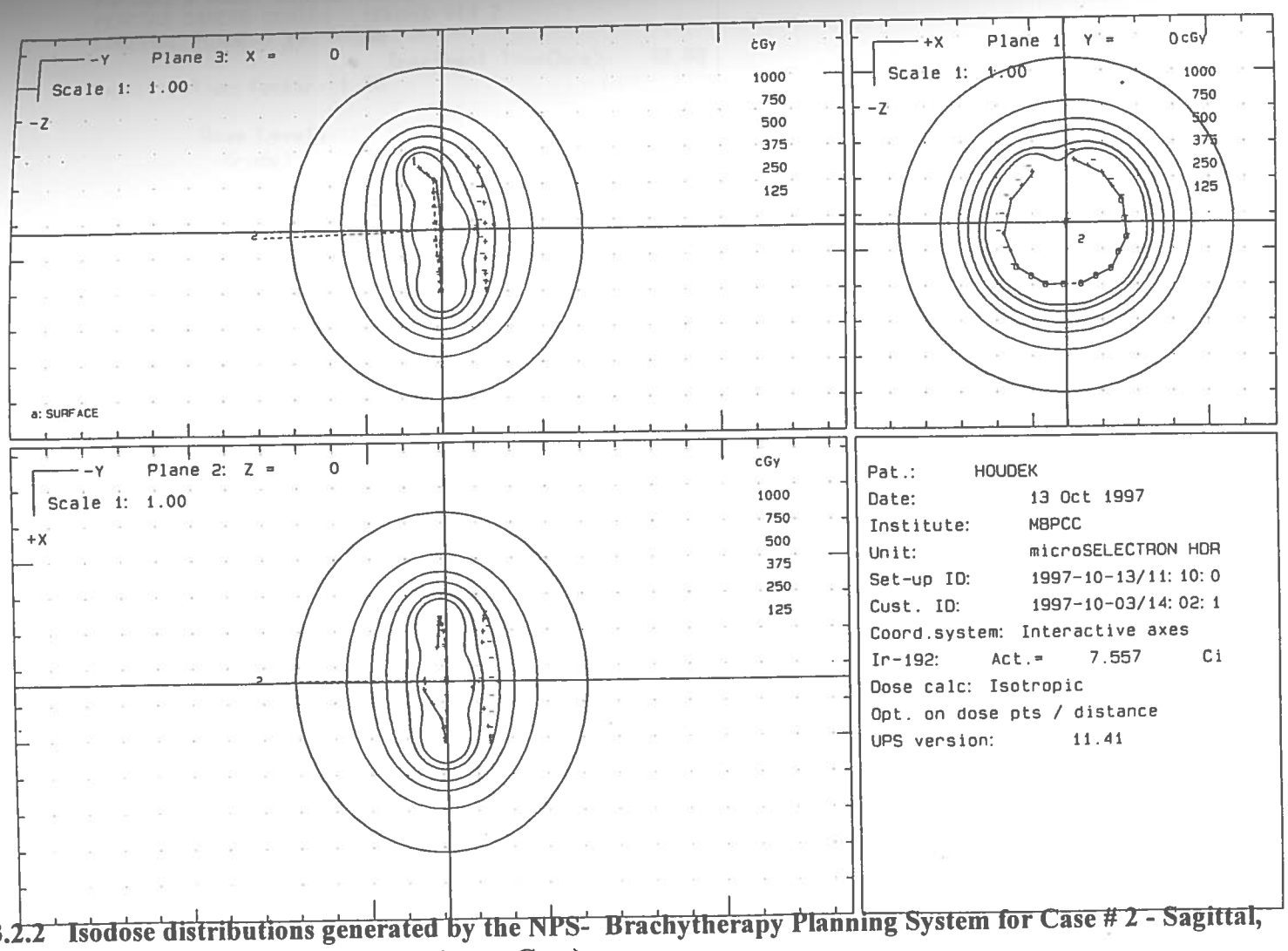


Figure 7.3.2.2 Isodose distributions generated by the NPS- Brachytherapy Planning System for Case # 2 - Sagittal, Transverse, and Coronal Planes (Houdek Applicator Case)

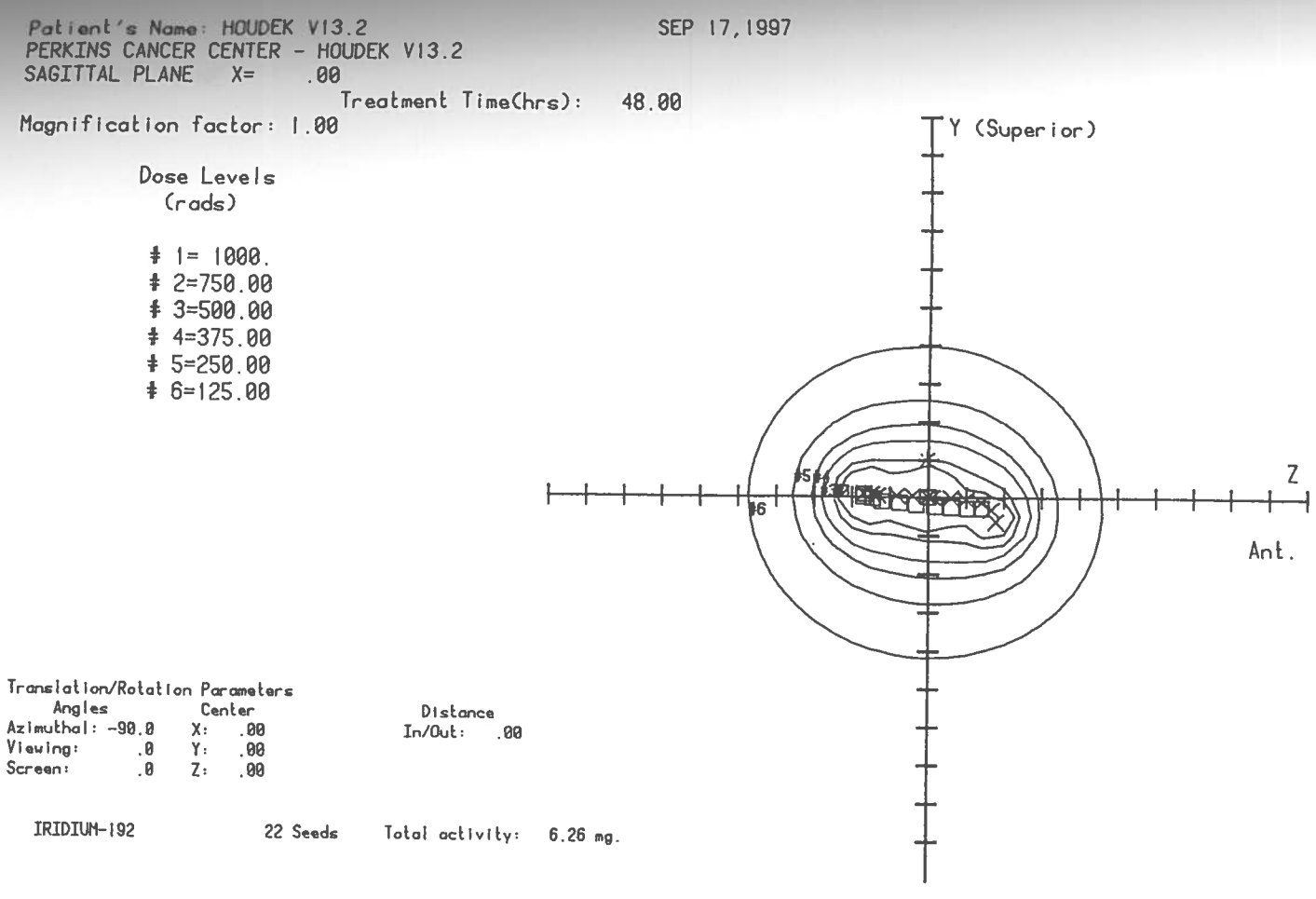


Figure 7.3.2.3 Isodose distributions generated by the Capintec Treatment Planning System for Case # 2 - Sagittal Plane (Houdek Applicator Case)

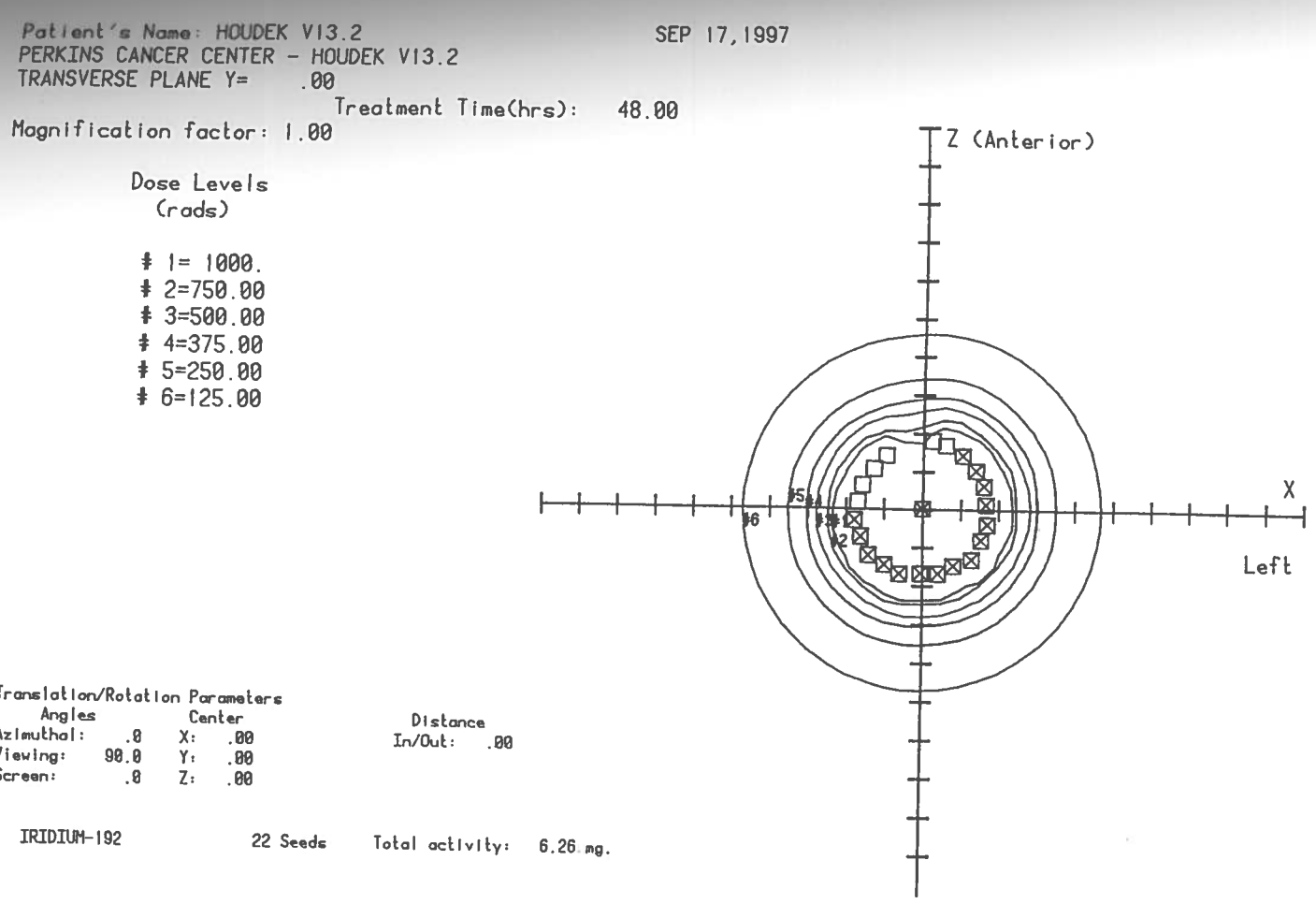


Figure 7.3.2.4 Isodose distributions generated by the CapintecTreatment Planning System for Case # 2 - Transverse Plane (Houdek Applicator Case)

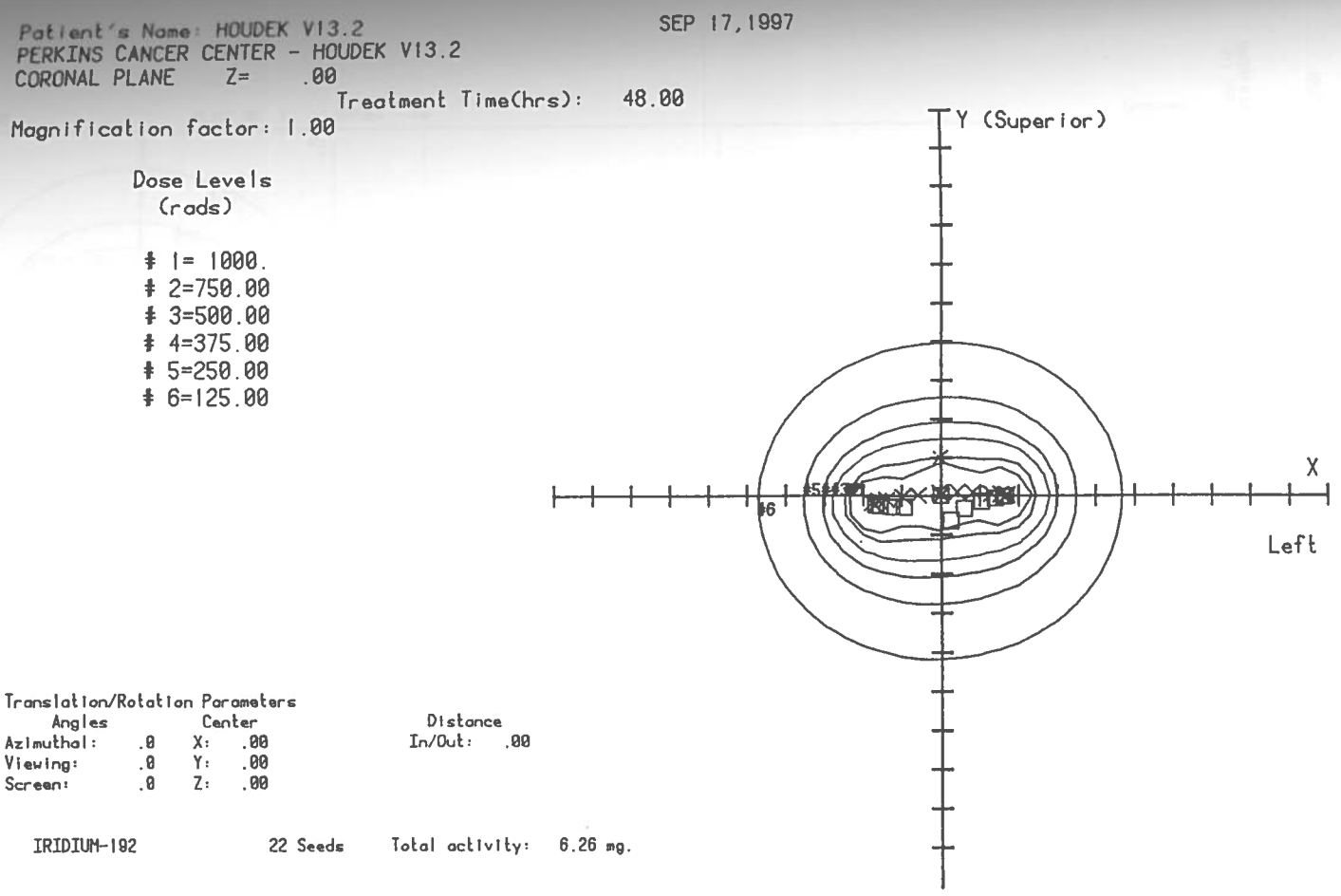


Figure 7.3.2.5 Isodose distributions generated by the Capintec Treatment Planning System for Case # 2 - Coronal Plane (Houdek Applicator Case)

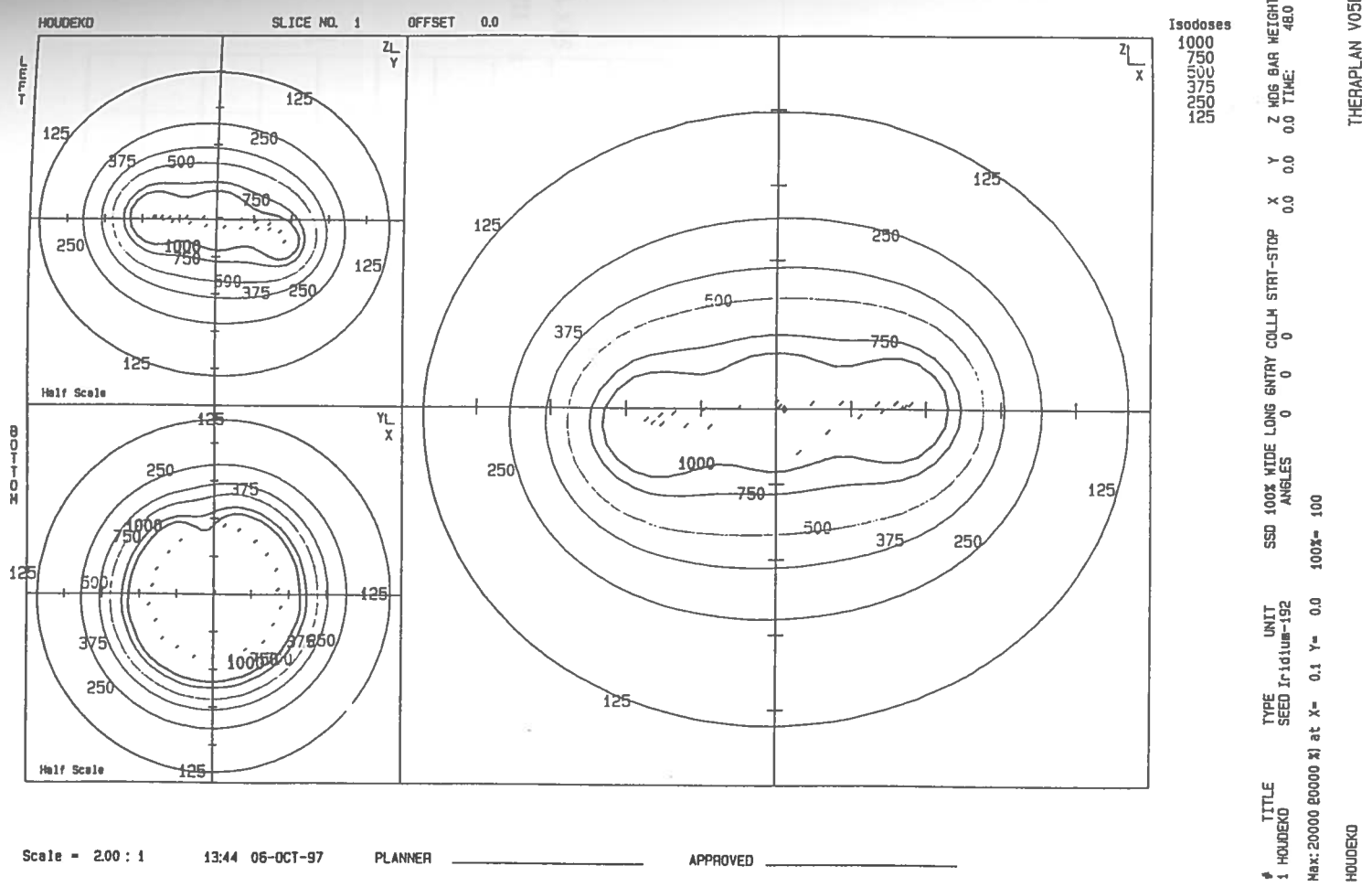


Figure 7.3.2.6 Isodose distributions generated by the Theraplan Treatment Planning System for Case # 2 - Sagittal, Transverse, and Coronal Planes (Houdek Applicator Case)

Ir-192 HDR
Sagittal Plane
Isodose Curves

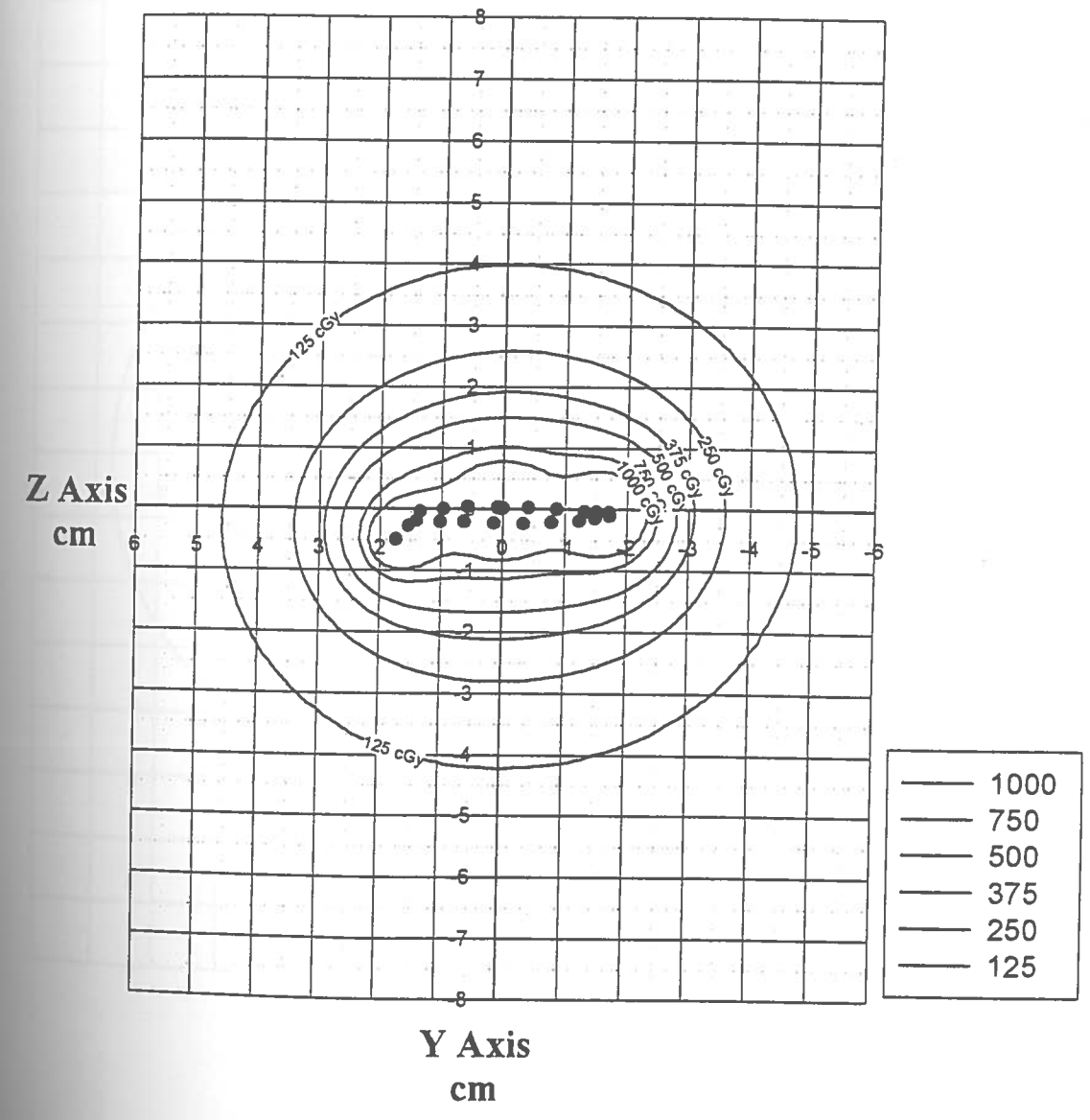


Figure 7.3.2.7 Isodose distributions generated by the MBPCC Spreadsheet Program for Case # 2 - Sagittal Plane (Houdek Applicator Case)

Ir-192 HDR
Transverse Plane
Isodose Curves

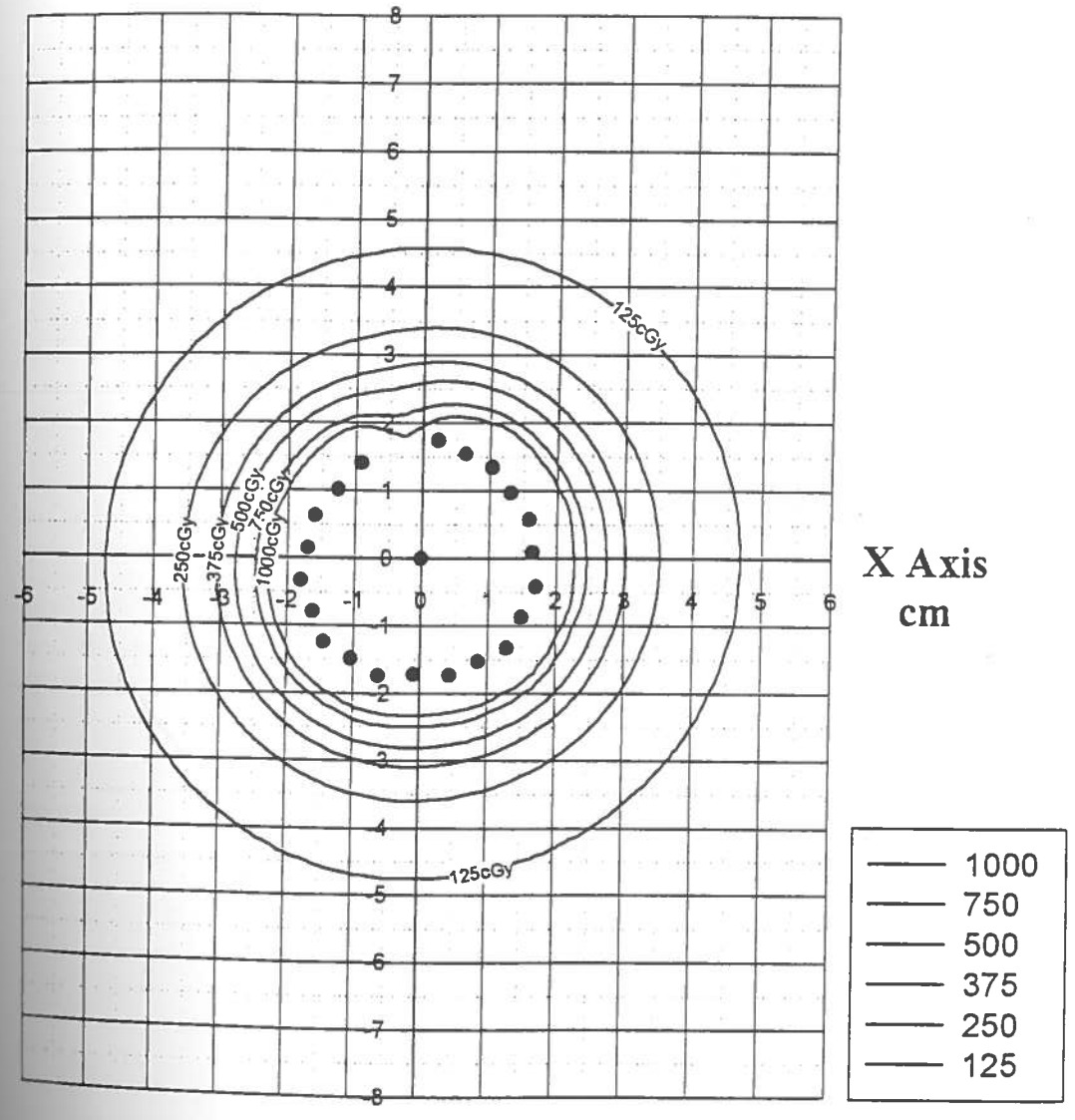


Figure 7.3.2.8 Isodose distributions generated by the MBPCC Spreadsheet Program for Case # 2 - Transverse Plane (Houdek Applicator Case)

