MCNP MODELING OF PROSTATE BRACHYTHERAPY AND ORGAN DOSIMETRY

A Thesis

by

SUSRUT RAJANIKANT USGAONKER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2003

Major Subject: Health Physics

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Approved as to style and content by:

John W. Poston Sr. (Chair of Committee)	Ian S. Hamilton (Member)
Michael Walker (Member)	William Burchill (Head of Department)

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ABSTRACT

MCNP Modeling of Prostate Brachytherapy and Organ Dosimetry. (May 2003)

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Chair of Advisory Committee: Dr. John W. Poston Sr.

Using the computer code Monte Carlo N-Particle (MCNP), doses were calculated for organs of interest such as the large intestine, urinary bladder, testes, and kidneys while patients were undergoing prostate brachytherapy. This research is important because the doses delivered to the prostate are extremely high and the organs near the prostate are potentially at risk for receiving high doses of radiation, leading to increased probabilities of adverse health effects such as cancer. In this research, two MCNP version 4C codes were used to calculate the imparted energies to the organs of interest delivered by ^{125}I and ^{103}Pd. As expected, the organs nearest to the prostate received the highest energy depositions and the organs farthest from the prostate received the lowest energy depositions. Once the energy depositions were calculated, the doses to the organs were calculated using the known volumes and densities of the organs. Finally, the doses to the organs over an infinite time period were calculated.

DEDICATION

I dedicate this work to my parents, Drs. Rajanikant S. and Rajani R. Usgaonker, my brother, Ajay R. Usgaonker, and his wife, Madhavi “Sonal” A. Usgaonker who have all provided their support for me throughout the course of my graduate studies at Texas A&M University and my research.

ACKNOWLEDGEMENTS

I would like to thank the following individuals for their assistance that led to the successful completion of this research and this thesis:

- Dr. John W. Poston Sr., for serving as my graduate committee chair and assisting with my admission into the graduate program in Health Physics in the Department of Nuclear Engineering and providing the assistance and support for my project;
- Dr. Ian S. Hamilton for providing Sabrina Bodybuilder, which provided invaluable assistance in creating the male phantom necessary for the modeling, cutting the time necessary to complete the project immensely;
- Dr. Michael Walker for serving on my committee and providing support for the project;
- Dr. John Ford, Dr. Leslie Braby, and Dr. Daniel W. Reece for answering research related questions; and
- Matthew G. Arno, Md. Nasir Uddin Bhuiyan, and Frank Szakaly for assisting with debugging the codes, leading to the successful completion of the execution of the programs.

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CHAPTER I

INTRODUCTION

OBJECTIVES

The objective of this research was to determine the radiation-absorbed doses to the organs that were likely to receive significant doses from the implantation of radioactive brachytherapy seeds in the prostate. This was achieved by using computer codes that were executed with Monte Carlo N-Particle (MCNP) to calculate the doses to the organs of interest (Briesmeister 2000).

BENEFITS VS. RISKS

For many decades, radiation has been beneficial in both diagnostic and therapeutic nuclear medicine. Radiation has been used to diagnose and treat cancer with processes such as ablation (as in ^{131}I therapy used to treat thyroid cancer), brachytherapy, and external beam therapy.

One of the most effective radiation therapies is prostate brachytherapy. Brachytherapy has been a successful mode of treatment for prostate cancer for years. Although other options such as surgery and external beam therapy exist, brachytherapy has been the best at preventing reoccurring tumors. Prostate brachytherapy involves the permanent placement in the prostate gland of radioactive seeds, which emit energetic particles through radioactive decay by modes of electron capture and emission of photons. These energetic particles irradiate the internal tissues of the prostate,

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This thesis follows the style and format of Health Physics.

[1] Personal Communication: Dr. George Warner, May 2002.

diminishing the volume of the tumor and killing the cancer cells, preventing them from reoccurring[1].

The seeds used in prostate brachytherapy are iodine-125 (^{125}I) and palladium-103 (^{103}Pd). These two radionuclides have relatively long half-lives compared to most radiopharmaceuticals: 59.4 days for ^{125}I and 16.99 days for ^{103}Pd (Chart of the Nuclides 1996). Both seeds are about the size of rice grains and are about 4.5 mm long and about 0.8 mm in diameter. The ^{125}I seeds consist of 0.05 mm thick titanium walls with welded ends and silver markers that are surrounded by ^{125}I (Nath, et al. 1995). The ^{103}Pd seeds also consist of 0.05 mm thick titanium walls, but contain lead x-ray markers instead of silver markers (Meigooni, et al. 1990).

The long-term benefit of undergoing this treatment is the minimized probability of reoccurring tumors, adding years to the patients' lives and allowing them to proceed with their regular daily activities. Although there are significant benefits to undergoing this therapy, there are also certain issues that must be considered. These issues include side effects and radiation safety. The focus of this research is to the dose delivered to other organs while undergoing this therapy, since the seeds are permanently implanted in the gland. The doses delivered to the prostate are large and can be as high as 145 gray (Gy) in typical treatments.

This research is important because, since the radiation dose to the prostate is large, the neighboring organs (i.e., urinary bladder and genitalia) are at risk of receiving high radiation doses. Areas such as the pelvis, kidneys, stomach, lungs, and organs in the lower portions of the trunk of the body, as well as certain organs in the upper portions of the trunk, may receive significant doses from the prostate treatment.

One disadvantage of prostate brachytherapy is that healthy prostate cells are killed along with cancerous cells. As a result of irradiation of the prostate gland, the neighboring genitalia and urinary bladder are likely to be damaged. One potential risk for some men is impotence since the radiation penetrates through the prostate and irradiates the cells in the testicles, preventing the production of sperm. Although this effect is not desirable, patients give it less consideration when comparing it to the importance of living a long and cancer-free life. Also, the patients generally are older men past the age of active procreation.

SIGNIFICANCE OF THE RESEARCH

The significance of this research is that doses to internal organs can be determined. Organs such as the urinary bladder and the genitalia are likely to receive the highest doses from the therapy, since they border the prostate gland. However, many consider the benefits of brachytherapy to greatly outweigh the risks of late effects.

Because of the complexities of using humans to determine doses to internal organs from prostate brachytherapy, using the computer code MCNP in modeling the energy deposition in the organs from brachytherapy would be appropriate. Doses to the internal organs can be determined using an MCNP code, based on actual brachytherapy cases.

CHAPTER II

THEORY

THE PROSTATE GLAND

The prostate gland is a partly muscular, partly glandular organ located distal to the neck of the urinary bladder and proximal to the penis. The gland surrounds the proximal urethra within the pelvic cavity, dorsal to the symphysis pubis and ventral to the deep layer of the triangular ligament, while immediately adjacent to the rectum. The prostate has an ellipsoidal shape and normally is about the size of a chestnut. The glandular part of the prostate consists of epithelial follicular pouches. The prostate has arteries originating in the internal pudic, vesicle, and haemorrhoidal areas. The veins form a plexus around the sides and the base of the gland. The nerves to the prostate originate from the pelvis plexus (Gray 1995).

The prostate is an essential organ in the male reproductive system that produces the fluid in semen, which is ejaculated during sexual intercourse and delivers many sperm into the female vagina while the penis is erect. The fluid is alkaline to protect the sperm from the acidity of the vagina as they travel to the female ovum. The prostate is also an essential organ for the production of male hormones such as androgens (Marieb 1998).

PROSTATE CANCER

Prostate cancer is the second most common neoplasm in males over the age of 50 (Handbook of Diseases 2000). The most common form of prostate cancer is adenocarcinoma, with sarcoma rarely occurring. Most of the tumors originate in the posterior prostate gland, while the rest originate near the urethra. When the prostate lesions metastasize, they invade the prostate capsule and spread along the ejaculatory ducts between the seminal vesicles or perivesicular fascia (Handbook of Diseases 2000).

In men, prostate cancer accounts for about 18% of all cancers. The incidence of prostate cancer is highest in blacks and lowest in the Asian populations. The symptoms of prostate cancer are difficulty in urinating, urine retention, and unexplained cystitis. The American Cancer Society recommends that men over the age of 40 receive a yearly digital examination. For men above the age of 50, it is recommended that blood tests be performed to detect the prostate specific antigen (PSA). Biopsies are used to detect malignant tumors in the prostate. Elevated PSA levels may be significant because serum phosphatase levels are increased in two-thirds of men with metastatic prostate cancers. The treatment options available are radiation, hormone therapy, and surgery. If these options are not effective, many physicians opt for the use of chemotherapy (Handbook of Diseases 2000).

PROSTATE BRACHYTHERAPY

Interstitial brachytherapy has received high interest due to the use of ultrasound to guide seed implantation, improved radionuclides for dose delivery, excellent treatment planning software for dosimetric calculations, and efficient implantations. Due to these factors, the use of brachytherapy implants in prostates is expected to increase (Vicini, et al. 1999). According to the American Brachytherapy Society (ABS), the dose distributions after implantation often differ from the planned doses before implantation. For this reason, ABS recommends that a postimplant dosimetric assessment be performed so those actual doses to the prostate and adjacent tissues over the treatment period can be documented. Using these dosimetry results, physicians can assess and modify implantation techniques and compare results with other institutions as quality assurance for clinical trials (Nag, et al. 2000).

A drawback to this treatment is the need for customized treatments for different patients. The main objective in prostate brachytherapy is to irradiate the entire prostate, in addition to a margin to take into account seed displacement and potential extracapsular disease extension (ECE). In most cases, the ECE is within 3 mm from the prostate edge. Usually, the seeds are not implanted perfectly, causing implant-related prostate swelling. Because of the relationship between the linear prostate dimensions and volume, there is a need for customized treatment planning for different patients. As the prostate volume increases, the prostate linear dimensions changes gradually (Ove, et al. 2001).

The process of prostate brachytherapy requires the services of a radiation dosimetrist. Once the dosimetrist determines the placement, and activity of the radioactive seeds, and the duration of the implant, a radiation oncologist follows the dosimetrist's plans and places the seeds into the prostate. Prior to the implantation of the seeds, the patient is given guidelines regarding side effects and minimizing radiation exposure of his family.

After implantation, computed tomography (CT) scans are usually performed for dosimetric analysis. The challenge with CT scans is that post-implant edema usually increases the prostate volume by over 50%. With a typical half-life of 9 days, the edema decreases exponentially with time (Waterman & Dicker 1999).

The side effects of this treatment are fatigue, skin reactions such as bruising, frequent and painful urination, diarrhea, and rectal bleeding. According to one study, rectal bleeding or ulceration was associated with treatments with doses over 100 Gy to the prostate as the sources irradiated the rectal wall (Waterman & Dicker 1999). Although not as frequent as from surgeries, prostate brachytherapy can lead to temporary impotence and incontinence. Many patients, however, have urinary problems such as polyuria, urgency, incomplete voiding, straining, and nocturia. Acute urinary retention occurs in approximately 3%-22% of the patients that undergo prostate brachytherapy (Merrick, et al. 2000). Once the treatment is complete, these side effects typically diminish[2].

As stated above, the brachytherapy process begins with the dosimetrist who plans the outline of the seed placement. First, the dosimetrist obtains an ultrasound recording of the patient's prostate. Using computer software, the dosimetrist examines the prostate and places a two dimensional grid on the prostate image, with the center of the grid placed directly over the center of the gland. The dosimetrist takes the three-dimensional organ and creates multiple ultrasound views of the prostate from all sides. Then, each of the ultrasound views of the prostate is outlined to create two-dimensional surfaces[3].

[2] Personal Communication: Dr. George Warner, May 2002.

[3] Personal Communication: Mrs. Elizabeth Dodge, July 2002.

After the dosimetrist maps the prostate from various views, computer software is used to determine the seed placement. The default seed placement is dependent on the size of the prostate and will usually place more seeds and/or needle insertions on larger prostates. Once the default seeds are displayed, isodose curves appear. The main objective of the dosimetrist is to ensure that the entire prostate is adequately irradiated without delivering a significant dose to certain critical areas beyond the prostate. Thus, the seeds, with the needles, are distributed appropriately so that the isodose curve surrounds the prostate gland and goes beyond the prostate only by about 3-4 mm. The dosimetrist tries to minimize radiation doses to the urethra and the rectal area. The dosimetrist places the seeds external to the prostatic urethra[4].

In interstitial brachytherapy planning, dose homogeneity is desired to uniformly irradiate the target tissues. Many methods have been used, such as the "inverse dose-rate effect" and less dose distribution to the urethra and rectum (D'Souza & Meyer 2001). Treatment planning for prostate brachytherapy is performed by assuming that the seeds are point source emitters in a homogeneous phantom. In the study of planning procedures, a Task Group report (TG-43) with dosimetric protocols was used to standardize dosimetric parameters for specific seed designs, which were measured in water (DeMarco, et al.1999).

Sample seed placements for ^{125}I and ^{103}Pd seeds are given in Figs. 1 and 2, respectively (provided courtesy of Elizabeth Dodge of Cancer Therapy and Research Center [CTRC], San Antonio). These two examples were for patients with different

[4] Personal Communication: Mrs. Elizabeth Dodge, July 2002.

prostate sizes, leading to slight differences in their therapies. These figures show two-dimensional seed placements on the prostate cross-section. For purposes of this research, these sample distributions were used in the MCNP codes for calculating the doses to the critical organs from these two sources. The geometrical shapes represent the different retractions of the needle placements. These retractions are the distances from the prostate surface where the needles are to be inserted to implant the seeds. The numbers inside each of the needle placements represent the number of seeds in those needles. As stated above, these arrangements were based on the isodose curve, which is calculated by the dosimetrist[5].

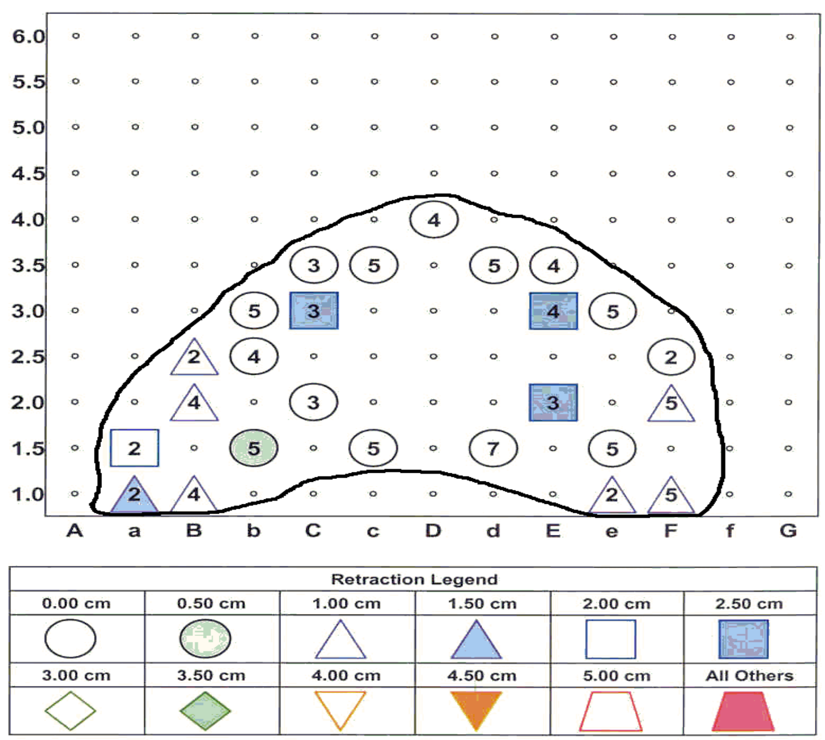

Fig. 1: Seed placement in prostate cross section (^{125}I)

[5] Personal Communication: Mrs. Elizabeth Dodge, July 2002.

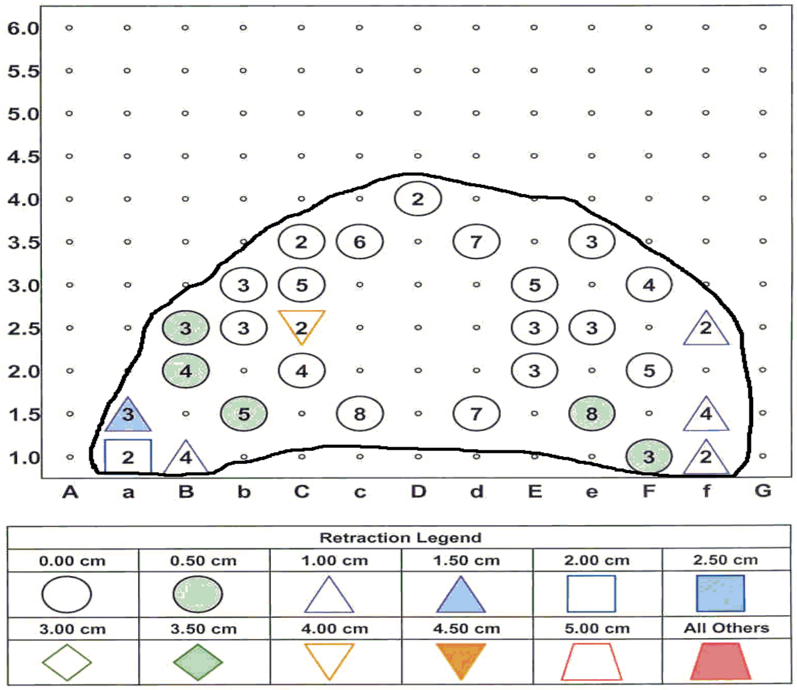

Fig. 2: Seed placement in prostate cross section (^{103}Pd)

This seed arrangement ensures that the entire prostate is irradiated while restricting the dose outside the surface of the gland. These figures show the seeds in the needles as they are placed into the prostate as well as the retraction of some of the placements. The retraction refers to the depth from the prostate surface at which the seeds are implanted. The urethra passes through the cross-section of the prostate, which is the reason for placing the seeds peripherally. The region at the bottom of the prostate, just below the prostate's fold, is the area that rests on the rectum. Once the dosimetrist determines the seed placement in the prostate with the number of seeds per needle, and the activity per seed, the seeds and needles are ordered.

