METHODOLOGICAL COMPARISON OF DOSE ESTIMATION FROM EXPOSURE DURING BOATING ACTIVITIES

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METHODOLOGICAL COMPARISON OF DOSE ESTIMATION FROM EXPOSURE DURING BOATING ACTIVITIES

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LIST OF ABBREVIATIONS

Abbreviation	Definition
DC	Dose Coefficient
DDE	Deep Dose Equivalent
FGR12/15	Federal Guidance Report No. 12 / 15
ICRP	International Commission on Radiological Protection
MCNP	Monte Carlo N-Particle code
NRC	Nuclear Regulatory Commission
PIMAL	Phantom wIth Moving Arms and Legs
VISED	MCNP Visual Editor Software

SUMMARY

The exposure scenario of an adult individual boating on a contaminated body of water is a plausible situation, given that nuclear power plants release radioactivity into bodies of water as part of normal operation through liquid discharge and through accidents that may occur. When calculating dose rate coefficients from external exposure during boating activities, it has been common practice to make a conservative estimate by halving coefficients from water immersion. To determine the appropriateness of this factor a physically realistic boating scenario was modelled in MCNP6, a Monte Carlo N-Particle code, for three radionuclides of interest to reactor liquid effluents: ^{60}Co, ^{137}Cs, and ^{54}Mn. However, the complexity of this MCNP geometry led to long simulation run-times before acceptable statistics were reached. Simpler modelling geometries and different modelling types were computed for comparison and determination of the acceptability of these methods. To accomplish this, a basic phantom and boat model was created for the point-kernel code QAD-CGGP-A and ran for select organs. Later, MCNP6 calculations of air dose were made in the original model with the phantom removed; these results were converted into expected dose in tissue and were attenuated by a factor representing the loss of tissue shielding after phantom removal. Comparisons were made using reference values taken from the LADTAP II code, as well as Federal Guidance Reports No. 12 and 15. Differences between reference values for boating dose rate coefficients and those coefficients found through the modelling techniques of this research are presented.

CHAPTER 1

INTRODUCTION

The release of liquid effluent containing radionuclides into the environment requires assessment of possible radiation dose to an individual through various pathways. Radionuclides can lead to radiation dose through multiple pathways, such as ingestion or inhalation. These two pathways cause internal damage through both chemical toxicity as well as radioactive decay damage to the inside of the body. The impact on health from external exposure to radionuclides that never physically reach the body must also be evaluated. Radionuclides that emit relatively high-energy radiation can traverse a path to an individual's body and cause ionization events in tissue. For external exposure to radiation, dose rate coefficients (shortened to dose coefficients in this paper) are often used to directly relate the amount of radioactivity in an amount of a contaminated volume to the dose rate to the human body. One such exposure scenario is that of an individual exposed while boating on a contaminated body of water.

Exposure to ionizing radiation while boating is a real scenario, and dose coefficients have not been specifically tabulated for an individual boating on a contaminated body of water. Multiple sources state that it is commonly assumed that boating dose coefficients are simply half of the dose coefficients for water immersion.[1][2][3] However, this general assumption overlooks important differences between the two scenarios. A boating scenario is closer in geometry to an individual standing on contaminated soil rather than being immersed, as almost all of the contamination will be below the body. Furthermore, a large portion of beta radiation, especially at low energies, will be absorbed by the hull of the boat; whereas in an immersion scenario, contamination is close up and unattenuated against the skin of the body. Usage of these differences in explaining the results and the suitability of a 50% dose reduction factor will be expanded upon in Chapter 6.

Although performing modelling with the most realistic geometry and source term will give the most accurate results, it is important to consider computational requirements during these calculations. Given that such complex Monte Carlo calculations can take a considerable amount of time to run, finding accurate results through simpler radiation transport modelling or different modelling types would also be helpful for future calculations of a boating scenario – such as for younger individuals on the boat or other radionuclides as the contamination. For these reasons, a comparison of dose calculation methodology is also of great interest for study.

Table 1.1: Common radionuclides in reported liquid effluent releases from nuclear plants [4]

Mixed Fission & Activation Products		Tritium & Dissolved/Entrained Noble Gases
Iron (55)	Cesium (134,137)	Hydrogen-3
Cobalt (58,60)	Chromium (51)	Krypton (85,85m,87,88)
Niobium-95	Manganese (54)	Xenon (131,133,133m,135,135m)
Iodine (131,133,135)	Zirconium-95	

This combination of dose calculation comparison to validated results and comparison between modelling methods will be performed for three isotopes of concern: ^{60}Co, ^{137}Cs, and ^{54}Mn. Table 1.1 shows a table prepared by the National Center for Biotechnology Information of common radionuclides in liquid effluent releases from nuclear power plants.[4] These three radionuclides are shown by the NCBI to likely appear in a body of contaminated water. As seen below in Table 1.2, these three radionuclides are also long-lived, with half-lives long enough to be a threat over a period of years. Lastly, these radionuclides also emit high-energy gamma rays, which have the ability to penetrate through water and boat shielding to reach the body. Note that for ^{137}Cs, the short-lived ^{137m}Ba daughter is the nuclide that produces the high-energy gamma ray. Therefore for Federal Guidance Reports No. 12 and 15, dose coefficients for this gamma ray will be taken from ^{137m}Ba. In LADTAP II, the code assumes ^{137}Cs is in secular equilibrium with the daughter and lists the dose coefficient for this gamma emission under ^{137}Cs.

Table 1.2: Physical characteristics of selected radionuclides [15]

			Dominant Gamma Emission	
Radionuclide	Decay Mode	$T_{1/2}$	Yield (nt^{-1})	Energy (MeV)
Mn-54	EC B- B+	312.2 d	0.9998	0.8348
Co-60	B-	5.271 y	0.9985	1.1732
			0.9998	1.3325
Cs-137	B-	30.17 y	5.8E-6	0.2835
Ba-137m	IT	2.552 m	0.8974	0.6617
Cs-137D*			0.8472	0.6617

*Notation assumes Ba-137m, formed in 0.944 of Cs-137 decays, is in secular equilibrium

In this study, exposure due to beta particles will be assumed to be zero, as the hull of a boat should provide near-complete shielding from electron sources. X-ray emissions and gamma emissions that are so low either in energy or emission probability that their contribution to dose can be neglected are ignored in the computations.

CHAPTER 2

BACKGROUND

2.1 Federal Guidance Reports No. 12 and 15

For validation of the results, generally accepted dose coefficient values are needed to compare against; specifically, dose coefficients for an adult individual immersed in contaminated water and dose coefficients for an adult individual standing on contaminated soil are relevant comparison points. As stated before, boating dose coefficients are typically taken as half of the water immersion dose coefficient. Also comparing against the case of infinitely contaminated soil will determine which comparison case is more accurate to the actual dose coefficient.