Ir-192 HDR
Coronal Plane
Isodose Curves

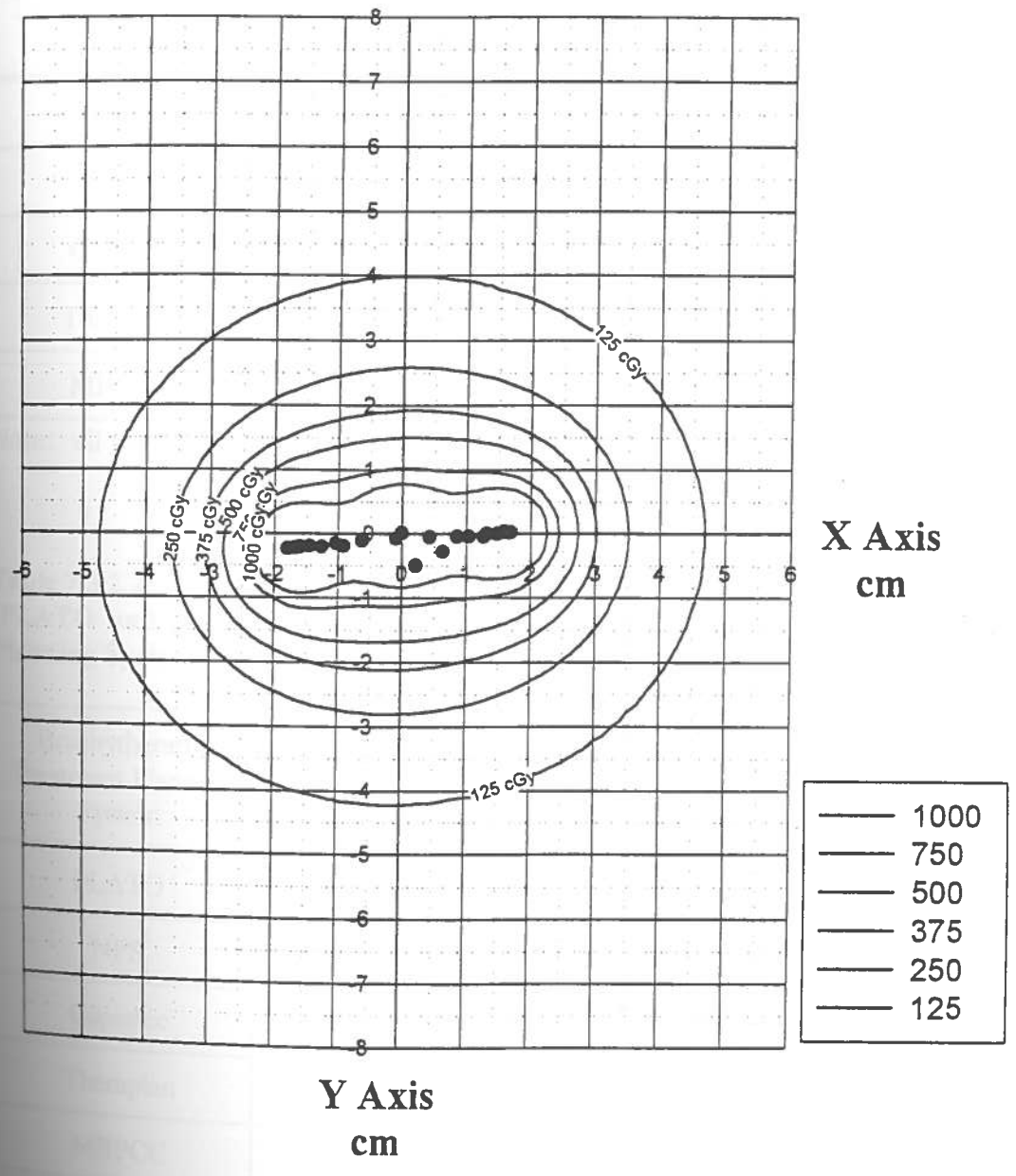


Figure 7.3.2.9 Isodose distributions generated by the MBPCC Spreadsheet Program for Case # 2 - Coronal Plane (Houdek Applicator Case)

Table 7.3.2.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS), Capintec, Theraplan, and MBPCC Spreadsheet Treatment Planning Systems for Case # 2 (Houdek Applicator Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 28$	$Y_P = 15$	$Z_P = 26$
NPS	$X_N = 28$	$Y_N = 15$	$Z_N = 26$
Capintec	$X_C = 28$	$Y_C = 15$	$Z_C = 26$
Theraplan	$X_T = 28$	$Y_T = 15$	$Z_T = 26$
MBPCC	$X_E = 28$	$Y_E = 15$	$Z_E = 26$

Note: all values (± 1 mm)

Table 7.3.2.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS), Capintec, Theraplan, and MBPCC Spreadsheet Treatment Planning Systems for Case # 2 (Houdek Applicator Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 28$	$Y_P = 17$	$Z_P = 28$
NPS	$X_N = 28$	$Y_N = 17$	$Z_N = 28$
Capintec	$X_C = 28$	$Y_C = 17$	$Z_C = 28$
Theraplan	$X_T = 28$	$Y_T = 17$	$Z_T = 28$
MBPCC	$X_E = 28$	$Y_E = 17$	$Z_E = 28$

Note: all values (± 1 mm)

and 7.3.2.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.4 Intercomparison of Brachytherapy Treatment Plans Performed with the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Clinical Case Treatment Plans

Four treatment plan cases previously performed at MBPCC are presented in sections 7.4.1 through 7.4.4. These cases are performed with the PLATO and NPS Brachytherapy Planning Systems and their results are presented in the figures and tables in each section.

7.4.1 Case # 3 - One Catheter Esophageal Case

Case # 3 represents a one catheter esophageal case with a dose prescription of 500 cGy at 7.5 mm distance along the length of the catheter. Orthogonal films are utilized for patient and applicator reconstruction. The dose is normalized on dose points oriented to the catheter with dose point optimization on distance. The resulting isodose distributions are presented in Figures 7.4.1.1 and 7.4.1.2. Tables 7.4.1.1 and 7.4.1.2 represent the comparison of the PLATO and NPS Brachytherapy Planning System isodose distributions for case # 3.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 3 (One Catheter Esophageal Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.4.1.1

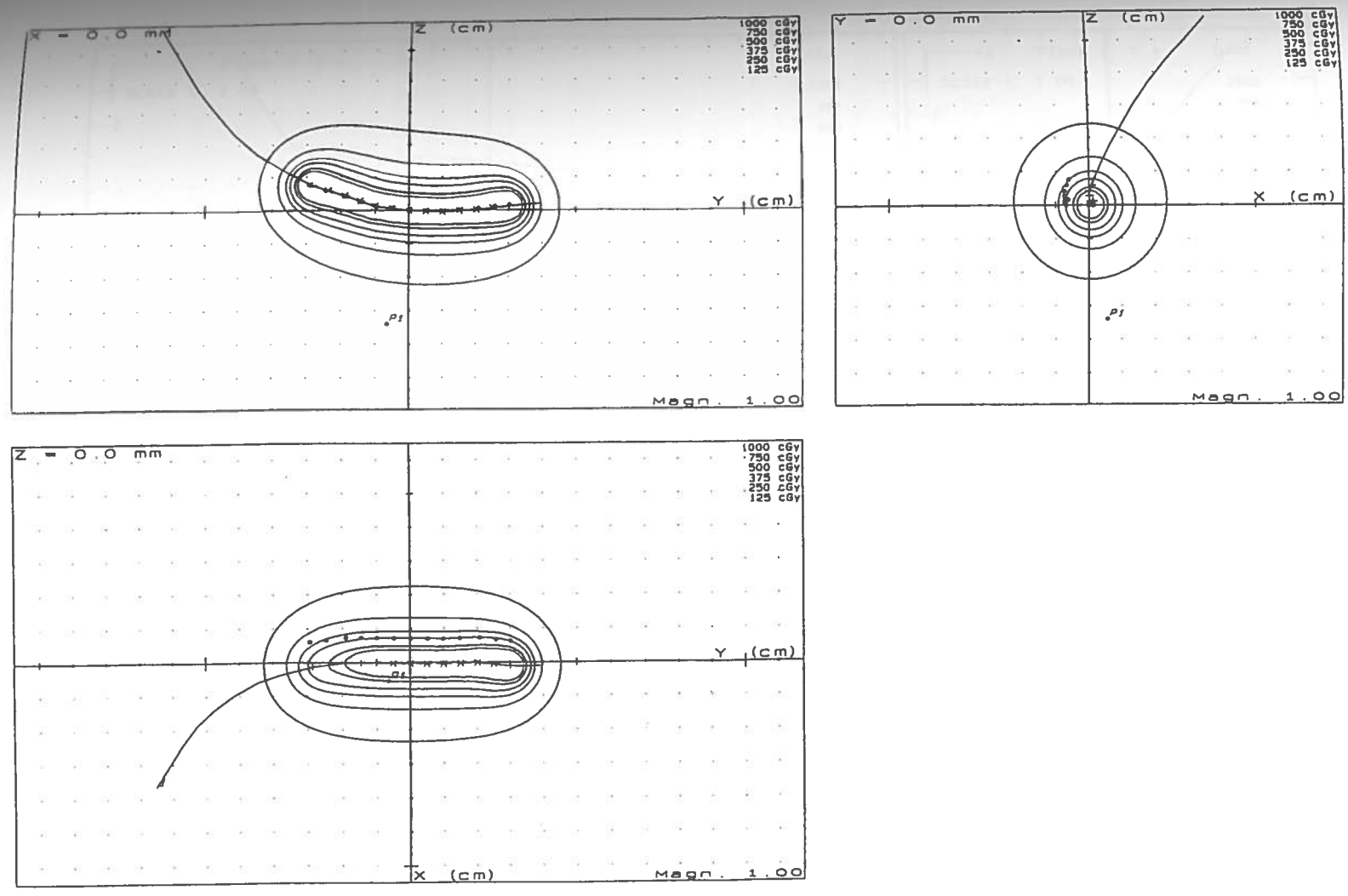


Figure 7.4.1.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 3 - Sagittal, Transverse, and Coronal Planes (One Catheter Esophageal Case)

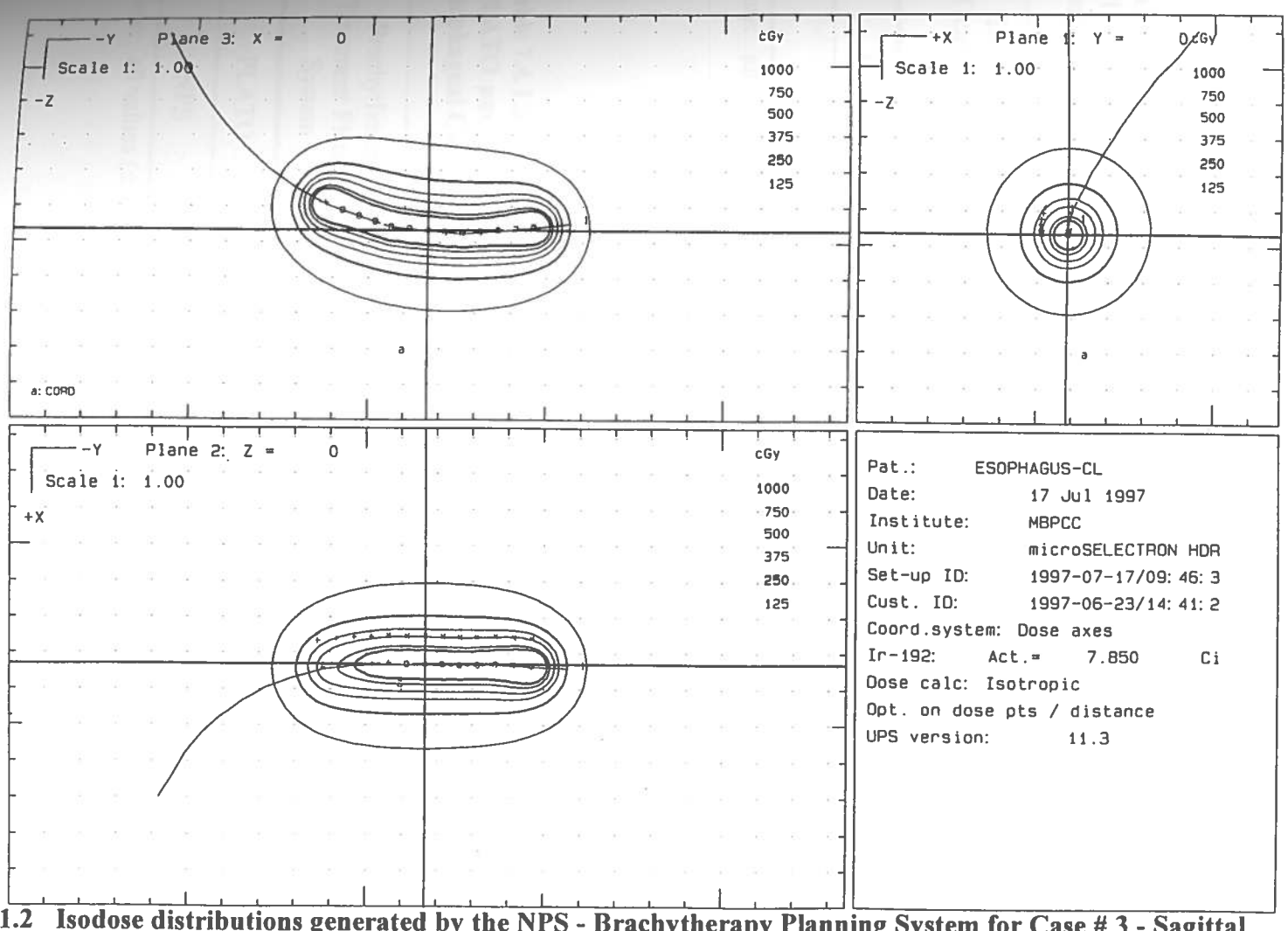


Figure 7.4.1.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 3 - Sagittal, Transverse, and Coronal Planes (One Catheter Esophageal Case)

Table 7.4.1.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 3 (One Catheter Esophageal Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 8$	$Y_P = 36$	$Z_P = 8$
NPS	$X_N = 8$	$Y_N = 36$	$Z_N = 8$

Note: all values (± 1 mm)

Table 7.4.1.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 3 (One Catheter Esophageal Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 7$	$Y_P = 30$	$Z_P = 7$
NPS	$X_N = 7$	$Y_N = 30$	$Z_N = 7$

Note: all values (± 1 mm)

and 7.4.1.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.4.2 Case # 4 - One Catheter Endobronchial Case

Case # 4 represents a one catheter endobronchial case with a dose prescription of 500 cGy at 10.0 mm distance along the length of the catheter. Orthogonal films are utilized for patient and applicator reconstruction. The dose is normalized on dose points oriented to the catheter with dose point optimization on distance. The resulting isodose distributions are presented in Figures 7.4.2.1 and 7.4.2.2. Tables 7.4.2.1 and 7.4.2.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 4.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 4 (One Catheter Endobronchial Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.4.2.1 and 7.4.2.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.4.3 Case # 5 - Ring and Tandem Applicator Case

Case # 5 represents a two catheter case for treatment of the cervix and endometrium. A ring and tandem applicator with a 26 mm diameter ring is utilized.

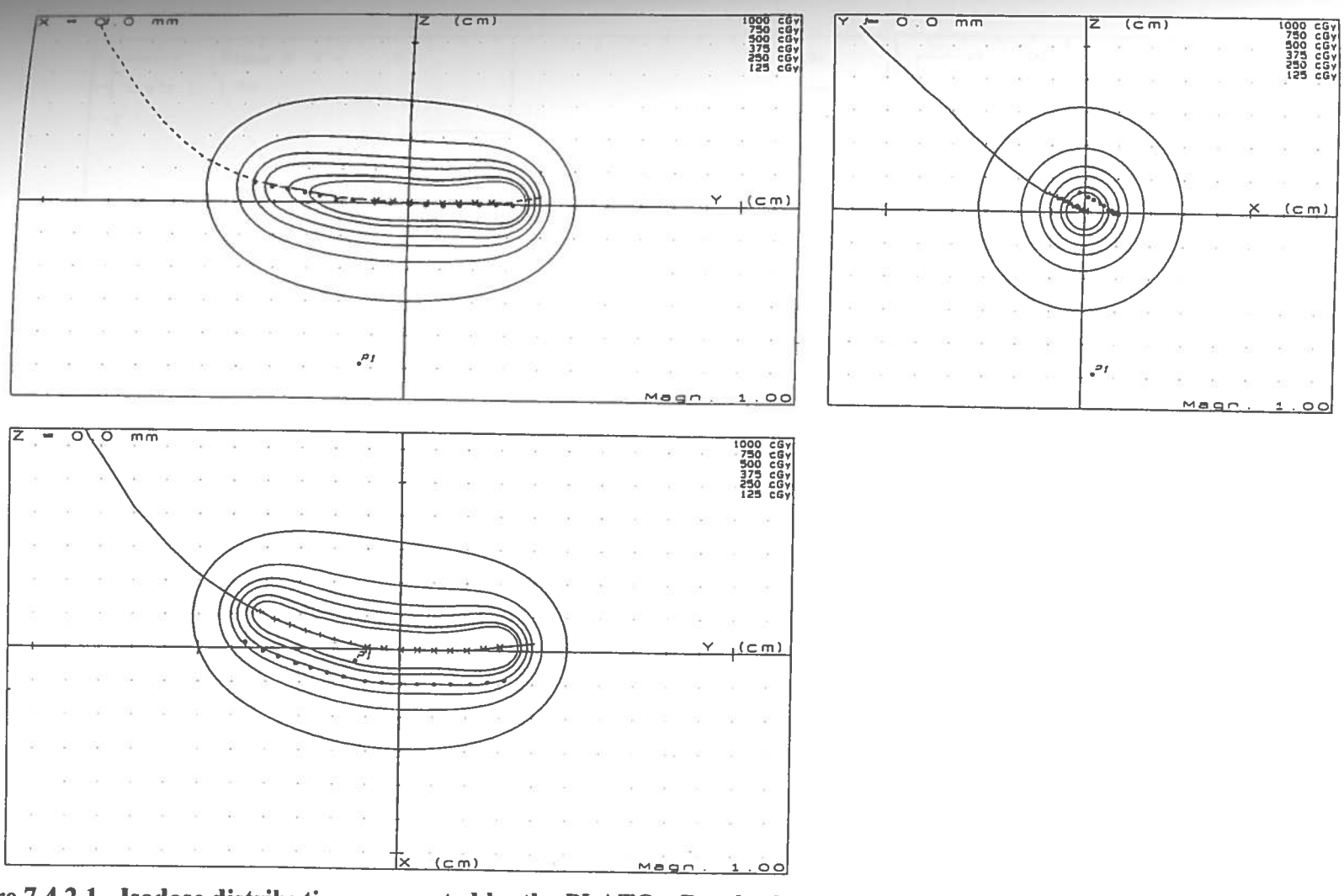


Figure 7.4.2.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 4 - Sagittal, Transverse, and Coronal Planes (One Catheter Endobronchial Case)

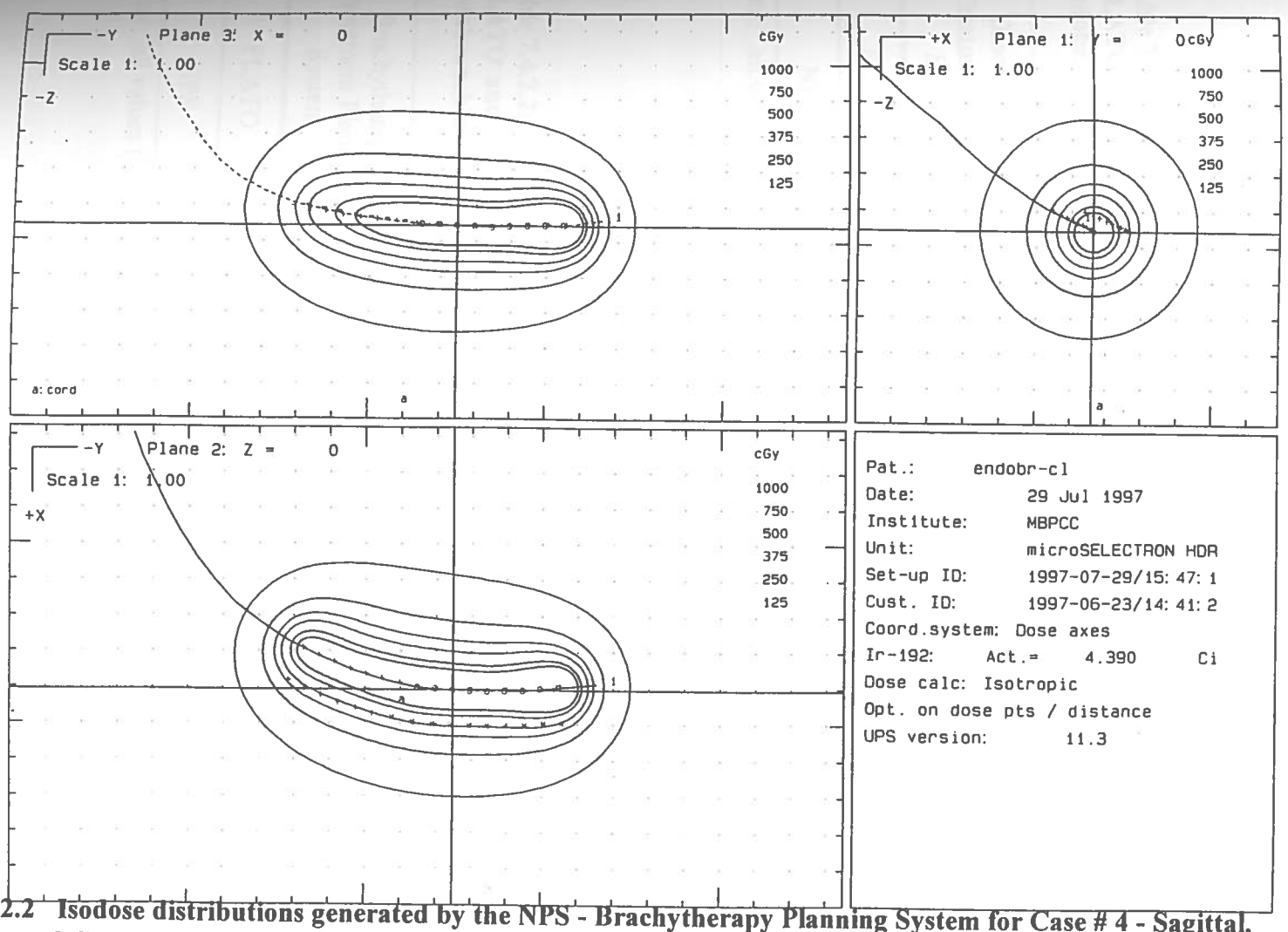


Figure 7.4.2.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 4 - Sagittal, Transverse, and Coronal Planes (One Catheter Endobronchial Case)

Table 7.4.2.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 4 (One Catheter Endobronchial Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 10$	$Y_P = 38$	$Z_P = 11$
NPS	$X_N = 10$	$Y_N = 38$	$Z_N = 11$

Note: all values (± 1 mm)

Table 7.4.2.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 4 (One Catheter Endobronchial Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 11$	$Y_P = 41$	$Z_P = 10$
NPS	$X_N = 11$	$Y_N = 41$	$Z_N = 10$

Note: all values (± 1 mm)

Orthogonal and variable angle films are utilized for patient and applicator reconstruction respectively. The catheters are weighted 1.0 to 1.0 for the ring and tandem dwell positions respectively. A dose prescription of 600 cGy is prescribed and normalized to two applicator points, right A and left A (Rt. A and Lt. A). The dose distribution is not optimized. Rt. A and Lt. A are defined relative to the origin of the applicator coordinate system, by measuring 2.5 cm superior to the collar of the tandem and 2.0 cm right and left laterally. This takes into account the 0.5 cm distance for the cap on the applicator. The duration of an implant is based on the dose rate calculated at points A, although the dose at the other points is taken into consideration in evaluating a treatment plan. Patient points are marked for the bladder and rectum as well as the lymph node areas of interest using Fletcher's Lymphatic Trapezoid. See Appendix A for diagrams and detailed descriptions of how to construct Fletcher's Lymphatic Trapezoid as well as how to locate points for organs at risk and point As and Bs.