The dose delivered to the prostate during brachytherapy is generally large. The placement of the seeds is highly dependent on the size of the prostate. For the ^{125}I example, there were 25 needles used with a total of 98 seeds, each with an activity of 0.31 mCi. For the ^{103}Pd example, there were 29 needles used with a total of 115 seeds, each with an activity of 1.4 mCi. Since the seeds remain in the prostate, the dose represents that delivered by the "total decay" of the radionuclide.

ULTRASOUND GRAPHS OF THE SEEDS IN PROSTATE

For the cases shown in Figs. 1 and 2, ultrasound graphs have been provided for the therapy. These ultrasound graphs show the seeds placed in the prostate cross-section with isodose curves for the prostate, the urinary bladder, the rectum, and the urethra. The ultrasound graphs show two-dimensional views of the isodose curves from various cross-sectional views of the prostate. The ultrasound views are shown in Figs. 3, 4, 5, and 6 for the ^{125}I case and Figs. 7, 8, 9, and 10 for the ^{103}Pd case (provided courtesy of Elizabeth Dodge of CTRC, San Antonio).

The isodose curves for the bladder, prostate, urethra, and rectum were used for dosimetric purposes so that the seeds could be arranged uniformly without significantly irradiating the bladder neck and the rectal area. The isodose curves represent the minimum doses to the areas of the prostate where they lie. As stated above in Figs. 1 and 2, the urethra passes through the prostate's cross section, which is the reason for the seeds being placed away from the center and the isodose curves not reaching the center. The rectum lies just below the prostate and as a result, the seeds are also distributed away from the rectum. Because the ^{125}I and ^{103}Pd cases were for two different patients with different prostate sizes, the seed distributions were also different. The nuclides have different emission energies; thus it was necessary to distribute the seeds differently to protect the rectum and urethra.

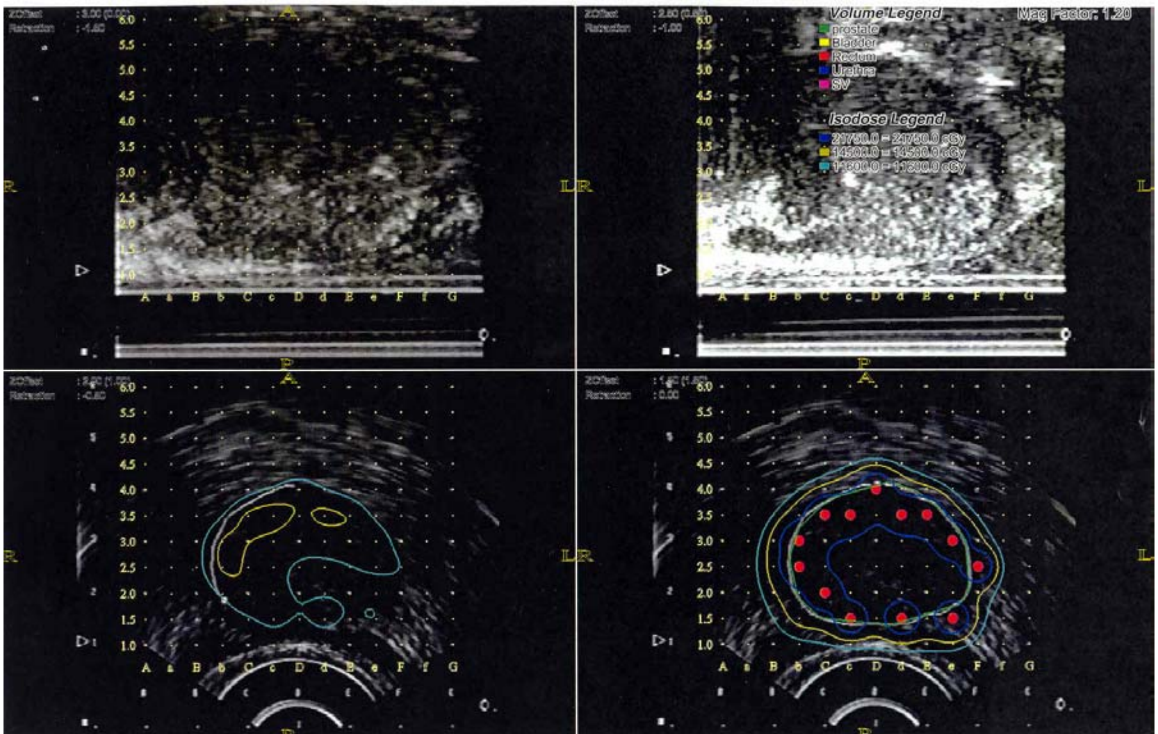

Fig. 3: Posterior view of prostate (^{125}I)

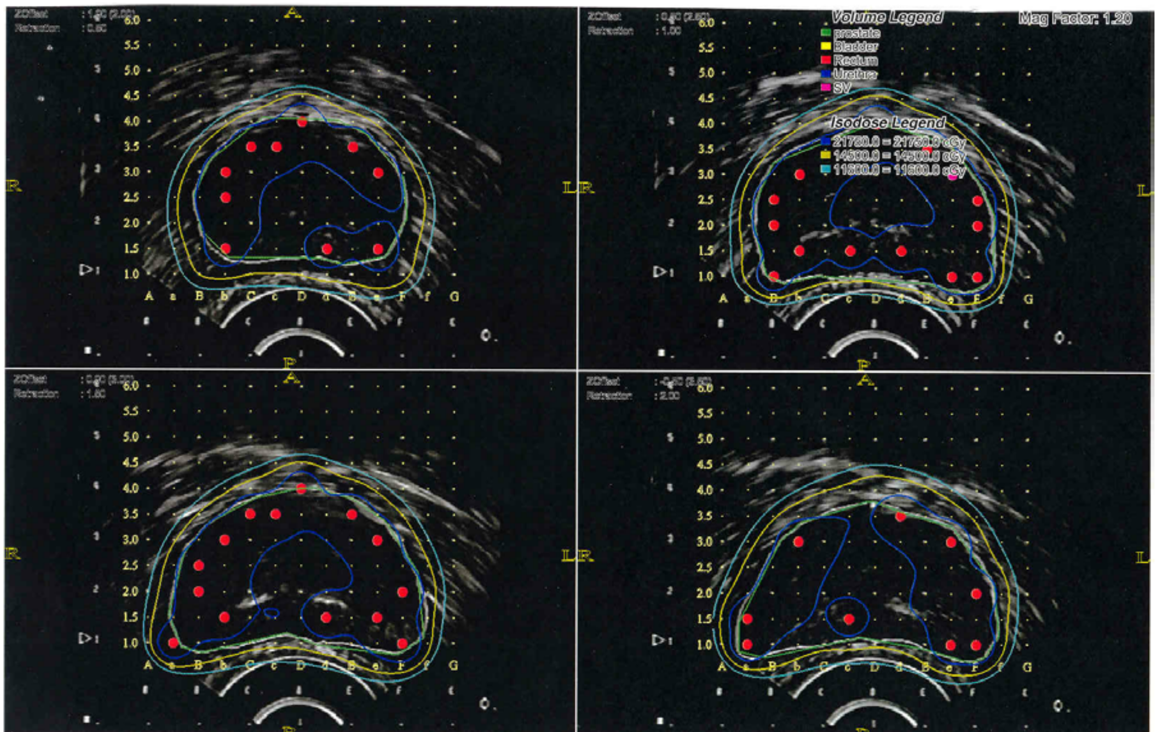

Fig. 4: Interior view of prostate (^{125}I)

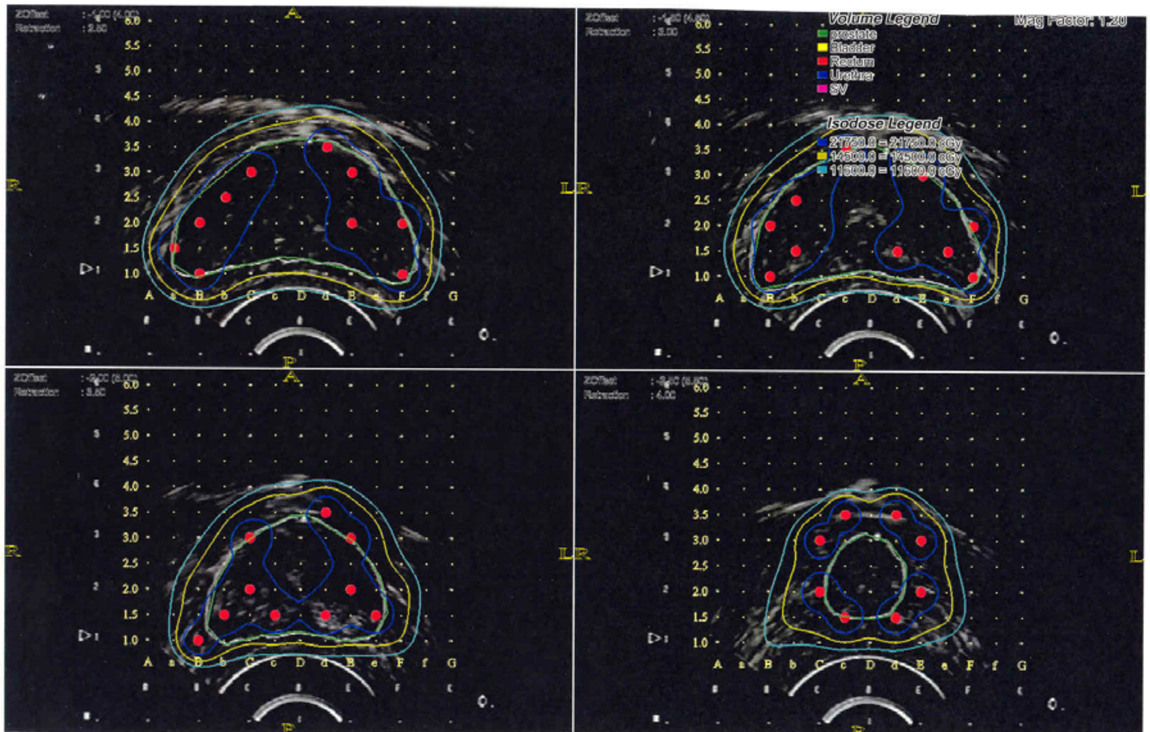

Fig. 5: Cross-sectional view of prostate (^{125}I)

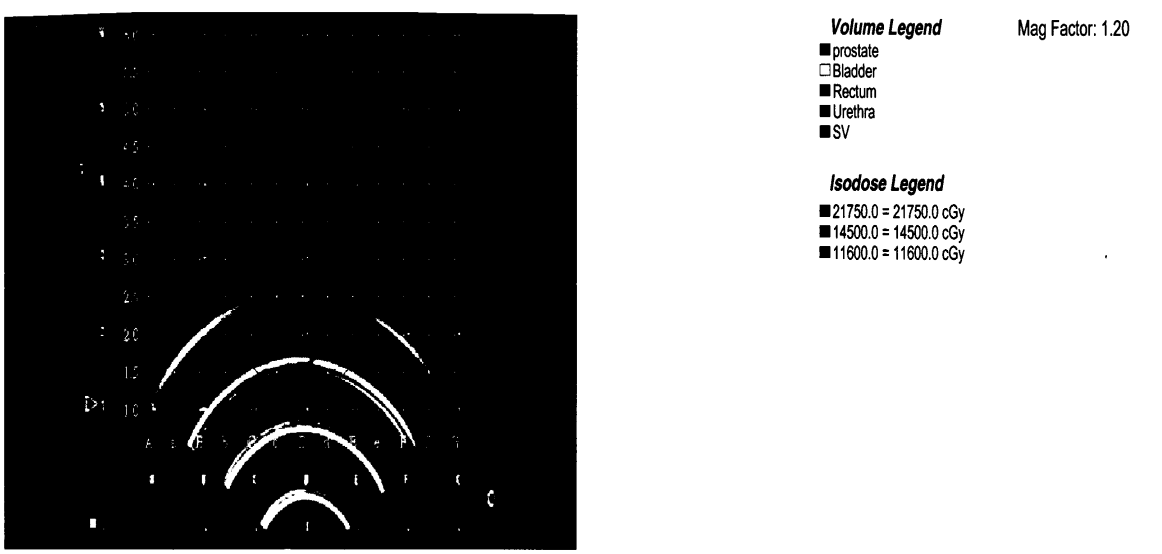

Fig. 6: Rectal view of prostate (^{125}I)

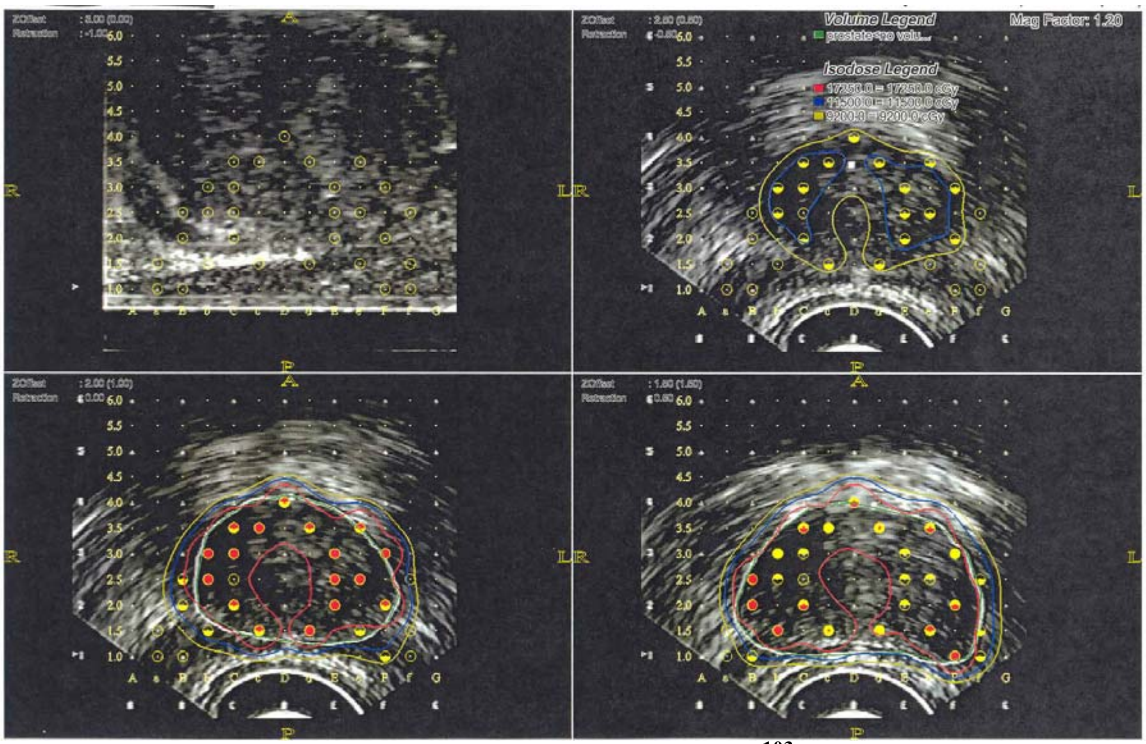

Fig. 7: Posterior view of prostate (^{103}Pd)

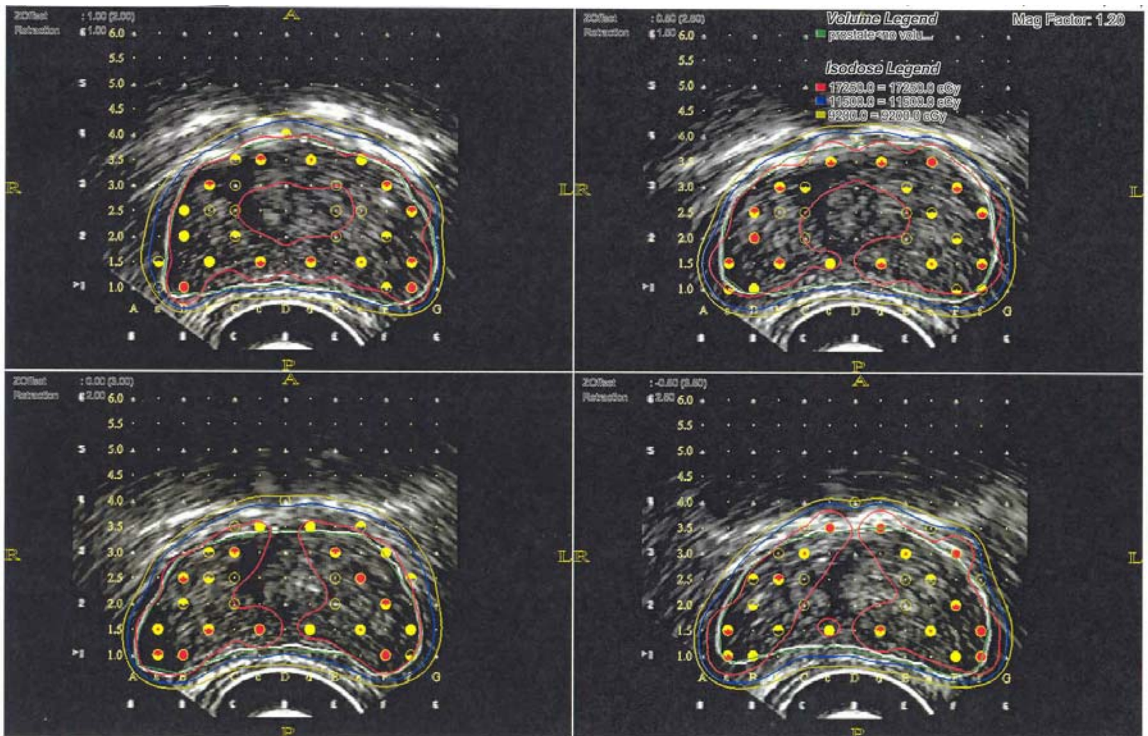

Fig. 8: Interior view of prostate (^{103}Pd)