Federal Guidance Reports No. 12 and 15 (FGR12/15) are documents published by the Environmental Protection Agency to establish dose coefficients for multiple scenarios of external exposure to radionuclides in air, water, and soil. As far as methodology of dose calculation goes, as will be discussed shortly, the two reports are quite similar. However, FGR12 was published in 1993 and utilized software and datasets that have since been improved upon. Differences that can be seen between the two sets of dose coefficients for the same geometry can be attributed to data and method changes, such as the differences in ICRP organ and effective dose definitions, as well as changes in phantom modelling. Table 2.1 contrasts these differences in more detail.

Table 2.1: FGR12/15 comparison points

Comparison Point	FGR12	FGR15
Radiation Transport Code	ALGAMP	MCNP6
Radionuclide Decay Data	ICRP Publication 38	ICRP Publication 107
Tissue weighting factors	ICRP Publication 26	ICRP Publication 103
Water immersion method	Two-step; coupled surface	Single-step direct calculation
Cross-section database	ENDF/B-V	ENDF/B-VI.8

For both FGR12[1] and FGR15[2], the computational calculation of organ dose from photon sources in soil was broken into two independent steps: (1) calculation of the incident radiation field on a coupling cylinder surrounding the phantom, and (2) the calculation of organ dose due to an equivalent surface source irradiating the phantom. This division of the transport calculations allows the complex phantom geometry to be removed from part 1, serving to speed up the calculation using an accurate coupling source. Figures 2.1 and 2.2 depict this geometry division.

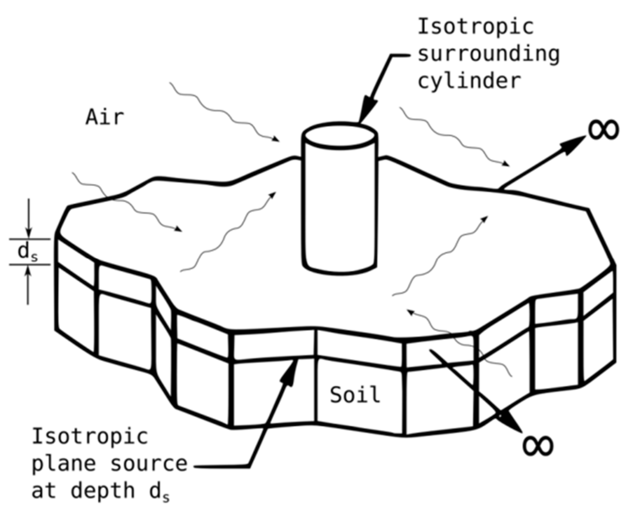

Figure 2.1: Radiation field due to a contaminated ground plane, on a cylinder surrounding the phantom [2]

Figure 2.1 shows that the plane of soil contamination is considered infinite in all directions surrounding the phantom and that calculations for external exposure to soil contamination were made at specific depths. Dose coefficients were found for planar sources at varying depths. Then, the dose coefficient for volumetric sources, in this case of an effectively infinite contaminated soil source of four mean free paths deep, was found through:

$$\hat{h}_{T,L}(E) = \frac{1}{\mu}\int_{0}^{\mu L} \hat{h}_{T,P}(E,\tau)\, d\tau \tag{1}$$

where $\hat{h}_{T,P}$ is the dose rate coefficient for tissue T for a plane isotropic source P at an emitted energy E at a depth τ in mean free paths, and μ is the linear attenuation coefficient for soil at energy E. The soil composition used in both FGR12 and FGR15 is given in Table 2.2.

Table 2.2: Soil composition

Element	Mass Fraction
H	0.021
C	0.016
O	0.577
Al	0.050
Si	0.271
K	0.013
Ca	0.041
Fe	0.011

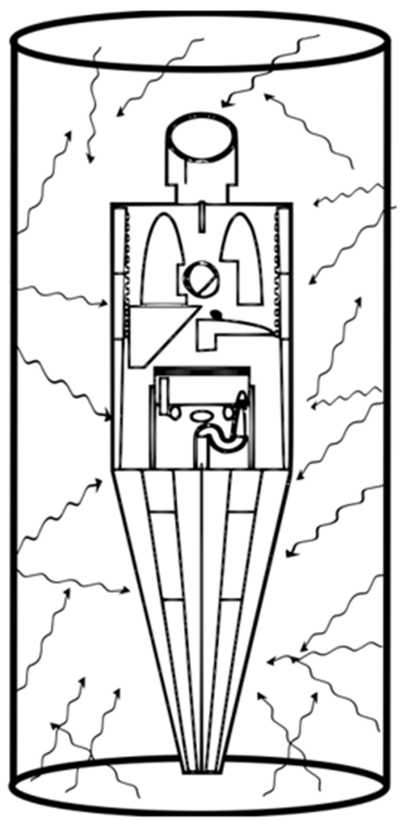

Figure 2.2: Angular current source on the coupling cylinder surrounding the phantom [2]

For water immersion, only FGR12 utilizes the coupled methodology described above and in Figure 2.2. With greater hardware capabilities now available in FGR15, this scenario was simulated as an effectively infinite contaminated pool surrounding the phantom. The reason this could not be done with soil calculations is a result of the much lower photon attenuation of surrounding air as compared to water, allowing smaller physical dimensions in the immersion MCNP calculations to simulate an effectively "infinite medium".

2.2 PIMAL – Phantom wIth Moving Arms and Legs

To simulate a boating scenario in MCNP, a phantom to represent the individual must be selected. Phantoms have typically been positioned standing upright in dose coefficient calculations; however, boating is normally performed sitting down. Therefore, a phantom that has either been created in the seated position or has the ability to have limbs repositioned was desired for this study.

The U.S Nuclear Regulatory Commission (NRC) has distributed the computer software code PIMAL – Phantom wIth Moving Arms and Legs – which has the capabilities of generating an adult male or female phantom in many different postures.[12] Through flexibility at the hip, knee, shoulder, and elbow, PIMAL allows its user to position a phantom in a wide variety of poses; PIMAL is also accompanied by visual software to aid in the creation of the model. After arranging limbs as desired, the software will then output an MCNP phantom model similar to those used in FGR12/15 but in a selected position. Using PIMAL, an adult male and female phantom were created in a seated position representative of how someone in a boating scenario would be positioned. Figure 2.3 depicts the female PIMAL phantom that will be utilized in the MCNP model of a boating scenario in Chapter 3.