The resulting isodose distributions for case # 5 are presented in Figures 7.4.3.1 and 7.4.3.2. Tables 7.4.3.1 and 7.4.3.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 5.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 5 (Ring and Tandem Applicator Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.4.3.1

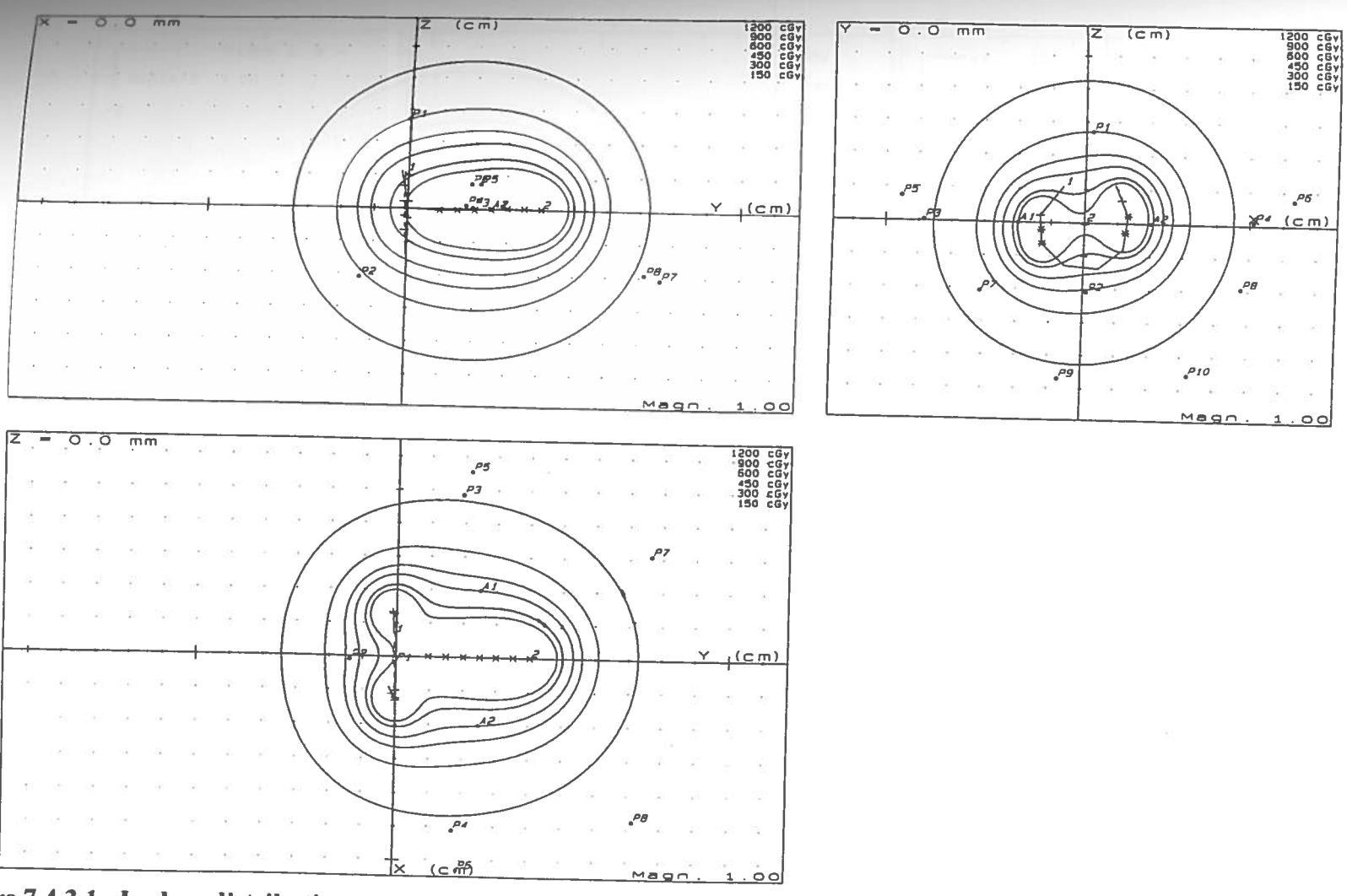


Figure 7.4.3.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 5 - Sagittal, Transverse, and Coronal Planes (Ring and Tandem Applicator Case)

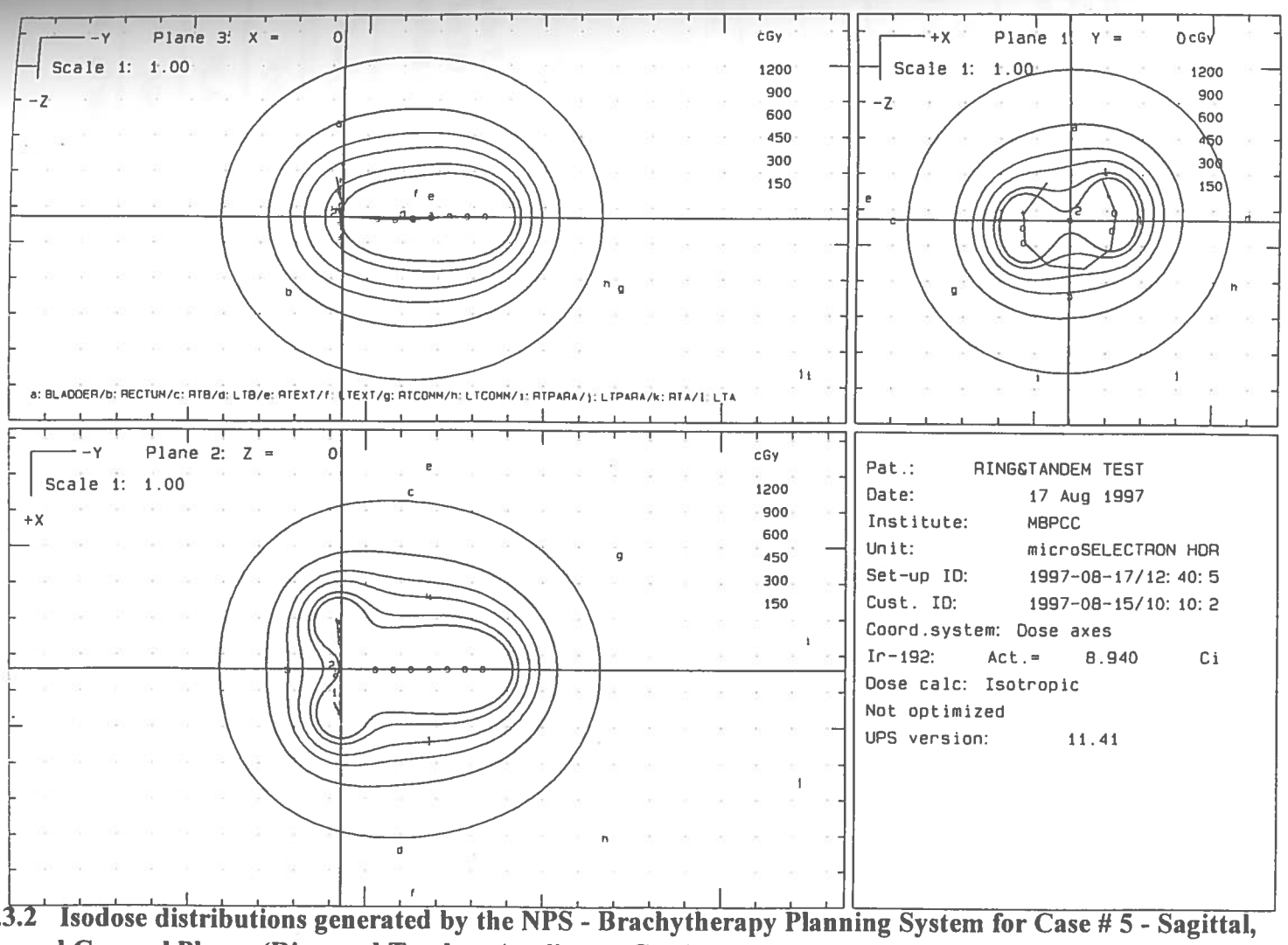


Figure 7.4.3.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 5 - Sagittal, Transverse, and Coronal Planes (Ring and Tandem Applicator Case)

Table 7.4.3.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 5 (Ring and Tandem Applicator Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 24$	$Y_P = 53$	$Z_P = 15$
NPS	$X_N = 24$	$Y_N = 53$	$Z_N = 15$

Note: all values (± 1 mm)

Table 7.4.3.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 5 (Ring and Tandem Applicator Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 25$	$Y_P = 11$	$Z_P = 16$
NPS	$X_N = 25$	$Y_N = 11$	$Z_N = 16$

Note: all values (± 1 mm)

and 7.4.3.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.4.4 Case # 6 - Tandem and Cylinder Applicator Case

Case # 6 represents a one catheter case for treatment of the cervix and vaginal wall. Cylinders, 2.5 cm in diameter, along with a intra-uterine tandem applicator are utilized to obtain a dose prescription of 600 cGy at 5.0 mm distance into tissue from the cylinder and the dome surface. Semi-orthogonal films are utilized for patient and applicator reconstruction. Dose points are placed at a distance of 17.5 mm along the tandem applicator. The dose is normalized on the dose points oriented to the catheter with dose point optimization on distance. The resulting isodose distributions are presented in Figures 7.4.4.1 and 7.4.4.2. Tables 7.4.4.1 and 7.4.4.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 6.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 6 (Cylinder and Tandem Applicator Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.4.4.1 and 7.4.4.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

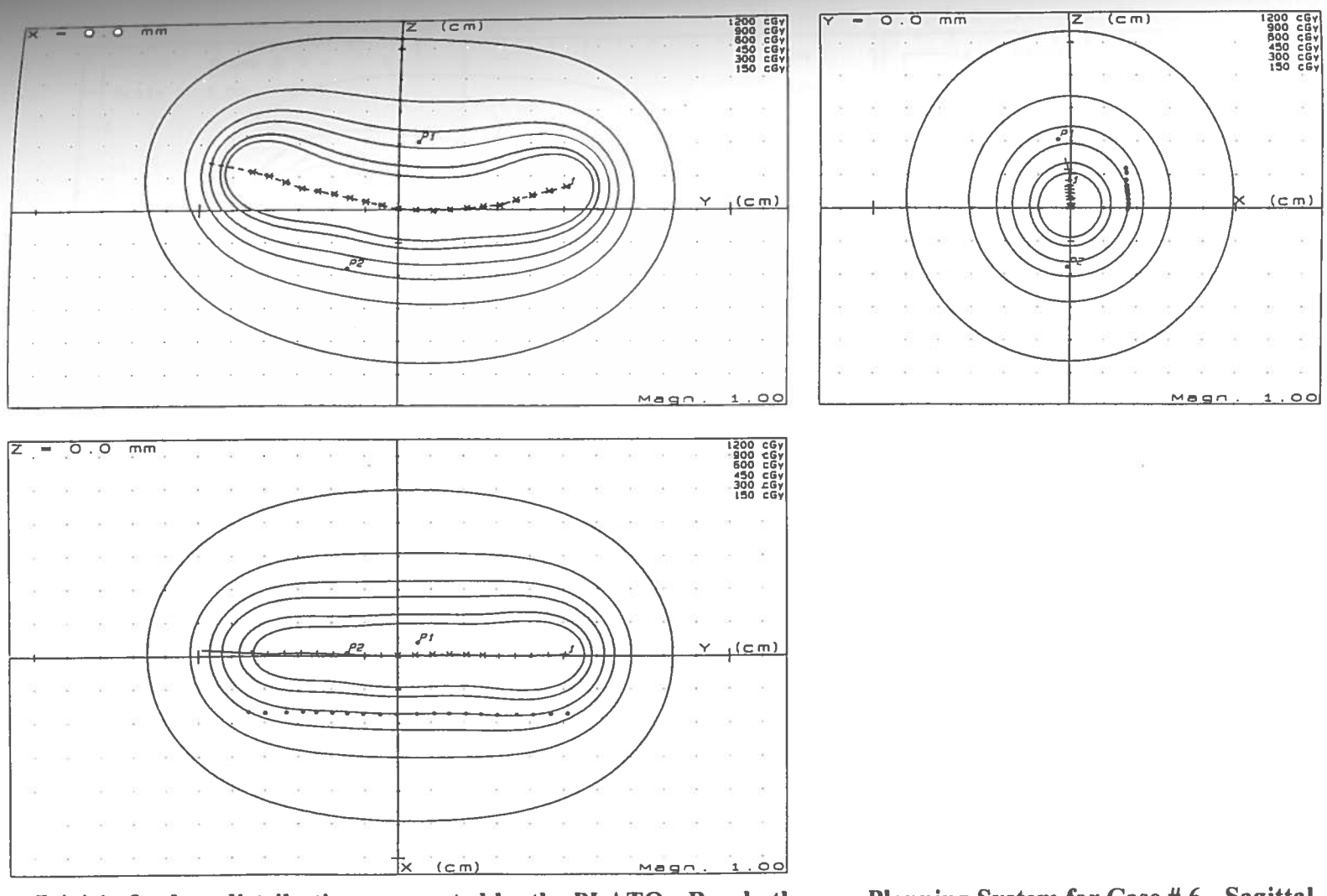


Figure 7.4.4.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 6 - Sagittal, Transverse, and Coronal Planes (Tandem and Cylinder Applicator Case)

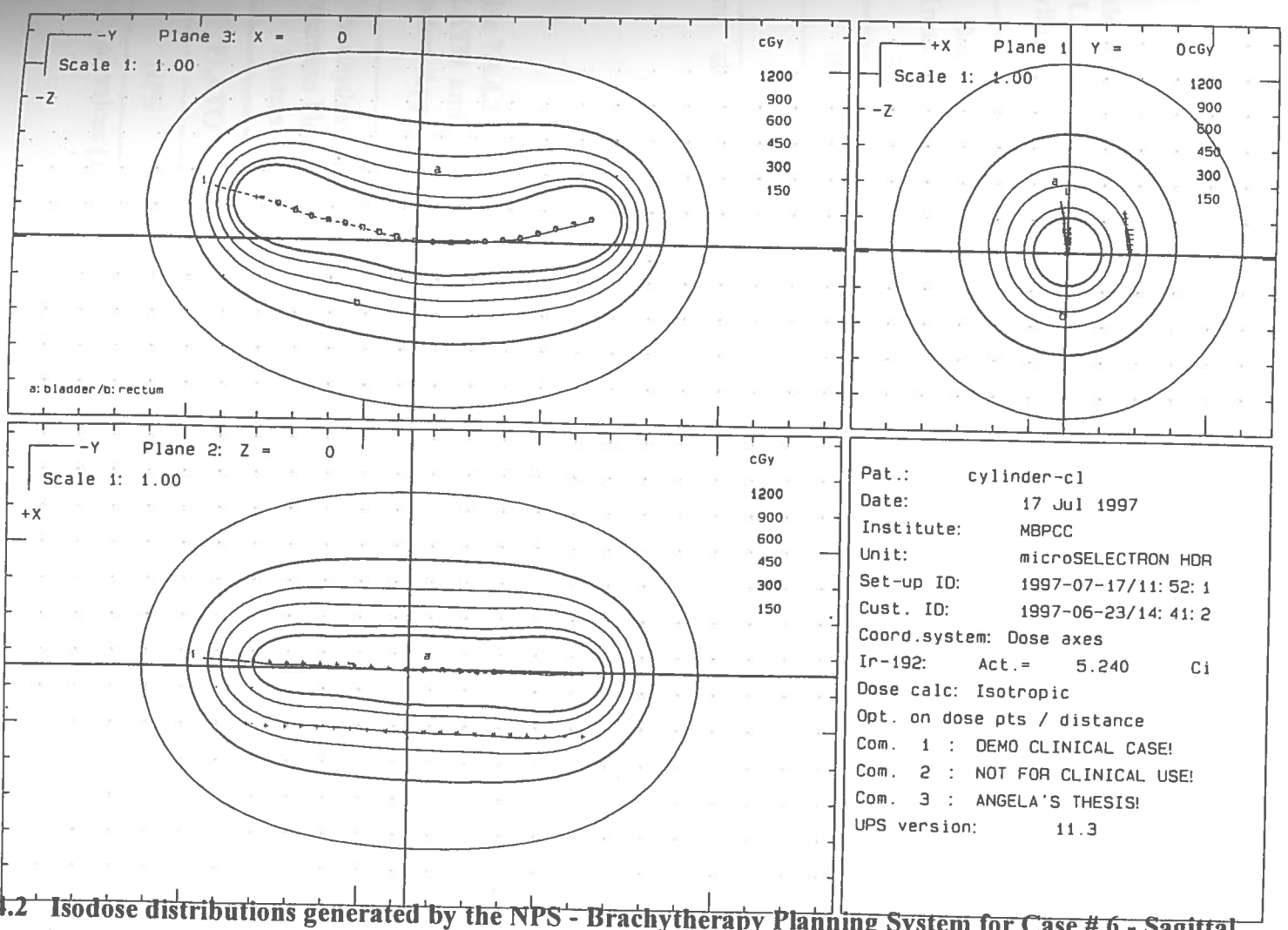


Figure 7.4.4.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 6 - Sagittal, Transverse, and Coronal Planes (Tandem and Cylinder Applicator Case)

Table 7.4.4.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 6 (Tandem and Cylinder Applicator Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 17$	$Y_P = 62$	$Z_P = 19$
NPS	$X_N = 17$	$Y_N = 61$	$Z_N = 19$

Note: all values (± 1 mm)

Table 7.4.4.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 6 (Cylinder and Tandem Applicator Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 18$	$Y_P = 53$	$Z_P = 16$
NPS	$X_N = 18$	$Y_N = 53$	$Z_N = 16$

Note: all values (± 1 mm)

7.5 Intercomparison of Brachytherapy Treatment Plans Performed with the Nucletron (PLATO and NPS) Treatment Planning Systems for Nucletron Supplied Treatment Plans

Seven treatment plan cases provided by the Nucletron Corporation in the instruction manuals are presented in sections 7.5.1 through 7.5.7. These cases are performed with the PLATO and NPS Brachytherapy Planning Systems and their results are presented in the figures and tables in each section.

7.5.1 Case # 7 - One Catheter Esophageal Case

Case # 7 represents a one catheter esophageal case for treatment of the distal end of the esophagus with a dose prescription of 500 cGy at 10.0 mm distance along the length of the catheter. Semi-orthogonal films are utilized for patient and applicator reconstruction. The dose is normalized on dose points oriented to the catheter with dose point optimization on distance. The resulting isodose distributions are presented in Figures 7.5.1.1 and 7.5.1.2. Tables 7.5.1.1 and 7.5.1.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 7.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 7 (One Catheter Esophageal Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.5.1.1 and 7.5.1.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

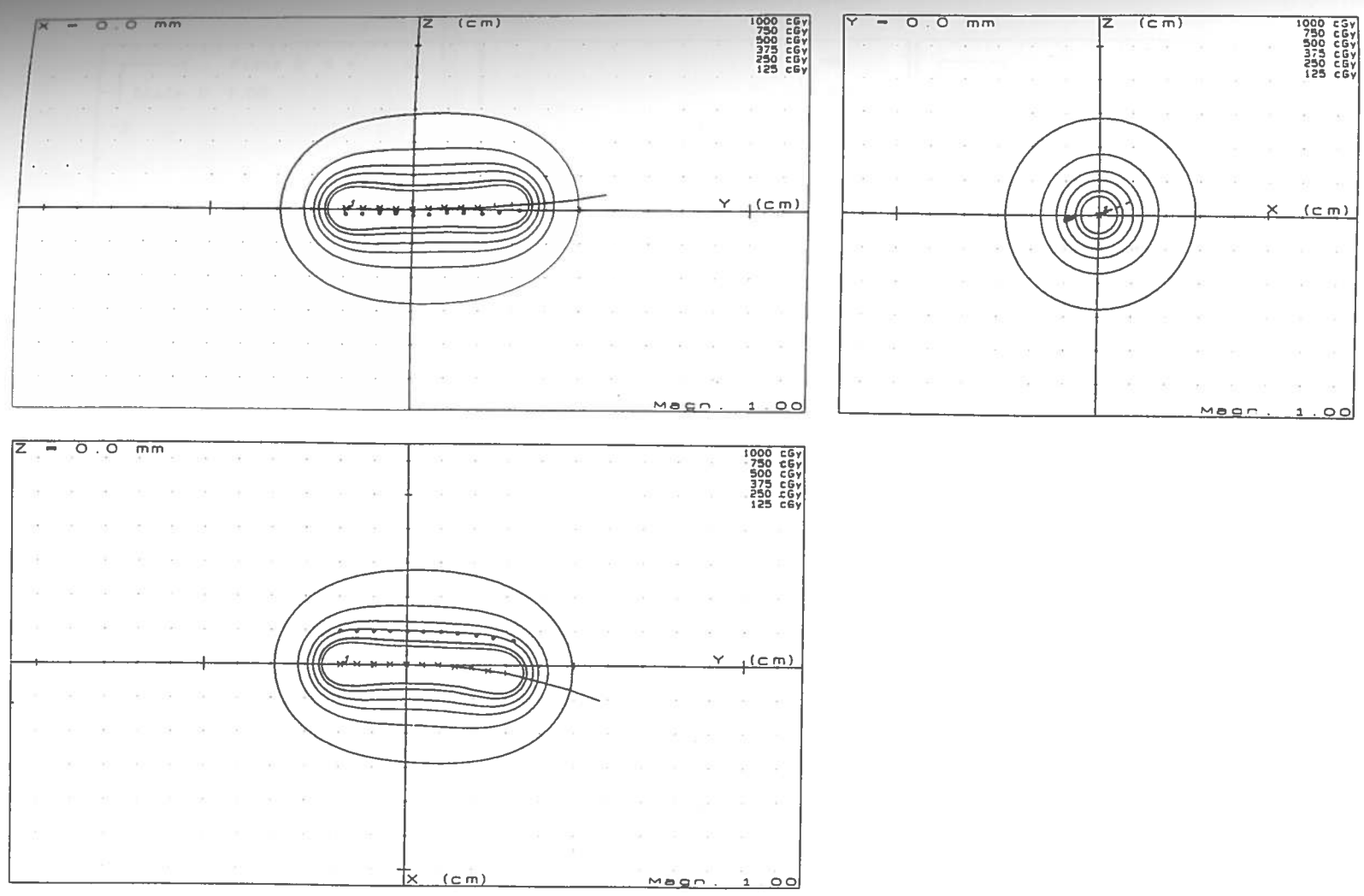


Figure 7.5.1.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 7 - Sagittal, Transverse, and Coronal Planes (One Catheter Esophageal Case)

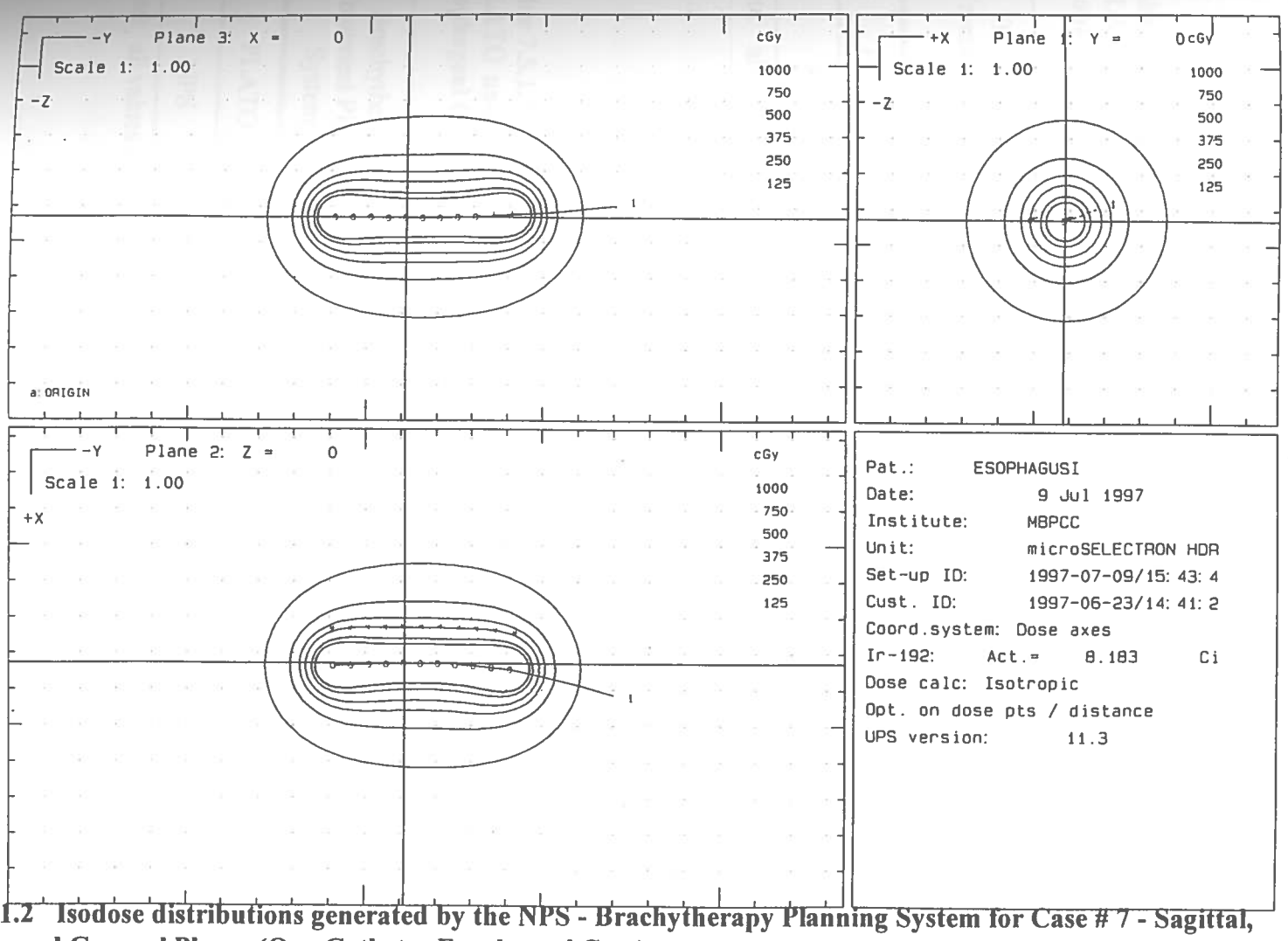


Figure 7.5.1.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 7 - Sagittal, Transverse, and Coronal Planes (One Catheter Esophageal Case)

Table 7.5.1.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Test # 7 (One Catheter Esophageal Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 10$	$Y_P = 38$	$Z_P = 10$
NPS	$X_N = 10$	$Y_N = 38$	$Z_N = 10$

Note: all values (± 1 mm)

Table 7.5.1.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Test # 7 (One Catheter Esophageal Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 10$	$Y_P = 28$	$Z_P = 10$
NPS	$X_N = 10$	$Y_N = 28$	$Z_N = 10$

Note: all values (± 1 mm)

7.5.2 Case # 8 - Two Catheter Endobronchial Case

Case # 8 represents a two catheter endobronchial case with a dose prescription of 500 cGy at 10.0 mm along the lengths of the two catheters. Variable angle films are utilized for patient and applicator reconstruction. The dose is normalized on dose points oriented to the catheters with dose point optimization on distance. The resulting isodose distributions are presented in Figures 7.5.2.1 and 7.5.2.2. Tables 7.5.2.1 and 7.5.2.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 8.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 8 (Two Catheter Endobronchial Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ±_Z) are shown in Tables 7.5.2.1 and 7.5.2.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.5.3 Case # 9 - Two Catheter Endobronchial Case

Case # 9 represents a two catheter endobronchial case with a dose prescription of 500 cGy at 10.0 mm distance along the lengths of the two catheters. Semi-orthogonal films are utilized for patient and applicator reconstruction. The dose is normalized on dose points oriented to the catheters with dose point optimization on distance. The resulting isodose distributions are presented in Figures 7.5.3.1 and 7.5.3.2.