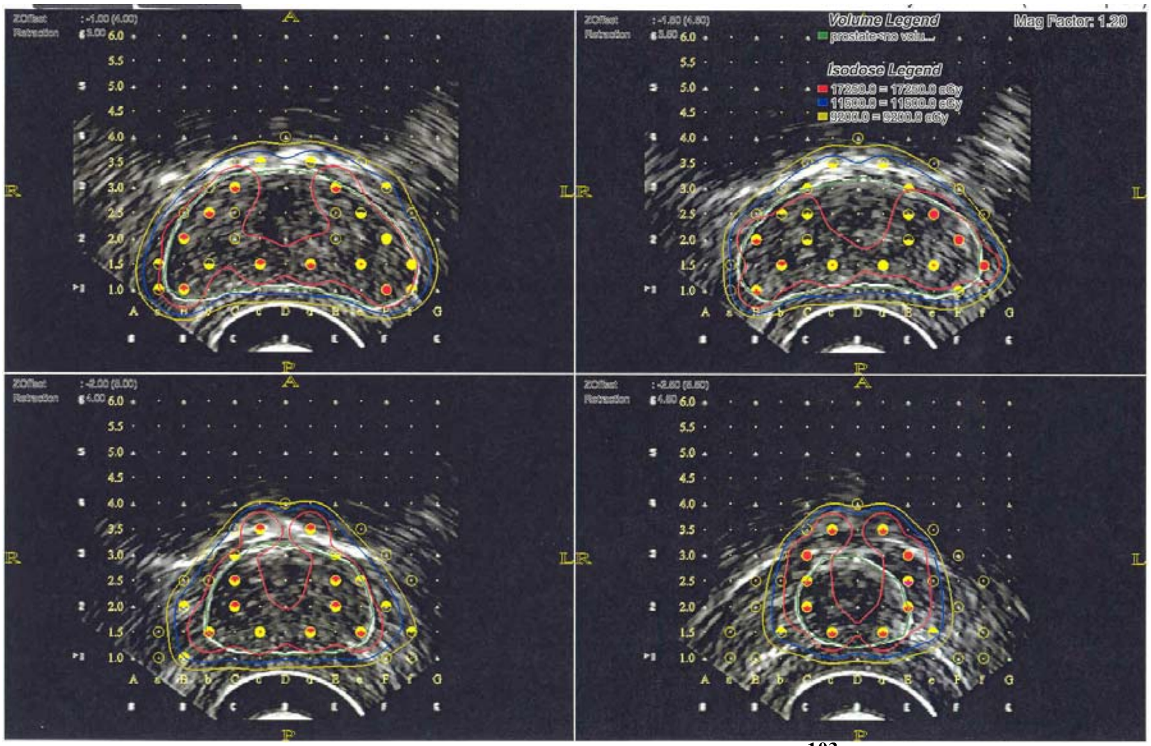

Fig. 9: Cross-sectional view of prostate (^{103}Pd)

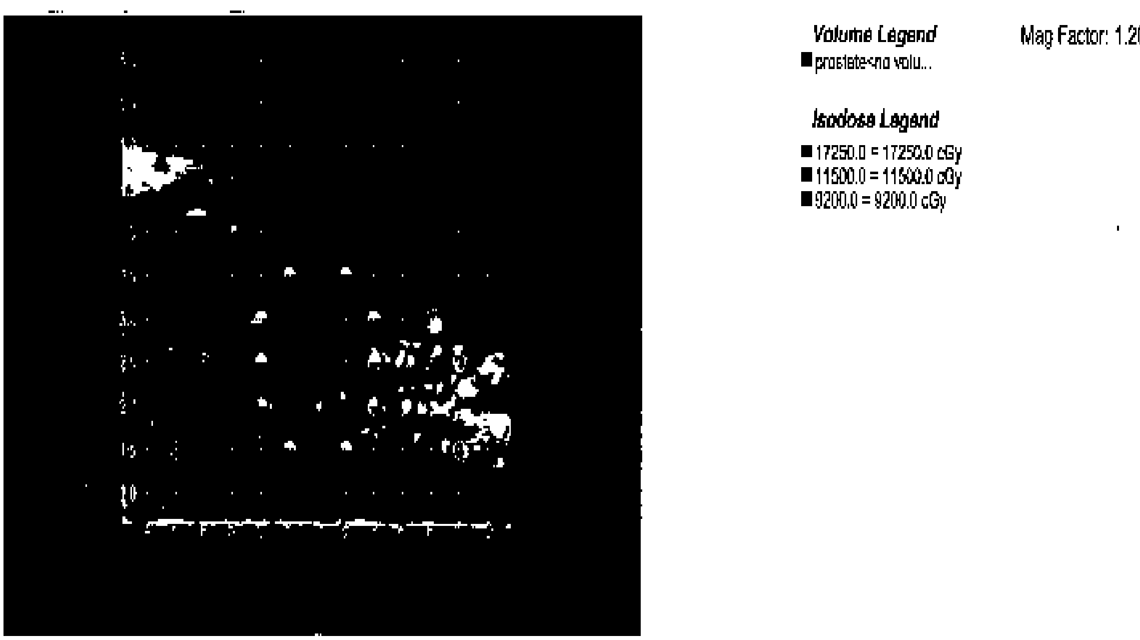

Fig. 10: Rectal view of prostate (^{103}Pd)

CHAPTER III

MATERIALS AND METHODS

MONTE CARLO N-PARTICLE

Monte Carlo N-Particle (MCNP) is a computational code that can be used for various applications. The code uses a calculation method called Monte Carlo simulation to calculate the quantities of interest in various complex geometries. Because of this property, it was a useful tool in determining the radiation-absorbed doses to the organs of interest in the prostate brachytherapy process. The version of MCNP used in this research was 4C (Briesmeister 2000).

The MCNP code is setup with entries that are used to create the model of interest. The first set of entries is referred to as a cell card. These entries are used to setup the areas of interest and combine surfaces by using union, intersection, or complement operators. These cells are important for the determining region in which the user wishes to calculate the quantity of interest (i.e., energy deposition, energy fluence).

The next set of entries is referred to as a surface card. These entries are used to define the surfaces that make up the cells of interest. The surfaces that MCNP can model are basic three-dimensional shapes such as spheres, cylinders, torri, and cones. The code can model two-dimensional planes that can be used to set upper and lower boundaries for three-dimensional geometries with infinite dimensions, such as cylinders.

The third set of entries is referred to a material card. These entries are used to specify the material composition of the cells, in terms of the chemical composition.

These can be entered using the atomic numbers and mass numbers of the elements followed by either percent or atomic compositions. Once all necessary cards have been entered, the model has been setup with the surfaces and the materials.

Once the three main cards have been setup, the next step is to define the sources, particle types, number of particle histories, and types of tally calculations to be performed. Since the code can be used to calculate interactions by neutrons, electrons, and photons, the mode needs to be entered so that the code will calculate the interactions for the appropriate radiation (n=neutrons, p=photons, e=electrons). The number of particle histories must be entered and should be selected to provide the required statistical accuracy. The sources can be setup either as Cartesian sources such as point and line sources, or as three-dimensional sources such as spherical and cylindrical sources. The source information must be entered with particle energies, source positions, and emitted particle types specified by number (neutrons=1, photons=2, electrons=3). After the source information has been entered, tally cards are entered which define the calculations of interest, such as energy fluence, energy deposition in mass, and energy pulse. Once the sources, particle histories, and tallies are entered, the code is completed with the “print” command at the end. When all these steps are completed, the user is ready to execute the codes and perform calculations. The execution of the codes is complete when all particle histories have been followed.

COMPUTER MODELING

In many cases, computer modeling is necessary for simulating complex situations, such as the irradiation of a human organ because many issues such as geometry and target materials must be considered. One form of modeling uses an independent dose-to-point calculation program for a high-dose-rate prostate brachytherapy planning system. This program can be used by hospitals to verify the doses in brachytherapy planning (Cohen, et al. 2000). A Monte Carlo technique can be used to calculate many parameters, such as dose rates as a function of photon energies by using the photon-energy spectrum of the radionuclide (Rivard 2001).

SABRINA BODYBUILDER

Sabrina Bodybuilder is a software package that can be used to model a male or a female from a newborn to a 21-year old as well as pregnant women and phantoms with male and female reproductive organs. The software also can show graphically the phantoms that are being modeled in an MCNP code.

The software has all the equations for the major skeletal bones, organs of the gastrointestinal tract, lungs, kidneys, brain, adrenals, spleen, thyroid, thymus, and skin. For the male, the software has equations for the genitals, which includes the penis and the scrotum in addition to their skin. For the female, the software has equations for the ovaries and the cervix. These equations create a mathematical phantom that can be used to model various situations, from internal dosimetry in brachytherapy to external dosimetry in external beam therapy. Because these equations are based on typical phantoms used for dosimetry, some organs, such as the prostate, are not available in the codes. Because of this, it would be necessary for the user to model these organs based on the geometries and the positions of the other organs modeled with Sabrina Bodybuilder.

PROCEDURES

Using Sabrina Bodybuilder, an 18-year old male was modeled with most of the organs in the lower trunk as well as the major organs in the upper trunk. Once the phantom was created, the organs of interest were selected that were likely to receive significant doses from prostate brachytherapy. The organs of interest were the leg bones, the pelvis, the spine (upper, middle, lower), the ribs, the stomach wall, the small intestine wall, the large intestine wall (ascending, transverse, descending, sigmoid), the kidneys, the liver, the lungs, the testicles, the urinary bladder wall, the penis and scrotum (with skin), and the legs (with skin). Since the prostate was not included in Sabrina Bodybuilder, it was added into the code and was set between the urinary bladder and the genitalia as a sphere with radius of 2.5 cm. Spherical shape was used in prostate modeling rather than an ellipsoidal shape to simplify the geometry by using a single radius as opposed to major and minor axes.

Once the organs were selected and the prostate was added, the source card was setup. Point sources were used for source definitions, were distributed inside the volume of the prostate gland and were laid out with arrangements discussed previously. Two codes were created to simulate the therapy: one for ^{125}I and the other for ^{103}Pd. For ^{125}I, a total of 98 point sources were arranged with each source emitting photons of 35.49 keV. For ^{103}Pd, a total of 115 point sources were arranged with each source emitting photons of 21 keV. Since both radionuclides decay via electron capture, they emit Auger electrons and photons. Because of this decay mode, the modes considered in both codes were electron and photon transport, however, the energy deposited in the organs was due entirely to photons (Nath, et al. 1995). The coordinates for each of the seeds used in both ^{125}I and ^{103}Pd treatments are given in Appendix A.

After the source cards were entered for both codes, the tally cards were entered to allow calculation of the energy deposited in the organs of interest. The doses from electrons cannot be calculated by using MCNP. Because of the constraint with electron transport and calculating energy deposition in mass tallies, it was necessary to calculate the energy deposited (in MeV) and then calculate the doses using known densities and volumes of the tissues, given in Sabrina Bodybuilder.

Finally, once the necessary cards were entered, the number of particle histories was entered for both of the codes. For both ^{125}I and ^{103}Pd, 10,000,000 particle histories were selected. This number of histories was considered to provide reasonable statistical accuracy with minimal execution time. Once all of the necessary information was entered, the codes were set to execute, which calculated the energy deposited in the regions of interest.

The phantom was created in a Cartesian coordinate system (x,y,z). The origin of the coordinate system was in the center of the phantom just below the pelvic region. The x-axis was the horizontal axis that traversed the phantom (width of phantom). The y-axis was the axis from the front of the phantom to the rear (depth of phantom). The z-axis was the vertical axis from the head to the feet (height of phantom). The prostate was designed as a sphere with a radius of 2.5 cm and its center at (0, -6.0025, 2.805), just between the urinary bladder and the genitals. The position and size of the prostate is described by:

$$6.25 = x^2 + (y + 6.0025)^2 + (z - 2.805)^2. \quad (1)$$

The geometry for the male phantom from the lateral view (cut at x=2) is shown in Fig. 11. An anterior view of the phantom (cut at y=2) is shown in Fig. 12. A lateral view of the mid-section of the phantom (cut at y=2 and extent=20) with the prostate position with respect to the urinary bladder is shown in Fig. 13. The extent command magnifies the area of interest on the plot of the geometry.

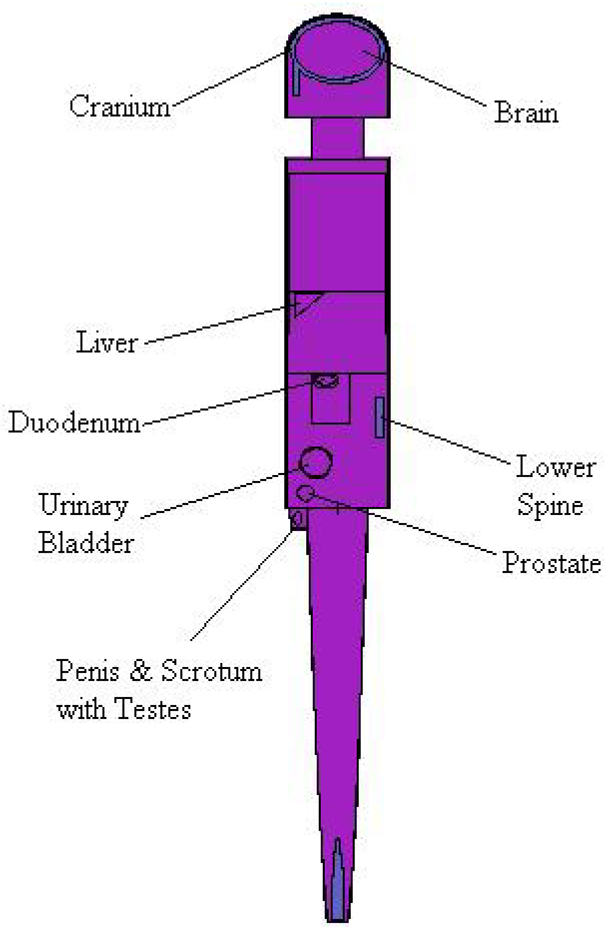

Fig. 11: Side view (cut at x=2) of male phantom

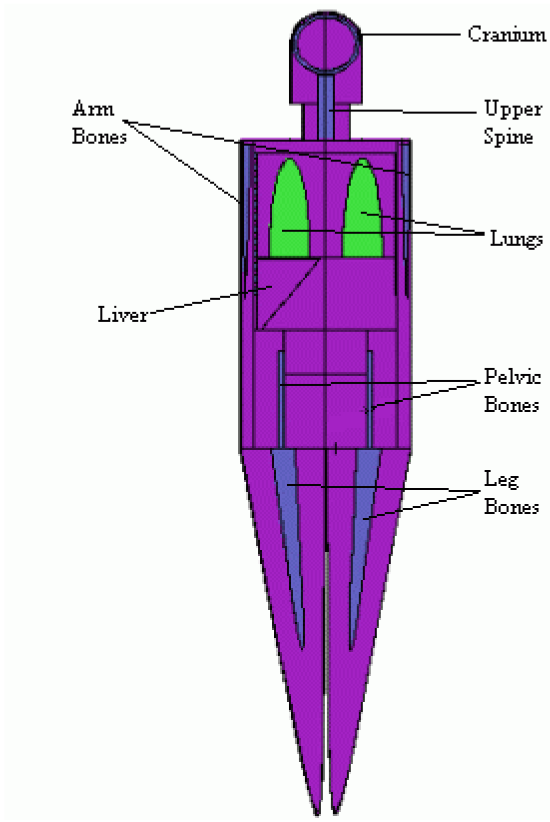

Fig. 12: Anterior view (cut at y=2) of male phantom

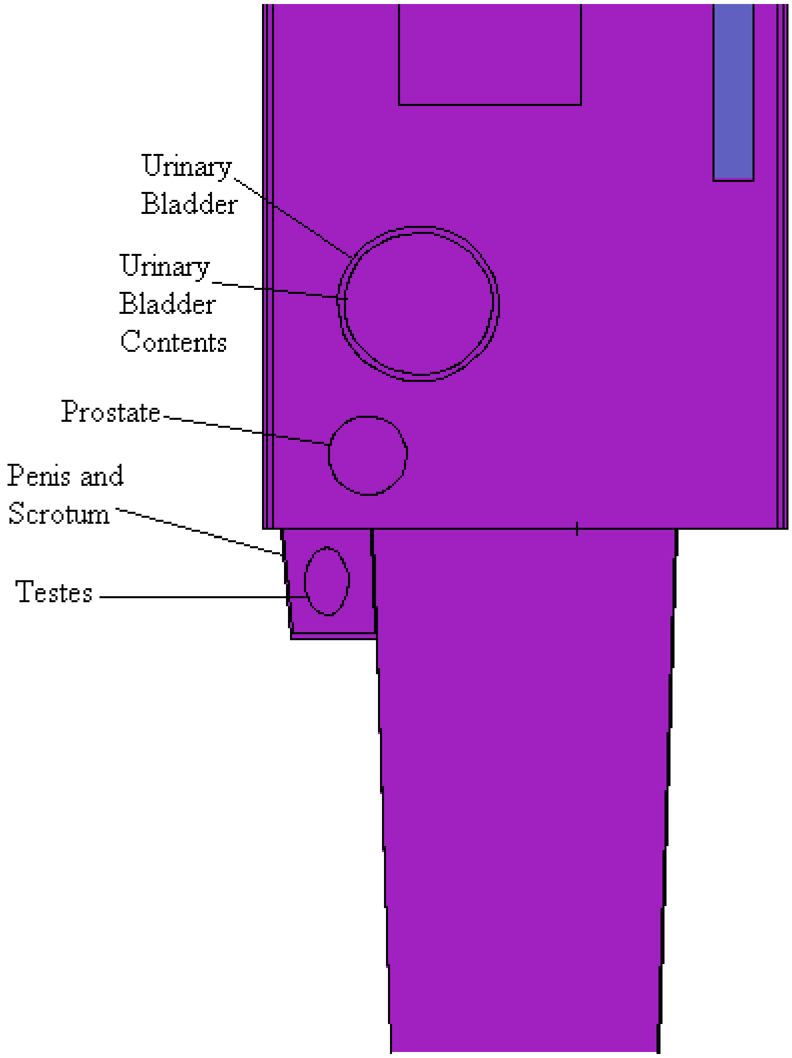

Fig. 13: Lateral view of the prostate region (cut at y=2)

The figures show the various views of the 18-year old male phantom with the internal organs. The shapes of the organs of the phantom modeled were approximate to actual human organs. Many of the organs in the actual human body, particularly in the pelvic region are squeezed together and are not as far apart as the figures show. Many of the actual human organs, such as the prostate and the bladder even have close contact with each other, which is not represented by the above figures. Using this 18-year old male phantom, the doses to the organs of interest were calculated using the Monte Carlo technique. Because actual therapy cases were used in the MCNP model, these doses were considered to be representative of the doses the organs would receive through this therapy.