Figure 2.3: Female PIMAL phantom in boating position

2.3 ICRP Tissue Weighting and Fluence-to-Dose Factors

The limiting dose quantity used in radiation protection is the effective dose, designated by E. The effective dose is determined through a weighted sum of the dose to radiosensitive organs and tissues of the body:

$$E = \sum_{T} w_T \sum_{R} w_R D_{T,R} \qquad (2)$$

where w_T is the tissue weighting factor, w_R is the radiation weighting factor, and $D_{T,R}$ is the average absorbed dose in tissue T by radiation type R.[14] Since only photons will be considered in this study, the radiation weighting factor is unity. The tissue weighting factors are tabulated in Table 2.3, with changes between ICRP Publication 26 and 103 compared. These tissue weighting factors consider a large number of tissues within the body, with the accompanying tissue weighting factor representing the health detriment associated with radiation damage within said tissue. Since much research has been accomplished between these two sets of factors, large differences are notable between the publications with the same tissue or organ.

Table 2.3: ICRP 26 & 103 tissue weighting factors [14]

Organ/Tissue	w_T (ICRP 26)	w_T (ICRP 103)
Gonads	0.25	0.08
Breast	0.15	0.12
Colon		0.12
Red Marrow	0.12	0.12
Lungs	0.12	0.12
Stomach		0.12
Urinary Bladder		0.04
Liver		0.04
Esophagus		0.04
Thyroid	0.03	0.04
Bone Surface	0.03	0.01
Skin		0.01
Brain		0.01
Salivary Glands		0.01
Remainder[1]	0.3	0.12

[1] Remainder tissues constitute multiple other tissues/organs averaged, such as the adrenals, brain, small intestine, kidney, muscle, pancreas, prostate, spleen, thymus, and uterus.

As will be discussed in Chapter 4, fluence-to-dose conversion factors will be needed to convert computationally calculated flux in certain organs to absorbed dose. Such factors may be found for photons in Appendix B of ICRP Publication 116.[7] Data there are given for both the reference male and female phantoms, for each organ, and for different irradiation geometries, such as antero-posterior, postero-anterior, left and right lateral axes, and rotational and isotropic directions. Considering that none of these irradiation geometries strikingly align with a boating scenario, the rotational and isotropic fluence-to-dose conversion factors at source energy will be used in comparison as they are the closest in approximation of a surrounding source underneath the phantom.

2.4 Methods of Dose Estimation Outline

The purpose of this study is to compare and contrast multiple methods of determining dose coefficients to an adult individual boating on a contaminated body of water. These comparisons will serve as guidance to future calculations on how to approach such an approximation in a reasonable computational effort. Understandably, the quickest means of determining an accurate result will be a method of choice. Therefore the study will begin by modelling the boating scenario as closely as possible through MCNP simulations. These results will be held as the benchmark for comparison purposes; if faster methods result in comparable data, then such complex modelling requiring excessive computational time for a boating scenario may be deemed unnecessary. Next, the point-kernel code QAD-CGGP-A[10] will be utilized with a simpler phantom model to determine dose at certain important organs within the body. Next, the complex model will be simulated again to compute air dose with the phantom removed and point-flux detector tallies in lieu. The flux in air above the boat will be converted to dose expected in tissue and compared to the other results. Lastly, dose conversion factors used to find dose to a recreational boater will be taken from LADTAP II, a code which performs environmental dose analysis for releases of radioactive effluents.[9] All of these results will be compared to the FGR12 and FGR15 values for infinite soil contamination and water immersion to determine which approaches are acceptable methods of dose estimation for the boating scenario.

CHAPTER 3

REALISTIC MCNP MODEL

3.1 Boat Model & Properties

For the purpose of studying dose coefficients to recreational boaters, a rowboat (jonboat) was modelled to represent a general watercraft one might use. A popular jonboat brand, Alumacraft, was utilized as the template to create a model in MCNP. When contacted for boat plans for academic study, Alumacraft declined to provide blueprints of the boat. Therefore, a free 12 foot jonboat plan found in an online archive[5] was used for most specifications. Hull thickness and seat thickness were taken from specifications found on Alumacraft's own website for the Jon Sierra LT brand boat. The boat model creation was facilitated through the use of VISED, a visual software tool to help create geometries in MCNP. The boat model was created as a combination of many planes determined to give the boat correct dimensions. The model was also created so that the front of the boat would rise upwards out of the water, as typically seen with these types of watercraft.

Table 3.1: Jonboat properties

Length	3.65 m
Max Width (rear)	1.20 m
Min Width (front)	0.68 m
Depth	0.4065 m
Hull thickness	1.3 mm
Seat thickness	3.175 mm
Boat composition	5052 aluminum alloy[1]
Boat density	2.68 g/cm^3
Approx. Weight	110 lbs or 50 kg
Water Vol. Displaced	0.05 m^3
Depth of boat in water	0.07 m