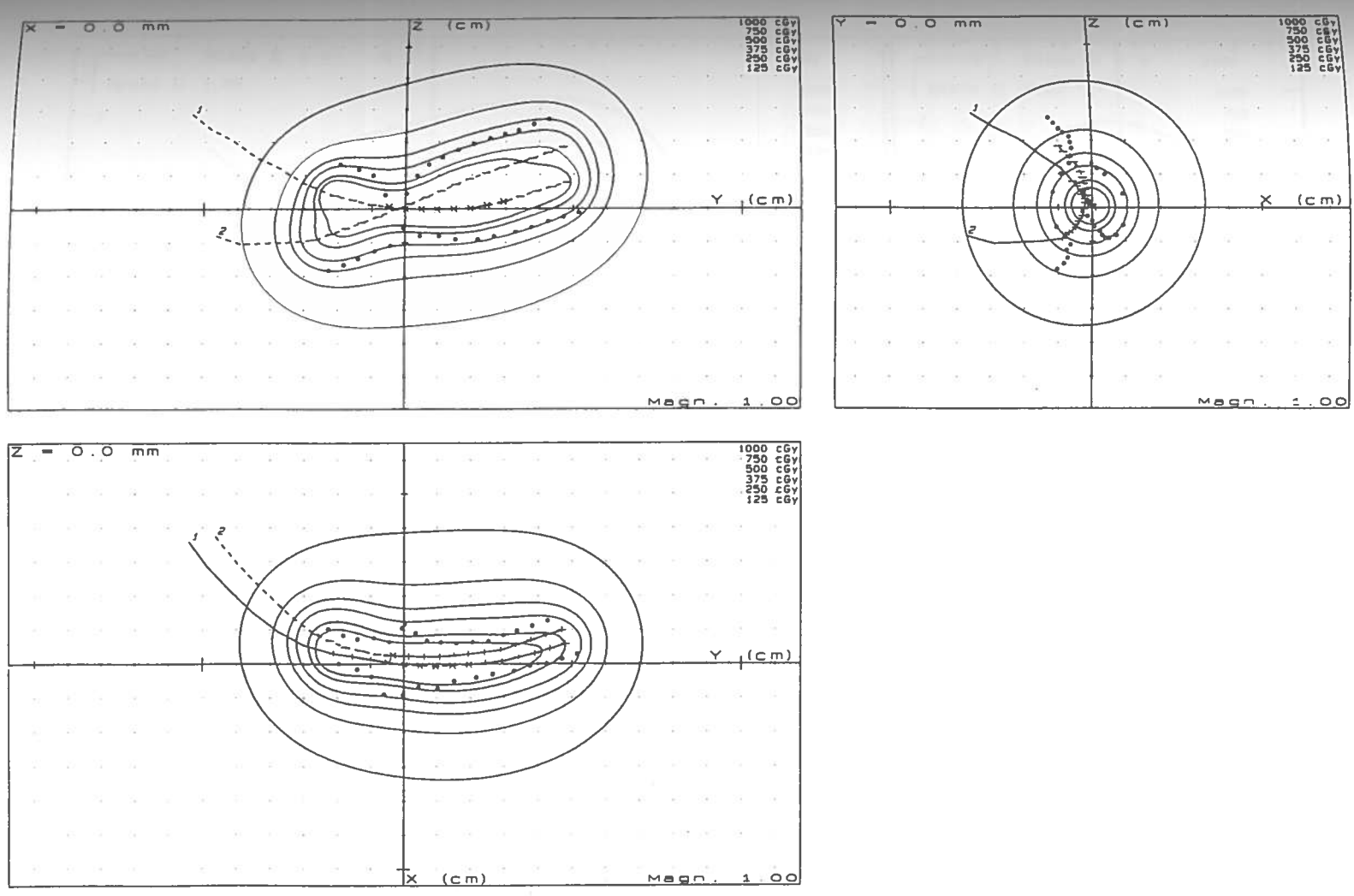


Figure 7.5.2.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 8 - Sagittal, Transverse, and Coronal Planes (Two Catheter Endobronchial Case)

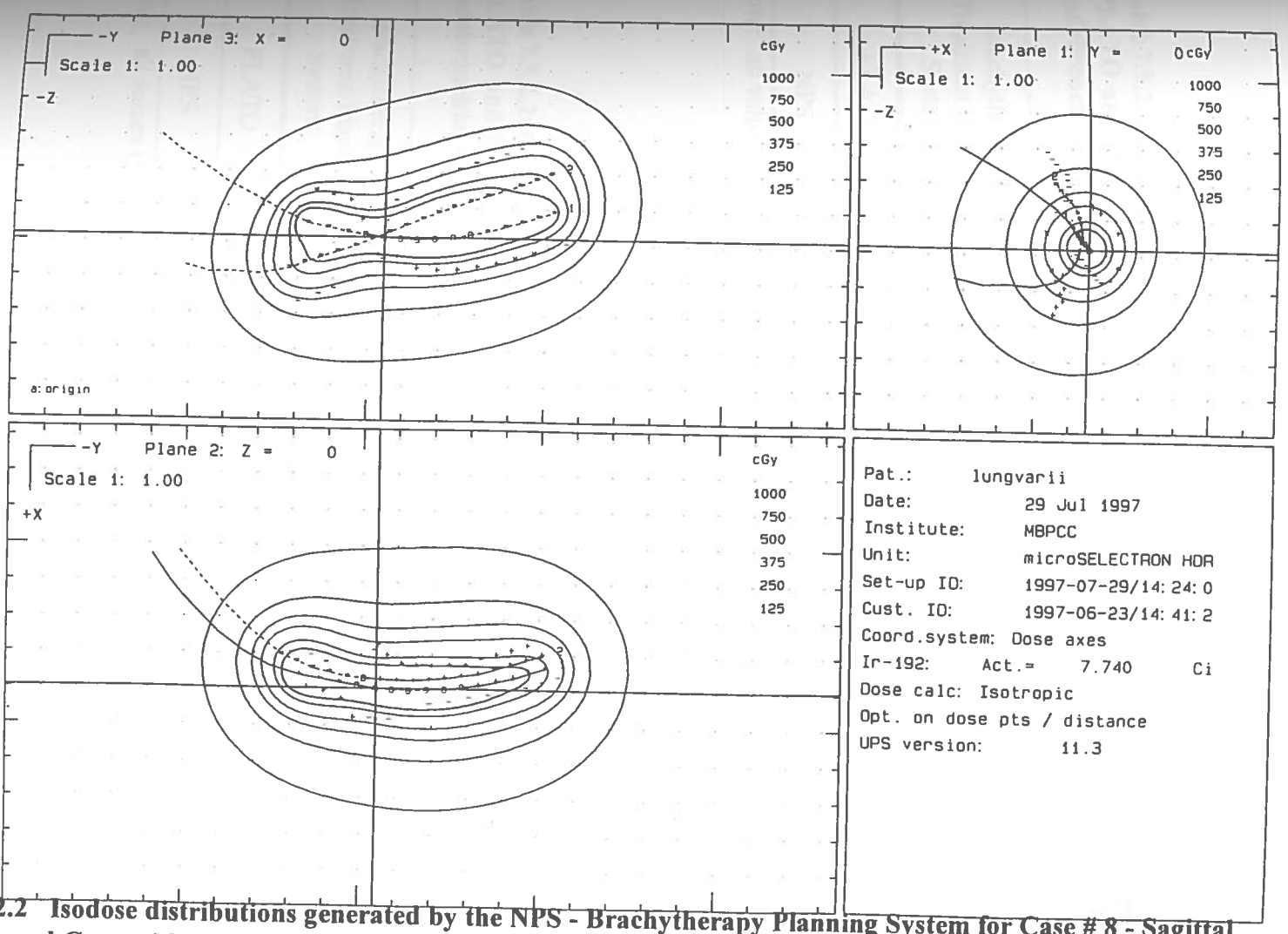


Figure 7.5.2.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 8 - Sagittal, Transverse, and Coronal Planes (Two Catheter Endobronchial Case)

Table 7.5.2.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 8 (Two Catheter Endobronchial Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 10$	$Y_P = 65$	$Z_P = 11$
NPS	$X_N = 10$	$Y_N = 65$	$Z_N = 11$

Note: all values ($\pm$ 1 mm)

Table 7.5.2.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 8 (Two Catheter Endobronchial Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 38$	$Y_P = 28$	$Z_P = 11$
NPS	$X_N = 38$	$Y_N = 28$	$Z_N = 11$

Note: all values ($\pm$ 1 mm)

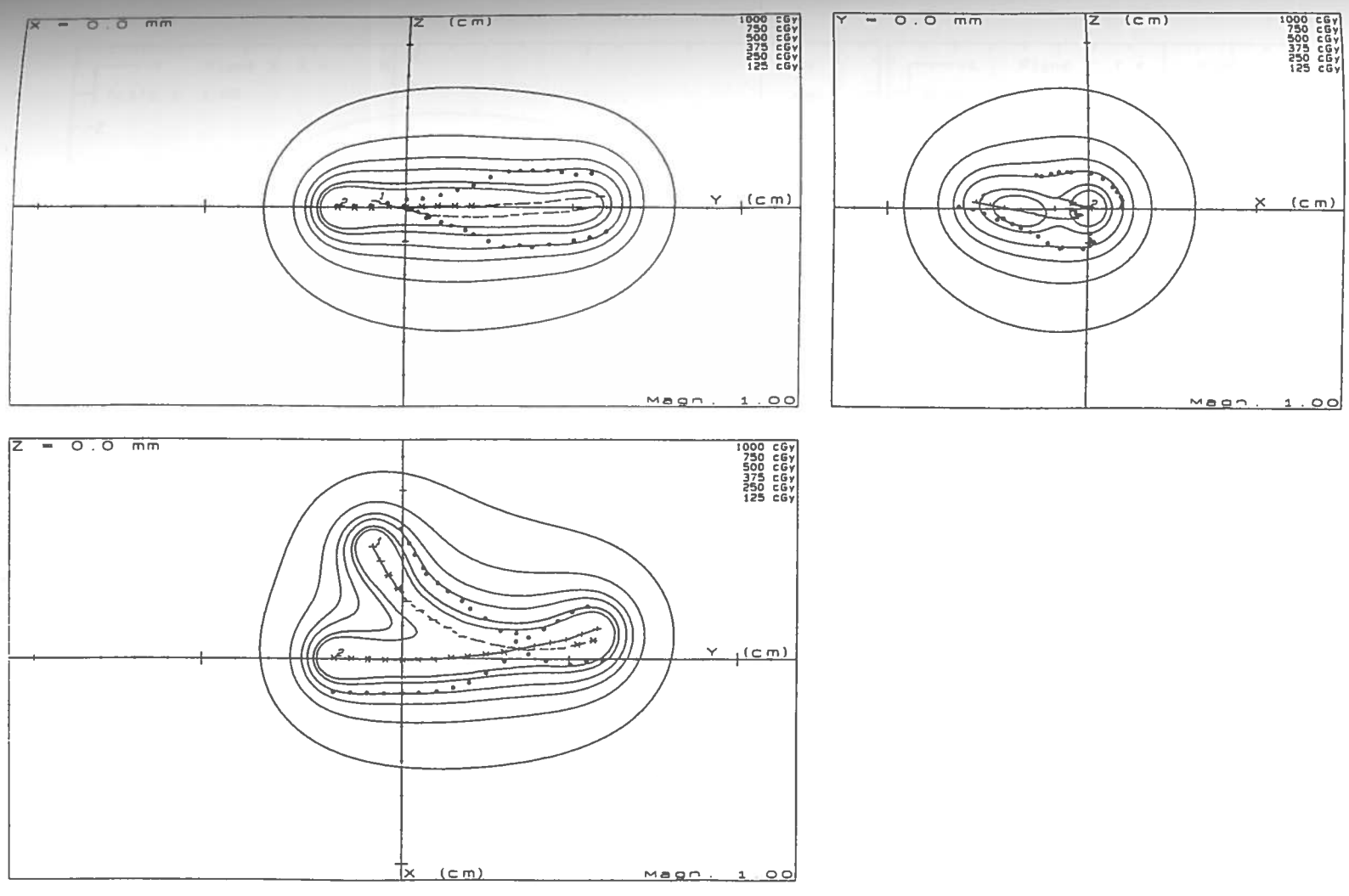


Figure 7.5.3.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 9 - Sagittal, Transverse, and Coronal Planes (Two Catheter Endobronchial Case)

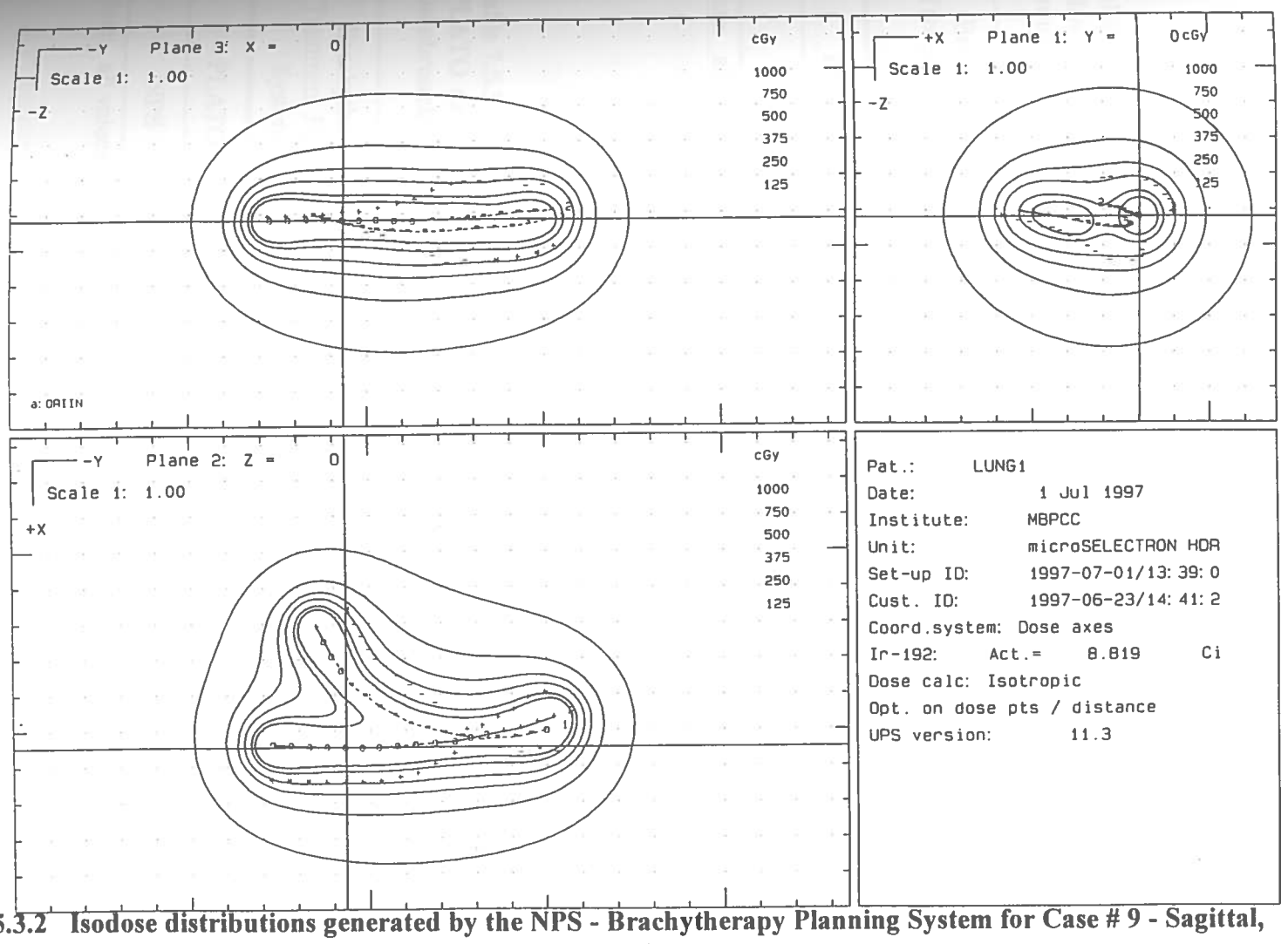


Figure 7.5.3.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 9 - Sagittal, Transverse, and Coronal Planes (Two Catheter Endobronchial Case)

Table 7.5.3.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 9 (Two Catheter Endobronchial Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 10$	$Y_P = 51$	$Z_P = 12$
NPS	$X_N = 10$	$Y_N = 51$	$Z_N = 12$

Note: all values ($\pm$ 1 mm)

Table 7.5.3.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 9 (Two Catheter Endobronchial Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 12$	$Y_P = 31$	$Z_P = 11$
NPS	$X_N = 13$	$Y_N = 31$	$Z_N = 11$

Note: all values ($\pm$ 1 mm)

Tables 7.5.3.1 and 7.5.3.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 9.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 9 (Two Catheter Endobronchial Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.5.3.1 and 7.5.3.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.5.4 Case # 10 - Ring and Tandem Applicator Case

Case # 10 represents a two catheter case for treatment of the carcinoma of the cervix and endometrium. A ring and tandem applicator with a 34 mm diameter ring is utilized. Variable angle films are utilized for patient and applicator reconstruction. The catheters are weighted 0.6 to 1.0 for the ring and tandem dwell positions respectively. A dose prescription of 500 cGy is prescribed and normalized to two applicator points, right A and left A (Rt. A and Lt. A). The dose distribution is not optimized. The resulting isodose distributions are presented in Figures 7.5.4.1 and 7.5.4.2. Tables 7.5.4.1 and 7.5.4.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 10.

The comparison of isodose distributions generated by the PLATO-Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for case

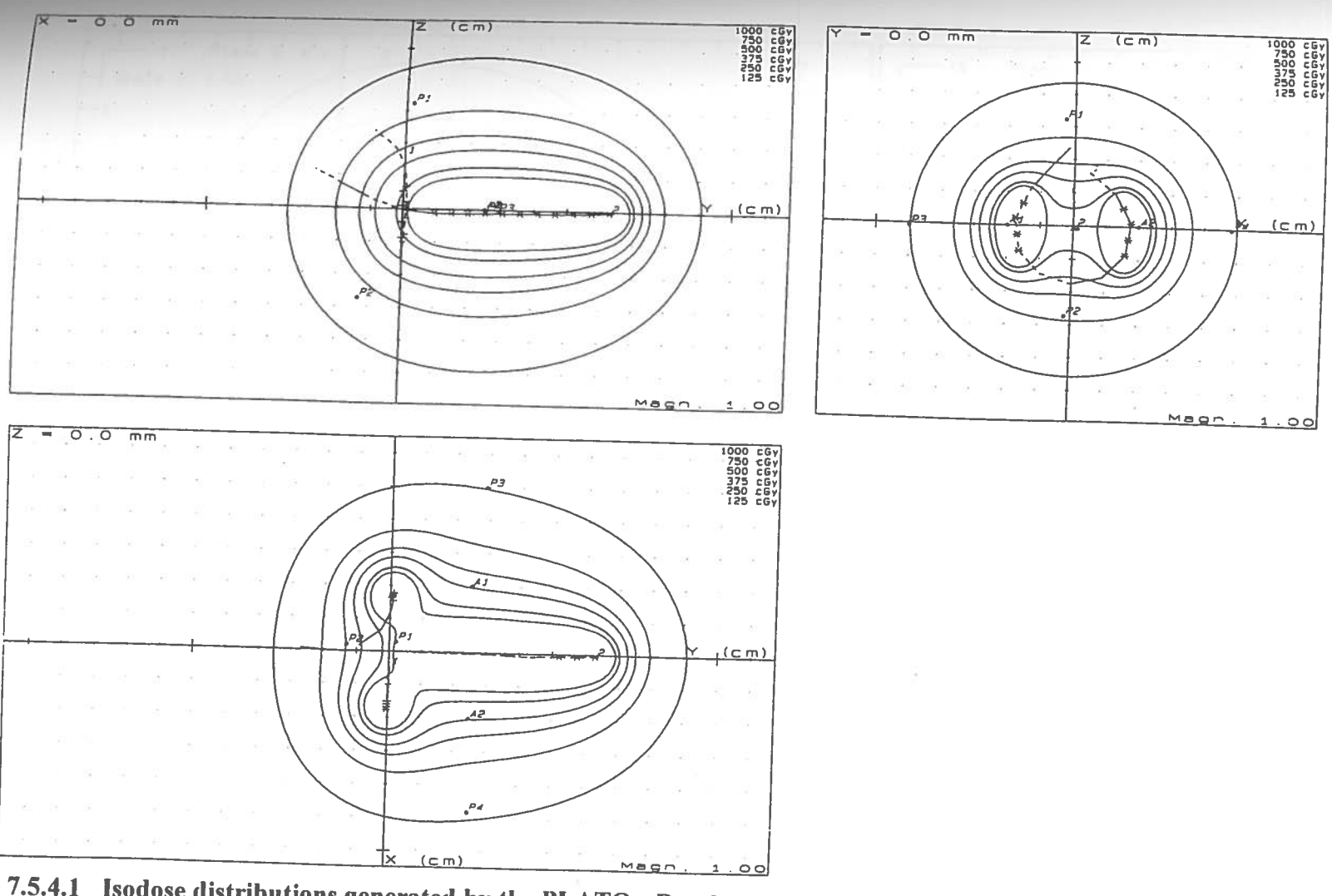


Figure 7.5.4.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 10 - Sagittal, Transverse, and Coronal Planes (Ring and Tandem Applicator Case)

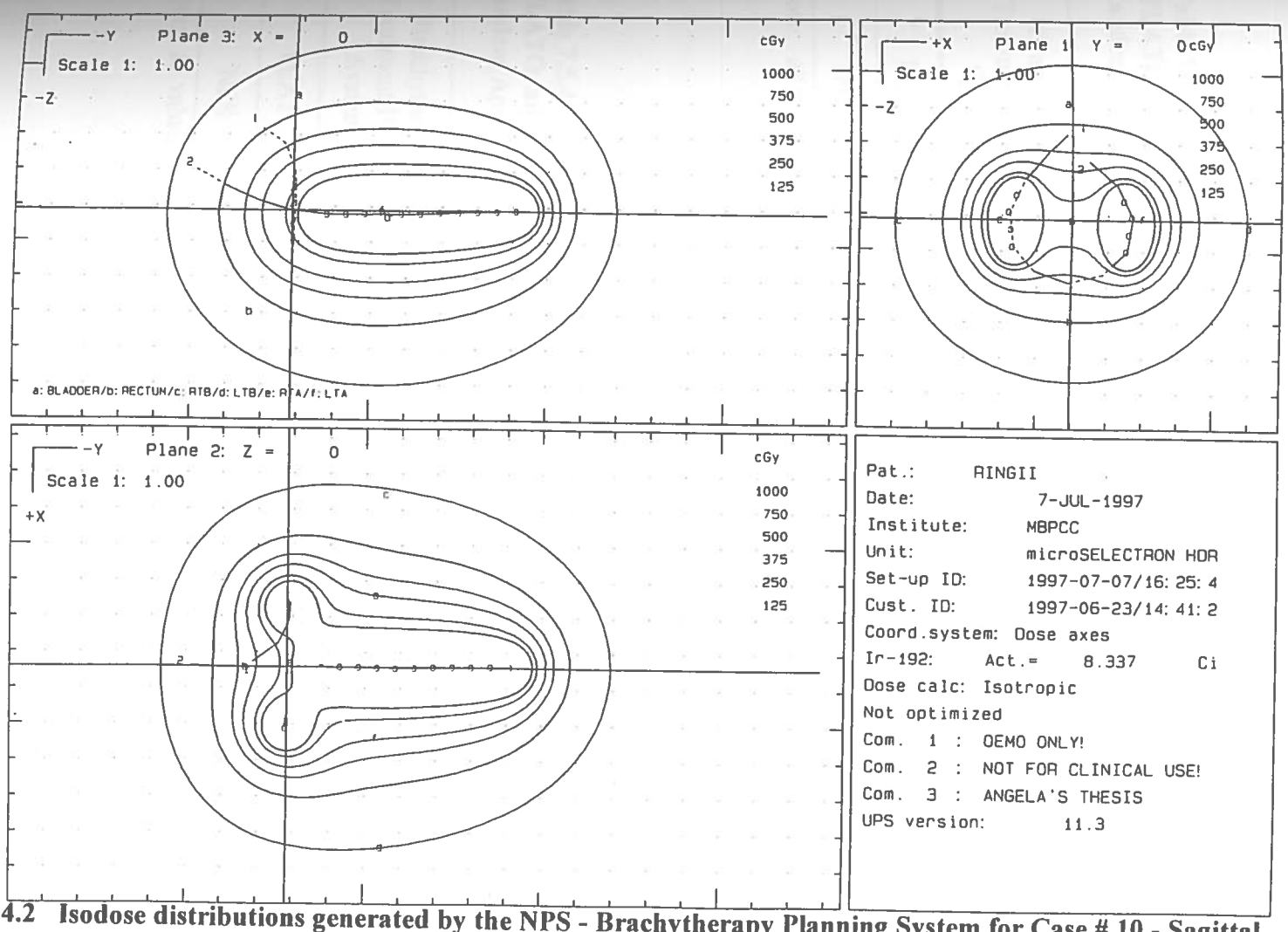


Figure 7.5.4.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 10 - Sagittal, Transverse, and Coronal Planes (Ring and Tandem Applicator Case)

Table 7.5.4.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 10 (Ring and Tandem Applicator Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 28$	$Y_P = 73$	$Z_P = 14$
NPS	$X_N = 28$	$Y_N = 72$	$Z_N = 14$

Note: all values ($\pm$ 1 mm)

Table 7.5.4.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 10 (Ring and Tandem Applicator Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 28$	$Y_P = 8$	$Z_P = 15$
NPS	$X_N = 28$	$Y_N = 9$	$Z_N = 15$

Note: all values ($\pm$ 1 mm)

10 (Ring and Tandem Applicator Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.5.4.1 and 7.5.4.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.5.5 Case # 11 - Tandem and Ovoids Applicator Case

Case # 11 represents a three catheter case for treatment of the carcinoma of the cervix and endometrium with one intra-uterine tandem plus two lateral ovoids for application. Orthogonal films are utilized for patient and applicator reconstruction. The catheters are weighted 1.0 to 1.0 to 1.0 for the tandem and ovoids dwell positions respectively. A dose prescription of 500 cGy is prescribed and normalized to two applicator points, right A and left A (Rt. A and Lt. A). The dose distribution is not optimized. The resulting isodose distributions are presented in Figures 7.5.5.1 and 7.5.5.2. Tables 7.5.5.1 and 7.5.5.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 11.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 11 (Tandem and Ovoids Applicator Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the points