CHAPTER IV

RESULTS

MCNP RESULTS

Once the codes were executed, the energy deposited (in MeV) in each organ of interest was determined (see Appendix B for the input files). The doses to the organs of interest were consistent with the distance from the prostate for both, ^{125}I and ^{103}Pd. Generally, the energies deposited in the organs were higher in the ^{125}I case than in the ^{103}Pd case as expected due to the higher energy photons emitted by ^{125}I.

DOSES TO THE CRITICAL ORGANS

Once the imparted energies were calculated, the absorbed doses per transformation (in Gy trans^{-1}) were calculated using known densities and volumes of the organs. These doses represented the radiation absorbed doses per transformation in the organs of the phantom modeled in the codes. These doses are shown in Table 1.

Table 1: Calculated doses to organs in phantom

Organ	Organ Density (g cm^{-3})	Organ Volume (cm^3)	^{125}I Absorbed Energy Per Trans (MeV trans^{-1})	^{103}Pd Absorbed Energy Per Trans (MeV trans^{-1})	^{125}I Absorbed Dose Per Trans (Gy trans^{-1})	^{103}Pd Absorbed Dose Per Trans (Gy trans^{-1})
Leg Bones	1.4	$2.5X10^3$	$1.1X10^{-3}$	$1.6X10^{-3}$	$5.2X10^{-17}$	$2.37X10^{-18}$
Pelvis	1.4	$5.3X10^2$	$4.7X10^{-4}$	$6.6X10^{-4}$	$1.0X10^{-16}$	$2 X10^{-18}$
Lower Spine	1.4	$4.3X10^2$	$1.8X10^{-6}$	$1.4X10^{-4}$	$4.7X10^{-19}$	0.00
Middle Spine	1.4	$3.3X10^2$	$3.4X10^{-8}$	$3.9X10^{-6}$	$1.2X10^{-20}$	0.00
Upper Spine	1.4	$1.1X10^2$	$2.8X10^{-9}$	$2.8X10^{-20}$	$3.0X10^{-21}$	0.00
Ribs	1.4	$6.1X10^2$	$3.2X10^{-7}$	$5.4X10^{-7}$	$6.0X10^{-20}$	$1.05 X10^{-21}$
Stomach	1.04	$1.3X10^2$	$1.4X10^{-7}$	$3.0X10^{-7}$	$1.6X10^{-19}$	0.00
Small Intestine	1.04	$9.3X10^2$	$4.1X10^{-5}$	$6.9X10^{-5}$	$7.0X10^{-18}$	$1.27 X10^{-20}$
Ascending Colon	1.04	80.00	$3.6X10^{-6}$	$5.9X10^{-6}$	$7.0X10^{-18}$	$1.19 X10^{-20}$
Transverse Colon	1.04	$1.1X10^2$	$1.0X10^{-6}$	$1.9X10^{-6}$	$1.5X10^{-18}$	0.00
Descending Colon	1.04	79.00	$2.1X10^{-5}$	$3.1X10^{-5}$	$4.1X10^{-17}$	$1.1 X10^{-18}$
Sigmoid Colon	1.04	62.00	$1.4X10^{-3}$	$1.1X10^{-3}$	$3.3X10^{-15}$	$1.15 X10^{-15}$
Kidneys	1.04	$2.6X10^2$	$1.9X10^{-7}$	$4.6X10^{-7}$	$1.1X10^{-19}$	0.00
Liver	1.04	$1.6X10^3$	$5.6X10^{-7}$	$1.4X10^{-6}$	$5.4X10^{-20}$	0.00
Lungs	0.3	$2.8X10^3$	$2.0X10^{-8}$	$5.5X10^{-8}$	$3.8X10^{-21}$	$3.77 X10^{-22}$
Testes	1.04	26.00	$1.4X10^{-4}$	$1.6X10^{-4}$	$8.2X10^{-16}$	$2.08 X10^{-16}$
Urinary Bladder	1.04	40.00	$1.3X10^{-4}$	$1.4X10^{-4}$	$4.8X10^{-16}$	$7.49 X10^{-17}$
Penis & Scrotum	1.04	$1.3X10^2$	$8.8X10^{-4}$	$9.1X10^{-4}$	$1.1X10^{-15}$	$4.09 X10^{-16}$
Penis & Scrotum Skin	1.04	18.00	$4.1X10^{-5}$	$4.9X10^{-5}$	$3.4X10^{-16}$	$7.91 X10^{-17}$
Leg Skin (Left)	1.04	$5.2X10^2$	$1.9X10^{-5}$	$2.5X10^{-5}$	$5.5X10^{-18}$	$1.4 X10^{-18}$
Leg Skin (Right)	1.04	$5.2X10^2$	$9.6X10^{-6}$	$1.2X10^{-5}$	$2.8X10^{-18}$	$2.96 X10^{-19}$
Legs	1.04	$1.5X10^4$	$6.6X10^{-3}$	$7.1X10^{-3}$	$6.9X10^{-17}$	$2.27 X10^{-17}$
Prostate	1.04	16.00	$1.3X10^{-3}$	$1.3X10^{-3}$	$1.2X10^{-14}$	$8.32 X10^{-15}$

The doses shown on Table 1 represent the doses per particle history to the organs at the time of implantation. To assess the actual doses the organs of interest, these doses must be evaluated over a period equal to total decay of the radionuclide. Because of this, it was necessary to calculate the total number of transformations that would occur in the sources over this time period. The activity, which represents the number of transformations per second, is given by Equation (2):

$$A = A_0\, e^{-\lambda t} \qquad (2)$$

where A= Activity at time t in bequerels (Bq);

A_0= Initial activity in bequerels (Bq);

λ= Decay constant of the radionuclide (s^{-1}); and

t= Time from the initial decay to the final decay (s).

The decay constant, λ, can be determined using the half-life of the radionuclide and is calculated using Equation (3):

$$\lambda = \frac{\ln 2}{T_{1/2}} \qquad (3)$$

where $T_{1/2}$ represents the half-life. Using Equations (2) and (3), the number of transformations occurring can be calculated for any time period. But, in this research, an infinite time was of interest because the lifetime patient doses were the main interest. Using Equation (4), the total number of transformations (U_s) can be determined over an infinite time period:

$$U_s = \int_0^{\infty} A_0 e^{-\lambda t}\, dt \qquad (4).$$

The solution for this equation over an infinite time interval is given by Equation (5):

$$U_s = \frac{A_0}{\lambda} \quad (5).$$

Once the total number of transformations has been determined, the total dose (in Gy) to the organs can be calculated using Equation (6):

$$\text{Absorbed Dose} = 1.602X10^{-10} \sum_i U_S \, SEE(T \leftarrow S)_i \, m^{-1} \quad (6)$$

where $1.602X10^{-10}$ = conversion factor from MeV to J and g to kg;

$SEE(T \leftarrow S)$ = specific effective (absorbed) energy transferred from source to target (MeV), here the radiation quality factor is unity for photons; and

m = mass of the target organ (g).

The mass of the target organs was calculated using the known densities and volumes of the organs, created by Sabrina Bodybuilder. Once the calculations were performed, the dose to each of the organs was calculated. The results represented the doses the male phantom received from these brachytherapy seeds, which were representative of the doses the patient would receive during his lifetime. The results of the calculations are given in Table 2.

Table 2: Calculated lifetime doses to the phantom

Organ	^{125}I Transformation Over Infinite Period	^{103}Pd Transformation Over Infinite Period	^{125}I Lifetime Dose (Gy)	^{103}Pd Lifetime Dose (Gy)
Leg Bones	$8.3X10^{15}$	$1.3X10^{16}$	0.43	$3X10^{-2}$
Pelvis	$8.3X10^{15}$	$1.3X10^{16}$	0.84	0.03
Lower Spine	$8.3X10^{15}$	$1.3X10^{16}$	$3.9X10^{-3}$	0.00
Middle Spine	$8.3X10^{15}$	$1.3X10^{16}$	$1.0X10^{-4}$	0.00
Upper Spine	$8.3X10^{15}$	$1.3X10^{16}$	$2.5X10^{-5}$	0.00
Ribs	$8.3X10^{15}$	$1.3X10^{16}$	$5.0X10^{-4}$	$1.33X10^{-5}$
Stomach	$8.3X10^{15}$	$1.3X10^{16}$	$1.4X10^{-3}$	0.00
Small Intestine	$8.3X10^{15}$	$1.3X10^{16}$	0.06	$1.6X10^{-4}$
Ascending Colon	$8.3X10^{15}$	$1.3X10^{16}$	0.06	$1.5X10^{-4}$
Transverse Colon	$8.3X10^{15}$	$1.3X10^{16}$	0.01	0.00
Descending Colon	$8.3X10^{15}$	$1.3X10^{16}$	0.34	$1.38X10^{-2}$
Sigmoid Colon	$8.3X10^{15}$	$1.3X10^{16}$	27.85	14.45
Kidneys	$8.3X10^{15}$	$1.3X10^{16}$	$9.1X10^{-4}$	0.00
Liver	$8.3X10^{15}$	$1.3X10^{16}$	$4.5X10^{-4}$	0.00
Lungs	$8.3X10^{15}$	$1.3X10^{16}$	$3.1X10^{-5}$	$4.75X10^{-6}$
Testes	$8.3X10^{15}$	$1.3X10^{16}$	6.80	2.62
Urinary Bladder	$8.3X10^{15}$	$1.3X10^{16}$	4.00	1.00
Penis & Scrotum	$8.3X10^{15}$	$1.3X10^{16}$	8.90	5.16
Penis & Scrotum Skin	$8.3X10^{15}$	$1.3X10^{16}$	2.90	1.00
Leg Skin (Left)	$8.3X10^{15}$	$1.3X10^{16}$	0.05	$1.8X10^{-2}$
Leg Skin (Right)	$8.3X10^{15}$	$1.3X10^{16}$	0.02	$3.74X10^{-3}$
Legs	$8.3X10^{15}$	$1.3X10^{16}$	0.58	0.29
Prostate	$8.3X10^{15}$	$1.3X10^{16}$	102.40	105.00

As shown in Table 2, the 18-year old male phantom received prostate doses of approximately 102 Gy and 105 Gy from ^{125}I and ^{103}Pd, respectively. Since the activity of the ^{103}Pd seeds was higher than that for ^{125}I, a slightly higher dose to the prostate gland was expected. Generally, ^{125}I delivered higher doses to the organs compared to ^{103}Pd and in both cases, the organs nearest to the prostate received the highest doses, while the organs more distant from the prostate received the lowest doses, which was expected for these radiation therapies. The organs that received significantly high doses were the penis and scrotum, the urinary bladder, the testicles, and the sigmoid colon.

CHAPTER V

DISCUSSION AND CONCLUSIONS

DISCUSSION

These absorbed doses were approximately what patients would receive from prostate brachytherapy from either ^{125}I or ^{103}Pd. The use of Monte Carlo calculations allowed this task to be completed successfully, which would have been extremely complicated with conventional mathematics due to the complex geometries as well as issues such as attenuation and buildup.

As expected, the doses to the prostate were in the range above 100 Gy. Also as expected, the prostate doses from both nuclides were approximately the same, since the ^{103}Pd case had more seeds with lower photon energies compared to the ^{125}I case, which had lower number of seeds with higher photon energies. The urinary bladder, sigmoid colon, testes, and penis and scrotum received the highest doses from the radioactive sources in the prostate, which was expected due to their proximity to the prostate. Generally, the doses to the other organs were below 1 Gy and the organs more distant from the prostate such as those near the rib cage were much less than 1 Gy.

Even though these doses were representative of the actual cases, there are some factors that must be considered. The phantom used to perform the modeling was based on a body of an 18-year old male. This phantom was used because there were no phantoms representing 70 year-old males in Sabrina Bodybuilder. Because of this, there would be slightly different values for the absorbed doses to the organs due to the varying skeleton volume, fat content in the trunk, and body mass. However, because the differences in the sizes and positions of the organs between young adult males and elderly males are generally in the millimeter range, the differences are minimal. Another factor that must be taken into account is that the prostate was modeled as a sphere with a diameter of 5 cm, which is not actually the case in most males. The sizes and shapes of prostates can vary from patient to patient, which would lead to varying results.

Presently, health effects are neither a concern to the patients, nor to the physicians because of the overall effect in treating tumors. Although there may be a risk of getting secondary cancers over many decades, this therapy is generally preferred over the certainty of dying from prostate cancer. Because prostate cancer occurs during the later years of the individual's life, the probability of adverse health effects from this treatment would not be a major concern for the patients, especially because the treatment will save their lives from a terminal illness to which they will definitely succumb without treatment. Because of this, prostate brachytherapy can continue to be an effective procedure in treating prostate cancer and increasing the years of life for the patients.

However, risk assessments can be performed by considering the risks of getting fatal cancers and risk coefficients provided by the International Commission on Radiation Protection (ICRP 1990). Using these coefficients and the calculated doses to each of the organs, the risk of getting fatal cancer can be calculated for each organ as well as for the individual. Because the energies emitted were due to photons, the dose is equal to the dose equivalent, since the radiation weighing factor is one, so 1 Gy equals 1 sievert (Sv). Since the doses to the red bone marrow, thyroid, breast, esophagus, and ovary were not calculated, the dose equivalents to these organs were not considered. Since hereditary effects are not significant, the testes were not included in the risk assessment. The calculated risks are given in Table 3.

Table 3: Fatal cancer risk assessment

Organs	Risk Coefficients (Sv^{-1})	^{125}I Organ Dose Equivalent (Sv)	^{103}Pd Organ Dose Equivalent (Sv)	^{125}I Fatal Cancer Risk	^{103}Pd Fatal Cancer Risk
Bladder	$3X10^{-3}$	4.00	1.00	$1.2X10^{-2}$	$3X10^{-3}$
Bone Marrow	$5X10^{-3}$	0.00	0.00	0.00	0.00
Bone Surface	$5X10^{-4}$	0.43	0.03	$2.2X10^{-4}$	$1.5X10^{-5}$
Breast	$2X10^{-3}$	0.00	0.00	0.00	0.00
Colon	$8X10^{-3}$	28.26	14.46	0.24	0.12
Liver	$1.5X10^{-3}$	$4.5X10^{-4}$	0.00	$6.8X10^{-7}$	0.00
Lung	$8.5X10^{-3}$	$3.1X10^{-5}$	$4.75X10^{-6}$	$2.6X10^{-7}$	$4.04X10^{-8}$
Esophagus	$3X10^{-3}$	0.00	0.00	0.00	0.00
Ovary	$1X10^{-3}$	0.00	0.00	0.00	0.00
Skin	$2X10^{-4}$	2.97	1.02	$5.9X10^{-4}$	$2.04X10^{-4}$
Stomach	$1.1X10^{-2}$	$1.4X10^{-3}$	0.00	$1.5X10^{-5}$	0.00
Thyroid	$8X10^{-4}$	0.00	0.00	0.00	0.00
Kidney	$5X10^{-3}$	$9.1X10^{-4}$	0.00	$4.6X10^{-6}$	0.00
Total	**$5X10^{-2}$**			**$2.53X10^{-1}$**	**$1.26X10^{-1}$**

The calculated risks for fatal cancer to the individual from ^{125}I and ^{103}Pd were about 25% and 13%, respectively. As expected, the risk of developing fatal secondary cancers was higher in ^{125}I because of the higher photon energies. The organs that had the highest risk of developing fatal cancers were the urinary bladder and the colon, which was expected since these organs were adjacent to the prostate. However, the organ that contributed the significant risk of developing fatal cancer was the colon, due to the high dose delivery to the sigmoid colon by both sources.

FUTURE WORK

Although this research involved the use of actual brachytherapy cases, they do not necessarily represent the exact doses the patients are receiving due to geometric factors and distances between the organs. Because of these factors, there are recommendations for future work.

A recommendation for future research is to use tissue equivalent phantoms using brachytherapy seeds and placing dosimeters in the regions of interest. This project would probably provide more accurate results because this would eliminate the discrepancy with the sizes of the organs, particularly the prostate. This would also help in eliminating the complications of distances between the organs.