[1] See Table 3.2 for aluminum alloy composition

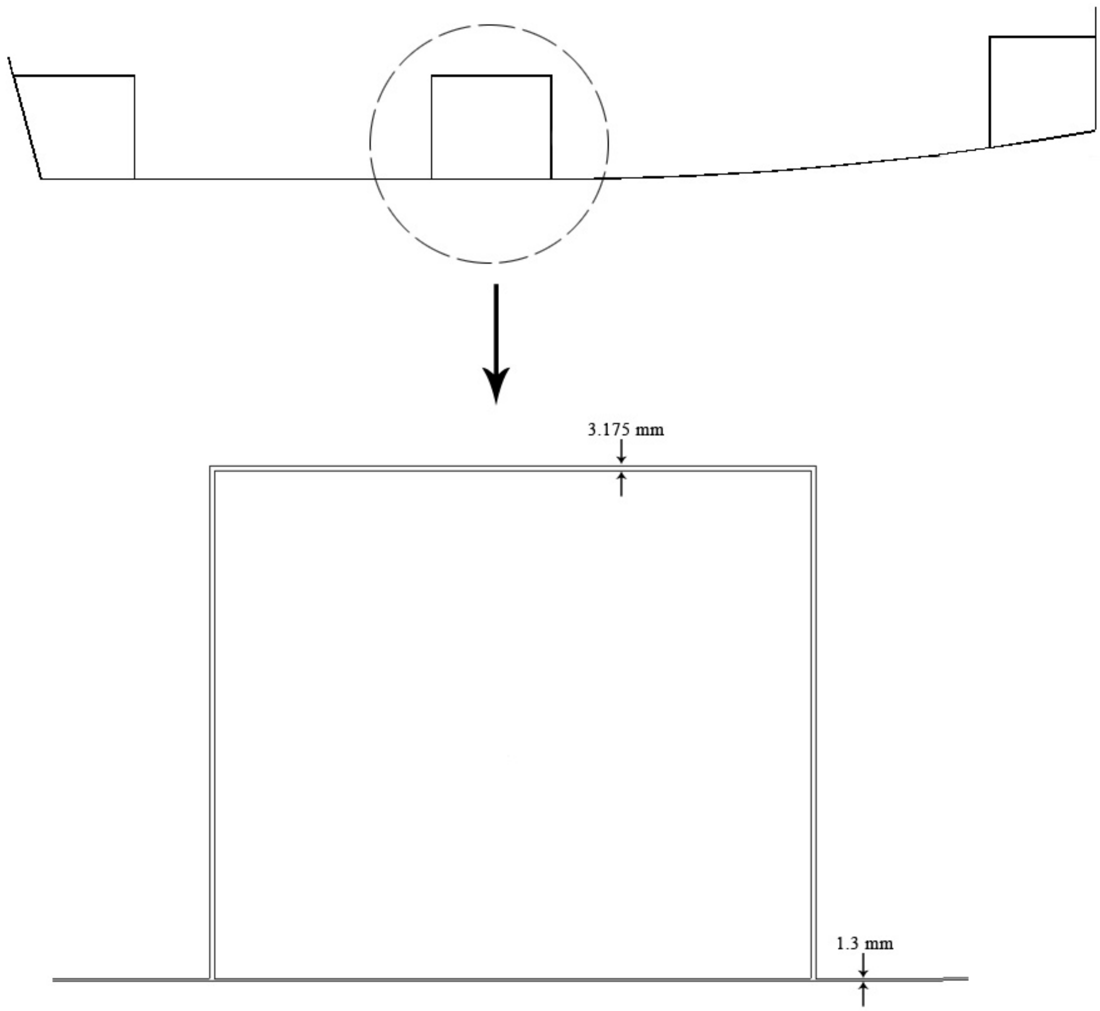

Figure 3.4: Jonboat model – VISED side view of boat and bench seat, cut midplane

Table 3.2: 5052 Aluminum alloy composition [6]

Element	Mass fraction
Mg	0.025
Cr	0.0025
Cu	0.001
Zn	0.001
Fe	0.004
Mn	0.001
Si	0.0025
Al	0.963

3.2 MCNP Scenario Modelling

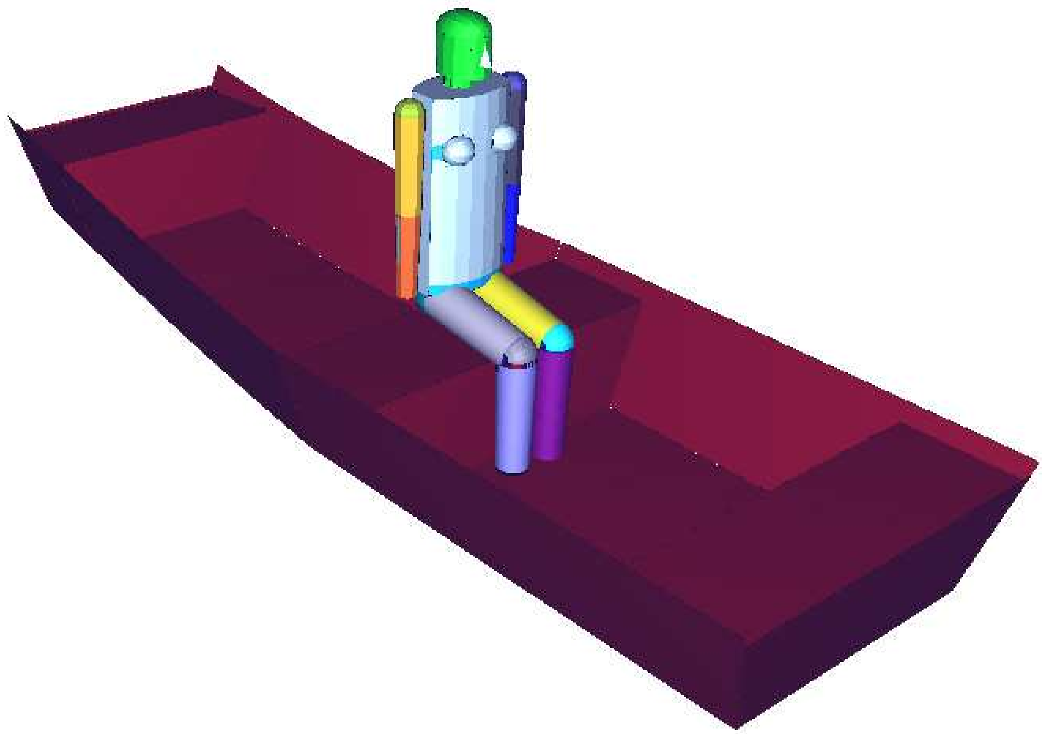

Figure 3.5: PIMAL phantom seated in modelled jonboat

After creation of the jonboat model, the adult male and female phantoms need to be seated on this jonboat on a contaminated body of water. The NRC's ORNL-developed PIMAL software was utilized to create a seated adult MCNP phantom for placement on the boat. The phantom's arms were kept at its side, and its legs were placed at a 79 degree angle at the hips and a -79 degree angle at the knees. The output received from PIMAL can be seen above in Figure 3.2.

It was necessary to integrate the phantom into the boat model representing the contamination scenario. Though both models were created with mind to one another, the positioning of the phantom with respect to the jonboat was not precise. The surface transformation card (TR) feature in MCNP was therefore utilized to translate all jonboat surfaces in a way that placed the phantom in a seated position on the boat's middle section facing the rear. This simply meant a 10 cm translation in the negative z-direction and 15 cm translation in the y-direction.

Next, it was necessary to create the surroundings, namely the water and air. For accuracy of the modelled situation, it was required to consider all photons that could reach the phantom from the contaminated water source. Each of the three considered radionuclides has different gamma energies with varying penetrating power; therefore, different surrounding geometry properties were used for each case. To consider all photons that may reach the phantom from the body of water, first the depth of the contaminated water was taken to 5.5 mean free paths in water for each energy. This accounts for 99.6% of all photons that could reach the air by travelling straight upwards from the bottom of the water volume. However, to account for nearly all photons reaching the phantom that originate near or at the water-air interface would require a similar mean free path thickness of air surrounding the phantom. Considering the limitations of MCNP calculations and the very large mean free path in air for photons around 1 MeV, the water source was only extended cylindrically outwards to three mean free paths in air for each case. This accounts for 95% of all photons that originate at the water's surface and take a direct path to the phantom. This was taken as sufficient radial boundary extension, as the probability of a source particle taking this type of path is very small. The three mean free path thickness was also applied for the air volume above the phantom. Photons that scatter in the atmosphere at this height or greater must travel at least six mean free paths (three up and three down with respect to the air-water surface) to reach the phantom. At distances starting further away radially, they must travel an even greater length and therefore cannot make an important contribution to the dose tally. At this point in the modelling stage, geometry properties can be seen in Table 3.3 and visually noted in Figure 3.3, where the wireframe represents the contaminated water. Note that a portion of the jonboat is underwater, at the depth specified in Table 3.1.