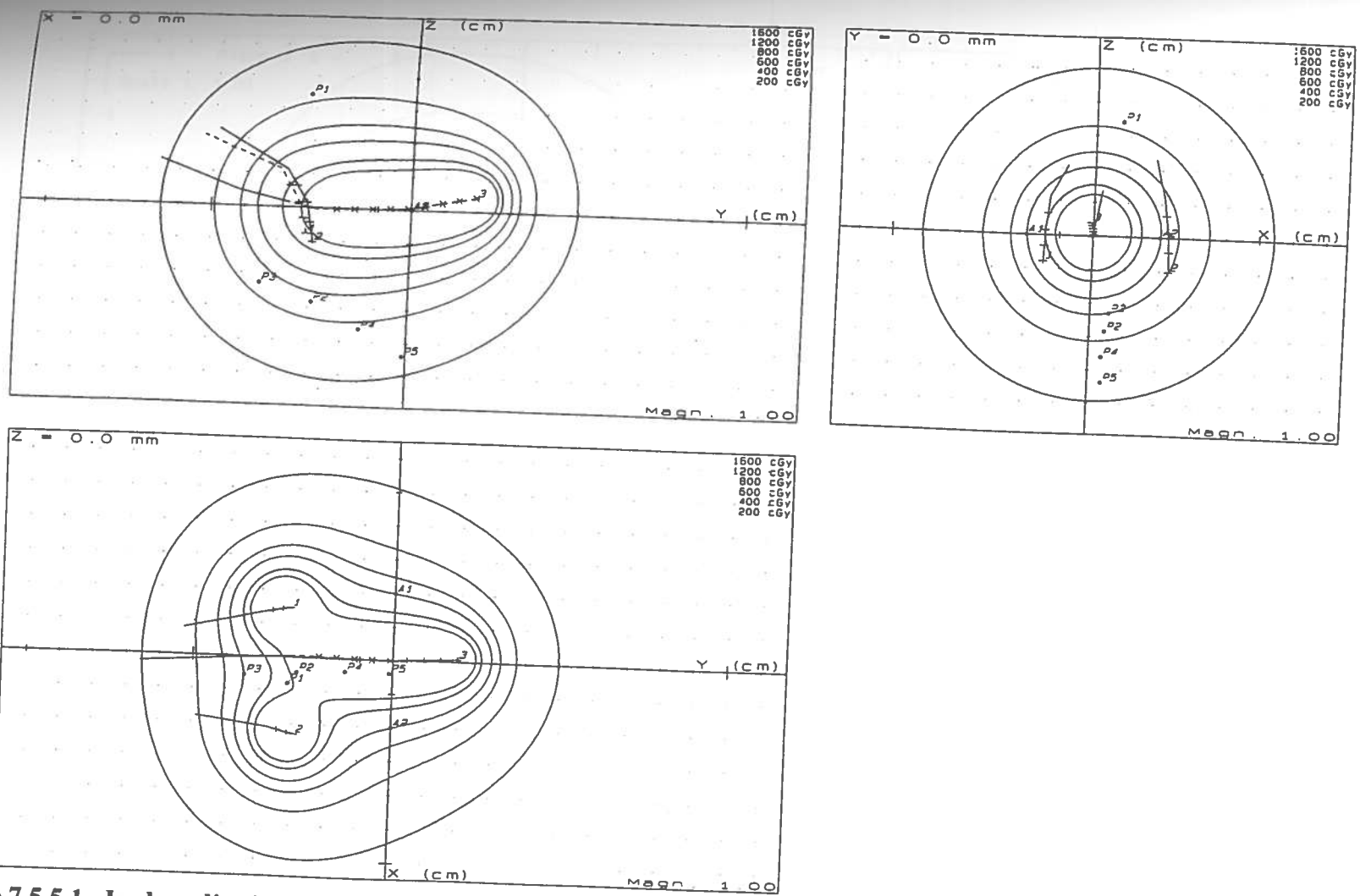


Figure 7.5.5.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 11- Sagittal, Transverse, and Coronal Planes (Tandem and Ovoids Applicator Case)

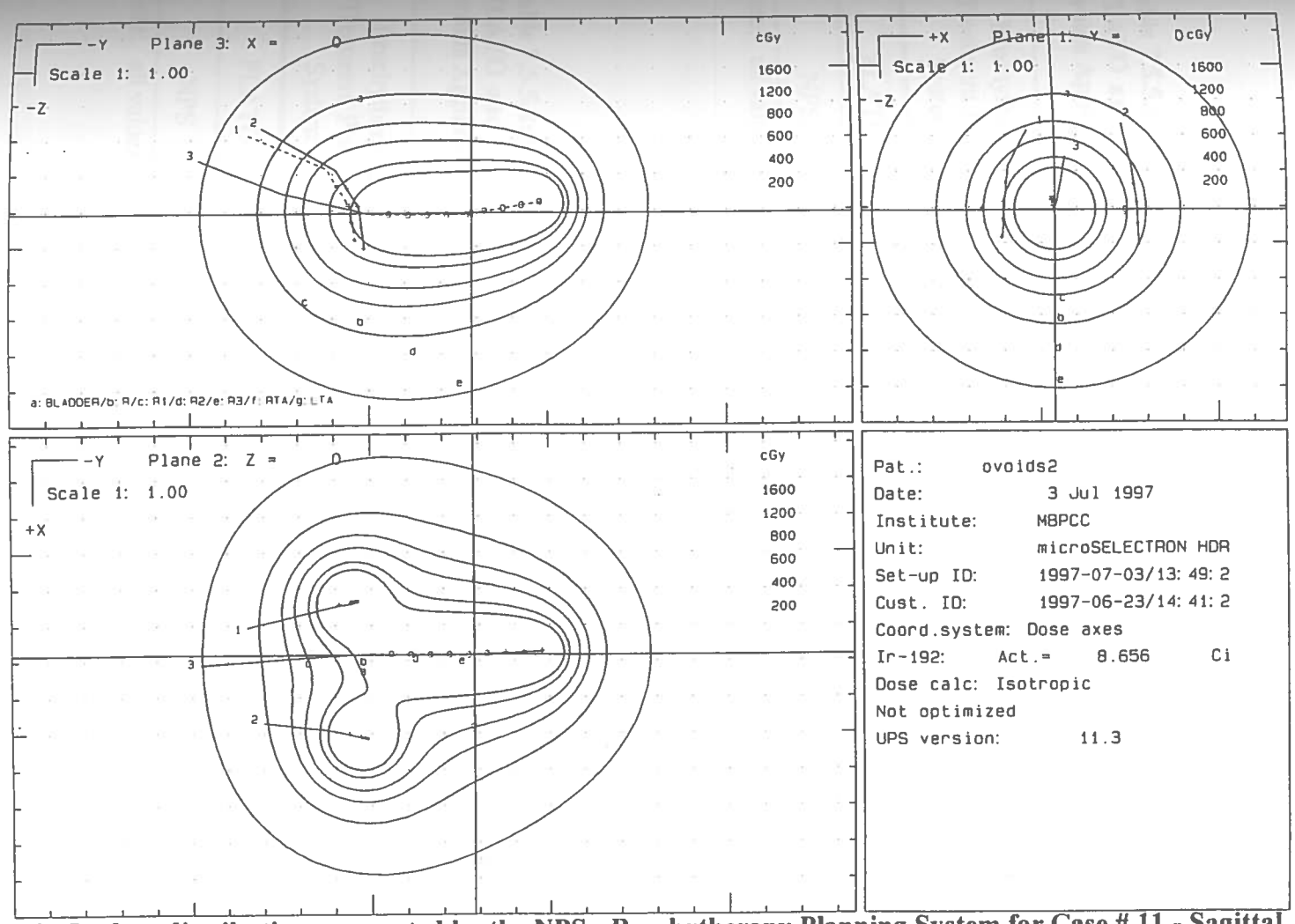


Figure 7.5.5.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 11 - Sagittal, Transverse, and Coronal Planes (Tandem and Ovoids Applicator Case)

Table 7.5.5.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 11 (Tandem and Ovoids Applicator Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 20$	$Y_P = 30$	$Z_P = 21$
NPS	$X_N = 20$	$Y_N = 30$	$Z_N = 20$

Note: all values ($\pm$ 1 mm)

Table 7.5.5.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 11 (Tandem and Ovoids Applicator Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 20$	$Y_P = 46$	$Z_P = 19$
NPS	$X_N = 20$	$Y_N = 47$	$Z_N = 19$

Note: all values ($\pm$ 1 mm)

at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.5.5.1 and 7.5.5.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.5.6 Case # 12 - Cylinder and Tandem Applicator Case

Case # 12 represents a one catheter case for treatment of the cervix and vaginal wall. A cylinder and an intra-uterine tandem applicator are utilized to obtain a dose prescription of 1000 cGy at 10.0 mm distance along the tandem. Semi-orthogonal films are utilized for patient and applicator reconstruction. The dose is normalized on dose points oriented to the axis with dose point optimization on distance. The resulting isodose distributions are presented in Figures 7.5.6.1 and 7.5.6.2. Tables 7.5.6.1 and 7.5.6.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 12.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 12 (Cylinder and Tandem Applicator Case) show an excellent agreement between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.5.6.1 and 7.5.6.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

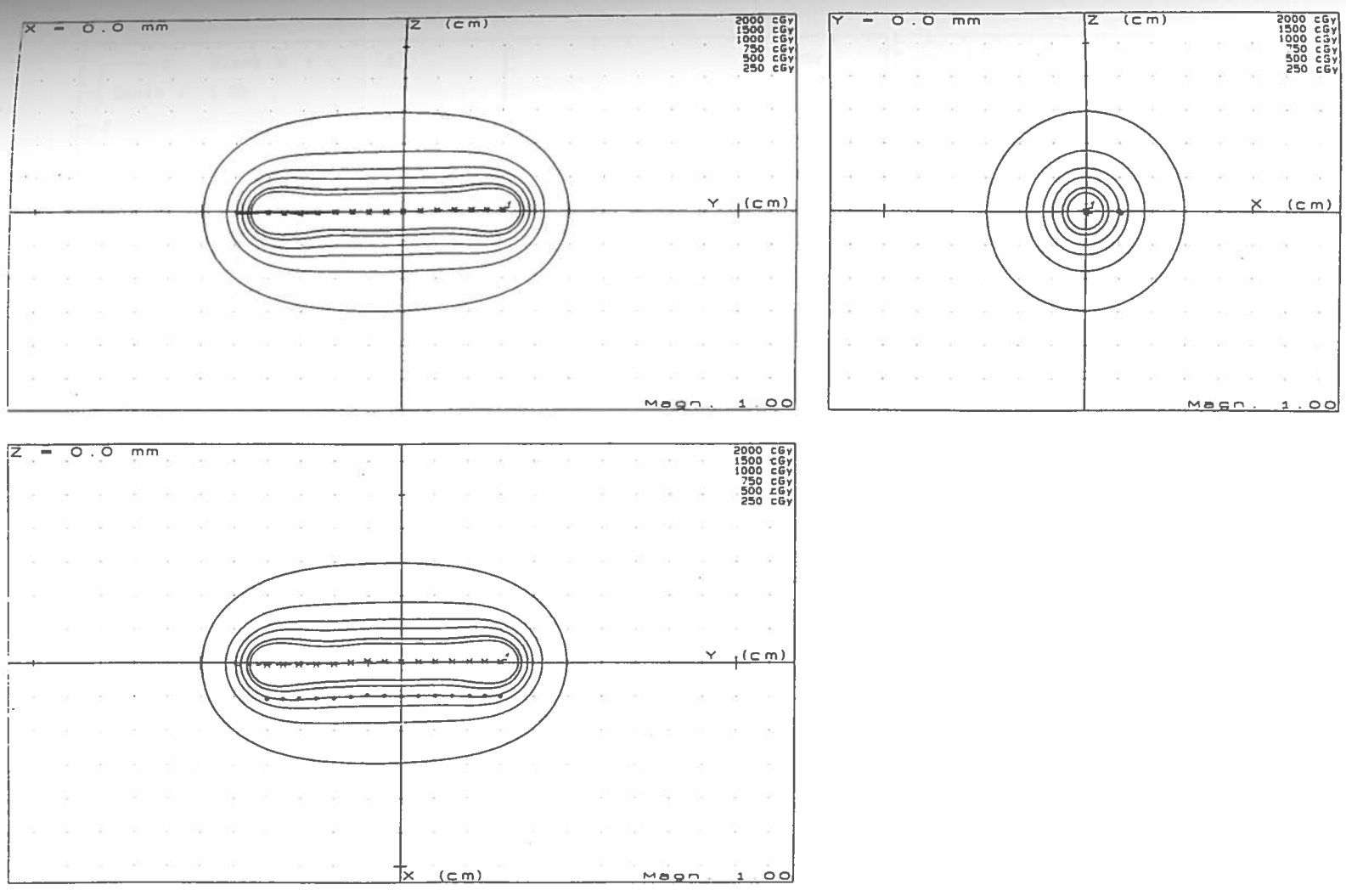


Figure 7.5.6.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 12 - Sagittal, Transverse, and Coronal Planes (Cylinder and Tandem Applicator Case)

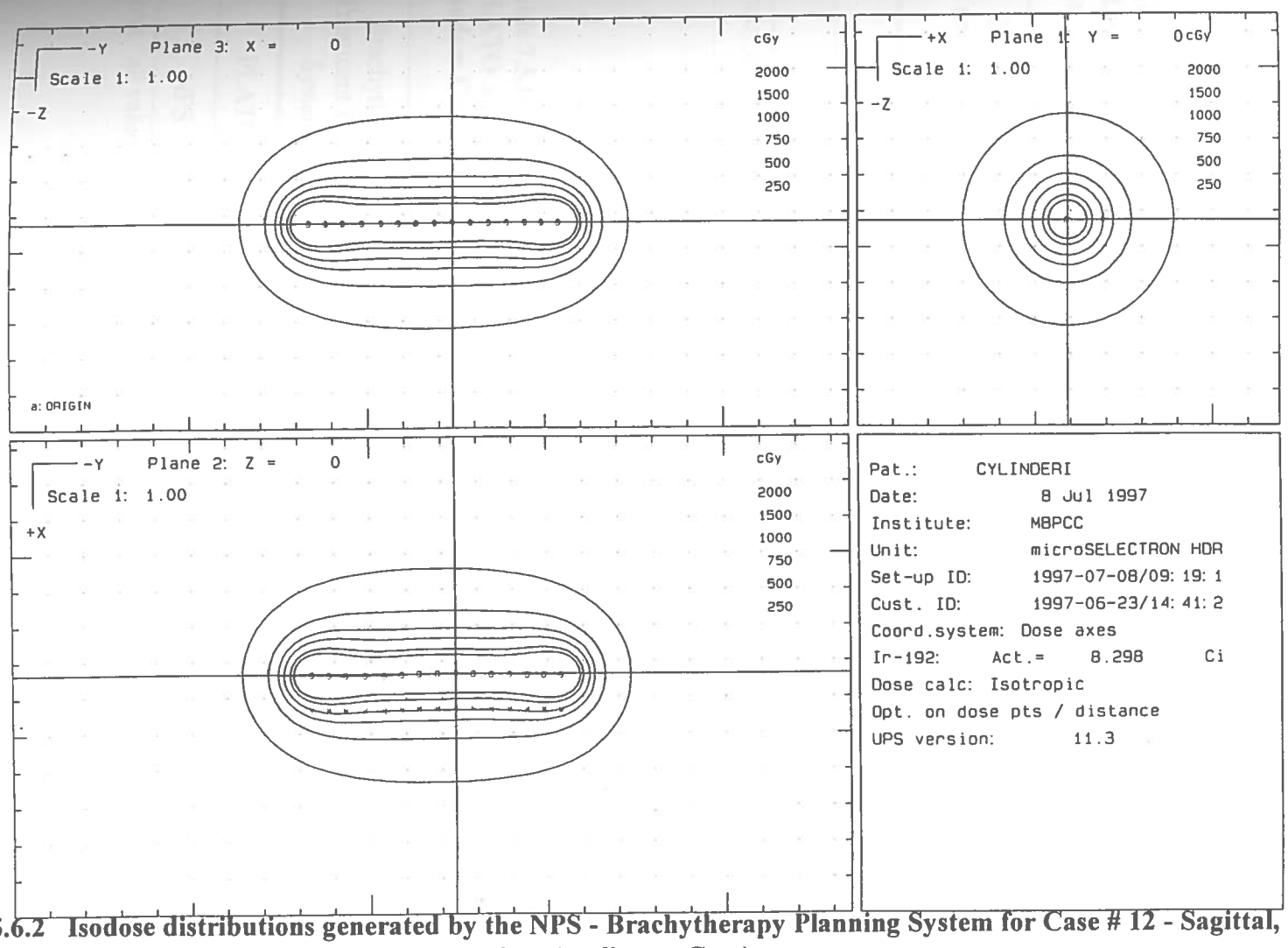


Figure 7.5.6.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 12 - Sagittal, Transverse, and Coronal Planes (Cylinder and Tandem Applicator Case)

Table 7.5.6.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 12 (Cylinder and Tandem Applicator Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 10$	$Y_P = 38$	$Z_P = 10$
NPS	$X_N = 10$	$Y_N = 38$	$Z_N = 10$

Note: all values ($\pm$ 1 mm)

Table 7.5.6.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 12 (Cylinder and Tandem Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 10$	$Y_P = 48$	$Z_P = 10$
NPS	$X_N = 10$	$Y_N = 48$	$Z_N = 10$

Note: all values ($\pm$ 1 mm)

7.5.7 Case # 13 - Five Needle Interstitial Breast Case

Case # 13 represents a five catheter interstitial breast case with a dose prescription of 750 cGy to an applicator (reference) point placed at coordinates (0,0,15) from the dose distribution origin. Variable angle films are utilized for patient and applicator reconstruction. The dose is normalized on the applicator point with the dose distribution optimized on geometry for volume.

Optimization on geometry can be performed for distance or volume. Distance optimization is primarily used where only a few catheters are involved. Whereas, volume optimization is primarily used for irregular shaped implants, where a uniform dose distribution is required within the implant. In distance optimization, all catheters participate in the calculation. When the relative weight for an active position is calculated, the neighboring active dwell positions in the same catheter will have the largest influence. However, in volume optimization, limits are imposed on the total dwell times per catheter. The distances of the other catheters relative to the current active dwell position will determine the relative weight in that position. The catheter on which the current dwell position is located is not included in the calculation.

The resulting isodose distributions for case # 13 are presented in Figures 7.5.7.1 and 7.5.7.2. Tables 7.5.7.1 and 7.5.7.2 represent the comparison of the PLATO and NPS Brachytherapy Planning Systems isodose distributions for case # 13.

The comparison of isodose distributions generated by the PLATO - Brachytherapy Planning System and the Nucletron Planning System treatment planning systems for Case # 13 (Five Needle Interstitial Breast Case) show an excellent agreement

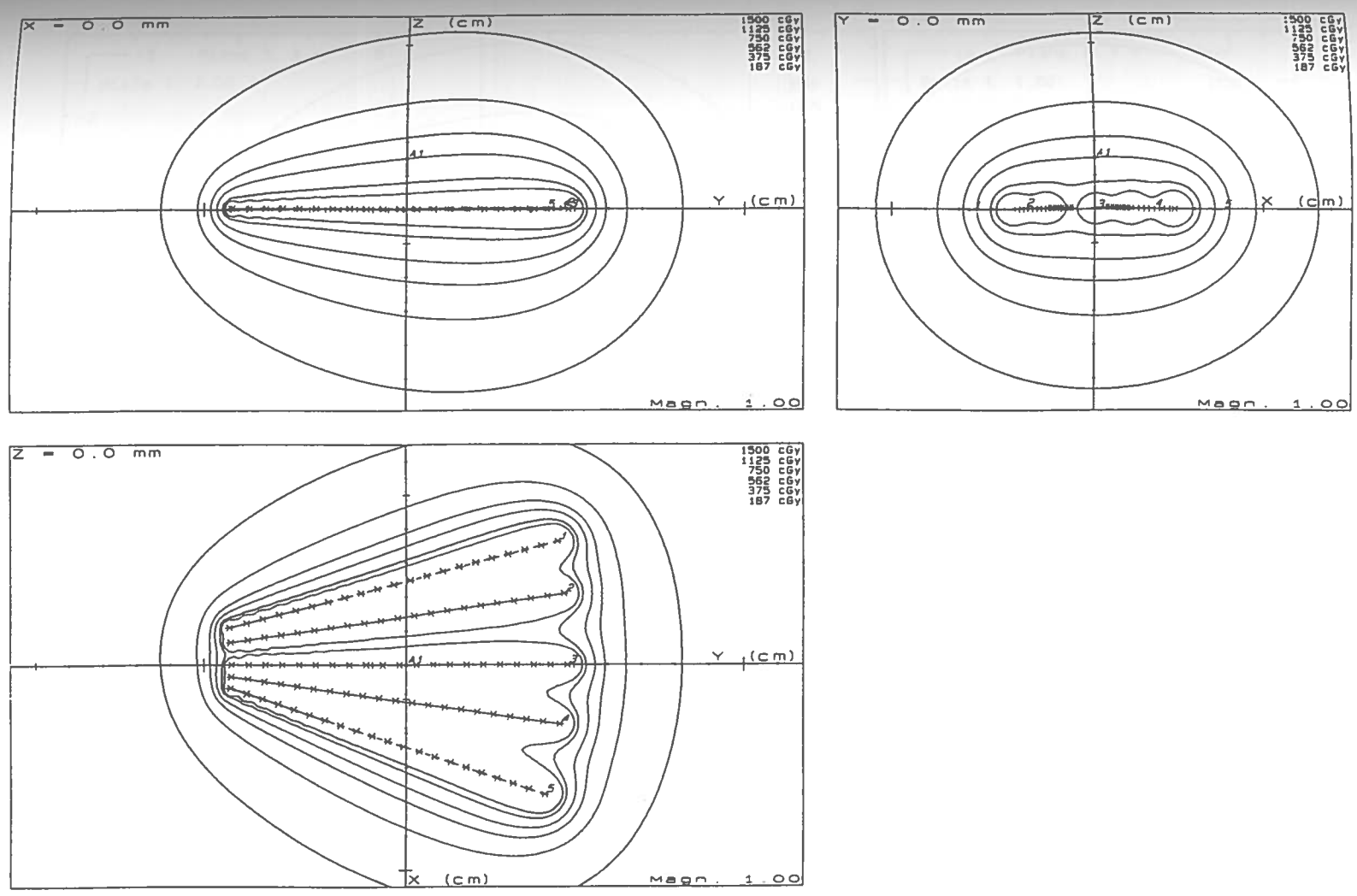


Figure 7.5.7.1 Isodose distributions generated by the PLATO - Brachytherapy Planning System for Case # 13 - Sagittal, Transverse, and Coronal Planes (Five Needle Interstitial Breast Case)

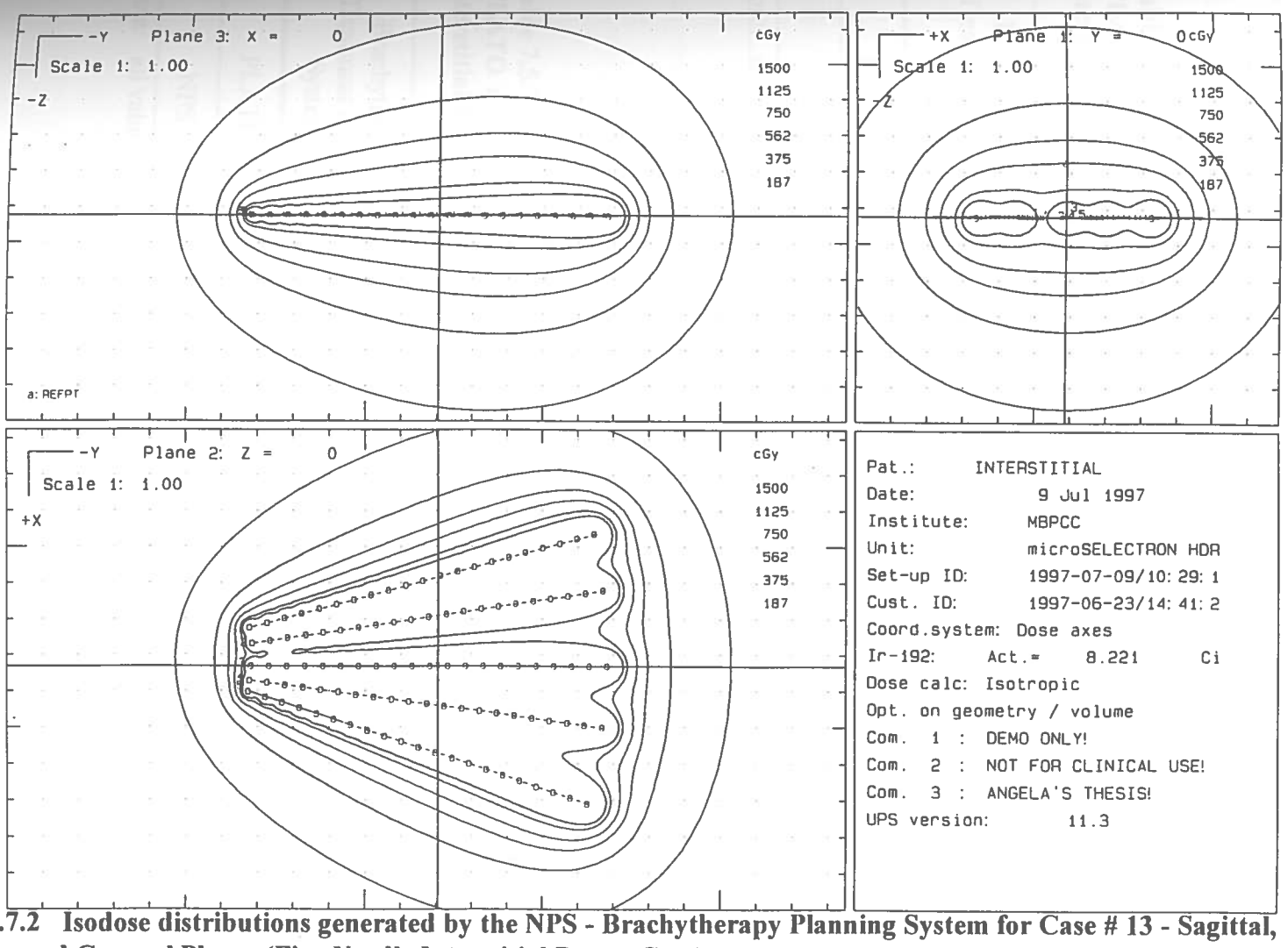


Figure 7.5.7.2 Isodose distributions generated by the NPS - Brachytherapy Planning System for Case # 13 - Sagittal, Transverse, and Coronal Planes (Five Needle Interstitial Breast Case)

Table 7.5.7.1: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 13 (Five Needle Interstitial Breast Case) Along the Positive Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at + X axis (mm)	Prescribed Isodose Line at + Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 36$	$Y_P = 56$	$Z_P = 15$
NPS	$X_N = 36$	$Y_N = 56$	$Z_N = 15$

Note: all values ($\pm$ 1 mm)

Table 7.5.7.2: Comparison of Isodose Distributions Generated by the Nucletron (PLATO and NPS) Brachytherapy Planning Systems for Case # 13 (Five Needle Interstitial Breast Case) Along the Negative Axes

Brachytherapy Treatment Planning System	Prescribed Isodose Line at - X axis (mm)	Prescribed Isodose Line at - Y axis (mm)	Prescribed Isodose Line at - Z axis (mm)
PLATO	$X_P = 35$	$Y_P = 56$	$Z_P = 15$
NPS	$X_N = 35$	$Y_N = 56$	$Z_N = 15$

Note: all values ($\pm$ 1 mm)

between both treatment planning systems. When the isodose distributions were overlaid, the criterion of ± 3.0 mm spatial accuracy was met for all equal isodose levels. The distances measured from the origin of the dose distribution axis to the point(s) at which the prescribed isodose level crosses each axis (± X, ± Y, ± Z) are shown in Tables 7.5.7.1 and 7.5.7.2. The results in these tables also show that the criterion of acceptability for equal isodose levels was met.