Another recommendation for future research is to create a phantom of an elderly male and to write an MCNP code based on this phantom. Some potential differences between the 18-year old and the elderly male phantoms would be in their masses, heights, fat content, and varying bone masses. Among many other factors, these factors may impact the results obtained in this research because generally people lose weight and become shorter. Because of this, many of the doses would probably be higher due to the closer distances to the prostate, considering the reduced muscle content in the elderly males as opposed to younger males.

A third recommendation is to create a void between the organs in the pelvic region to account for the organ surfaces contacting each other by setting a vacuum between these organs. Setting a void between these organs in the pelvic region will provide a more accurate account of the doses to these organs from prostate brachytherapy, which are likely to be higher since there will be no material for the photons to interact before reaching the organs of interest.

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APPENDIX A

^{125}I SEED PLACEMENTS

Seed #	Activity	x	y	z
1	0.31 mCi	0	-6.003	4.305
2	0.31 mCi	0	-5.503	4.305
3	0.31 mCi	0	-5.003	4.305
4	0.31 mCi	0	-4.503	4.305
5	0.31 mCi	-1	-6.003	3.805
6	0.31 mCi	-1	-5.503	3.805
7	0.31 mCi	-1	-4.503	3.805
8	0.31 mCi	-0.5	-6.003	3.805
9	0.31 mCi	-0.5	-5.503	3.805
10	0.31 mCi	-0.5	-4.503	3.805
11	0.31 mCi	-0.5	-3.003	3.805
12	0.31 mCi	-0.5	-2.003	3.805
13	0.31 mCi	0.5	-6.003	3.805
14	0.31 mCi	0.5	-4.003	3.805
15	0.31 mCi	0.5	-3.503	3.805
16	0.31 mCi	0.5	-2.503	3.805
17	0.31 mCi	0.5	-2.003	3.805
18	0.31 mCi	1	-6.003	3.805
19	0.31 mCi	1	-5.503	3.805
20	0.31 mCi	1	-5.003	3.805
21	0.31 mCi	1	-4.503	3.805
22	0.31 mCi	-1.5	-6.003	3.805
23	0.31 mCi	-1.5	-5.503	3.805
24	0.31 mCi	-1.5	-5.003	3.805
25	0.31 mCi	-1.5	-4.503	3.805
26	0.31 mCi	-1.5	-4.003	3.805
27	0.31 mCi	-1	-3.503	3.805
28	0.31 mCi	-1	-2.503	3.805
29	0.31 mCi	-1	-2.003	3.805
30	0.31 mCi	1	-3.503	3.805
31	0.31 mCi	1	-3.003	3.805
32	0.31 mCi	1	-2.503	3.805
33	0.31 mCi	1	-2.003	3.805
34	0.31 mCi	1.5	-6.003	3.805
35	0.31 mCi	1.5	-5.503	3.805

^{125}I SEED PLACEMENTS (Con't)

Seed #	Activity	x	y	z
36	0.31 mCi	1.5	-5.003	3.805
37	0.31 mCi	1.5	-4.503	3.805
38	0.31 mCi	1.5	-4.003	3.805
39	0.31 mCi	-2	-5.003	3.805
40	0.31 mCi	-2	-4.503	3.805
41	0.31 mCi	-1.5	-6.003	3.805
42	0.31 mCi	-1.5	-5.503	3.805
43	0.31 mCi	-1.5	-3.503	3.805
44	0.31 mCi	-1.5	-3.003	3.805
45	0.31 mCi	2	-6.003	3.805
46	0.31 mCi	2	-5.003	3.805
47	0.31 mCi	-2	-5.003	2.305
48	0.31 mCi	-2	-4.503	2.305
49	0.31 mCi	-2	-3.503	2.305
50	0.31 mCi	-2	-3.003	2.305
51	0.31 mCi	-1	-6.003	2.305
52	0.31 mCi	-1	-2.503	2.305
53	0.31 mCi	-1	-2.003	2.305
54	0.31 mCi	1	-3.503	2.305
55	0.31 mCi	1	-2.503	2.305
56	0.31 mCi	1	-2.003	2.305
57	0.31 mCi	2	-5.003	2.305
58	0.31 mCi	2	-4.503	2.305
59	0.31 mCi	2	-4.003	2.305
60	0.31 mCi	2	-3.503	2.305
61	0.31 mCi	2	-3.003	2.305
62	0.31 mCi	-2.5	-4.003	1.805
63	0.31 mCi	-2.5	-3.503	1.805
64	0.31 mCi	-1.5	-5.503	1.805
65	0.31 mCi	-1.5	-5.003	1.805
66	0.31 mCi	-1.5	-4.503	1.805
67	0.31 mCi	-1.5	-3.003	1.805
68	0.31 mCi	-1.5	-2.503	1.805
69	0.31 mCi	-0.5	-6.003	1.805
70	0.31 mCi	-0.5	-5.003	1.805
71	0.31 mCi	-0.5	-4.003	1.805

^{125}I SEED PLACEMENTS (Con't)

Seed #	Activity	x	y	z
72	0.31 mCi	-0.5	-2.503	1.805
73	0.31 mCi	-0.5	-2.003	1.805
74	0.31 mCi	0.5	-6.003	1.805
75	0.31 mCi	0.5	-5.503	1.805
76	0.31 mCi	0.5	-5.003	1.805
77	0.31 mCi	0.5	-4.503	1.805
78	0.31 mCi	0.5	-3.003	1.805
79	0.31 mCi	0.5	-2.503	1.805
80	0.31 mCi	0.5	-2.003	1.805
81	0.31 mCi	1.5	-6.003	1.805
82	0.31 mCi	1.5	-5.503	1.805
83	0.31 mCi	1.5	-4.503	1.805
84	0.31 mCi	1.5	-3.003	1.805
85	0.31 mCi	1.5	-2.503	1.805
86	0.31 mCi	-2.5	-4.503	1.305
87	0.31 mCi	-2.5	-4.003	1.305
88	0.31 mCi	-2	-5.003	1.305
89	0.31 mCi	-2	-3.503	1.305
90	0.31 mCi	-2	-3.003	1.305
91	0.31 mCi	-2	-2.503	1.305
92	0.31 mCi	1.5	-5.003	1.305
93	0.31 mCi	1.5	-4.003	1.305
94	0.31 mCi	2	-5.003	1.305
95	0.31 mCi	2	-4.503	1.305
96	0.31 mCi	2	-4.003	1.305
97	0.31 mCi	2	-3.503	1.305
98	0.31 mCi	2	-3.003	1.305

^{103}Pd SEED PLACEMENTS

Seed #	Activity	x	y	z
1	1.4 mCi	0	-6.003	4.305
2	1.4 mCi	0	-5.503	4.305
3	1.4 mCi	-1	-6.003	3.805
4	1.4 mCi	-1	-5.503	3.805
5	1.4 mCi	-0.5	-6.003	3.805
6	1.4 mCi	-0.5	-5.003	3.805
7	1.4 mCi	-0.5	-4.503	3.805
8	1.4 mCi	-0.5	-2.503	3.805
9	1.4 mCi	-0.5	-2.003	3.805
10	1.4 mCi	-0.5	-1.503	3.805
11	1.4 mCi	0.5	-6.003	3.805
12	1.4 mCi	0.5	-5.503	3.805
13	1.4 mCi	0.5	-5.003	3.805
14	1.4 mCi	0.5	-4.503	3.805
15	1.4 mCi	0.5	-2.503	3.805
16	1.4 mCi	0.5	-2.003	3.805
17	1.4 mCi	0.5	-1.503	3.805
18	1.4 mCi	1.5	-6.003	3.805
19	1.4 mCi	1.5	-5.003	3.805
20	1.4 mCi	1.5	-4.503	3.805
21	1.4 mCi	-1.5	-6.003	3.305
22	1.4 mCi	-1.5	-5.003	3.305
23	1.4 mCi	-1.5	-4.503	3.305
24	1.4 mCi	-1	-6.003	3.305
25	1.4 mCi	-1	-4.003	3.305
26	1.4 mCi	-1	-3.503	3.305
27	1.4 mCi	-1	-3.003	3.305
28	1.4 mCi	-1	-1.503	3.305
29	1.4 mCi	1	-6.003	3.305
30	1.4 mCi	1	-4.503	3.305
31	1.4 mCi	1	-3.503	3.305
32	1.4 mCi	1	-3.003	3.305
33	1.4 mCi	1	-1.503	3.305
34	1.4 mCi	2	-6.003	3.305
35	1.4 mCi	2	-5.003	3.305
36	1.4 mCi	2	-4.503	3.305
37	1.4 mCi	2	-2.503	3.305

^{103}Pd SEED PLACEMENTS (Con't)

Seed #	Activity	x	y	z
38	1.4 mCi	-2	-5.503	2.805
39	1.4 mCi	-2	-4.503	2.805
40	1.4 mCi	-2	-4.003	2.805
41	1.4 mCi	-1.5	-6.003	2.805
42	1.4 mCi	-1.5	-2.503	2.805
43	1.4 mCi	-1.5	-3.003	2.805
44	1.4 mCi	-1	-2.003	2.805
45	1.4 mCi	-1	-1.503	2.805
46	1.4 mCi	1	-6.003	2.805
47	1.4 mCi	1	-2.003	2.805
48	1.4 mCi	1	-1.503	2.805
49	1.4 mCi	1.5	-6.003	2.805
50	1.4 mCi	1.5	-4.003	2.805
51	1.4 mCi	1.5	-2.503	2.805
52	1.4 mCi	2.5	-5.003	2.805
53	1.4 mCi	2.5	-4.503	2.805
54	1.4 mCi	-2	-5.503	2.305
55	1.4 mCi	-2	-4.503	2.305
56	1.4 mCi	-2	-3.003	2.305
57	1.4 mCi	-2	-2.503	2.305
58	1.4 mCi	-1	-6.003	2.305
59	1.4 mCi	-1	-5.503	2.305
60	1.4 mCi	-1	-2.003	2.305
61	1.4 mCi	-1	-1.503	2.305
62	1.4 mCi	1	-6.003	2.305
63	1.4 mCi	1	-2.003	2.305
64	1.4 mCi	1	-1.503	2.305
65	1.4 mCi	2	-6.003	2.305
66	1.4 mCi	2	-5.503	2.305
67	1.4 mCi	2	-4.003	2.305
68	1.4 mCi	2	-3.503	2.305
69	1.4 mCi	2	-2.503	2.305
70	1.4 mCi	-2.5	-4.503	1.805
71	1.4 mCi	-2.5	-4.003	1.805
72	1.4 mCi	-2.5	-3.503	1.805
73	1.4 mCi	-1.5	-5.503	1.805
74	1.4 mCi	-1.5	-4.503	1.805

^{103}Pd SEED PLACEMENTS (Con't)

Seed #	Activity	x	y	z
75	1.4 mCi	-1.5	-4.003	1.805
76	1.4 mCi	-1.5	-2.503	1.805
77	1.4 mCi	-1.5	-2.003	1.805
78	1.4 mCi	-0.5	-6.003	1.805
79	1.4 mCi	-0.5	-5.503	1.805
80	1.4 mCi	-0.5	-5.003	1.805
81	1.4 mCi	-0.5	-4.003	1.805
82	1.4 mCi	-0.5	-3.003	1.805
83	1.4 mCi	-0.5	-2.503	1.805
84	1.4 mCi	-0.5	-2.003	1.805
85	1.4 mCi	-0.5	-1.503	1.805
86	1.4 mCi	0.5	-6.003	1.805
87	1.4 mCi	0.5	-5.003	1.805
88	1.4 mCi	0.5	-4.503	1.805
89	1.4 mCi	0.5	-3.503	1.805
90	1.4 mCi	0.5	-3.003	1.805
91	1.4 mCi	0.5	-2.003	1.805
92	1.4 mCi	0.5	-1.503	1.805
93	1.4 mCi	1.5	-5.503	1.805
94	1.4 mCi	1.5	-5.003	1.805
95	1.4 mCi	1.5	-4.503	1.805
96	1.4 mCi	1.5	-4.003	1.805
97	1.4 mCi	1.5	-3.503	1.805
98	1.4 mCi	1.5	-3.003	1.805
99	1.4 mCi	1.5	-2.503	1.805
100	1.4 mCi	1.5	-2.003	1.805
101	1.4 mCi	2.5	-5.003	1.805
102	1.4 mCi	2.5	-4.503	1.805
103	1.4 mCi	2.5	-3.503	1.805
104	1.4 mCi	2.5	-2.503	1.805
105	1.4 mCi	-2.5	-4.003	1.305
106	1.4 mCi	-2.5	-3.503	1.305
107	1.4 mCi	-2	-5.003	1.305
108	1.4 mCi	-2	-4.003	1.305
109	1.4 mCi	-2	-3.003	1.305
110	1.4 mCi	-2	-2.503	1.305

^{103}Pd SEED PLACEMENTS (Con't)

Seed #	Activity	x	y	z
111	1.4 mCi	2	-5.503	1.305
112	1.4 mCi	2	-4.003	1.305
113	1.4 mCi	2	-3.003	1.305
114	1.4 mCi	2.5	-5.003	1.305
115	1.4 mCi	2.5	-3.503	1.305