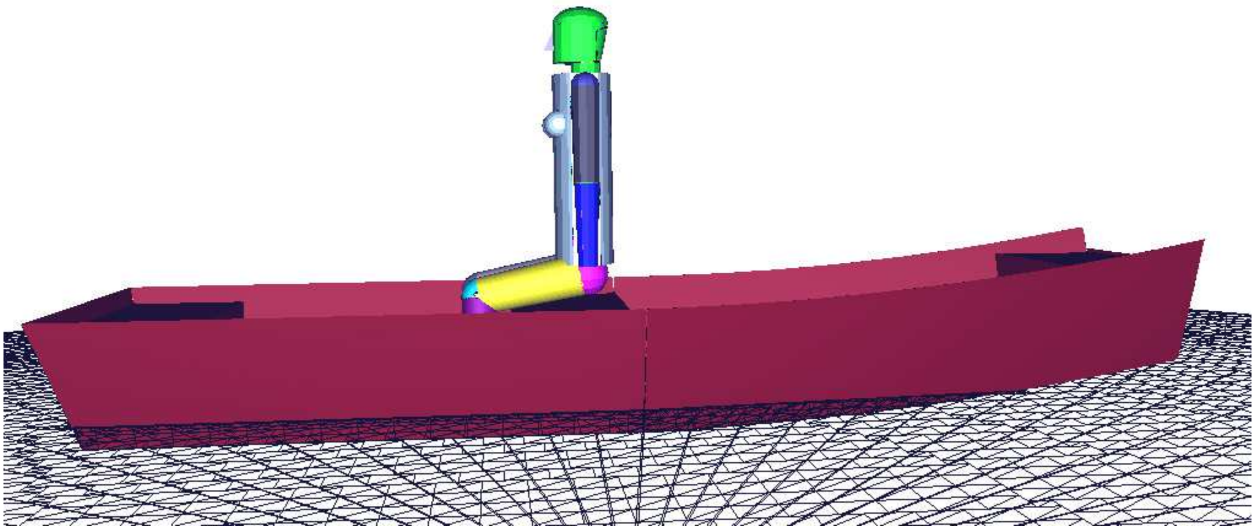

Figure 3.3: Female PIMAL phantom in boating scenario

Table 3.3: Water and air boundary requirements [8]

Radionuclide	Energy (MeV)	μ/ρ – mass atten. coeff. water (cm^2/g)	5.5 MFP in water (cm)	μ/ρ – mass atten. coeff. air (cm^2/g)	3 MFP in air (cm)
Co-60	$1.25^{\dagger}$	6.323×10^{-2}	87	5.687×10^{-2}	43060
Cs-137	0.6617	8.629×10^{-2}	64	7.761×10^{-2}	31550
Mn-54	0.8348	7.726×10^{-2}	71	6.949×10^{-2}	35250

†Average energy of gamma emission, where Co-60 has a yield of 2 nt^{-1} (Table 1.2)

3.3 Variance Reduction Techniques

As previously discussed, calculating tissue and organ dose through MCNP requires the radiation transport of a simulated particle to reach and interact with the phantom. Statistical error is introduced through this process but can be reduced by utilizing techniques to allow more particles to reach the tally zone in the same run-time. Often, one of the best variance reduction techniques to utilize is geometry simplification. In the case of the modelled boating scenario, a large portion of the source particles are very likely to never reach the phantom if the water source is modelled as a cylinder, due to both shielding and distance. For instance, a photon source particle originating at the maximum depth and near the radial edge of the model's boundary would have to both travel through at least 5.5 mean free paths of water, scatter toward the phantom, and travel through three mean free paths of air. Source particles originating in this region would almost never reach the phantom and would waste valuable computing resources; they also are in the majority's supply, as the volume of water in a cylinder is proportional to r^2. For this reason, cone geometry was utilized in the final MCNP model. This geometry can be seen below in Figure 3.4, where the depth of the water is at least one mean free path thick at the boundary and 5.5 mean free paths thick underneath the phantom; this was accomplished through the combination of a cylinder and cone water volume. Not only does this reduce the number of useless particles being transported in water, but it also confines the surrounding air to a cone region where only scattered photons that can likely make it to the tally location are tracked.

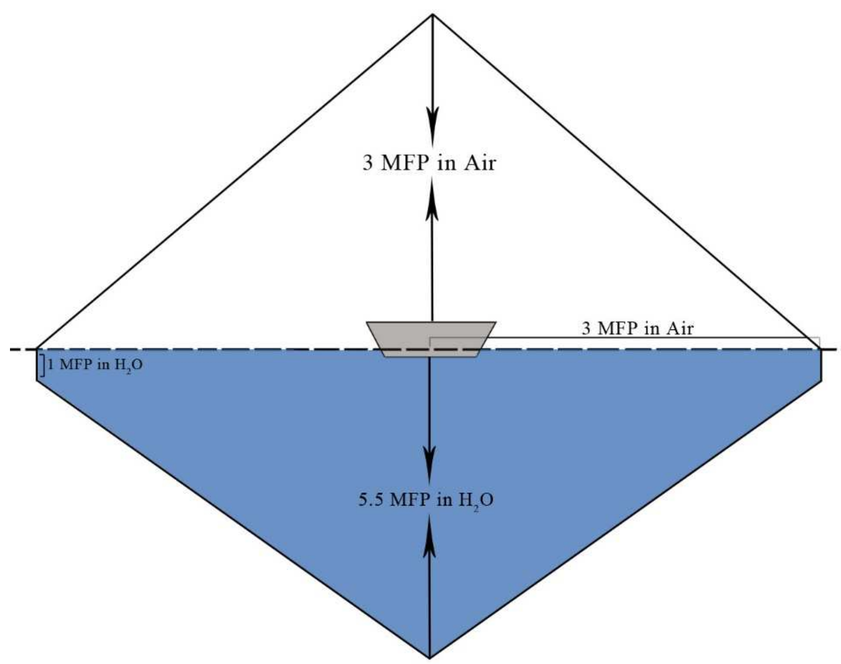

Figure 3.4: MCNP surrounding geometry with minimum depth of 1 MFP at edge and maximum depth of 5.5 MFP (not to scale)

Although source particles near the boundary can still provide dose to the phantom, it is notable that those that are produced nearby are not only more likely to reach the phantom but are also less attenuated in energy. For this reason, the majority of the dose to the phantom will come from contaminated water closer to the phantom. Therefore, each case had its source divided into two sections, an inner "cylinder" and outer "concentric cylinder" as seen in Figure 3.5. This allowed more run-time to be spent on particles that have the best chance to reach the phantom. Greater statistics were achieved for this combination than compared to a model with no division of source. The dose tallies were normalized by source volume to create dose coefficients and then summed together with error propagated forward.