7.6 Results

Comparisons of treatment plan results between treatment planning systems of each case were done by overlaying the isodose distributions as well as physically measuring the distance from the origin of the dose distribution axes to the point at which the prescribed isodose levels cross each axis (± X, ± Y, and ± Z). The criterion of acceptability used was ± 3.0 mm spatial accuracy for equal isodose levels. Based on the isodose distributions and measurements presented in the tables of each section, all cases met the criterion of acceptability.

The results of the tests performed over a range of clinical conditions presented in this chapter therefore confirm the quality and accuracy of the PLATO - Brachytherapy Planning System algorithm. With the proper staff training and practice, the PLATO - Brachytherapy Planning System is ready for clinical use at MBPCC.

CHAPTER 8

EVALUATION, DISCUSSION, AND CONCLUSIONS

8.1 Evaluation of the PLATO - Brachytherapy Planning System

The evaluation procedures were incorporated and completed during the commissioning procedures. The evaluation procedures involved the investigation and evaluation of the strengths and weaknesses of both the PLATO and NPS - Brachytherapy Planning Systems. Comparisons between the systems were based on the ease of data entry, ability to make corrections, graphics quality, planning options, and the ability to manipulate the data.

8.2 Pros and Cons

Tables 8.2.1 and 8.2.2 list the pros and cons of the PLATO and NPS - Brachytherapy Planning Systems respectively. All of the factors listed in these tables are incorporated into the evaluation of the brachytherapy planning systems in determining which system is overall superior.

In evaluating the PLATO and NPS - Brachytherapy Planning Systems, the evidence clearly shows that the PLATO - Brachytherapy Planning System is superior to the Nucletron Planning System (NPS) - Brachytherapy Planning System currently in use. The NPS - Brachytherapy Planning System is a FORTRAN based, two-dimensional software package with poor graphics capabilities. The correction of small errors in data entry required multiple plans in the commissioning and evaluation process to be aborted and re-entered. This problem has overlaying implications in that it causes problems and delays for the treatment planning staff which ultimately affect the patients.

Table 8.2.1: Pros and Cons of the PLATO - Brachytherapy Planning System

PLATO - Brachytherapy Planning System		
Pro	**Con**	**Issue**
X		PLATO is run in a X-Windows environment.
X		PLATO is mouse driven.
X		PLATO has a user friendly environment where errors are easily corrected with far less confusion than seen in NPS.
X		PLATO has 3-D viewing of the applicators giving enhanced graphics and viewing options.
X		The cm dots are defined from the dose distribution origin.
X		+Y is always towards the head of the patient.
X		The applicator coordinate system is defined by digitizing the origin and any point on the y-axis. It is not necessary to place two points on the y-axis for defining + and - directions. The origin and y-axis orientation is immediately shown when digitized in case changes need to be made.
X		All radiographs are oriented in the same direction. They are all placed on the light box with the head of the patient towards the top of the light box. This causes less confusion for the user.
X		Three dimensional views can be rotated or laterally moved to any required position using the mouse and dragging.
X		Changing dwell times involves moving histogram bars up or down simply by clicking and dragging them with the mouse.
X		Patient points can be re-entered even after reconstruction has been completed and closed.
X		Placement of dose points oriented to the catheter or oriented to the axis is done with the mouse and keyboard in a straight forward manner (U, V, and W notation is used).
X		There is an audible alert as you digitize corresponding points from one film to another.
X		The patient Edit Menu allows you to enter the staging, sex, birth date, and other information in an input field.
X		Doctor's name is one of the selections to enter data into in the input field of the Patient Edit Menu.
X		There is a Plan Status window that tells you which stages of planning you have completed and which stages are left to be completed.
X		Any patient shifts or inaccurate reconstruction length errors can easily be viewed at a central location at any time in the Show Results Menu.

(table continued)

Table 8.2.1 continued

PLATO - Brachytherapy Planning System		
Pro	**Con**	**Issue**
X		The Dose Prescription window allows you to choose the date and time for a treatment directly. This option can be used for new or existing patients.
X		Active source positions on catheters can be viewed by turning them on in the View Options window. They appear as red dots on the catheters.
X		Desired planes can be shown on any axis and at any distance. The plane will be viewed in the 3-D window and will show its relationship to the implant.
X		The following features can be turned off or on within the plots: patient points, marking points, reference points, dose points, applicator points, sources, cm dots, and absolute dose.
X		Reference points can be added to plots with the mouse on the screen.
X		The applicator coordinate system can be changed by re-entering the reconstruction module and changing it.
X		Any percent line (i.e. 98%) can be treated to by choosing it in the dose prescription window.
X		Source data entry is easy and straight forward with windows. The specification of reconstruction box has the choice of large or small with all the default values preset.
X		The 995 indexer length is set as a default.
X		Deletion of source positions, patient points, and marking points are done with mouse selection.
X		The reference dose is set in the Dose Prescription window with reference dose equal to a percentage.
X		Rotation and translation can be done by clicking and dragging of the mouse. All views will be updated with any change.
X		There is a window called "Define Image Orientation" which alerts you and allows you to define the dose distribution origin and +X if films have been moved.
	X	The cm dots (scale) is defaulted off. You must manually turn them on for each plan you do.
	X	PLATO is not fully functional. It does not have shielding capabilities in cylinders and ovoids. This capability will be released in V15.0.

(table continued)

Table 8.2.1 continued

PLATO - Brachytherapy Planning System		
Pro	**Con**	**Issue**
	X	Patient shift from one film (AP) to the other (LAT) is shown after all points are digitized rather than as each point is completed. The results must be viewed in the Show Results Window.
	X	Legends are not present on the plots of the isodose curves that define the applicator points or patient points. The points are plotted but descriptions are not available on the plot. You have to go to the plan or journal printout to identify them.
	X	You should store the plan between leaving the reconstruction and entering dose distribution module just in case you get thrown out of the system. The plan is not stored as LAST automatically.
	X	You have more mouse activated strokes. You must prompt yourself to each procedure in reconstruction and dose distribution modules. This may take a longer period of time than the automatic system which prompts the user at each planning step. However, this gives the user more control over the planning which is a pro.
	X	Each time you activate another radiograph, you are prompted to "define the image orientation" (digitize the origin of the radiograph and a point on the + x-axis) even if you haven't moved the radiographs on the table. However, if the films haven't been moved, you can select "cancel" and continue.

Table 8.2.2: Pros and Cons of the Nucletron Planning System - Brachytherapy Planning System

NPS - Brachytherapy Planning System		
Pro	**Con**	**Issue**
X		NPS has full functionality including shielding capabilities in cylinders and ovoids.
X		Patient shift from one film (AP) to the other (LAT) is shown on the screen as each point is digitized.
	X	Rotation or lateral movement of catheters is possible by use of the keyboard. You must know the distance and select the axis you wish to move on.
	X	NPS is run in a DOS environment.
	X	NPS is keystroke, not mouse driven.

(table continued)

Table 8.2.2 continued

NPS - Brachytherapy Planning System		
Pro	**Con**	**Issue**
	X	The cm dots are not aligned and defined from the origin of the dose distribution axis.
	X	Back-stepping involves escape function usage as well as deciding between Local and Global error specification. It is difficult to determine whether to use local or global error functions to change data or fix errors. This can cause great confusion and has resulted in the system locking up or a core dump to occur in the past on several occasions.
	X	Placement of dose points oriented to the catheter or oriented to the axis is confusing and difficult to follow (+U, +V, +W and -U, -V, -W notation is used).
	X	When defining the applicator coordinate system, you must enter the origin of the dose coordinate system, Y_1 and Y_2. Y_1 must be in the cranial direction and Y_2 must be in the caudal direction. These points must be entered in this orientation and in the proper order to give the correct y-axis definition. The NPS system requires that the feet of the patient be set as the +Y direction and the head of the patient as the -Y direction. If Y_1 and Y_2 are digitized incorrectly, this orientation may become flipped due to the fact that Y_1 is -Y in direction and Y_2 is positive Y in direction with respect to the dose distribution origin you have chosen.
	X	You must go to the Application Input Menu to change a source strength for a specific calculation. This requires searching through lines of text to find the proper command choice.
	X	The indexer length must be entered during each treatment planning.
	X	Reference Dose F * mean dose, enter F = 1.0 is the designation that you are treating to the 100% line. This is a vague notation for the user.
	X	NPS orients the LAT film with the head towards the right side of the light box. All other films are placed with the head towards the top of the light box. This causes confusion.
	X	The treatment time has to be specified in the beginning of the program, when you start a new patient or read in an existing one.
	X	Origin of dose distribution must be entered on all sets of films used for reconstruction.

The PLATO - Brachytherapy Planning System was found to be a more "user friendly" system. It runs in an X Windows UNIX environment to facilitate treatment planning which allows the user to change patient data and make corrections or alterations very quickly and simply. The PLATO - Brachytherapy Planning System's enhanced graphics capabilities and ability to view applicators in three dimensions aids in the overall visualization of the implant.

The main benefit of the NPS - Brachytherapy Planning System is it's ability to utilize applicator shielding. The PLATO - Brachytherapy Planning System does not have the full functionality of the NPS - Brachytherapy Planning System with respect to applicator shielding. However, the technical personnel at the Nucletron Corporation state that this functionality is in the very near future for the PLATO - Brachytherapy Planning System. It should also be noted that shielded cases are rare at MBPCC and the NPS - Brachytherapy Planning System can still be used for these tasks.

8.3 Discussion and Conclusions

The development of a comprehensive commissioning and continued quality assurance program is usually a trade-off between cost and benefit. There can always be more testing that can be done to reduce the probability of error; however, ultimately the cost of the continued testing becomes restrictive. "While testing will not ensure complete accuracy for all situations, it is intended to provide a high level of reliability for today's treatment planning computers" [3]. Because HDR remote afterloading treatments are completed in minutes, there is little opportunity to correct treatment errors; therefore, a comprehensive commissioning and continued QA program is imperative for successful high dose rate brachytherapy.

The commissioning of the PLATO - Brachytherapy Planning System began with the familiarization with the software which led into the hardware testing phase of the commissioning. Properly functioning hardware devices are crucial to accurate treatment planning. The PLATO - Brachytherapy Planning System has built-in diagnostic programs for self-tests of the digitizer tablet, display screen, pen plotter, and printer. In addition to the self tests, these devices were independently tested by entering known dimensions and outputting the results for analysis. Van Dyk et al. stated that "the inherent accuracy of all input and output devices should be better than 1 mm" [3]. These devices were all determined to be functioning properly prior to testing the calculational method and the implementation of the algorithm. The hardware tests performed prior to commissioning the PLATO - Brachytherapy Planning System all met the criteria of inherent accuracy of better than 1 mm.

The verification of the calculational method for the PLATO - Brachytherapy Planning System involved calculation of dose to points, placed at distances of 2, 5, 10, 15, 20, 30, 40, and 50 mm from the source. The results calculated by the PLATO - Brachytherapy Planning System showed an excellent agreement with the results of the manual method and were all within the criterion of acceptability of 5.0 % dose accuracy for calculational points. The results of the digitizer reproducibility tests showed variability in distance due to human error which in turn caused variation in the dose from one trial to another at points that were digitized at the same distances. The calculational method of the PLATO - Brachytherapy Planning System was found to be accurate in the data shown in this Chapter 6; however, the ability to calculate dose within the first 5 mm from the source is not accurate. Due to the fact that a high dose gradient exists close to

the source, small digitizing errors greatly affect dose calculations at short distances whereas at longer distances, small errors are not as evident. Therefore, since humans cannot digitize without error, one cannot expect to calculate dose accurately within the first 5 mm from the source and the dose therefore should not be prescribed at distances less than 5 mm.

The verification of the implementation of the PLATO - Brachytherapy Planning System involved performing tests of the output over a range of clinical conditions from very simple cases to rare and unusual circumstances. The output was then be evaluated for its quality and accuracy. The PLATO and Nucletron Planning System (NPS) Brachytherapy Planning Systems were used for calculation of isodose distributions for thirteen treatment plan cases. For Case # 1 and Case # 2, the PLATO and NPS Brachytherapy Planning Systems as well as three additional treatment planning systems were used for calculation of isodose distributions. The additional treatment planning systems used for comparison included the Capintec, Theraplan, and the MBPCC spreadsheet. These computers made good comparisons of the results obtained with the PLATO - Brachytherapy Planning System. The results of each of the treatment plans were compared with respect to spatial accuracy for equal isodose levels. Comparisons of treatment plan results between treatment planning systems of each case were done by overlaying the isodose distributions as well as physically measuring the distance from the origin of the dose distribution axes to the point at which the prescribed isodose levels crosses each axes ($\pm$ X, $\pm$ Y, and $\pm$ Z). The criterion of acceptability used was 3.0 mm spatial accuracy for equal isodose levels. The results of each case, including isodose distributions and measured distances met this criteria.

The objectives of this research were to commission and evaluate the PLATO - Brachytherapy Planning System Version 13.2 software package for clinical use at MBPCC. With the results found in this research, it can be concluded that the PLATO - Brachytherapy Planning System, should allow the treatment planning staff to enter patient and source data accurately without the constant difficulties historically encountered with the NPS - Brachytherapy Planning System. In return, this should reduce treatment planning time, reduce patient "table time", and ultimately reduce prolonged patient discomfort.

Since all the stated criteria in the commissioning was met and with the factors pointed out in Tables 8.2.1 and 8.2.2 showing that the PLATO - Brachytherapy Planning System is superior to the NPS - Brachytherapy Planning System, it is therefore recommended that the PLATO - Brachytherapy Planning System replace the existing NPS - Brachytherapy Planning System for clinical use at MBPCC for future HDR Brachytherapy Treatment Planning.

8.4 Impact and Future of Brachytherapy

As stated earlier, dose specification problems have risen and the uncertainty in brachytherapy calculations is more difficult to avoid due to the fact that brachytherapy involves treatment at short distances in areas of high dose gradients. The presence of the steep dose gradient in this area and difficulties in visualization on radiographs has caused high uncertainties in dose calculations [3, 15, 32].

While HDR brachytherapy has been part of gynecologic treatment programs for 15 to 20 years, it is currently moving into a phase of greater sophistication in dose specification and dose optimization. New technology is now moving into the era of CT-

based three-dimensional treatment planning along with the ability to utilize stereotactic techniques. These methodologies along with the use of dose-volume histograms for brachytherapy are enhancements for the future of brachytherapy. This new technology shows promise and encouragement for the future of a more accurate specification of dose and therefore resulting in a more accurate treatment planning process [5].

Schoeppel et al. have shown the implications of dose specification with three-dimensional planning with the use of a CT-compatible Fletcher system applicator for ten intracavitary gynecologic implants. The results of their study demonstrated the inadequacy of conventional orthogonal radiographs in determining doses to critical anatomical structures during gynecological brachytherapy. They found maximum doses to the bladder and rectum to be grossly underestimated and doses to the cervix overestimated by point A definition in all cases using conventional methods compared to CT-based three-dimensional treatment planning. From their results we see that the use of three-dimensional imaging can play a major role in dose specification and overall in the future advancement of brachytherapy treatment planning systems [33].

All systems seek to produce homogenous dose distributions and minimize irradiation of the normal tissue [34]. A new area of treatment planning that is under investigation involves computer aided optimization of three-dimensional conformal treatment planning to predict the clinical consequences of dose distributions. The goal of computer aided optimization of three-dimensional conformal treatment plans is to lower normal tissue complications and increase tumor control. This system must balance patient specific factors provided by the doctors and must determine its optimization and calculations oriented to "clinically relevant" parameters, not simply be dose distribution

oriented. This will become a major step in brachytherapy future advancement [35]. The future of brachytherapy is expanding day by day. With modern technological advancements and continuing research in the area of brachytherapy, applications are becoming more accurate and procedures are becoming more user friendly. The ability to perform a treatment plan with as accurately as possible and with as little effort as possible is the objective of brachytherapy clinicians. The latest advancements in computer technology and treatment planning software has made treatment planning more streamlined and precise; however, computers will never replace the care and commitment role that clinicians play. Brachytherapy is a hands-on practice that must be carefully monitored to allow patients the opportunity for a cancer-free future.

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APPENDIX A

FLETCHER'S LYMPHATIC TRAPEZOID, PATIENT POINT(S), AND APPLICATOR POINT(S) PROCEDURES

Appendix A includes diagrams and detailed descriptions of how to construct Fletcher's Lymphatic Trapezoid, as well as how to locate and enter points for organs at risk, point As, and point Bs [15, 36].

A.1. Trapezoid Construction Procedures

AP View (See Figure A.1.1)

1. Draw a **line** from the top of the **symphysis** to the **S1-S2** junction

   (this line is used to denote the **midline** of the patient).

   *NOTE: All measured distances must have magnification factor applied. (Ex: 6 cm * 1.4 MAG = 8.4 cm to be measured and marked).*

2. Bottom of Trapezoid:

   From the midpoint of the line (located between the top of the symphysis and the S1-S2 junction), points are measured and marked **6 cm** right and **6 cm** left laterally from the midline (**Rt.Ext and Lt.Ext**).

3. Top of Trapezoid:

   From the middle of **L4**, points are measured and marked **2 cm** right and **2 cm** left laterally from the midline (**Rt. Para and Lt. Para**). A line is drawn between these two points to denote the top of the trapezoid.

4. A line is then drawn connecting the Rt. Para and Rt. Ext points and another line is drawn connecting Lt. Para and Lt. Ext points. The midpoint of these two lines denotes the **Rt. Comm** and **Lt.Comm** points respectively.

Lateral View (See Figure A.1.2)

1. Draw a line from the top of the **symphysis** to the **S1-S2** junction.
2. Top of Trapezoid: Mark the Anterior middle of L4 (mark **Para** points).
3. Bottom of Trapezoid: Measure length from the top of the **symphysis** to the **S1-S2** junction. Divide the length in half (mark **Ext** points).
4. Draw a line from Ext points to Para points.
5. Measure half-way from Ext points to Para points (mark **Comm** points).

A.2. Procedure for Locating the Bladder and Rectal Points

Bladder: AP ➜ located in the center of the bulb

LAT ➜ located at middle of the bulb closest to the applicator system

Rectal Point: AP ➜ indicated by marker

LAT ➜ 5 mm from the posterior vaginal wall marked with BBs

(this puts it 5 mm into tissue)

A.3. Procedure for Locating Point As and Point Bs:

For intracavitary treatments using the Ring and Tandem, Tandem and Ovoids, and Houdek applicators, the dose prescription is prescribed and normalized to two applicator points, right A and left A (Rt. A and Lt. A). The dose distribution is not optimized. Rt. A and Lt. A are defined *relative to the origin of the applicator* coordinate system. Points B are defined as being in the transverse axis through points A, 5.0 cm from the patient's midline. The duration of an implant is based on the dose rate calculated at point As, although the dose at the other points is taken into consideration in evaluating a treatment plan. Typically point As designate the locations where the uterine vessel crosses the

ureters. This location is believed to be the limiting factor in the irradiation of the uterine cervix and therefore would be predictive of late radiation complications.

Point As:

1. Measure 2.5 cm superior to the collar of the tandem and 2.0 cm right and 2.0 cm left laterally from the tandem.

   (The 2.5 cm measurement takes into account the 0.5 cm distance for the ring cap.)

   NOTE: All measured distances must have magnification factor applied.

Point Bs:

1. Measure 2.5 cm superior to the collar of the tandem and 5.0 cm right and 5.0 cm left laterally from the patient's midline.

   (The 2.5 cm measurement takes into account the 0.5 cm distance for the ring cap.)

   NOTE: All measured distances must have magnification factor applied.

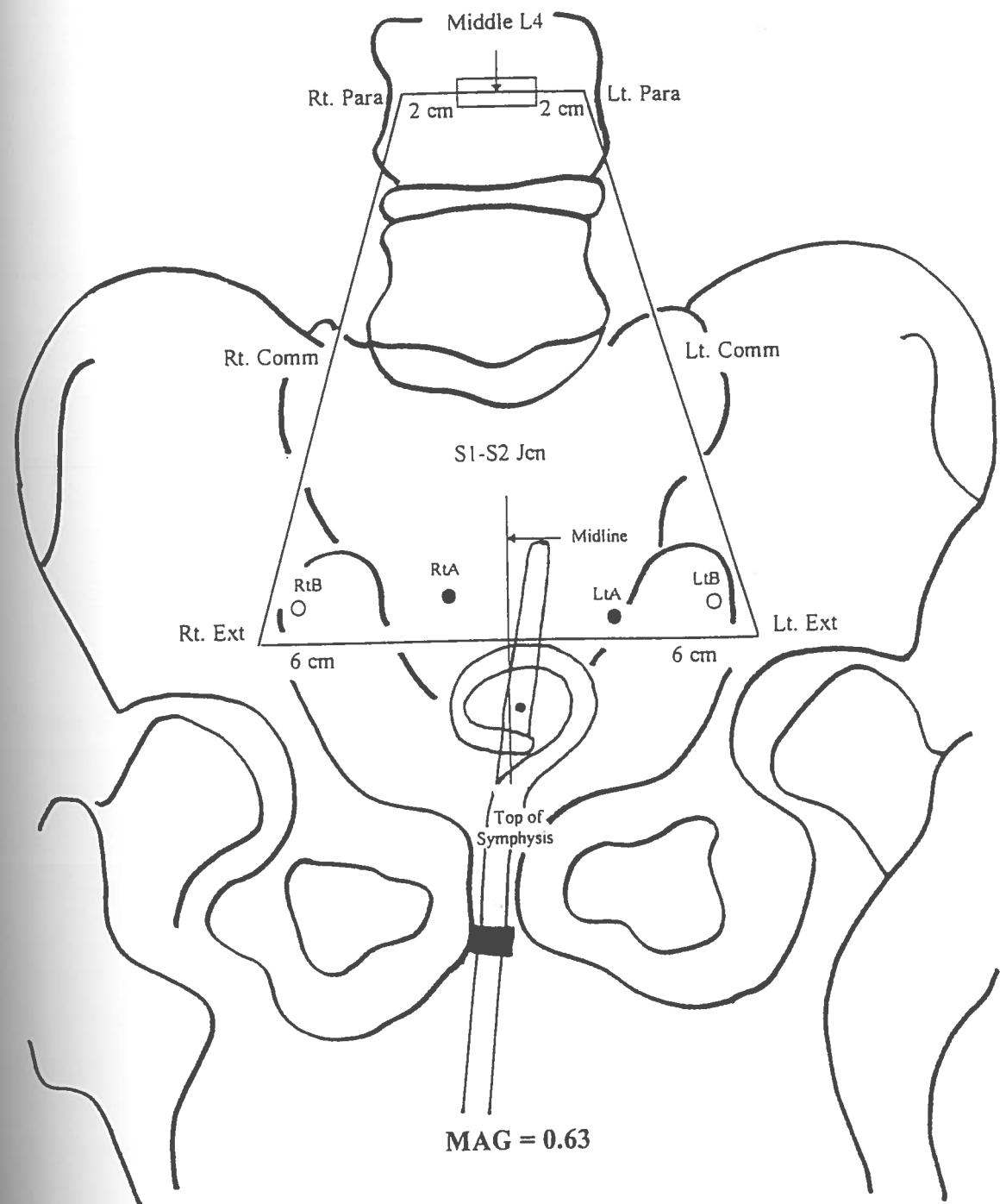

Figure A.1.1 Fletcher's Lymphatic Trapezoid - AP View

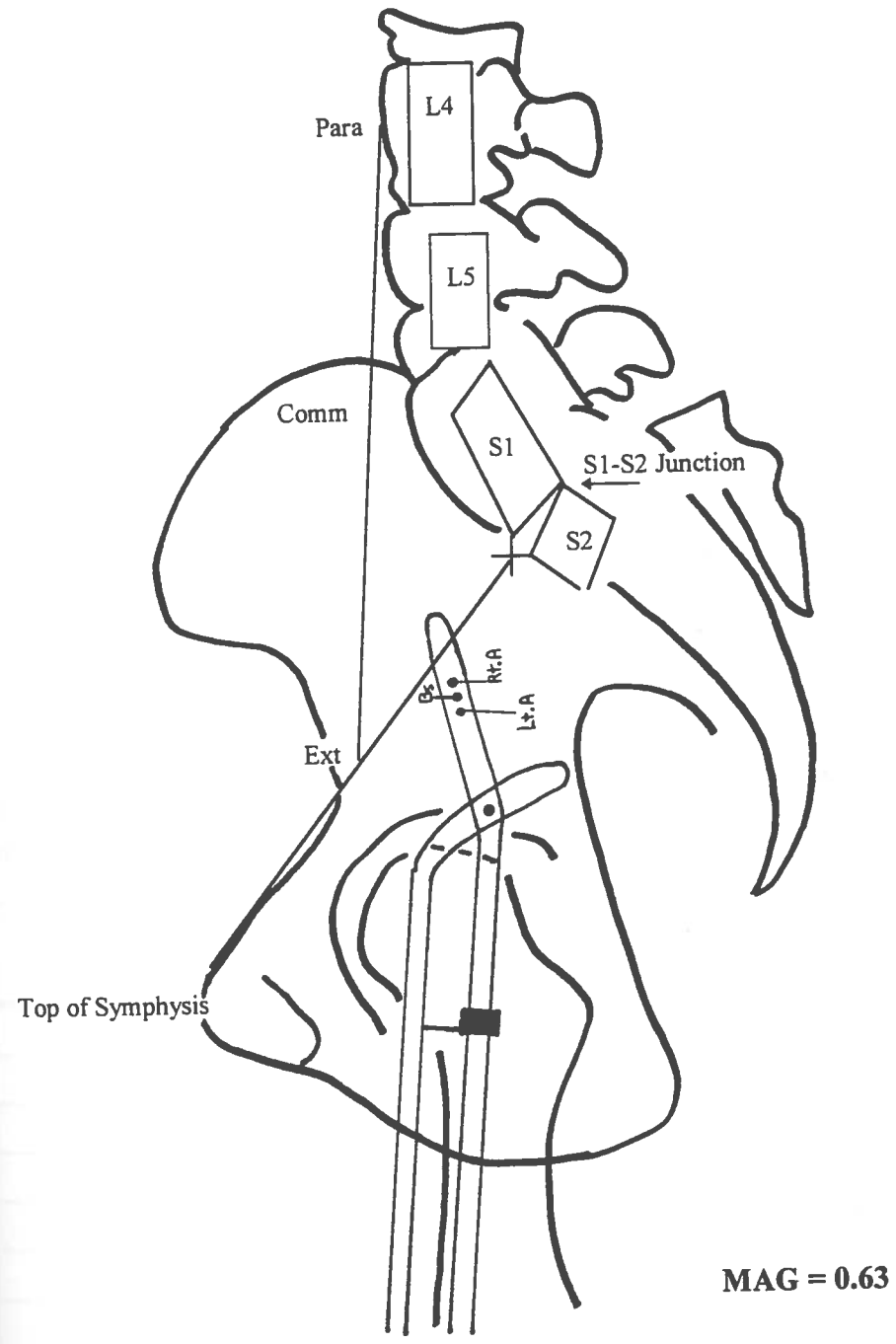

Figure A.1.2 Fletcher's Lymphatic Trapezoid - Lateral View

APPENDIX B

DIGITIZER FUNCTIONALITY TEST DATA FOR REPRODUCIBILITY OF REPEATED POINT ENTRIES

Appendix B includes tables of data for digitizer functionality tests for reproducibility of repeated point entries. Variability was found in the distances calculated in the digitizer reproducibility test in Chapter 6 - Reproducibility Testing and Verification of the Calculational Method of the PLATO - Brachytherapy Planning System. The variability may be due to malfunctioning of the digitizer or to human error. In order to ensure that the variability between trials was not due to digitizer malfunctioning, the digitizer was tested for reproducibility of repeated point entries. This procedure involved taping the digitizer to the tablet at selected points and repeatedly digitizing the exact same point without moving the digitizer in order to determine if any variability in the digitizer occurred. The coordinates of each repeatedly digitized point are shown in Tables B.1 through B.7.