APPENDIX B

^{125}I INPUT FILE

```
Male Phantom at  18.0 Years
c ++++++++++++++++++++++++++++++++++++++++
c
c    File Prepared by Body Builder
c    CopyRight 1996-1998, White Rock Science
c
c    This input file is for the use of
c    BodyBuilder License holder only.
c    Distribution is Prohibited.
c
c ++++++++++++++++++++++++++++++++++++++++
c
c +++++++++++++++++++++++++++++++++++++++++++++
c           CELLS
c +++++++++++++++++++++++++++++++++++++++++++++
c SkeletonVolume = 6366.150000, skel_vol = 6303.571429
c
c         LEG BONES
1      2 -1.40    -4 53 (-51:-52)
                 vol=  2450.00 imp:p,e = 1
c
c         ARM BONES
2     2 -1.40     4 -73 (-71:-72)
                 vol=   843.50 imp:p,e = 1
c
c         PELVIS
3     2 -1.40     91 -92 93 4 -101 (95:-94)
                 vol=   533.00 imp:p,e = 1
c
c         SPINE
4    2 -1.40   -100 -103 101 vol= 434.2500 imp:p,e = 1
5    2 -1.40   -100 -8   103 vol= 325.6875 imp:p,e = 1
6    2 -1.40   -105 -102 8   vol= 108.5625 imp:p,e = 1
c               Total Spine vol=   868.50
c
c         SKULL & FACE
7    2 -1.40   (111 -110):(121 -120 122 -1 -123 110)
                 vol=   832.50 imp:p,e = 1
c
c         RIBS
8    2 -1.40    132 -131 ((134 -133):(136 -135):(138 -137):(74 -139):
                 (76 -75):(78 -77):(80 -79):(82 -81):(84 -83):
                 (86 -85):(88 -87):(98 -89))
                 vol=   612.50 imp:p,e = 1
c
c         CLAVICLES
9    2 -1.40    -140 ((141 -143):(-142 144))
```

```
                 vol=    48.15 imp:p,e = 1
c
c         SCAPULAE
10    2 -1.40     131 -156 154 -155 ((150 -152):(-151 153))
                 vol=   178.00 imp:p,e = 1
c
c         BRAIN
11     1 -1.04    -111
                 vol=  1360.00 imp:p,e = 1
c
c
c         STOMACH  Wall
14   1 -1.04       -210 211
                 vol=   132.50 imp:p,e = 1
c                  Contents
15   1 -1.04       -211
                 vol=   218.50 imp:p,e = 1
c
c         SMALL INTESTINE
16   1 -1.04       -91 221 -222 223 -7
C                exclude         Ascending Colon
                        (232:230:-223)
c                exclude         Transverse Colon
                        (240 :241 :-242 )
c                exclude         Descending Colon
                        (232:250:-223)
                  vol=   933.00 imp:p,e = 1
c
c         ASCENDING COLON  Wall
17   1 -1.04       -230 233 231 -232
                  vol=    80.35 imp:p,e = 1
c                          Contents
18   1 -1.04       -233 231 -232
                  vol=    84.85 imp:p,e = 1
c
c         TRANSVERSE COLON  Wall
19   1 -1.04       -240 243 -241 242
            vol=   106.65 imp:p,e = 1
c                           Contents
20   1 -1.04       -243 -241 242
            vol=   111.50 imp:p,e = 1
c
c         DESCENDING COLON  Wall
21   1 -1.04       -250 252 251 -232
             vol=   79.10 imp:p,e = 1
c                            Contents
22   1 -1.04       -252 251 -232
             vol=   90.10 imp:p,e = 1
c
c         SIGMOID COLON  Wall
23   1 -1.04       (-280 282 -251):(-281 -282 4)
             vol=   62.10 imp:p,e = 1
c
c         KIDNEYS
```

```
25     1 -1.04     (-310 312):(-311 -313)
                  vol=   263.00 imp:p,e = 1
c
c         LIVER
26     1 -1.04     -320 -321 7 -322 -132
                   vol=  1590.00 imp:p,e = 1
c
c         LUNGS
27     3 -0.296   332 ((-331 (-335:336:334:-333)):
                        (-330 ( 339:338:337)))
                 vol=  2790.00 imp:p,e = 1
c
c         TESTICLES
28   1 -1.04       -370:-371
             vol=   26.30 imp:p,e = 1
c
c         URINARY BLADDER  Wall
29   1 -1.04       -410 411
             vol=   40.10 imp:p,e = 1
c                          Contents
30   1 -1.04       -411
             vol=  178.50 imp:p,e = 1
c
c         PENIS & SCROTUM
31     1 -1.04       -1 -4 47 -45 49 -48 37 38
c                exclude         Testicles
                  370 371
             vol=  126.20 imp:p,e = 1
c
c         SKIN
c
c              Head & Neck Skin
32    1 -1.04       ((-21 22 9):(-20 23 -9 12))
                   imp:p,e = 1
33    1 -1.04       28 -27 8 -12
             vol=  284.50 imp:p,e = 1
c            (Above Volume for Head + Neck Skin Combined
c
c           Trunk Skin
34    1 -1.04       (-8 18 20 -10)
                   : (4 -18 -10 11
                  )
             vol= 1220.00 imp:p,e = 1
c
c         Penis & Scrotum Skin
35     1 -1.04       -1 -4  41 -42 43 -44 31 32 #31
c                exclude         Testicles
                  370 371
             vol=   18.45 imp:p,e = 1
c        Legs Skin
36    1 -1.04      (-4 34 -31 36 32):(-31 33 -36 32)
             vol=  522.25 imp:p,e = 1
37    1 -1.04      (-4 35 -32 36 31):(-32 33 -36 31)
             vol=  522.25 imp:p,e = 1
```

```
c
c            HEAD
c
38    1 -1.04       ((-22 9):(-23 -9 12))
c                exclude         Skull
                       110
c                exclude         Face Bones
                       (-121:120:-122:1:123:-110)
c                exclude         Spine
                       (105:-8:102)
                 imp:p,e = 1
c
c            NECK
c
39    1 -1.04       -28 8 -12
c                exclude         Spine
                        105
                 imp:p,e = 1
c
c         OUTER TRUNK---ARMS & SCAPULAE
c
40    1 -1.04       4 131 -18 -11
c                exclude         Scapulae
                       (-131:156:-150:152:-154:155)
                       (-131:156:151:-153:-154:155)
c                exclude         Arm Bones
                       (-4:71:73) (-4:72:73)
                 imp:p,e = 1
c
c         UPPER TRUNK---ABOVE RIBS
c
41    1 -1.04   ((-18 -131 133) : (-8 18 -20 -10))
c                exclude         Spine
                      (105:102:-8)(100:8:-133)
c                exclude         Clavicles
                      (140:-141:143) (140:142:-144)
c                exclude         Upper Lungs
                       (-133:330) (-133:331)
                 imp:p,e = 1
c
c
c         UPPER RIB CAGE
c
42    1 -1.04       -131 132 79 -133
c                exclude         Ribs 1-9
                  (131:-132:133:-134) (131:-132:135:-136) (131:-
132:137:-138)
                  (131:-132:139:-74) (131:-132:75:-76) (131:-132:77:-
78)
                 imp:p,e = 1
c
c
c         LOWER RIB CAGE
c
```

```
43    1 -1.04       -131 132 -79 98
c                exclude         Ribs 10-12
                  (131:-132:85:-86) (131:-132:87:-88) (131:-132:89:-98)
                  (131:-132:79:-80) (131:-132:81:-82) (131:-132:83:-84)
                 imp:p,e = 1
c
c
c         HIGH CHEST ORGANS
c
44    1 -1.04       -132 -133 332
c                exclude          Spine
                        (100:133:-332)
c                exclude          Lungs
                        (330:133:-332:(-339 -338 -337))
                        (331:133:-332:(335 -336 -334 333))
                 imp:p,e = 1
c
c         CHEST---LIVER LEVEL
c
45    1 -1.04       ((-132 -332 98):(-131 -98 7))
c                exclude          Spine
                        (100:332:-7)
c                exclude          Kidneys
                        (310:-312) (311:313)
c                exclude          Liver
                        #26
c                       (320:321:322:-7)
c                exclude         Stomach
                       210
                 imp:p,e = 1
c
c
c         LOWER TRUNK
c
46    1 -1.04       -131 4 -7
c                exclude           Spine
                        (100:-101:7)
c                exclude           Pelvis
                        #3
c                exclude           Small Intestine
                        (91:-221:222:-223:7)
c                exclude           Ascending Colon
                        (232:230:-231)
c                exclude           Descending Colon
                        (232:250:-251)
c                exclude           Sigmoid Colon
                        (280:-282:251) (281:282:-4)
c                exclude           Urinary Bladder
                        410
c                exclude           Prostate
                        500
                 imp:p,e = 1
                 imp:p,e = 1
c
```

```
c        LEGS
c
47    1 -1.04       -4 (-34:-35) 36
c               exclude           Leg Bones
                       (4:51:-53) (4:52:-53)
             vol= 14605.50 imp:p,e = 1
c
c         SURROUNDING AIR
48    4 -0.001293   -600
c            exclude         HEAD & NECK
                      (21:-9)  (20:9:-8)
c            exclude         TRUNK
                       (-4:10:8)
c            exclude         LEGS
                       (4:-33:(31 32))
c                exclude         GENITALIA
                   (1:4:-41:42:-43:44:-31:-32)
             imp:p,e = 1
c            air            OUTSIDE of NECK
49    4 -0.001293   -20 27 8 -12
             imp:p,e = 1
c
c         PROSTATE
70    1 -1.04  -500 vol= 16.3625 imp:p,e = 1
c
c         VOID
50   0              600
             imp:p,e = 0

c +++++++++++++++++++++++++++++++++++++++++++++++
c           SURFACES
c +++++++++++++++++++++++++++++++++++++++++++++++
c Planes used in several places
c
1     py 0
4     pz 0
332   pz    41.3550
7     pz    25.6700
8     pz    66.5500
9     pz    87.3000
12    pz    74.6000
c
c         BODY SURFACE
c
c            HEAD
21    sq  5280.8272  3394.8568  6597.4275 0 0 0 -343913.3409 0 0
87.300
22    sq  4831.0562  3077.0291  6069.0021 0 0 0 -300362.3462 0 0
87.300
20    sq   101.3042    65.1249 0 0 0 0 -6597.427523 0 0 0
23    sq    97.6144    62.1732 0 0 0 0 -6069.002054 0 0 0
c
c
c            NECK
```

```
27    cz     5.4850
28    cz     5.3000
c
c
c            TORSO
10    sq   101.7072   353.8161 0 0 0 0 -35985.653691 0 0 0
11    sq    98.0100   346.8906 0 0 0 0 -33998.750156 0 0 0
18    pz    66.3650
c
c            LEGS
c      left
31    gq 1 1 0 0 0  -0.1862   -18.8100 0 0 0
32    gq 1 1 0 0 0   0.1862    18.8100 0 0 0
33    pz  -79.185
34    gq 1 1 0 0 0  -0.1862   -18.6250 0 0 0
35    gq 1 1 0 0 0   0.1862    18.6250 0 0 0
36    pz  -79.000
37    gq 1 1 0 0 0  -0.1862   -18.9950 0 0 0
38    gq 1 1 0 0 0   0.1862    18.9950 0 0 0
c
c        PENIS & SCROTUM
41    pz    -4.1750
42    p  0 -10.74 -1 100.00
43    p   -10.74 0 1 -100.00
44    p    -10.74 0 -1 100.00
47    pz    -3.9900
45    p  0 -10.85 -1 100.00
49    p   -10.85 0 1 -100.00
48    p    -10.85 0 -1 100.00
c
c     SKELETON
c
c
c        LEG BONES
51    gq   1 1  0.007875 0 0  -0.186687   -18.625000
        0   1.549817      76.0991
52    gq   1 1  0.007875 0 0   0.186687    18.625000
        0   1.549817      76.0991
53    pz   -78.8150
c
c        ARM BONES ( left/right) )
71     gq   0.587190     0.139750 0 0 0     0.011681
         -20.889300 0    -0.215400   185.534211
72    gq   0.587190   0.139750 0 0 0    -0.011681
          20.889300 0    -0.215400     185.534211
73    pz      65.6000
c
c        PELVIS
91    sq   125.1042   110.7756 0 0 0 0 -13858.4987
       0    -3.7600 0
92    sq   141.1344   124.8806 0 0 0 0 -17624.9521 0    -2.9700 0
93    py    -2.9700
94    py     4.9500
95    pz    13.3100
```

```
c
c         SPINE
100       sq      6.1256     3.4782 0 0 0 0   -21.3063 0     5.4450 0
105       sq      6.1256     3.4782 0 0 0 0   -21.3063 0     1.2250 0
101       pz    20.9150
102       pz    80.7300
103       pz    33.3700
c
c     SKELETON
c
c
c             SKULL (head)
c
c
c             CRANIUM
110     sq  3826.2328  2376.5040  4880.3218 0 0 0
     -210658.6023 0 0    87.3000
111     sq   2428.3114  1430.8517  3200.7476 0 0 0
          -105456.9515 0 0    87.3000
c
c         FACIAL
120       sq     80.1920    48.4416 0 0 0 0 -3884.6300 0 0 0
121       sq     59.3670    32.6041 0 0 0 0 -1935.6084 0 0 0
c
122       pz    78.4950
123       pz    88.9900
c
c         RIBS
131       sq     94.0900   250.5889 0 0 0 0 -23577.9096 0 0 0
132       sq     84.9162   235.4690 0 0 0 0 -19995.1407 0 0 0
133       pz    63.9750
134      pz    62.6450
135      pz     61.3150
136      pz     59.9850
137      pz     58.6550
138      pz     57.3250
139      pz     55.9950
74       pz     54.6650
75       pz     53.3350
76       pz     52.0050
77       pz     50.6750
78       pz     49.3450
79       pz     48.0150
80       pz     46.6850
81       pz     45.3550
82       pz     44.0250
83       pz     42.6950
84       pz     41.3650
85       pz    40.0350
86       pz    38.7050
87       pz    37.3750
88       pz    36.0450
89       pz    34.7150
98      pz    33.3850
```

```
c
c         CLAVICLES
140     tz    0     9.1600    64.8850
           17.9650   0.757850   0.757850
141     p   6.759700 1 0      9.160
142     p   6.759700 -1 0     -9.160
143     p   0.812760 1 0      9.160
144     p   0.812760 -1 0     -9.160
c
c         SCAPULAE
156     sq    94.0900   312.5824 0 0 0 0 -29410.8780
           0 0 0
150   p      0.2650 1 0 0
151   p      0.2650 -1 0 0
152   p      0.8550 1 0 0
153   p      0.8550 -1 0 0
154   pz    48.3900
155   pz    63.9855
c
c         STOMACH
210    sq   503.4100   792.9687   120.9208 0 0 0 -6947.6746
             7.4500    -3.9600    33.2750
211    sq   275.5292   478.6979    55.1380 0 0 0 -2696.7454
             7.4500    -3.9600    33.2750
c extent     3.7350    11.1650    -6.9200    -1.0000    25.6950
40.8550
c
c         SMALL INTESTINE
221    py    -4.8100
222    py     2.1800
223    pz    16.1600
c
c         ASCENDING COLON
230    sq     6.1256     5.4289 0 0 0 0   -33.2554    -7.9150    -
2.3350 0
233    sq     3.2247     2.7250 0 0 0 0    -8.7873    -7.9150    -
2.3350 0
231    pz    13.7400
232    pz    22.8150
c
c         TRANSVERSE COLON
240    sq  0   2.030625     6.1256 0 0 0   -12.4388 0    -2.3350
24.2450
243    sq  0   0.839972     3.8671 0 0 0    -3.2483 0    -2.3350
24.2450
241    px     9.7800
242    px    -9.7800
c
c
c         DESCENDING COLON
251     pz      8.2900
250    gq   4.452100   3.062500     0.100054 0     1.043675    -
0.445302
            -66.550119      -8.652063       1.853917   241.174590
```

```
252    gq   2.544025   1.525225     0.050647 0     0.519784    -
0.254455
            -38.028159      -4.309010       1.167563   141.274707
c
c
c         SIGMOID COLON
282    px     2.7950
280    ty     2.7950 0     8.2900     5.4400     1.6650     1.3750
281    ty      2.795 0 0      2.850     1.6650     1.3750
283    ty     2.7950 0     8.2900     5.4400     1.0400     0.7500
284    ty      2.795 0 0      2.850     1.0400     0.7500
c
c         KIDNEYS
310    sq    62.7811   499.8913    41.9467 0 0 0 -1147.3631
              5.5900     5.9400    30.9000
311    sq    62.7811   499.8913    41.9467 0 0 0 -1147.3631
             -5.5900     5.9400    30.9000
312    px     2.7400
313    px    -2.7400
c
c         LIVER
320    sq    62.7264   235.4690 0 0 0 0 -14770.1242 0 0 0
321     p      1834.5      1359.5     -1492.3    -61006.0
322    pz    40.8800
c
c
c         LUNGS
330    sq      26.0083      10.2495       1.0828 0 0 0
               -537.2548     7.9150 0    41.3550
331   sq      26.0083      10.2495       1.0828 0 0 0
              -537.2548    -7.9150 0    41.3550
333    px    -5.2000
334    py     1.3500
335    pz    43.8000
336    pz    51.2500
337    px     7.5000
338    py     0.8500
339    pz    52.0000
c
c         TESTICLES
370    sq     6.7262422     5.082094     2.157961 0 0 0    -8.5887387
              1.1300    -7.5500    -1.9950
371    sq     6.7262422     5.082094     2.157961 0 0 0    -8.5887387
             -1.1300    -7.5500    -1.9950
c
c         URINARY BLADDER
410    sq   126.0679   229.5945   248.8590 0 0 0 -2683.8589 0
             -4.0550     8.6050
411    sq    93.5215   177.0773   193.1376 0 0 0 -1788.4246 0
             -4.0550     8.6050
c extent    -4.6140     4.6140    -7.8740    -1.0360     4.3210
10.8890
c
c      PROSTATE
```

```
500    s    0 -6.0025 2.805 2.5
c      Void
600    so 301
c
c     STATISTICS
c  Weight =    64.67 kg ( =   142.58 pounds)
c  Height =   173.70 cm ( =    68.39 inches)

c
c         ESOPHAGUS
tr6       0.000      2.432     40.190
       0.722234  -0.621258  -0.303247
       0.651955   0.757926   0.000000
       0.229844  -0.197697       0.953
c
c +++++++++++++++++++++++++++++++++++++++++++++
c      MATERIALS
c      Compositions from ORNL Report TM-8381
c +++++++++++++++++++++++++++++++++++++++++++++
c      Adult Tissues (Density = 1.04 g/cc)
m1        1001  -0.10454
          6000  -0.22663
          7014  -0.02490
          8016  -0.63525
         11023  -0.00112
         12000  -0.00013
         14000  -0.00030
         15031  -0.00134
         16000  -0.00204
         17000  -0.00133
         19000  -0.00208
         20000  -0.00024
         26000  -0.00005
         30000  -0.00003
         37085  -0.00001
         40000  -0.00001
c
c       Skeleton (Density = 1.4 g/cc)
m2        1001  -0.07337
          6000  -0.25475
          7014  -0.03057
          8016  -0.47893
          9019  -0.00025
         11023  -0.00326
         12000  -0.00112
         14000  -0.00002
         15031  -0.05095
         16000  -0.00173
         17000  -0.00143
         19000  -0.00153
         20000  -0.10190
         26000  -0.00008
         30000  -0.00005
         37085  -0.00002
```

```
c       38084  -0.00003
        82000  -0.00001
c
c       Lung (Density = 0.296 g/cc)
m3       1001  -0.10134
         6000  -0.10238
         7014  -0.02866
         8016  -0.75752
        11023  -0.00184
        12000  -0.00007
        14000  -0.00006
        15031  -0.00080
        16000  -0.00225
        17000  -0.00266
        19000  -0.00194
        20000  -0.00009
        26000  -0.00037
        30000  -0.00001
        37085  -0.00001
c
c      Air (Density = 0.001020 /cc)
m4       6000  -0.00012
         7014  -0.75527
         8016  -0.23178
        18000  -0.01283
c
c ++++++++++++++++++++++++++++++++++++++++++++++
c   User Supplied Cards
c ++++++++++++++++++++++++++++++++++++++++++++++
mode p e
nps 10000000
sdef erg=.03549 par= 2 pos= 0 -6.0025 4.305
     erg=.03549 par= 2 pos= 0 -5.5025 4.305
     erg=.03549 par= 2 pos= 0 -5.0025 4.305
     erg=.03549 par= 2 pos= 0 -4.5025 4.305
     erg=.03549 par= 2 pos= -1 -6.0025 3.805
     erg=.03549 par= 2 pos= -1 -5.5025 3.805
     erg=.03549 par= 2 pos= -1 -4.5025 3.805
     erg=.03549 par= 2 pos= -.5 -6.0025 3.805
     erg=.03549 par= 2 pos= -.5 -5.5025 3.805
     erg=.03549 par= 2 pos= -.5 -4.5025 3.805
     erg=.03549 par= 2 pos= -.5 -3.0025 3.805
     erg=.03549 par= 2 pos= -.5 -2.0025 3.805
     erg=.03549 par= 2 pos= .5 -6.0025 3.805
     erg=.03549 par= 2 pos= .5 -4.0025 3.805
     erg=.03549 par= 2 pos= .5 -3.5025 3.805
     erg=.03549 par= 2 pos= .5 -2.5025 3.805
     erg=.03549 par= 2 pos= .5 -2.0025 3.805
     erg=.03549 par= 2 pos= 1 -6.0025 3.805
     erg=.03549 par= 2 pos= 1 -5.5025 3.805
     erg=.03549 par= 2 pos= 1 -5.0025 3.805
     erg=.03549 par= 2 pos= 1 -4.5025 3.805
     erg=.03549 par= 2 pos= -1.5 -6.0025 3.305
     erg=.03549 par= 2 pos= -1.5 -5.5025 3.305
```

```
erg=.03549 par= 2 pos= -1.5 -5.0025 3.305
erg=.03549 par= 2 pos= -1.5 -4.5025 3.305
erg=.03549 par= 2 pos= -1.5 -4.0025 3.305
erg=.03549 par= 2 pos= -1 -3.5025 3.305
erg=.03549 par= 2 pos= -1 -2.5025 3.305
erg=.03549 par= 2 pos= -1 -2.0025 3.305
erg=.03549 par= 2 pos= 1 -3.5025 3.305
erg=.03549 par= 2 pos= 1 -3.0025 3.305
erg=.03549 par= 2 pos= 1 -2.5025 3.305
erg=.03549 par= 2 pos= 1 -2.0025 3.305
erg=.03549 par= 2 pos= 1.5 -6.0025 3.305
erg=.03549 par= 2 pos= 1.5 -5.5025 3.305
erg=.03549 par= 2 pos= 1.5 -5.0025 3.305
erg=.03549 par= 2 pos= 1.5 -4.5025 3.305
erg=.03549 par= 2 pos= 1.5 -4.0025 3.305
erg=.03549 par= 2 pos= -2 -5.0025 2.805
erg=.03549 par= 2 pos= -2 -4.5025 2.805
erg=.03549 par= 2 pos= -1.5 -6.0025 2.805
erg=.03549 par= 2 pos= -1.5 -5.5025 2.805
erg=.03549 par= 2 pos= -1.5 -3.5025 2.805
erg=.03549 par= 2 pos= -1.5 -3.0025 2.805
erg=.03549 par= 2 pos= 2 -6.0025 2.805
erg=.03549 par= 2 pos= 2 -5.0025 2.805
erg=.03549 par= 2 pos= -2 -5.0025 2.305
erg=.03549 par= 2 pos= -2 -4.5025 2.305
erg=.03549 par= 2 pos= -2 -3.5025 2.305
erg=.03549 par= 2 pos= -2 -3.0025 2.305
erg=.03549 par= 2 pos= -1 -6.0025 2.305
erg=.03549 par= 2 pos= -1 -2.5025 2.305
erg=.03549 par= 2 pos= -1 -2.0025 2.305
erg=.03549 par= 2 pos= 1 -3.5025 2.305
erg=.03549 par= 2 pos= 1 -2.5025 2.305
erg=.03549 par= 2 pos= 1 -2.0025 2.305
erg=.03549 par= 2 pos= 2 -5.0025 2.305
erg=.03549 par= 2 pos= 2 -4.5025 2.305
erg=.03549 par= 2 pos= 2 -4.0025 2.305
erg=.03549 par= 2 pos= 2 -3.5025 2.305
erg=.03549 par= 2 pos= 2 -3.0025 2.305
erg=.03549 par= 2 pos= -2.5 -4.0025 1.805
erg=.03549 par= 2 pos= -2.5 -3.5025 1.805
erg=.03549 par= 2 pos= -1.5 -5.5025 1.805
erg=.03549 par= 2 pos= -1.5 -5.0025 1.805
erg=.03549 par= 2 pos= -1.5 -4.5025 1.805
erg=.03549 par= 2 pos= -1.5 -3.0025 1.805
erg=.03549 par= 2 pos= -1.5 -2.5025 1.805
erg=.03549 par= 2 pos= -.5 -6.0025 1.805
erg=.03549 par= 2 pos= -.5 -5.0025 1.805
erg=.03549 par= 2 pos= -.5 -4.0025 1.805
erg=.03549 par= 2 pos= -.5 -2.5025 1.805
erg=.03549 par= 2 pos= -.5 -2.0025 1.805
erg=.03549 par= 2 pos= .5 -6.0025 1.805
erg=.03549 par= 2 pos= .5 -5.5025 1.805
erg=.03549 par= 2 pos= .5 -5.0025 1.805
erg=.03549 par= 2 pos= .5 -4.5025 1.805
```

```
     erg=.03549 par= 2 pos= .5 -3.0025 1.805
     erg=.03549 par= 2 pos= .5 -2.5025 1.805
     erg=.03549 par= 2 pos= .5 -2.0025 1.805
     erg=.03549 par= 2 pos= 1.5 -6.0025 1.805
     erg=.03549 par= 2 pos= 1.5 -5.5025 1.805
     erg=.03549 par= 2 pos= 1.5 -4.5025 1.805
     erg=.03549 par= 2 pos= 1.5 -3.0025 1.805
     erg=.03549 par= 2 pos= 1.5 -2.5025 1.805
     erg=.03549 par= 2 pos= -2.5 -4.5025 1.305
     erg=.03549 par= 2 pos= -2.5 -4.0025 1.305
     erg=.03549 par= 2 pos= -2 -5.0025 1.305
     erg=.03549 par= 2 pos= -2 -3.5025 1.305
     erg=.03549 par= 2 pos= -2 -3.0025 1.305
     erg=.03549 par= 2 pos= -2 -2.5025 1.305
     erg=.03549 par= 2 pos= 1.5 -5.0025 1.305
     erg=.03549 par= 2 pos= 1.5 -4.0025 1.305
     erg=.03549 par= 2 pos= 2 -5.0025 1.305
     erg=.03549 par= 2 pos= 2 -4.5025 1.305
     erg=.03549 par= 2 pos= 2 -4.0025 1.305
     erg=.03549 par= 2 pos= 2 -3.5025 1.305
     erg=.03549 par= 2 pos= 2 -3.0025 1.305
*f18:p,e 1
*f38:p,e 3
*f48:p,e 4
*f58:p,e 5
*f68:p,e 6
*f88:p,e 8
*f148:p,e 14
*f168:p,e 16
*f178:p,e 17
*f198:p,e 19
*f218:p,e 21
*f238:p,e 23
*f258:p,e 25
*f268:p,e 26
*f278:p,e 27
*f288:p,e 28
*f298:p,e 29
*f318:p,e 31
*f358:p,e 35
*f368:p,e 36
*f378:p,e 37
*f478:p,e 47
*f708:p,e 70
prdmp 2j -1 2j
print -130 -140
```