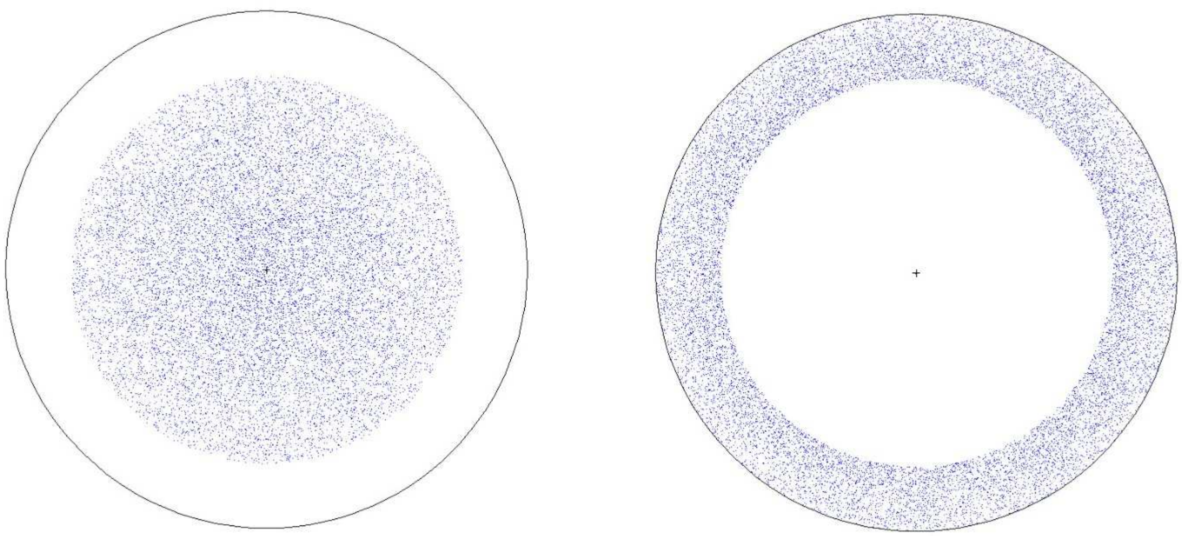

Figure 3.5: ^{54}Mn source creation locations for the inner and outer source divisions (VISED X-Y cross section view)

Lastly, the exponential transform path-length stretching card (EXT) was employed in all MCNP models. The EXT card works to increase tally efficiency by decreasing the total photon cross-section in a preferred direction and increasing it in the opposite direction. The cross-section adjustment equation is shown below:

$$\Sigma_{T,adjusted} = \Sigma_T \cdot (1 - p\mu) \tag{3}$$

where p is the stretching factor and μ is the cosine of the angle between the preferred direction and any given direction. With a stretching factor of 1.0, the cross-section would disappear for photons travelling in the preferred direction and double in the opposing direction. This allowed for a stretch of the average path length towards the phantom, increasing the likelihood of transmission through the air and water. For the purposes of this study, a stretching factor of 0.4 was tested for the male phantom boating on ^{137}Cs contaminated water. The preferred direction was set so that the average path length was stretched towards the chest of the phantom. The results shown below in Table 3.4 demonstrate the effectiveness of the EXT card in reducing tally error while keeping accurate results in comparison to the analog simulation. To obtain the error seen for skin dose with the stretching factor of 0.4 without using the EXT card would have required a total run-time of 32.92 hours.

Table 3.4: Exponential transform card stretching factor results

EXT Factor	NPS (# particles)	Run-time (h)	Skin dose tally	Error	Lung dose tally	Error
None	$1.8x10^{9}$	17.81	$1.097x10^{-12}$	0.0987	$7.761x10^{-13}$	0.1618
0.4	$1.8x10^{9}$	18.69	$1.036x10^{-12}$	0.0726	$7.371x10^{-13}$	0.1356

3.4 Summary of Dose Calculation from MCNP results

These modelling techniques as described were combined into sets of different MCNP6[13] runs: adult male and female, for ^{60}Co, ^{137}Cs, and ^{54}Mn, for inner and outer source locations. Absorbed doses to organs were found using the kerma approximation through MCNP's F6:P track-length estimator for photons. Each MCNP6 simulation was ran for a number of source particles (NPS) ranging from $1x10^{9}$ to $6x10^{9}$. If statistics were poor, a continue card was used to pick up from MCNP's last simulated source particle. After the trials were ran, all outputs were condensed to a folder and code was written in Python language to parse through outputs for individual organ dose tallies and associated relative errors. The code then converted tally units

(Mev/gram) to units (Gy/Bq s) through the following conversion process, where *sp* is source photon and *nt* is nuclear transformation:

$$F6\,Tally\,\left(\frac{MeV}{g\,sp}\right)*\left(\frac{1000\,g}{1\,kg}\right)*\left(\frac{1.602x10^{-13}\,J}{MeV}\right)*\left(\frac{1\,Gy}{1\,\frac{J}{kg}}\right)*\left(\frac{\#\,sp}{nt}\right)*\left(\frac{nt}{Bq\,s}\right) \tag{4}$$

This conversion multiplied by the associated source volume results in dose coefficients in units (Gy m^3 Bq^{-1} s^{-1}). As stated previously, the inner and outer dose coefficients were then summed to result in dose coefficients for each radionuclide for male and female adults. Effective dose was also found using ICRP 103 tissue weighting factors as discussed in Chapter 2.3. This Python code may be seen in Appendix C.

CHAPTER 4

SIMPLIFIED QAD MODEL

4.1 Simplified Phantom Model

Although the use of MCNP to determine dose coefficients allows for realistic modelling through the use of a seated PIMAL phantom, deterministic methods of determining dose are often much quicker and have no inherent statistical uncertainly associated with them. One such modelling method is the use of QAD-CGGP-A (QAD), which uses a point-kernel ray-tracing technique for gamma dose calculations. QAD-CGGP-A was published through the Radiation Safety Information Computational Center of Oak Ridge National Laboratory in 1995.[10] The GP stands for the version which makes use of the Geometric Progression fitting function for the gamma-ray buildup factor; CG stands for combinatorial geometry, which allows specification in the code input file for constructing geometry zones based on body surfaces, similar to MCNP.