Table B.1 Coordinates Determined by the PLATO - Brachytherapy Planning System for Point 1 with the Digitizer Taped to the Tablet

Point #	Repetition #	Computer Determined Coordinates of Digitized Point		
		X	Y	Z
1	1	-49.6	52.1	0.2
	2	-49.6	52.1	0.2
	3	-49.6	52.1	0.2
	4	-49.6	52.1	0.2
	5	-49.6	52.1	0.2
	6	-49.6	52.1	0.2
	7	-49.6	52.1	0.2
	Average	-49.6	52.1	0.2
	Standard Deviation	0	0	0

Table B.2 Coordinates Determined by the PLATO - Brachytherapy Planning System for Point 2 with the Digitizer Taped to the Tablet

Point #	Repetition #	Computer Determined Coordinates of Digitized Point		
		X	Y	Z
2	1	50.1	47.7	0.2
	2	50.1	47.7	0.2
	3	50.1	47.7	0.2
	4	50.1	47.7	0.2
	5	50.1	47.7	0.2
	6	50.1	47.7	0.2
	7	50.1	47.7	0.2
	Average	50.1	47.7	0.2
	Standard Deviation	0	0	0

Table B.3 Coordinates Determined by the PLATO - Brachytherapy Planning System for Point 3 with the Digitizer Taped to the Tablet

Point #	Repetition #	Computer Determined Coordinates of Digitized Point		
		X	Y	Z
3	1	-49.6	-50.3	-0.1
	2	-49.6	-50.3	-0.1
	3	-49.6	-50.3	-0.1
	4	-49.6	-50.3	-0.1
	5	-49.6	-50.3	-0.1
	6	-49.6	-50.3	-0.1
	7	-49.6	-50.3	-0.1
	Average	-49.6	-50.3	-0.1
	Standard Deviation	0	0	0

Table B.4 Coordinates Determined by the PLATO - Brachytherapy Planning System for Point 4 with the Digitizer Taped to the Tablet

Point #	Repetition #	Computer Determined Coordinates of Digitized Point		
		X	Y	Z
4	1	50.3	-49.7	-0.4
	2	50.3	-49.7	-0.4
	3	50.3	-49.7	-0.4
	4	50.3	-49.7	-0.4
	5	50.3	-49.7	-0.4
	6	50.3	-49.7	-0.4
	7	50.3	-49.7	-0.4
	Average	50.3	-49.7	-0.4
	Standard Deviation	0	0	0

Table B.5 Coordinates Determined by the PLATO - Brachytherapy Planning System for Point 5 with the Digitizer Taped to the Tablet

Point #	Repetition #	Computer Determined Coordinates of Digitized Point		
		X	Y	Z
5	1	99.8	0.2	0.1
	2	99.8	0.2	0.1
	3	99.8	0.2	0.1
	4	99.8	0.2	0.1
	5	99.8	0.2	0.1
	6	99.8	0.2	0.1
	7	99.8	0.2	0.1
	Average	99.8	0.2	0.1
	Standard Deviation	0	0	0

Table B.6 Coordinates Determined by the PLATO - Brachytherapy Planning System for Point 6 with the Digitizer Taped to the Tablet

Point #	Repetition #	Computer Determined Coordinates of Digitized Point		
		X	Y	Z
6	1	-79.7	-0.1	0.1
	2	-79.7	-0.1	0.1
	3	-79.7	-0.1	0.1
	4	-79.7	-0.1	0.1
	5	-79.7	-0.1	0.1
	6	-79.7	-0.1	0.1
	7	-79.7	-0.1	0.1
	Average	-79.7	-0.1	0.1
	Standard Deviation	0	0	0

Table B.7 Coordinates Determined by the PLATO - Brachytherapy Planning System for Point 7 with the Digitizer Taped to the Tablet

Point #	Repetition #	Computer Determined Coordinates of Digitized Point		
		X	Y	Z
7	1	0.2	0	0.1
	2	0.2	0	0.1
	3	0.2	0	0.1
	4	0.2	0	0.1
	5	0.2	0	0.1
	6	0.2	0	0.1
	7	0.2	0	0.1
	Average	0.2	0	0.1
	Standard Deviation	0	0	0

The results shown in Tables B.1 through B.7 are discussed in Chapter 6.

APPENDIX C

HIGH DOSE RATE BRACHYTHERAPY
TREATMENT PLANNING PROCEDURES FOR:

THE PLATO - BRACHYTHERAPY PLANNING SYSTEM

SCIENCE - "If the study of all these sciences which we have enumerated, should ever bring us to their mutual association and relationship, and teach us the nature of the ties which bind them together, I believe that the diligent treatment of them will forward the objects which we have in view, and that the labor, which otherwise would be fruitless, will be well bestowed." - Plato

APPENDIX C - TABLE OF CONTENTS

SECTION

C.1. Brachytherapy Treatment Planning Prerequisites

1. Pretreatment QA must be completed for the day of the treatment

2. The prescription must be written and signed by the physician

3. A minimum of two (2) radiographs must be taken

   NOTE: 4 radiographs are required in cases where it is considered necessary to apply 2 different reconstruction methods due to geometry constraints (i.e. two radiographs can be taken for the implant and two for patient anatomy).

4. Radiographs can be taken using different methods including:

   a) **Orthogonal (AP/PA and Lateral) Radiographs**
      - simulator films are taken with seed markers inside applicator(s)
      - these radiographs are used for patient point(s) reconstruction and/or applicator reconstruction depending on the applicator geometry and patient anatomy

   b) **Semi-Orthogonal (AP/PA and Lateral) Radiographs**
      - films are taken with a portable X-ray unit and large reconstruction box with seed markers inside the applicator(s)
      - film cassettes are placed parallel to the box faces with each face of the box containing radio-opaque markers
      - when almost (semi) orthogonal radiographs are taken, these markers are projected onto the radiographs
      - using markers, the position and orientation of the radiograph can be determined as well as the position of the X-ray focus

   c) **Variable Angle [Left Anterior Oblique (LAO) and Right Anterior Oblique (RAO)] Radiographs**
      - simulator films are taken with seed markers inside applicator(s)
      - these radiographs are used when the seed markers in the applicator(s) are difficult to accurately reconstruct from orthogonal films due to applicator geometry or patient anatomy
      - two angles α & β are determined with optimum visibility of the subject in question is obtained on the image intensifier
      - the angle between both projecting beams should preferably lie between 60 and 120 degrees
      - Oldelft gantry angles for LAO and RAO should be converted from Oldelft to Nucletron angles for proper entry into the PLATO - Brachytherapy Planning System

- GYN oblique films are generally taken at Oldelft angles of 205° and 155°. The conversion to Nucletron angles gives 25° and 335° respectively
- radiographs are made with film in a cassette on top of the Image Intensifier

NOTE: **GYN patient positioning must be as follows:**

- **supine**
- **feet toward gantry**

5. Radiograph positioning on the Digitizer Table should be as shown in Figure C.1.1.

6. The orientation of the x, y, and z axes with respect to the patient is shown in Figure C.1.2

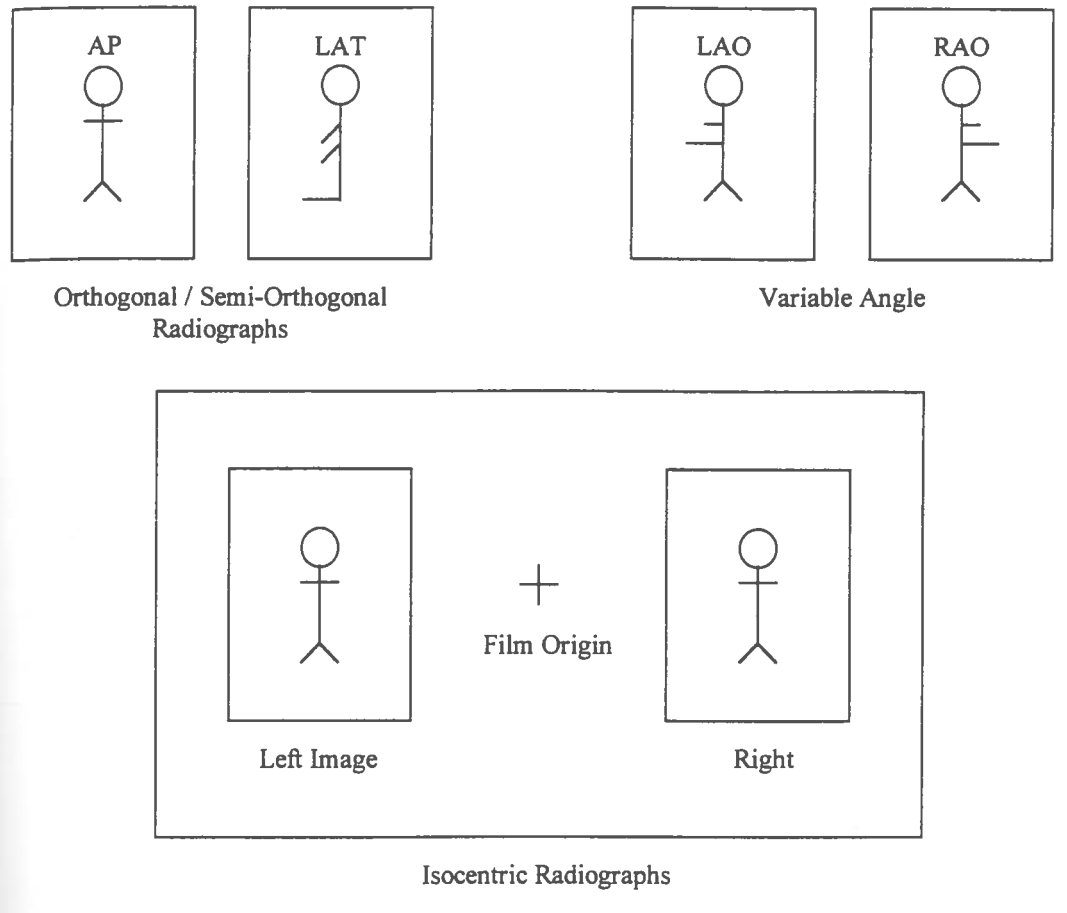

Figure C.1.1 Radiograph Positioning on the Digitizer Tablet

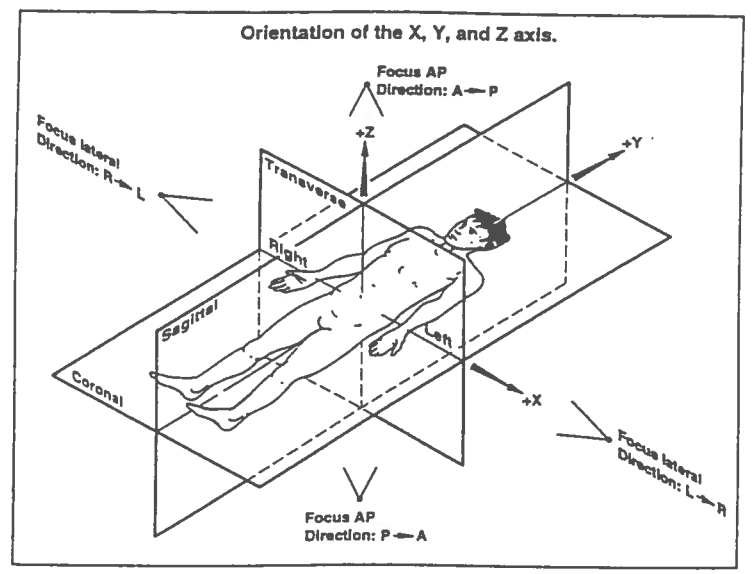

Figure C.1.2. Orientation of X, Y, and Z Axes with Respect to a Patient

C.2. Powering Up and Starting a New Patient

Power Up:

1. Turn on power strip on floor below plotter
2. Turn on (2) switches on right side of light box
3. Turn on computer (the switch is on the back of the CPU)
4. Select PLATO icon and select LOGIN at lower right corner with the mouse
5. Select PLATO Planning and PSS V2. Wait until the purple screen appears and the "watch" disappears

Patient Data:

1. Select "NEW" in the Patient Information Field
2. Type the Patient MR Number in the input field and "ENTER"
3. Type Patient's Last Name and Initials in appropriate input fields (CAPS lock must be on) and "SAVE"
4. Select Patient Sex Description (optional), Birth Date (optional), and "Save"
5. Enter Case and Study Information (optional) and "Save"

Initialize Planning:

1. Select "Brachytherapy" icon at right side of screen to start PLATO - Brachytherapy Planning System
2. Wait until "watch" disappears
3. Select "NEW" under the File Menu
4. Select "Edit" under the File Menu
    - Enter the doctor's name, applicator description, etc. and select "OK"

Machine Data:

1. Select "Treatment Units" under the Planning Menu
2. Select "micro-Selectron HDR"
3. Verify Stepsize = 5 mm
4. Verify Treatment Date
5. Verify Ir-192 Source Strength at Treatment Date against the Tabulated Data

    NOTE: The source strength is updated every 12 hours

6. Select "OK"

C.3. Setup and Initiation of Radiograph Reconstruction

1. Orient radiographs on the digitizer table as shown in the diagrams in the Brachytherapy Treatment Planning Prerequisite instructions

2. Select "Reconstruction" in the Planning Menu

3. Select "Digitizer" in the Images Menu

    - Digitize the Lower Left and Upper Right corners of the first radiograph, Select "Apply"
    - Digitize the Lower Left and Upper Right corners of the second radiograph, Select "OK"

4. Select both, Radiograph 1 and Radiograph 2, image icons to open the windows

5. Select "Setup" in the Images Menu

6. Select the reconstruction method of choice

    - Orthogonal
    - Semi-Orthogonal
    - Isocentric
    - Variable Angle

NOTE 1: Radiographs are activated by depressing the left mouse button with the cursor located over the radiograph icon of choice.

NOTE 2: Each time you switch from one radiograph to another, you will be prompted to "define the image orientation". This is done by digitizing the *origin* and *a point on the positive x-axis* of the radiograph you are activating. If the radiographs have <u>not</u> been moved, you can select "cancel" at this prompt.

C.4. Orthogonal Radiograph Reconstruction

1. Setup and Initiation of Radiograph Reconstruction must be performed prior to beginning this procedure

2. Activate Radiograph 1 by clicking on the icon with the mouse

3. Digitize the *origin* of Radiograph 1 and *a point on the positive x-axis*

   NOTE: You will be prompted to define the image orientation each time you switch from one radiograph to another. If the radiographs have <u>not</u> been moved, you can select "cancel" at this prompt.

4. In the Orthogonal Setup Window, enter the Film Magnification (MAG) , Focus to Isocenter Distance (FID), Beam Direction Related to Patient, and Image Usage (Applicator, Marking Points, and/or Patient Points) for the AP or PA radiograph

5. Select "Apply" (Upon completion, the header of the Image window will change from Radiograph 1 to Orthogonal A→P or Orthogonal P→ A)

6. Activate Radiograph 2 by clicking on the icon with the mouse

7. Digitize the *origin* of Radiograph 2 and *a point on the positive x-axis*

8. In the Orthogonal Setup Window, enter the Film Magnification (MAG), Focus to Isocenter Distance (FID), Beam Direction Related to Patient, and Image Usage (Applicator, Marking Points, and/or Patient Points) for the LAT radiograph

   NOTE: If the MAG, FID, and Image Usage is the same as designated in Radiograph 1, all you need to do is select the "Previous" button at the bottom of the Orthogonal Setup Window. Then enter the appropriate Beam Direction Related to Patient.

9. Select "Apply" (Upon completion, the header of the Image window will change from Radiograph 2 to Orthogonal L→R or Orthogonal R→L)

10. Close the Orthogonal Setup Window

C.5. Semi-Orthogonal Radiograph Reconstruction

1. Setup and Initiation of Radiograph Reconstruction must be performed prior to beginning this procedure

2. Activate Radiograph 1 by clicking on the icon with the mouse

3. Digitize the *left and right ends* of the *large* crosswire of Radiograph 1

4. Digitize the *left and right ends* of the *small* crosswire of Radiograph 1

5. In the Semi-Orthogonal Setup Parameters Window, select the Beam Direction, and Image Usage (Applicator, Marking Points, and/or Patient Points) for the AP or PA radiograph

6. Select "Apply" (Upon completion, the header of the Image window will change from Radiograph 1 to Semi-Orthogonal A→P or Semi-Orthogonal P→ A)

7. Activate Radiograph 2 by clicking on the icon with the mouse

   NOTE: You will be prompted to define the image orientation each time you switch from one radiograph to another. If the radiographs have <u>not</u> been moved, you can select "cancel" at this prompt.

8. Digitize the *upper and lower points* of the large crosswire of Radiograph 2

   NOTE: the large and small crosswires are presented vertically in the lateral image window

9. Digitize the *upper and lower points* of the small crosswire of Radiograph 2

10. In the Semi-Orthogonal Setup Window, select the Beam Direction, the Side Cross Used (Upper or Lower), and Image Usage (Applicator, Marking Points, and/or Patient Points) for the LAT radiograph

    NOTE: If the Side Cross Used and Image Usage is the same as designated in Radiograph 1, all you need to do is select the "Previous" button at the bottom of the Semi-Orthogonal Setup Window. Then enter the appropriate Beam Direction Related to Patient.

11. Select "Apply" (Upon completion, the header of the Image window will change from Radiograph 2 to Semi-Orthogonal L→R or Semi-Orthogonal R→L)

12. Close the Semi-Orthogonal Setup Window

C.6. Isocentric Radiograph Reconstruction

1. Setup and Initiation of Radiograph Reconstruction must be performed prior to beginning this procedure

2. Activate Radiograph 1 by clicking on the icon with the mouse

3. A red crosswire appears in the Image Window. It has to be adjusted to the crosswire of the radiograph as follows for orientational purposes:

    - Digitize the *center* of the crosswire and a *point to the right* on the horizontal crossline of the radiograph

4. In the Isocentric Setup Parameters Window, enter the following parameters:

    - Magnification Factor (MAG)
    - Angle in degrees
    - Focus to Isocenter Distance (FID) in mm and Isocenter to Film Distance (IFD) in mm
    - Image Usage (Applicator, Marking Points, and/or Patient Points)

5. Select "Apply" (Upon completion, the header of the Image window will change from Radiograph 1 to Isocentric 30.00)

6. Activate Radiograph 2 by clicking on the icon with the mouse

    NOTE: You will be prompted to define the image orientation each time you switch from one radiograph to another. If the radiographs have <u>not</u> been moved, you can select "cancel" at this prompt.

7. A red crosswire appears in the Image Window. It has to be adjusted to the crosswire of the radiograph as follows for orientation purposes:

    - Digitize the *center* of the crosswire and a *point to the right* on the horizontal crossline of the radiograph

8. In the Isocentric Setup Parameters Window, enter the following parameters:

    - Magnification Factor (MAG)
    - Angle in degrees
    - Focus to Isocenter Distance (FID) in mm and Isocenter to Film Distance (IFD) in mm
    - Image Usage (Applicator, Marking Points, and/or Patient Points)

NOTE: If the MAG, FID, IFD, and Image Usage is the same as designated in Radiograph 1, all you need to do is select the "Previous" button at the bottom of the Isocentric Setup Window. Then enter the appropriate Angle in degrees.

9. Select "Apply" (Upon completion, the header of the Image window will change from Radiograph 1 to Isocentric 330.00)

10. Close the Isocentric Setup Window

C.7. Variable Angle Radiograph Reconstruction

1. Setup and Initiation of Radiograph Reconstruction must be performed prior to beginning this procedure

    - GYN oblique films are generally taken at Oldelft angles of 205° and 155°. The conversion to Nucletron angles gives 25° and 335° respectively
    - Oldelft gantry angles for LAO and RAO should be converted from Oldelft to Nucletron angles for proper entry into the PLATO-BPS

2. Activate Radiograph 1 by clicking on the icon with the mouse

3. Digitize the *origin* of the radiograph and *a point on the positive x-axis*

4. In the Variable Angle Setup Window, enter the Beam Gantry Angle (Nucletron Angle), Film Magnification, Focus to Isocenter Distance, and Image Usage (Applicator, Marking Points, and/or Patient Points) for the LAO radiograph

5. Select "Apply" (Upon completion, the header of the Image window will change from Radiograph 1 to Variable Angle 25.00)

6. Activate Radiograph 2 by clicking on the icon with the mouse

    NOTE: You will be prompted to define the image orientation each time you switch from one radiograph to another. If the radiographs have <u>not</u> been moved, you can select "cancel" at this prompt.

7. Digitize the *origin* of the radiograph and *a point on the positive x-axis*

8. In the Variable Angle Setup Window, enter the Beam Gantry Angle (Nucletron Angle), Film Magnification (MAG), Focus to Isocenter Distance (FID), and Image Usage = Applicator for the RAO radiograph

    NOTE: If the MAG, FID, and Image Usage is the same as designated in Radiograph 1, all you need to do is select the "Previous" button at the bottom of the Variable Angle Setup Window. Then enter the appropriate Beam Gantry Angle.

9. Select "Apply" (Upon completion, the header of the Image window will change from Radiograph 1 to Variable Angle 335.00)

10. Close the Variable Angle Setup Window

C.8. Special Point Reconstruction (Patient Points or Marking Points)

1. Radiograph Reconstruction (Orthogonal, Semi-Orthogonal, Isocentric, or Variable Angle) procedures must be performed prior to beginning this procedure

2. Select "Define Special Points" in the Reconstruction Menu

3. In the Special Points Window:

    - Choose Type = Patient Points or Marking Points
    - Choose Mode = Append

4. Activate first radiograph to be used for special point reconstruction

5. Digitize appropriate patient points on first radiograph (i.e. Bladder, Rectum, Rt. Ext., etc.)

    - Enter the "Name" corresponding to each digitized point in the input field

6. Activate second radiograph to be used for special point reconstruction

7. Digitize the same patient points on the second radiograph, in the same sequence, as on the first radiograph

    - Observe and evaluate the patient shift values (mm)

8. Close the Special Points Window

NOTE 1: If Special (Patient) Point Reconstruction and Catheter Reconstruction are not performed from the same set of radiographs, you must follow Setup and Initiation of Radiograph Reconstruction steps and Reconstruction (Orthogonal, Semi-Orthogonal, Isocentric, or Variable Angle) procedures before beginning the Catheter Reconstruction procedures.

NOTE 2: If problems occur during any of the reconstruction phases, concerning inaccurate reconstruction lengths or shifts beyond allowable limits, you can view the results to determine the location of the problem by selecting "Show Results" in the View Menu.

C.9. Catheter Reconstruction

1. Radiograph Reconstruction (Orthogonal, Semi-Orthogonal, Isocentric, or Variable Angle) procedures must be performed prior to beginning this procedure

2. Select "Catheter Describing Points" in the Reconstruction Menu

3. Choose Mode = Append

4. Set Catheter = 1

5. Using the mouse, select dwell positions for Reconstruction (i.e. 1, 3, 5, etc.) in the input field

6. Increase Catheter # and repeat

7. Digitize the selected dwell positions on each radiograph (i.e. AP and LAT or RAO and LAO)

8. Remember to increase the catheter number as you digitize

9. Select "OK"

NOTE 1: If Special (Patient) Point Reconstruction and Catheter Reconstruction are not performed from the same set of radiographs, you must follow Setup and Initiation of Radiograph Reconstruction steps and Reconstruction (Orthogonal, Semi-Orthogonal, Isocentric, or Variable Angle) procedures before beginning the Catheter Reconstruction procedures.

NOTE 2: If problems occur during any of the reconstruction phases, concerning inaccurate reconstruction lengths or shifts beyond allowable limits, you can view the results to determine the location of the problem by selecting "Show Results" in the View Menu.

C.10. Define Applicator Coordinate System

NOTE: The applicator coordinate system is defined on the same set of radiographs used for catheter reconstruction

1. Select "Define Applicator Coordinate System" in the Reconstruction Menu

2. Activate the first radiograph used for Catheter Reconstruction

3. Digitize the *dose distribution origin* and *a point for the y-axis direction* (any point on the y-axis)

   NOTE: + y will always be oriented toward the head of the patient in PLATO, as long as the radiographs are positioned on the digitizer tablet as indicated in the Brachytherapy Treatment Planning Prerequisite instructions.

4. Select Applicator Coordinate System Definition with X-axis direction:

   - Parallel to Table
   - Rotated About the Applicator Y-axis
   - From Two Points

   <u>If "From Two Points" is chosen</u>:

   - Define the direction of the applicator coordinate system's x-axis: Using the mouse, mark two points to define the x-axis
   - Two blue circles will appear in the image window where the two points are placed

   <u>If "Rotated About Applicator Y-axis" is chosen</u>:

   - Enter rotation angle

5. Select "Close" in the Edit Menu for each open radiograph window

6. Exit Reconstruction by Selecting "Close" in the Images Menu

NOTE: If problems occur during any of the reconstruction phases, concerning inaccurate reconstruction lengths or shifts beyond allowable limits, you can view the results to determine the location of the problem by selecting "Show Results" in the View Menu.