^{103}Pd INPUT FILE

```
Male Phantom at  18.0 Years
c ++++++++++++++++++++++++++++++++++++++++
c
c    File Prepared by Body Builder
c    CopyRight 1996-1998, White Rock Science
c
c    This input file is for the use of
c    BodyBuilder License holder only.
c    Distribution is Prohibited.
c
c ++++++++++++++++++++++++++++++++++++++++
c
c +++++++++++++++++++++++++++++++++++++++++++++
c          CELLS
c +++++++++++++++++++++++++++++++++++++++++++++
c SkeletonVolume = 6366.150000, skel_vol = 6303.571429
c
c        LEG BONES
1      2 -1.40    -4 53 (-51:-52)
                 vol=  2450.00 imp:p,e = 1
c
c        ARM BONES
2     2 -1.40     4 -73 (-71:-72)
                 vol=   843.50 imp:p,e = 1
c
c        PELVIS
3     2 -1.40     91 -92 93 4 -101 (95:-94)
                 vol=   533.00 imp:p,e = 1
c
c        SPINE
4    2 -1.40   -100 -103 101 vol= 434.2500 imp:p,e = 1
5    2 -1.40   -100 -8   103 vol= 325.6875 imp:p,e = 1
6    2 -1.40   -105 -102 8   vol= 108.5625 imp:p,e = 1
c                Total Spine vol=   868.50
c
c        SKULL & FACE
7    2 -1.40   (111 -110):(121 -120 122 -1 -123 110)
                 vol=   832.50 imp:p,e = 1
c
c        RIBS
8    2 -1.40    132 -131 ((134 -133):(136 -135):(138 -137):(74 -139):
                 (76 -75):(78 -77):(80 -79):(82 -81):(84 -83):
                 (86 -85):(88 -87):(98 -89))
                 vol=   612.50 imp:p,e = 1
c
c        CLAVICLES
9    2 -1.40    -140 ((141 -143):(-142 144))
                 vol=    48.15 imp:p,e = 1
c
c        SCAPULAE
```

```
10    2 -1.40     131 -156 154 -155 ((150 -152):(-151 153))
                 vol=   178.00 imp:p,e = 1
c
c         BRAIN
11     1 -1.04    -111
                 vol=  1360.00 imp:p,e = 1
c
c
c         STOMACH  Wall
14   1 -1.04       -210 211
                 vol=   132.50 imp:p,e = 1
c                  Contents
15   1 -1.04       -211
                 vol=   218.50 imp:p,e = 1
c
c         SMALL INTESTINE
16   1 -1.04       -91 221 -222 223 -7
C                exclude         Ascending Colon
                        (232:230:-223)
c                exclude         Transverse Colon
                        (240 :241 :-242 )
c                exclude         Descending Colon
                        (232:250:-223)
                  vol=   933.00 imp:p,e = 1
c
c         ASCENDING COLON  Wall
17   1 -1.04       -230 233 231 -232
                  vol=    80.35 imp:p,e = 1
c                          Contents
18   1 -1.04       -233 231 -232
                  vol=    84.85 imp:p,e = 1
c
c         TRANSVERSE COLON  Wall
19   1 -1.04       -240 243 -241 242
             vol=   106.65 imp:p,e = 1
c                           Contents
20   1 -1.04       -243 -241 242
             vol=   111.50 imp:p,e = 1
c
c         DESCENDING COLON  Wall
21   1 -1.04       -250 252 251 -232
              vol=   79.10 imp:p,e = 1
c                            Contents
22   1 -1.04       -252 251 -232
              vol=   90.10 imp:p,e = 1
c
c         SIGMOID COLON  Wall
23   1 -1.04       (-280 282 -251):(-281 -282 4)
              vol=   62.10 imp:p,e = 1
c
c         KIDNEYS
25     1 -1.04     (-310 312):(-311 -313)
                  vol=   263.00 imp:p,e = 1
c
```

```
c         LIVER
26     1 -1.04     -320 -321 7 -322 -132
                   vol=  1590.00 imp:p,e = 1
c
c         LUNGS
27     3 -0.296   332 ((-331 (-335:336:334:-333)):
                        (-330 ( 339:338:337)))
                 vol=  2790.00 imp:p,e = 1
c
c         TESTICLES
28   1 -1.04       -370:-371
             vol=   26.30 imp:p,e = 1
c
c         URINARY BLADDER  Wall
29   1 -1.04       -410 411
             vol=   40.10 imp:p,e = 1
c                          Contents
30   1 -1.04       -411
             vol=  178.50 imp:p,e = 1
c
c         PENIS & SCROTUM
31     1 -1.04       -1 -4 47 -45 49 -48 37 38
c                exclude         Testicles
                  370 371
             vol=  126.20 imp:p,e = 1
c
c         SKIN
c
c              Head & Neck Skin
32    1 -1.04       ((-21 22 9):(-20 23 -9 12))
                   imp:p,e = 1
33    1 -1.04       28 -27 8 -12
             vol=  284.50 imp:p,e = 1
c            (Above Volume for Head + Neck Skin Combined
c
c           Trunk Skin
34    1 -1.04       (-8 18 20 -10)
                   : (4 -18 -10 11
                  )
             vol= 1220.00 imp:p,e = 1
c
c         Penis & Scrotum Skin
35     1 -1.04       -1 -4  41 -42 43 -44 31 32 #31
c                exclude         Testicles
                  370 371
             vol=   18.45 imp:p,e = 1
c        Legs Skin
36    1 -1.04      (-4 34 -31 36 32):(-31 33 -36 32)
             vol=  522.25 imp:p,e = 1
37    1 -1.04      (-4 35 -32 36 31):(-32 33 -36 31)
             vol=  522.25 imp:p,e = 1
c
c            HEAD
c
```

```
38    1 -1.04       ((-22 9):(-23 -9 12))
c                exclude         Skull
                       110
c                exclude         Face Bones
                       (-121:120:-122:1:123:-110)
c                exclude         Spine
                       (105:-8:102)
                 imp:p,e = 1
c
c            NECK
c
39    1 -1.04       -28 8 -12
c                exclude         Spine
                        105
                 imp:p,e = 1
c
c         OUTER TRUNK---ARMS & SCAPULAE
c
40    1 -1.04       4 131 -18 -11
c                exclude         Scapulae
                       (-131:156:-150:152:-154:155)
                       (-131:156:151:-153:-154:155)
c                exclude         Arm Bones
                       (-4:71:73) (-4:72:73)
                 imp:p,e = 1
c
c         UPPER TRUNK---ABOVE RIBS
c
41    1 -1.04    ((-18 -131 133) : (-8 18 -20 -10))
c                exclude         Spine
                      (105:102:-8)(100:8:-133)
c                exclude         Clavicles
                      (140:-141:143) (140:142:-144)
c                exclude         Upper Lungs
                       (-133:330) (-133:331)
                 imp:p,e = 1
c
c
c         UPPER RIB CAGE
c
42    1 -1.04       -131 132 79 -133
c                exclude         Ribs 1-9
                  (131:-132:133:-134) (131:-132:135:-136) (131:-
132:137:-138)
                  (131:-132:139:-74) (131:-132:75:-76) (131:-132:77:-
78)
                 imp:p,e = 1
c
c
c         LOWER RIB CAGE
c
43    1 -1.04       -131 132 -79 98
c                exclude         Ribs 10-12
                  (131:-132:85:-86) (131:-132:87:-88) (131:-132:89:-98)
```

```
                 (131:-132:79:-80) (131:-132:81:-82) (131:-132:83:-84)
                imp:p,e = 1
c
c
c         HIGH CHEST ORGANS
c
44    1 -1.04       -132 -133 332
c               exclude          Spine
                       (100:133:-332)
c               exclude          Lungs
                       (330:133:-332:(-339 -338 -337))
                       (331:133:-332:(335 -336 -334 333))
                imp:p,e = 1
c
c         CHEST---LIVER LEVEL
c
45    1 -1.04       ((-132 -332 98):(-131 -98 7))
c               exclude          Spine
                       (100:332:-7)
c               exclude          Kidneys
                       (310:-312) (311:313)
c               exclude          Liver
                       #26
c                      (320:321:322:-7)
c               exclude         Stomach
                      210
                imp:p,e = 1
c
c
c         LOWER TRUNK
c
46    1 -1.04       -131 4 -7
c               exclude           Spine
                       (100:-101:7)
c               exclude           Pelvis
                       #3
c               exclude           Small Intestine
                       (91:-221:222:-223:7)
c               exclude           Ascending Colon
                       (232:230:-231)
c               exclude           Descending Colon
                       (232:250:-251)
c               exclude           Sigmoid Colon
                       (280:-282:251) (281:282:-4)
c               exclude           Urinary Bladder
                       410
c               exclude           Prostate
                       500
                imp:p,e = 1
                imp:p,e = 1
c
c        LEGS
c
47    1 -1.04       -4 (-34:-35) 36
```

```
c                exclude           Leg Bones
                       (4:51:-53) (4:52:-53)
             vol= 14605.50 imp:p,e = 1
c
c          SURROUNDING AIR
48    4 -0.001293   -600
c            exclude         HEAD & NECK
                      (21:-9)  (20:9:-8)
c            exclude         TRUNK
                       (-4:10:8)
c            exclude         LEGS
                       (4:-33:(31 32))
c                exclude        GENITALIA
                   (1:4:-41:42:-43:44:-31:-32)
             imp:p,e = 1
c            air            OUTSIDE of NECK
49    4 -0.001293   -20 27 8 -12
             imp:p,e = 1
c
c          PROSTATE
70    1 -1.04  -500 vol= 16.3625 imp:p,e = 1
c
c          VOID
50   0              600
             imp:p,e = 0

c ++++++++++++++++++++++++++++++++++++++++++++++
c           SURFACES
c ++++++++++++++++++++++++++++++++++++++++++++++
c Planes used in several places
c
1     py 0
4     pz 0
332   pz    41.3550
7     pz    25.6700
8     pz    66.5500
9     pz    87.3000
12    pz    74.6000
c
c         BODY SURFACE
c
c             HEAD
21    sq  5280.8272  3394.8568  6597.4275 0 0 0 -343913.3409 0 0
87.300
22    sq  4831.0562  3077.0291  6069.0021 0 0 0 -300362.3462 0 0
87.300
20    sq   101.3042    65.1249 0 0 0 0 -6597.427523 0 0 0
23    sq    97.6144    62.1732 0 0 0 0 -6069.002054 0 0 0
c
c
c             NECK
27    cz     5.4850
28    cz     5.3000
c
```

```
c
c            TORSO
10    sq   101.7072   353.8161 0 0 0 0 -35985.653691 0 0 0
11    sq    98.0100   346.8906 0 0 0 0 -33998.750156 0 0 0
18    pz    66.3650
c
c            LEGS
c      left
31    gq 1 1 0 0 0  -0.1862   -18.8100 0 0 0
32    gq 1 1 0 0 0   0.1862    18.8100 0 0 0
33    pz  -79.185
34    gq 1 1 0 0 0  -0.1862   -18.6250 0 0 0
35    gq 1 1 0 0 0   0.1862    18.6250 0 0 0
36    pz  -79.000
37    gq 1 1 0 0 0  -0.1862   -18.9950 0 0 0
38    gq 1 1 0 0 0   0.1862    18.9950 0 0 0
c
c        PENIS & SCROTUM
41    pz    -4.1750
42    p  0 -10.74 -1 100.00
43    p   -10.74 0 1 -100.00
44    p    -10.74 0 -1 100.00
47    pz    -3.9900
45    p  0 -10.85 -1 100.00
49    p   -10.85 0 1 -100.00
48    p    -10.85 0 -1 100.00
c
c     SKELETON
c
c
c        LEG BONES
51    gq   1 1  0.007875 0 0  -0.186687   -18.625000
           0   1.549817      76.0991
52    gq   1 1  0.007875 0 0   0.186687    18.625000
           0   1.549817      76.0991
53    pz   -78.8150
c
c        ARM BONES ( left/right) )
71     gq   0.587190     0.139750 0 0 0     0.011681
            -20.889300 0    -0.215400   185.534211
72    gq   0.587190   0.139750 0 0 0    -0.011681
            20.889300 0    -0.215400     185.534211
73    pz     65.6000
c
c        PELVIS
91    sq   125.1042   110.7756 0 0 0 0 -13858.4987
       0    -3.7600 0
92    sq   141.1344   124.8806 0 0 0 0 -17624.9521 0    -2.9700 0
93    py    -2.9700
94    py     4.9500
95    pz    13.3100
c
c        SPINE
100      sq      6.1256     3.4782 0 0 0 0   -21.3063 0     5.4450 0
```

```
105      sq      6.1256     3.4782 0 0 0 0   -21.3063 0     1.2250 0
101      pz    20.9150
102      pz    80.7300
103      pz    33.3700
c
c     SKELETON
c
c
c             SKULL (head)
c
c
c             CRANIUM
110    sq  3826.2328  2376.5040  4880.3218 0 0 0
     -210658.6023 0 0    87.3000
111    sq   2428.3114  1430.8517  3200.7476 0 0 0
          -105456.9515 0 0    87.3000
c
c         FACIAL
120      sq     80.1920    48.4416 0 0 0 0 -3884.6300 0 0 0
121      sq     59.3670    32.6041 0 0 0 0 -1935.6084 0 0 0
c
122      pz    78.4950
123      pz    88.9900
c
c         RIBS
131      sq     94.0900   250.5889 0 0 0 0 -23577.9096 0 0 0