For gamma-ray calculations, the QAD code uses the point-kernel technique, which represents the transfer of energy by uncollided photon flux along a line-of-sight path. During these calculations, the average buildup factor seen by photons is tallied to account for the contribution from scattered photons. The user is asked to create a geometry medium, to place point source locations, and to place point detector locations. QAD-CGGP-A limits the number of source locations to 100 allowed in each direction (i.e. only 100 in each of the radial, z, and theta directions). Below is the expression for the gamma-ray dose rate at any detector point due to a number of isotropic source points emitting S photons of energy E_0 per second:

$$D(r) = K(E_0) \sum_{k=1}^{100} \sum_{j=1}^{100} \sum_{i=1}^{100} \frac{S(r'_{ijk}, E_0) B(\mu|r - r'_{ijk}|, E_0) \exp(-\mu|r - r'_{ijk}|)}{4\pi |r - r'_{ijk}|^2} \quad (5)$$

where K is the fluence-to-dose conversion factor, r is the point of dose rate interest, r'_{ijk} is the location of the source point, μ is the total attenuation coefficient at energy E_0, $|r - r'_{ijk}|$ is the distance between source point and point of interest, and $B(\mu|r - r'_{ijk}|, E_0)$ is the buildup factor. The summation shown is made over 100 detectors in each axial direction. These calculations of flux, if K is left unused, are made for each point detector location specified in the QAD input.

Given that MCNP geometry cannot be directly translated into QAD combinatorial geometry, the unchanged seated PIMAL model on a jonboat could not be used in this model. Instead, a rough model of the PIMAL phantom was created for use in the QAD code. Five organs were chosen for geometric simplicity to be modelled within the phantom: the brain, liver, lungs, thyroid, and gonads. All organ sizes and body sizes were chosen based on their corresponding PIMAL sizes. This simplistic phantom was first modelled in MCNP through VISED to make sure the geometry and zoning were correctly chosen, as QAD-CGGP-A does not have an intricate debugging tool. Seen below in Figure 4.1 are these created phantoms.

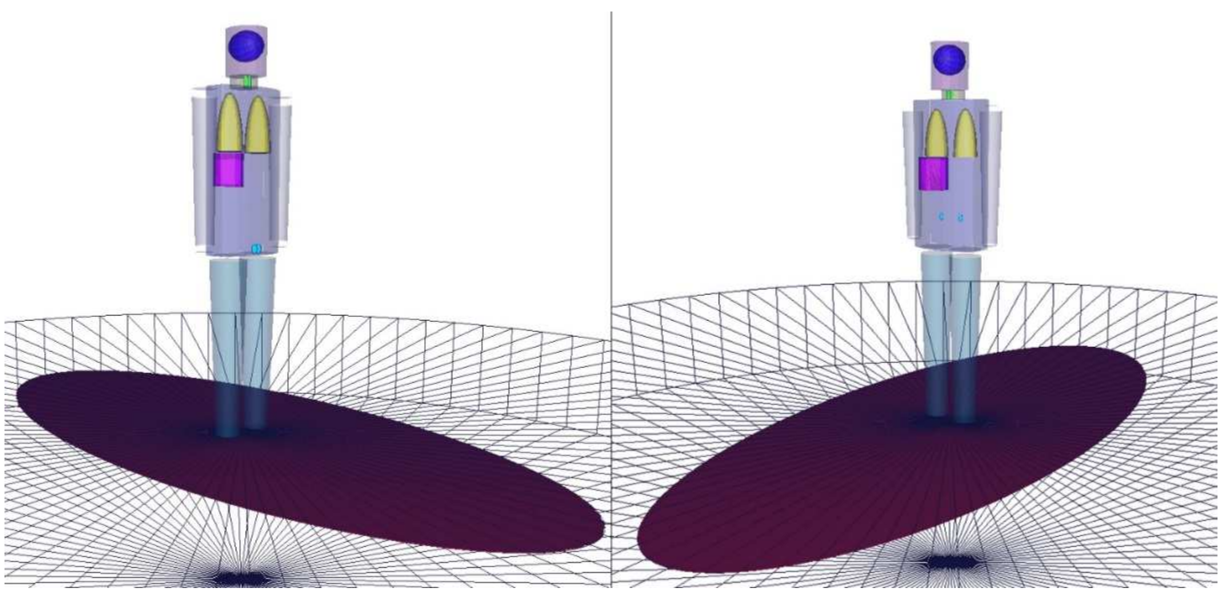

Figure 4.1: Male and female (respectively) phantoms used in QAD – visualized through VISED software

The brain and gonads are represented as ellipsoids; the lungs are represented by ellipsoids that are truncated in half by a box geometric body; lastly, the thyroid and liver are represented by cylinders. Though organs such as the brain, thyroid, and liver are not exact in geometry as compared to PIMAL, the volumes and dimensions of each organ were kept the same with the exception of the male gonads being positioned inside the torso. The soft tissue of the body was represented as truncated right cones for the arms and legs, right elliptical cylinders for the trunk of the body and head, and a cylinder for the neck. Dimensions of these body parts as well as tissue compositions were also kept the same.

As seen in Figure 4.1, the jonboat geometry was simplified into a roughly equivalent disk of aluminum alloy 5052 shielding underneath the phantom. Though the hull size of the jonboat was created with thickness 1.3mm, 2.0mm thickness was used in this model to account for shielding due to the seats.

4.2 QAD Scenario Modelling

In similar fashion to the MCNP realistic model, the water was extended down to a depth of 5.5 mean free paths in water for each energy and out to 3 mean free paths in air for each energy. Though unnecessary for a point-kernel code, air above the phantom was also extended to three mean free paths in air. Simple cylinders were used instead of truncated cones as before.

Unlike MCNP, where source volume is defined by the user, QAD code requires positioning of point sources within the contaminated water volume, with a maximum limit of 100 in any given axial direction. Notably, this also requires the user to uniformly spread out each source position, or else bias what was before a homogeneous contaminated body of water. In this case, spreading out 100 point sources along the radial direction means placing a source position about every three to four meters. Instead, once again in similar fashion to the MCNP model, the

QAD model's source was divided into two regions: an inner cylinder and outer concentric cylinder. The inner source division was given 50 radial point source intervals between the origin and 0.3 mean free paths in air. The outer source division was given 50 intervals between 0.3 to 3 mean free paths in air. All QAD models had 50 divisions in the z direction and 50 divisions in the theta direction. Source point locations divided axially can be seen in Figure 4.2, where an example water source has 10 divisions in the radial, z, and theta direction.