C.11. Dose Distribution Procedures

NOTE: All reconstruction (Special Patient Point and/or Catheter Reconstruction) procedures must be completed prior to beginning Dose Distribution procedures.

Activating Dose Distribution:

1. Select "Dose Distribution" in the Planning Menu
2. Select Planes (3D View, X=0, Y=0, and Z=0)
3. If you want to view other planes, select "Define Planes" in the Isodose Calculation Menu
   - Select "Orthogonal" or "Oblique"
   - Select perpendicular to the "X, Y, or Z" axis
   - Enter offset from origin in mm
   - Select "Define"
   - Select "Close" in the Define Plane Window

   NOTE: No more than 4 active views are allowed at one time

Defining Active Source Positions:

1. Select "Source Positions" in the Isodose Calculation Menu
2. Select "Active" button
3. Select Step = 1, 2, etc. (Step = 1 activates every dwell, Step = 2 activates every-other dwell, etc.)
4. Select positions on each catheter to activate desired dwell positions (hold shift down, click and drag)
5. Verify Indexer Length = 995 mm
6. Verify Stepsize (source position separation) = 5 mm
7. Select "OK"

Defining Applicator Points: (i.e. RTA and LTA)

1. Select "Define Applicator Points" in the Isodose Calculation Menu
2. Select "Append" in the Edit Menu (repeat for additional points)
3. Enter name and coordinates of each applicator point
   (i.e. RTA -20, 25, 0; LTA 20, 25, 0)
4. Select "OK"

C.12. Defining Dose Points

1. Select "Define Dose Points" in the Isodose Calculation Menu and select one of the following: "Oriented to Axis" , "Oriented to Catheter", or "By Coordinates"

<u>If Dose Points Oriented to Axis is chosen:</u>

1. Select catheter number
2. Select axis = "X, Y, or Z"
3. Enter coordinate in mm
4. Select source positions for orientation
5. Select "Apply" individually per position or select "All Active"
6. Select "Close"

<u>If Dose Points Oriented to Catheter is chosen:</u>

1. Select catheter number
2. Select axis = "U, V, or W"
3. Enter coordinate in mm
4. Select source positions for orientation
5. Select "Apply" individually per position or select "All Active"
6. Select "Close"

<u>If Dose Points By Coordinates is chosen:</u>

1. Edit "Append"
2. Enter coordinates
3. Select "OK"

C.13. Normalization, Dose Prescription, and Weighting

Select "Normalization" in Isodose Calculation Menu and select one of the following:

1. "On a Reference Point"
2. "On Applicator Points"
3. "On Patient Points"
4. "On Dose Points Oriented to Catheter"
5. "On Dose Points Oriented to Axis"
6. "On Dose Points by Coordinates"

NOTE: Once Normalization on Dose Points Oriented to Catheter, Normalization on Dose Points Oriented to Axis, or Normalization on Dose Points by Coordinates is selected under "Normalization" in the Isodose Calculation Menu, no further steps are necessary to carry out the normalization.

Normalization on a Reference Point:

1. Position the reference point using the mouse in one of the X, Y, and Z windows and depress the left mouse button at desired location and select "OK"

Normalization on Applicator Points:

1. Select applicator point(s) to normalize to (i.e. A1 and A2) and select "OK"

Normalization on Patient Points:

1. Select patient point(s) to normalize to (i.e. bladder, rectum, etc.) and select "OK"

Dose Prescription:

1. Select "Dose Prescription" in Isodose Calculation Menu
2. Enter "Reference Isodose %"
3. Enter "Reference Dose cGy"
4. Confirm Treatment Date and Treatment Start Time and select "OK"

Source Times and Catheter/Dwell Weighting:

1. Select "Source Times" in the Isodose Calculation Menu
2. Select catheter number and move histogram bars of appropriate source positions to desired "relative source time" per dwell and select "OK"

C.14. Translation and Rotation of Catheter(s)

1. Select "Coordinate System" in the Isodose Calculation Menu
2. Select "Create Coordinate System"
    - Open windows back up
3. Drag cross wires to desired location with mouse
4. Rotate by clicking on the (+ or -) x, y, or z axis at any point and drag it to the desired angle
5. Select 'Define"
6. All other windows will be updated

NOTE 1: To translate or rotate again, repeat step 1 and then select "Update Coordinate System". Continue by repeating steps 3 through 6.

NOTE 2: You may return to a previously defined coordinate system by repeating steps 1 through 3 and then selecting "World, Applicator, or Interactive" from the list.

C.15. Concluding the Treatment Planning Procedures

At this point, you will need to evaluate your treatment planning from the results displayed in the Plan Evaluation Menu as well as by viewing the resulting isodose distributions.

Plan Evaluation:

1. The options listed below may be viewed by selecting them:

   - Dose to patient points
   - Dose to marking points
   - Dose to applicator points
   - Dose to dose points
   - Source times
   - Plan
   - Journal

View Options for Isodose Curve Plots:

1. Select "View Options" in the View Menu of the Dose Distribution Module

2. View options available for selection include the following:

   - Patient points
   - Marking points
   - Reference points
   - Dose points
   - Applicator points
   - Show sources
   - cm dots
   - Show plane
   - Absolute dose

Adding or Deleting Isodose Lines:

1. Select "Isodose Lines" in the View Menu

2. Enter % isodose line value(s) desired

3. Select "Add" or "Delete"

4. Select "Apply"

Viewing the Plan Status:

1. Select "Plan Status Window" in the View Menu

2. This window tells you which stages of planning have been completed indicated by highlighting of the appropriate fields

NOTE: When you have carried out all of the procedures necessary to complete a treatment plan, the Output Menu must then be followed.

C.16. Obtaining Treatment Output

Treatment Plots and Print-Outs:

1. Check that the plotter and printer are switched on and that the ready lights are on
2. Select "A3 Plot" in Output Menu
3. Select "Print Plan" in Output Menu
4. Select "Print Journal" in Output Menu

Program Card:

1. Select "Program Card" in Output Menu
2. Select "Write Program Card"
3. Set catheters and channels
4. Select "Write"

Exiting Treatment Planning:

1. When planning is complete, select "Close" in the Standard Settings Menu
2. Select "Store" under the File Menu
   - Type the name of the plan in the "Save Plan As" field and select "OK"
3. Select "Exit" in the File Menu
4. Click on the highlighted "Exit Button" in the Patient Info Window
5. Select Log Out in the System Menu then click "Yes" for the question, "Do you really want to log out now?"

Power Down:

1. Select Shutdown in the System Menu then click "Yes" for the question "Do you really want to shut the system down now?"
2. Once music sounds, turn off computer (the switch is on the back of the CPU)
3. Turn off (2) switches at right side of light box
4. Turn off power strip on floor below plotter

APPENDIX D

THESIS DEFENSE PRESENTATION

Appendix D includes the thesis defense presentation slides for the Commissioning and Evaluation of the PLATO - Brachytherapy Planning System.

Commissioning and Evaluation of the PLATO - Brachytherapy Planning System

Thesis Defense Presentation in Nuclear Science and Engineering (Medical Physics Option)

By: Angela Marie Stam

March 26, 1998

PLATO

- "**Pla**nning and **T**reatment **O**ptimization"
- System Developed by the Nucletron Corporation
- Used to calculate dose distributions around an Ir-192 stepping source
- Designed to facilitate treatment planning for use in conjunction with the Nucletron microSelectron remote afterloading unit

Brachytherapy

- Definition: local delivery of radiation to a tumor with rapid dose fall-off in the surrounding healthy tissue
- Multiple steps are involved
- Uncertainties can accumulate and effect the outcome of patients treatment
  - Cure rate and radiation induced complications
- It is therefore vital to follow a comprehensive commissioning and continued QA program for brachytherapy treatment planning computers

Objectives

1 Commission the PLATO Brachytherapy Planning System for clinical use at MBPCC

2 Investigate & Evaluate the strengths & weaknesses:

- PLATO
- Nucletron Planning System (NPS)
- Determine which system is overall superior

3 Replace NPS with PLATO Brachytherapy Planning System

Commissioning

- User: little if any direct input in algorithm
- Verify algorithm: tests of the output
  - finite range of clinical conditions
  - simple cases to rare and unusual circumstances
- Output: evaluated for quality and accuracy
- Cannot test every parameter and situation
- "Degree of confidence" in the computer program
  - uncertainties & limitations

Reproducibility of Dose Point Calculations in cGy Using a Slow, Relaxed Technique

Trial #	Dose to Point (cGy) Digitized at Varying Distances from Source							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	606.5	134.6	35.7	15.5	8.5	3.9	2.1	1.4
2	559.8	145.7	33.6	15.3	8.5	3.8	2.1	1.4
3	791.6	140.0	34.3	15.1	8.7	3.8	2.2	1.4
4	786.3	139.7	36.4	15.5	8.8	3.8	2.2	1.4
5	856.1	145.2	36.4	15.7	8.6	3.9	2.2	1.4
6	784.0	158.2	32.9	15.5	8.4	3.9	2.1	1.4
7	714.8	145.7	37.2	16.2	8.6	3.9	2.1	1.4
Average	728.4	144.2	35.2	15.5	8.6	3.9	2.1	1.4
Standard Deviation	± 108.2	± 7.4	± 1.6	± 0.3	± 0.1	± 0.1	± 0.1	0
% Error in Dose	14.9	5.1	4.5	1.9	1.2	2.6	4.8	0

Reproducibility of Dose Point Calculations in cGy Using a Fast, Stressed Technique

Trial #	Dose to Point (cGy) Digitized at Varying Distances from Source							
	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	856.2	145.1	39.5	15.3	8.8	3.9	2.2	1.4
2	606.3	131.7	36.4	15.2	8.6	3.8	2.2	1.4
3	1216.2	133.7	37.1	15.5	8.8	3.9	2.2	1.4
4	607.8	145.6	35.0	16.2	8.7	3.9	2.1	1.4
5	771.8	128.9	37.1	15.7	8.9	3.9	2.1	1.4
6	707.3	134.3	33.6	15.6	8.9	3.9	2.2	1.4
7	625.2	137.0	34.3	15.1	8.9	3.8	2.2	1.4
Average	770.1	136.6	36.1	15.5	8.8	3.9	2.2	1.4
Standard Deviation	± 217.8	± 6.5	± 2.0	± 0.4	± 0.1	0	0	0
% Error in Dose	28.3	4.8	5.5	2.6	1.1	0	0	0

Standard Deviations in Dose (cGy) at Known Distances for Volunteer Users

Volunteer	2 mm	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm	50 mm
1	±236.3	±9.6	±1.1	±0.8	±0.3	±0.1	0	0
2	±346.6	±17.9	±2.6	±0.4	±0.3	±0.1	±0.1	0
3	±117.8	±15.3	±2.5	±0.6	±0.2	±0.1	0	0
4	±378.8	±14.6	±2.5	±0.5	±0.3	±0.1	±0.1	0

Dose Point Reproducibility Results

- Digitizing errors (human) gave large errors in dose at distances < 5 mm
- Small digitizing errors result in large variations in dose at short distances from the source
- High Dose Gradient
- Guidelines for input & output devices: 1 mm
  - humans should not be expected to digitize better than 1 mm
- Dose should not be prescribed at distances less than 5 mm

Verification of Calculational Method of PLATO

- Perform Manual Dose Point Calculations
  - "Manual" - without the aid of the treatment planning system
  - Spreadsheet Calculation
  - Distance from coordinates (2 to 50 mm)
  - Trial 1-7
- Compare Manual against PLATO Calculation Results
- Calculate Error Ratio:

$$\text{Error Ratio (\%)} = \frac{\text{PLATO (cGy)} - \text{Manual (cGy)}}{\text{Manual (cGy)}} * 100$$

Comparison of Dose Point Calculations: Manual vs PLATO-BPS (Trial #1)

Calculated Distance From Source to Dose Point (mm)	PLATO Calculation of D_p (cGy)	Manual Calculation of D_p (cGy)	Error Ratio (%)
2.4	606.5	603.1	0.6
5.1	134.6	133.9	0.5
9.9	35.7	35.5	0.5
15.0	15.5	15.5	0
20.3	8.5	8.4	0.7
29.9	3.9	3.9	0
40.2	2.1	2.1	0
50.1	1.4	1.4	0

Verification of Calculational Method Results

- Observations:
  - PLATO-BPS shows excellent agreement with manual calculations
  - Dose at all distances meet the criterion of acceptability of 5.0% dose accuracy
  - all points within 1% (max error ratio = 0.7 %)
- Conclusions:
  - Calculational method of PLATO is accurate and verified

Verification of PLATO Algorithm

- 13 Treatment Plan Cases
  - Clinical Cases and Nucletron Supplied Cases
  - Range of Testing Parameters
    - Treatment Sites / Applicator Types
    - Reconstruction Methods
    - Optimization Methods
- Compare Plans Against Other Systems:
  - Nucletron Planning System (NPS - BPS)
  - Capintec RTP110 Cap Plan - LDR
  - Theraplan V05B - LDR
  - MBPCC Developed Spreadsheet Program

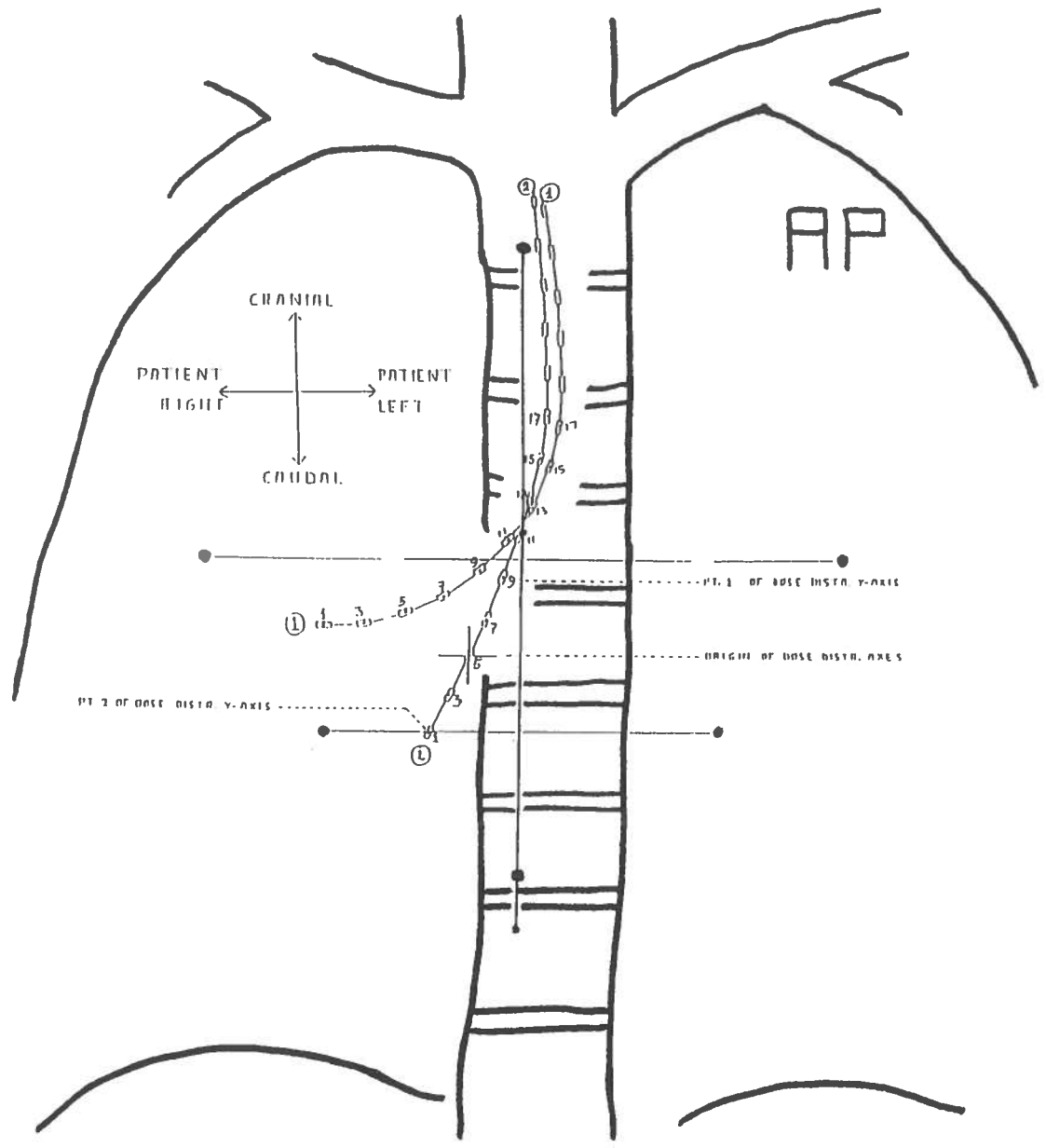

Figure D.8 AP Radiograph (2 Catheter Endobronchial Case)

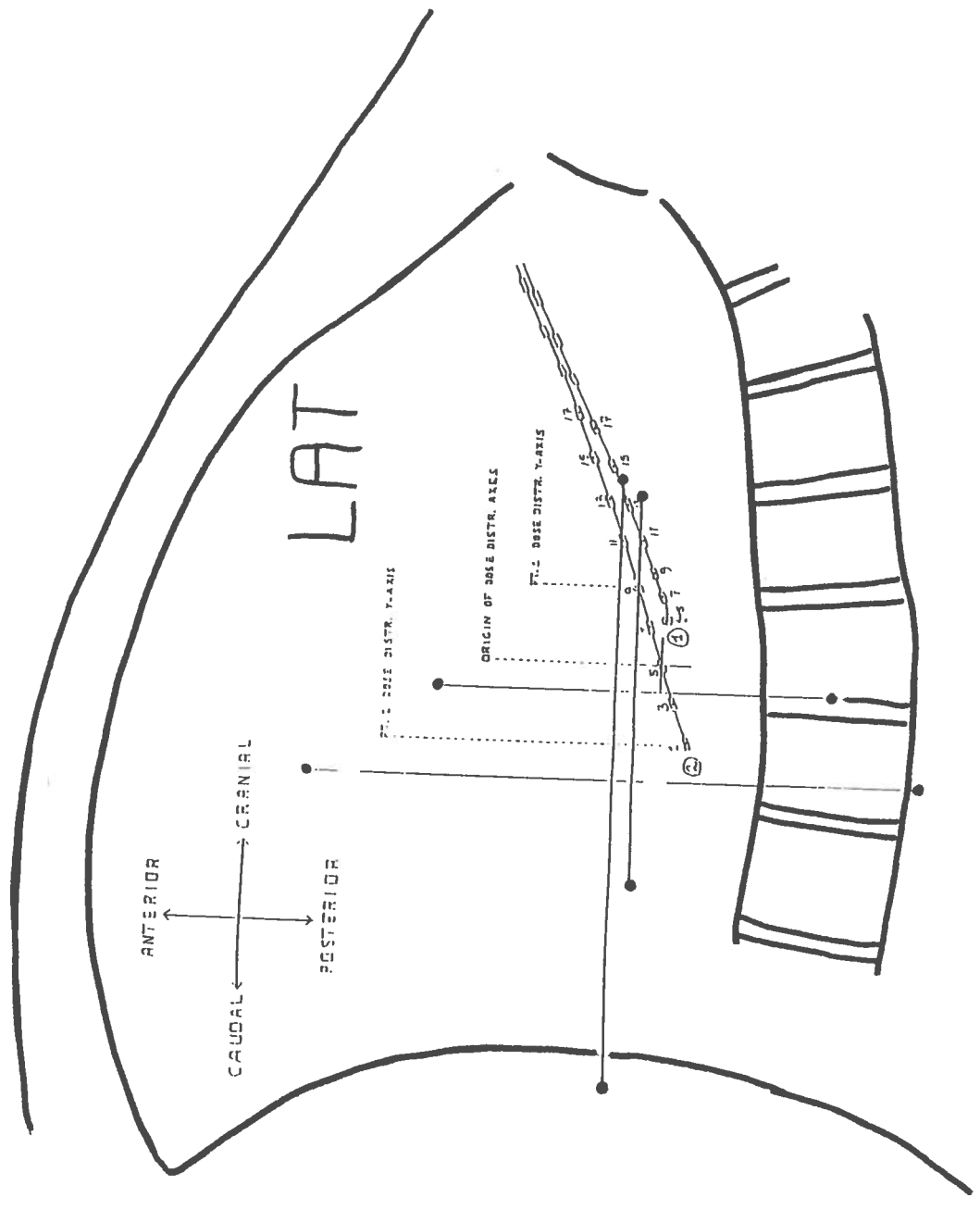

Figure D.9 Lateral Radiograph (2 Catheter Endobronchial Case)

Comparisons

- Compare results respect to spatial accuracy for equal isodose levels
  - ± 3.0 mm spatial accuracy
- Overlay isodose distributions
- Physically measure distances from origin of dose distribution axis to point(s) at which the prescribed isodose line intersects each axis

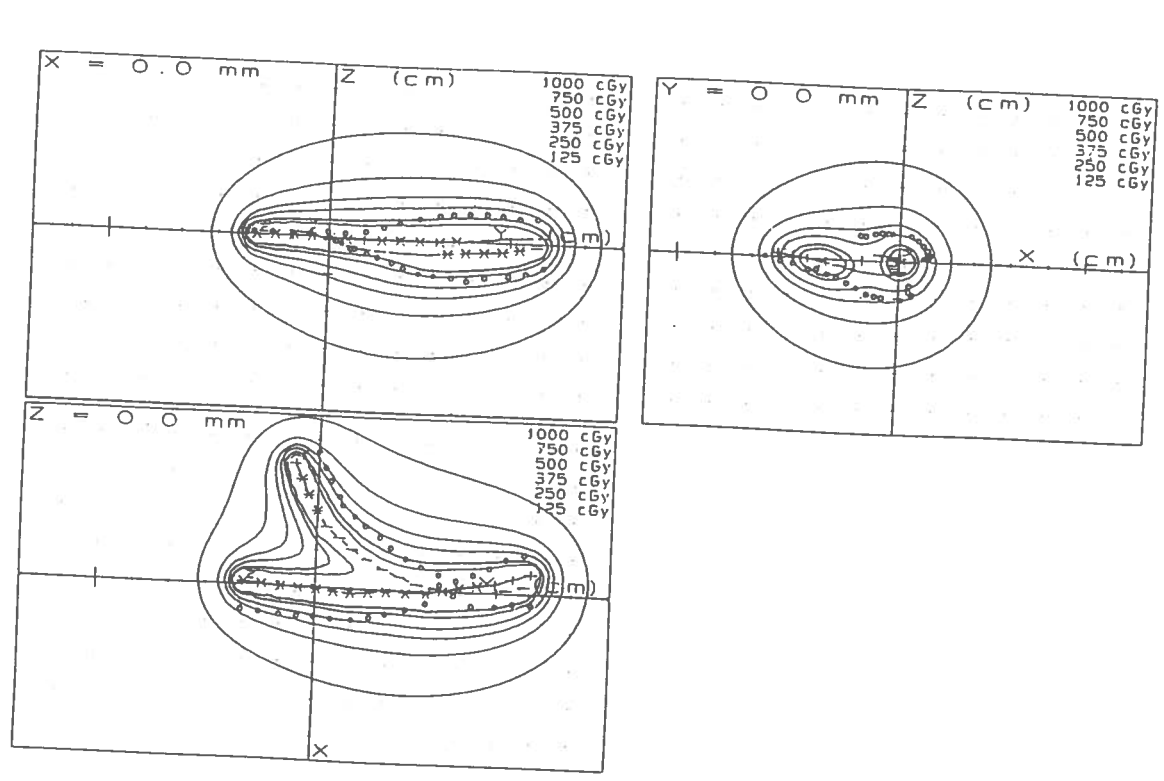

Figure D.10 Isodose Distributions for a 2 Catheter Endobronchial Case

Comparison of Treatment Planning Computer Results: 2 Catheter Endobronchial Case

Brachytherapy Treatment Planning System	Prescribed Isodose Line at +X axis (mm)	Prescribed Isodose Line at +Y axis (mm)	Prescribed Isodose Line at + Z axis (mm)
PLATO	$X_P = 10$	$Y_P = 51$	$Z_P = 12$
NPS	$X_N = 10$	$Y_N = 51$	$Z_N = 12$

Verification of PLATO Algorithm Results

- Excellent agreement between all five treatment planning systems
- All Isodose Comparisons Met Criterion of $\pm$ 3 mm
- All Isodose Comparisons were within + 1 mm
- PLATO Algorithm is accurate and verified

Evaluation of the PLATO and NPS BPSs

- Investigate the strengths and weaknesses
- Compare
  - Ease of Data Entry (speed)
  - Ability to Make Corrections
  - Graphics Quality
  - Planning Options
  - Ability to Manipulate Data
- Determine "Overall Superior" BPS
- Prepare Instruction Manual
- Train & Provide Support to Treatment Planning Staff on PLATO -BPS to ensure proper use of the algorithm

NPS & PLATO Evaluation Results

NPS

Pros

- Applicator Shielding

Cons

- FORTRAN based program
- Not "User Friendly"
- Correction of Errors - Backstepping
  - difficult & has required plans to be aborted
- Poor Graphics Quality (2D)
- Rotation & Translation of Applicators - keystroke driven
- cm grid not aligned with axes

PLATO

Pros

- X-Windows - UNIX Environment
- "User Friendly"
- Correction of Errors - mouse driven
- Enhanced Graphics Capabilities
  - 3D viewing of applicators
- Rotation & Translation of Applicators - mouse driven
- Audible alert for digitizing corresponding points

Cons

- No Applicator Shielding

Discussion & Conclusions

- PLATO Dose Point Calculations vs Manual Calculations Met Criterion of $\pm$ 5%
- PLATO Isodose Comparisons b/w Planning Systems Met Criterion of $\leq$ 3 mm
- Overall, PLATO Evaluates as a Superior BPS Compared to NPS
  - NPS - Applicator Shielding (Coming Soon to PLATO)
  - Shielded Cases are Rare
- Proper Training
  - Reduce Patient Table Time
  - Reduce Prolonged Patient Discomfort
- Recommendation: PLATO replace the existing NPS for Clinical HDR Brachytherapy Treatment Planning at MBPCC.

VITA

Angela Marie Stam was born on January 6, 1971 in Faribault, Minnesota. She attended Denham Springs High School in Denham Springs, Louisiana, and graduated in May of 1989. She obtained her bachelor's degree in Microbiology with a Chemistry minor in December of 1993, from Louisiana State University in Baton Rouge, Louisiana. She entered graduate school in August of 1994 and received a graduate assistantship at Louisiana State University. She is currently a candidate for a master of science degree in Nuclear Science and Engineering, Medical Physics Option, which will be awarded in May of 1998.

MASTER'S EXAMINATION AND THESIS REPORT

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Major Field: Nuclear Science and Engineering

Title of Thesis: Commissioning and Evaluation of the PLATO - Brachytherapy Planning System

Approved:

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Date of Examination:

March 26, 1998