132      sq     84.9162   235.4690 0 0 0 0 -19995.1407 0 0 0
133      pz    63.9750
134     pz    62.6450
135     pz     61.3150
136     pz     59.9850
137     pz     58.6550
138     pz     57.3250
139     pz     55.9950
74      pz     54.6650
75      pz     53.3350
76      pz     52.0050
77      pz     50.6750
78      pz     49.3450
79      pz     48.0150
80      pz     46.6850
81      pz     45.3550
82      pz     44.0250
83      pz     42.6950
84      pz     41.3650
85      pz    40.0350
86      pz    38.7050
87      pz    37.3750
88      pz    36.0450
89      pz    34.7150
98     pz    33.3850
c
c         CLAVICLES
140     tz    0     9.1600    64.8850
```

```
           17.9650   0.757850   0.757850
141     p   6.759700 1 0      9.160
142     p   6.759700 -1 0     -9.160
143     p   0.812760 1 0      9.160
144     p   0.812760 -1 0     -9.160
c
c         SCAPULAE
156     sq    94.0900   312.5824 0 0 0 0 -29410.8780
           0 0 0
150   p      0.2650 1 0 0
151   p      0.2650 -1 0 0
152   p      0.8550 1 0 0
153   p      0.8550 -1 0 0
154   pz    48.3900
155   pz    63.9855
c
c         STOMACH
210    sq   503.4100   792.9687   120.9208 0 0 0 -6947.6746
             7.4500    -3.9600    33.2750
211    sq   275.5292   478.6979    55.1380 0 0 0 -2696.7454
             7.4500    -3.9600    33.2750
c extent     3.7350    11.1650    -6.9200    -1.0000    25.6950
40.8550
c
c         SMALL INTESTINE
221    py    -4.8100
222    py     2.1800
223    pz    16.1600
c
c         ASCENDING COLON
230    sq     6.1256     5.4289 0 0 0 0   -33.2554    -7.9150    -
2.3350 0
233    sq     3.2247     2.7250 0 0 0 0    -8.7873    -7.9150    -
2.3350 0
231    pz    13.7400
232    pz    22.8150
c
c         TRANSVERSE COLON
240    sq  0   2.030625     6.1256 0 0 0   -12.4388 0    -2.3350
24.2450
243    sq  0   0.839972     3.8671 0 0 0    -3.2483 0    -2.3350
24.2450
241    px     9.7800
242    px    -9.7800
c
c
c         DESCENDING COLON
251     pz     8.2900
250    gq   4.452100   3.062500     0.100054 0     1.043675    -
0.445302
            -66.550119      -8.652063       1.853917   241.174590
252    gq   2.544025   1.525225     0.050647 0     0.519784    -
0.254455
            -38.028159      -4.309010       1.167563   141.274707
```

```
c
c
c         SIGMOID COLON
282    px     2.7950
280    ty     2.7950 0     8.2900     5.4400     1.6650     1.3750
281    ty      2.795 0 0      2.850     1.6650     1.3750
283    ty     2.7950 0     8.2900     5.4400     1.0400     0.7500
284    ty      2.795 0 0      2.850     1.0400     0.7500
c
c         KIDNEYS
310    sq    62.7811   499.8913    41.9467 0 0 0 -1147.3631
              5.5900     5.9400    30.9000
311    sq    62.7811   499.8913    41.9467 0 0 0 -1147.3631
             -5.5900     5.9400    30.9000
312    px     2.7400
313    px    -2.7400
c
c         LIVER
320    sq    62.7264   235.4690 0 0 0 0 -14770.1242 0 0 0
321     p      1834.5      1359.5     -1492.3    -61006.0
322    pz    40.8800
c
c
c         LUNGS
330    sq      26.0083      10.2495       1.0828 0 0 0
               -537.2548     7.9150 0    41.3550
331   sq      26.0083      10.2495       1.0828 0 0 0
             -537.2548    -7.9150 0    41.3550
333    px    -5.2000
334    py     1.3500
335    pz    43.8000
336    pz    51.2500
337    px     7.5000
338    py     0.8500
339    pz    52.0000
c
c         TESTICLES
370    sq     6.7262422     5.082094     2.157961 0 0 0    -8.5887387
              1.1300    -7.5500    -1.9950
371    sq     6.7262422     5.082094     2.157961 0 0 0    -8.5887387
             -1.1300    -7.5500    -1.9950
c
c         URINARY BLADDER
410    sq   126.0679   229.5945   248.8590 0 0 0 -2683.8589 0
             -4.0550     8.6050
411    sq    93.5215   177.0773   193.1376 0 0 0 -1788.4246 0
             -4.0550     8.6050
c extent    -4.6140     4.6140    -7.8740    -1.0360     4.3210
10.8890
c
c      PROSTATE
500    s    0 -6.0025 2.805 2.5
c      Void
600    so 301
```

```
c
c     STATISTICS
c  Weight =    64.67 kg ( =   142.58 pounds)
c  Height =   173.70 cm ( =    68.39 inches)

c
c         ESOPHAGUS
tr6       0.000       2.432     40.190
       0.722234  -0.621258  -0.303247
       0.651955   0.757926   0.000000
       0.229844  -0.197697       0.953
c
c ++++++++++++++++++++++++++++++++++++++++++++++
c      MATERIALS
c      Compositions from ORNL Report TM-8381
c ++++++++++++++++++++++++++++++++++++++++++++++
c      Adult Tissues (Density = 1.04 g/cc)
m1        1001  -0.10454
          6000  -0.22663
          7014  -0.02490
          8016  -0.63525
         11023  -0.00112
         12000  -0.00013
         14000  -0.00030
         15031  -0.00134
         16000  -0.00204
         17000  -0.00133
         19000  -0.00208
         20000  -0.00024
         26000  -0.00005
         30000  -0.00003
         37085  -0.00001
         40000  -0.00001
c
c       Skeleton (Density = 1.4 g/cc)
m2        1001  -0.07337
          6000  -0.25475
          7014  -0.03057
          8016  -0.47893
          9019  -0.00025
         11023  -0.00326
         12000  -0.00112
         14000  -0.00002
         15031  -0.05095
         16000  -0.00173
         17000  -0.00143
         19000  -0.00153
         20000  -0.10190
         26000  -0.00008
         30000  -0.00005
         37085  -0.00002
c        38084  -0.00003
         82000  -0.00001
c
```

```
c       Lung (Density = 0.296 g/cc)
m3       1001  -0.10134
         6000  -0.10238
         7014  -0.02866
         8016  -0.75752
        11023  -0.00184
        12000  -0.00007
        14000  -0.00006
        15031  -0.00080
        16000  -0.00225
        17000  -0.00266
        19000  -0.00194
        20000  -0.00009
        26000  -0.00037
        30000  -0.00001
        37085  -0.00001
c
c      Air (Density = 0.001020 /cc)
m4       6000  -0.00012
         7014  -0.75527
         8016  -0.23178
        18000  -0.01283
c
c ++++++++++++++++++++++++++++++++++++++++++++++
c   User Supplied Cards
c ++++++++++++++++++++++++++++++++++++++++++++++
mode p e
nps 10000000
sdef erg=.021 par= 2 pos= 0 -6.0025 4.305
     erg=.021 par= 2 pos= 0 -5.5025 4.305
     erg=.021 par= 2 pos= -1 -6.0025 3.805
     erg=.021 par= 2 pos= -1 -5.5025 3.805
     erg=.021 par= 2 pos= -.5 -6.0025 3.805
     erg=.021 par= 2 pos= -.5 -5.0025 3.805
     erg=.021 par= 2 pos= -.5 -4.5025 3.805
     erg=.021 par= 2 pos= -.5 -2.5025 3.805
     erg=.021 par= 2 pos= -.5 -2.0025 3.805
     erg=.021 par= 2 pos= -.5 -1.5025 3.805
     erg=.021 par= 2 pos= .5 -6.0025 3.805
     erg=.021 par= 2 pos= .5 -5.5025 3.805
     erg=.021 par= 2 pos= .5 -5.0025 3.805
     erg=.021 par= 2 pos= .5 -4.5025 3.805
     erg=.021 par= 2 pos= .5 -2.5025 3.805
     erg=.021 par= 2 pos= .5 -2.0025 3.805
     erg=.021 par= 2 pos= .5 -1.5025 3.805
     erg=.021 par= 2 pos= 1.5 -6.0025 3.805
     erg=.021 par= 2 pos= 1.5 -5.0025 3.805
     erg=.021 par= 2 pos= 1.5 -4.5025 3.805
     erg=.021 par= 2 pos= -1.5 -6.0025 3.305
     erg=.021 par= 2 pos= -1.5 -5.0025 3.305
     erg=.021 par= 2 pos= -1.5 -4.5025 3.305
     erg=.021 par= 2 pos= -1 -6.0025 3.305
     erg=.021 par= 2 pos= -1 -4.0025 3.305
     erg=.021 par= 2 pos= -1 -3.5025 3.305
```

```
erg=.021 par= 2 pos= -1 -3.0025 3.305
erg=.021 par= 2 pos= -1 -1.5025 3.305
erg=.021 par= 2 pos= 1 -6.0025 3.305
erg=.021 par= 2 pos= 1 -4.5025 3.305
erg=.021 par= 2 pos= 1 -3.5025 3.305
erg=.021 par= 2 pos= 1 -3.0025 3.305
erg=.021 par= 2 pos= 1 -1.5025 3.305
erg=.021 par= 2 pos= 2 -6.0025 3.305
erg=.021 par= 2 pos= 2 -5.0025 3.305
erg=.021 par= 2 pos= 2 -4.5025 3.305
erg=.021 par= 2 pos= 2 -2.5025 3.305
erg=.021 par= 2 pos= -2 -5.5025 2.805
erg=.021 par= 2 pos= -2 -4.5025 2.805
erg=.021 par= 2 pos= -2 -4.0025 2.805
erg=.021 par= 2 pos= -1.5 -6.0025 2.805
erg=.021 par= 2 pos= -1.5 -2.5025 2.805
erg=.021 par= 2 pos= -1.5 -3.0025 2.805
erg=.021 par= 2 pos= -1 -2.0025 2.805
erg=.021 par= 2 pos= -1 -1.5025 2.805
erg=.021 par= 2 pos= 1 -6.0025 2.805
erg=.021 par= 2 pos= 1 -2.0025 2.805
erg=.021 par= 2 pos= 1 -1.5025 2.805
erg=.021 par= 2 pos= 1.5 -6.0025 2.805
erg=.021 par= 2 pos= 1.5 -4.0025 2.805
erg=.021 par= 2 pos= 1.5 -2.5025 2.805
erg=.021 par= 2 pos= 2.5 -5.0025 2.805
erg=.021 par= 2 pos= 2.5 -4.5025 2.805
erg=.021 par= 2 pos= -2 -5.5025 2.305
erg=.021 par= 2 pos= -2 -4.5025 2.305
erg=.021 par= 2 pos= -2 -3.0025 2.305
erg=.021 par= 2 pos= -2 -2.5025 2.305
erg=.021 par= 2 pos= -1 -6.0025 2.305
erg=.021 par= 2 pos= -1 -5.5025 2.305
erg=.021 par= 2 pos= -1 -2.0025 2.305
erg=.021 par= 2 pos= -1 -1.5025 2.305
erg=.021 par= 2 pos= 1 -6.0025 2.305
erg=.021 par= 2 pos= 1 -2.0025 2.305
erg=.021 par= 2 pos= 1 -1.5025 2.305
erg=.021 par= 2 pos= 2 -6.0025 2.305
erg=.021 par= 2 pos= 2 -5.5025 2.305
erg=.021 par= 2 pos= 2 -4.0025 2.305
erg=.021 par= 2 pos= 2 -3.5025 2.305
erg=.021 par= 2 pos= 2 -2.5025 2.305
erg=.021 par= 2 pos= -2.5 -4.5025 1.805
erg=.021 par= 2 pos= -2.5 -4.0025 1.805
erg=.021 par= 2 pos= -2.5 -3.5025 1.805
erg=.021 par= 2 pos= -1.5 -5.5025 1.805
erg=.021 par= 2 pos= -1.5 -4.5025 1.805
erg=.021 par= 2 pos= -1.5 -4.0025 1.805
erg=.021 par= 2 pos= -1.5 -2.5025 1.805
erg=.021 par= 2 pos= -1.5 -2.0025 1.805
erg=.021 par= 2 pos= -.5 -6.0025 1.805
erg=.021 par= 2 pos= -.5 -5.5025 1.805
erg=.021 par= 2 pos= -.5 -5.0025 1.805
```

```
     erg=.021 par= 2 pos= -.5 -4.0025 1.805
     erg=.021 par= 2 pos= -.5 -3.0025 1.805
     erg=.021 par= 2 pos= -.5 -2.5025 1.805
     erg=.021 par= 2 pos= -.5 -2.0025 1.805
     erg=.021 par= 2 pos= -.5 -1.5025 1.805
     erg=.021 par= 2 pos= .5 -6.0025 1.805
     erg=.021 par= 2 pos= .5 -5.0025 1.805
     erg=.021 par= 2 pos= .5 -4.5025 1.805
     erg=.021 par= 2 pos= .5 -3.5025 1.805
     erg=.021 par= 2 pos= .5 -3.0025 1.805
     erg=.021 par= 2 pos= .5 -2.0025 1.805
     erg=.021 par= 2 pos= .5 -1.5025 1.805
     erg=.021 par= 2 pos= 1.5 -5.5025 1.805
     erg=.021 par= 2 pos= 1.5 -5.0025 1.805
     erg=.021 par= 2 pos= 1.5 -4.5025 1.805
     erg=.021 par= 2 pos= 1.5 -4.0025 1.805
     erg=.021 par= 2 pos= 1.5 -3.5025 1.805
     erg=.021 par= 2 pos= 1.5 -3.0025 1.805
     erg=.021 par= 2 pos= 1.5 -2.5025 1.805
     erg=.021 par= 2 pos= 1.5 -2.0025 1.805
     erg=.021 par= 2 pos= 2.5 -5.0025 1.805
     erg=.021 par= 2 pos= 2.5 -4.5025 1.805
     erg=.021 par= 2 pos= 2.5 -3.5025 1.805
     erg=.021 par= 2 pos= 2.5 -2.5025 1.805
     erg=.021 par= 2 pos= -2.5 -4.0025 1.305
     erg=.021 par= 2 pos= -2.5 -3.5025 1.305
     erg=.021 par= 2 pos= -2 -5.0025 1.305
     erg=.021 par= 2 pos= -2 -4.0025 1.305
     erg=.021 par= 2 pos= -2 -3.0025 1.305
     erg=.021 par= 2 pos= -2 -2.5025 1.305
     erg=.021 par= 2 pos= 2 -5.5025 1.305
     erg=.021 par= 2 pos= 2 -4.0025 1.305
     erg=.021 par= 2 pos= 2 -3.0025 1.305
     erg=.021 par= 2 pos= 2.5 -5.0025 1.305
     erg=.021 par= 2 pos= 2.5 -3.5025 1.305
*f18:p,e 1
*f38:p,e 3
*f48:p,e 4
*f58:p,e 5
*f68:p,e 6
*f88:p,e 8
*f148:p,e 14
*f168:p,e 16
*f178:p,e 17
*f198:p,e 19
*f218:p,e 21
*f238:p,e 23
*f258:p,e 25
*f268:p,e 26
*f278:p,e 27
*f288:p,e 28
*f298:p,e 29
*f318:p,e 31
*f358:p,e 35
```

```
*f368:p,e 36
*f378:p,e 37
*f478:p,e 47
*f708:p,e 70
prdmp 2j -1 2j
print -130 -140
```

VITA

Susrut Rajanikant Usgaonker was born in Caribou, Maine on August 2, 1978. He moved to Eagle Pass, Texas with his family in 1983, where he studied from elementary to high school. He graduated from Eagle Pass High School in 1997 and pursued his studies to obtain a Bachelor of Science degree in radiological health engineering from the Nuclear Engineering Department of the Dwight Look College of Engineering at Texas A&M University in College Station, Texas, which he received in 2001. He then pursued a Master of Science degree in health physics, also at Texas A&M University, which he received in 2003.

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