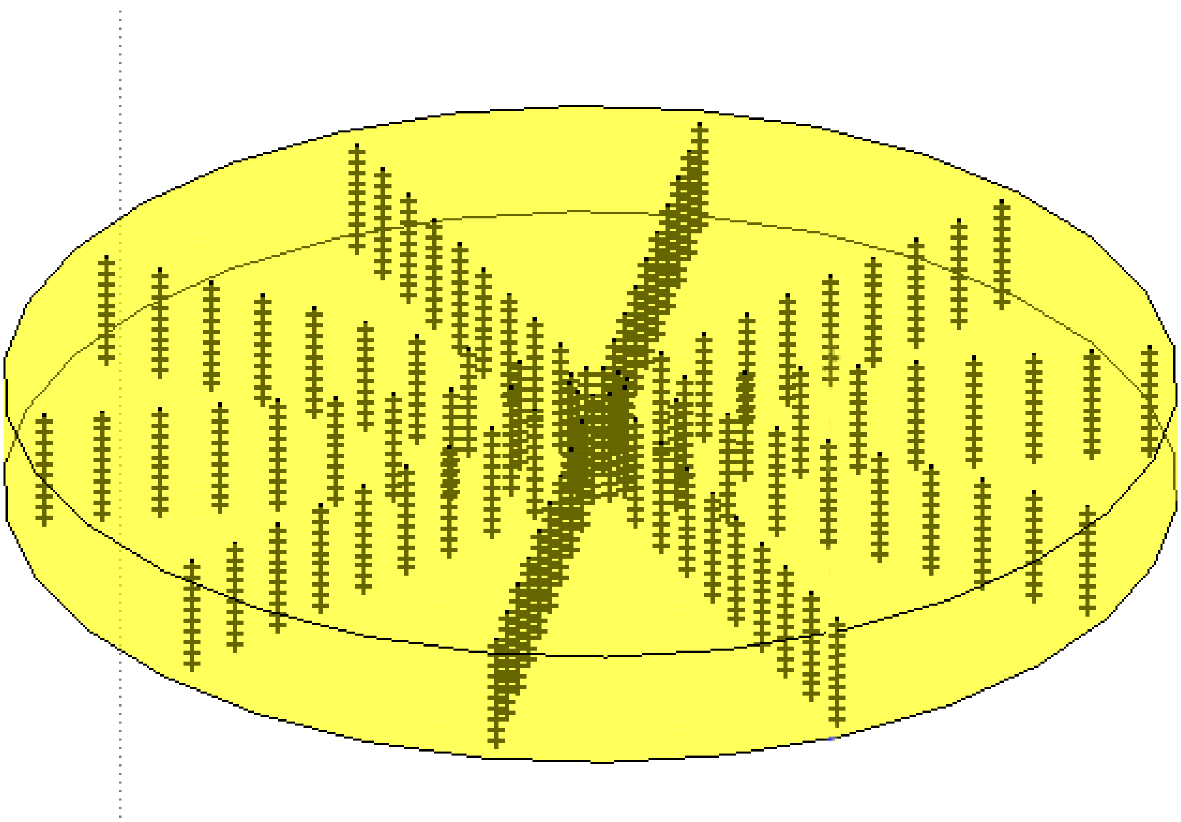

Figure 4.2: EASY-QAD visualization of source point locations, with 10 axial divisions

The software tool EASY-QAD[11] was utilized to help create the QAD-CGGP-A input files. Certain bugs within EASY-QAD prevented the complete use of the software package to create and run QAD code. However, EASY-QAD allowed quick entry of source spectrum information and material composition, which could be cut from created files and used in the input files for the simplified phantom. Fluence-to-dose conversion factors were also taken and used for comparison purposes to the ICRP 116 factors discussed previously in Chapter 2.3.

4.3 Summary of Dose Calculation from QAD Results

In order to calculate dose rate, the user of QAD code must specify the location of point detectors; however, most organs are significant volumes that cannot be approximated as points. Therefore, for each organ except gonads, multiple detectors were placed within each organ to determine an average flux that can be related to dose. In Figure 4.3, each organ is depicted within the phantom with detector points shown. Detectors for gonads were simply placed at the center.

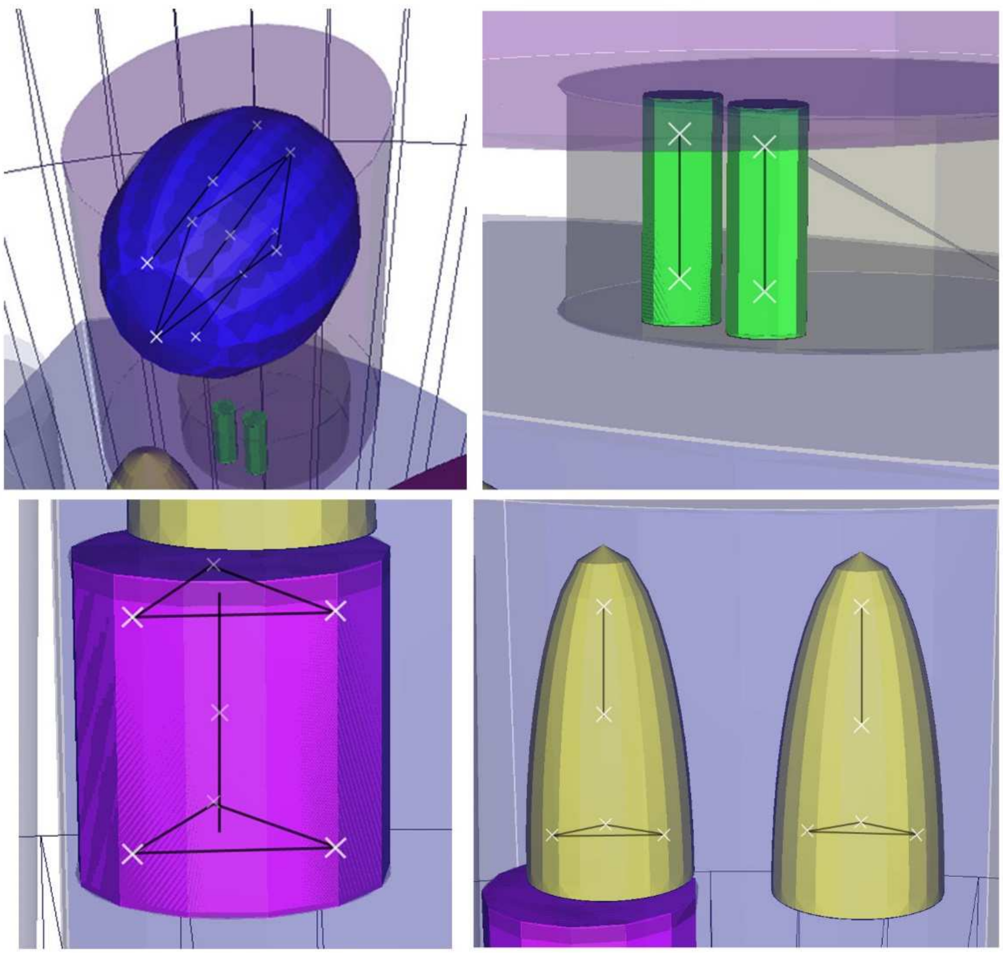

Figure 4.6: QAD location of point detectors (clockwise from top-left) for brain, thyroid, lungs, and liver

QAD-CGGP-A input files were ran using DOSBOX, an open-source DOS emulator for the PC. Input files were separated by organ of interest, where point detectors were placed in each organ, for each radionuclide, and for both adult male and female phantoms. Considering the low hardware requirements for running the code, all five organ input files were able to be ran at the same time; therefore, run-time for each model will be reported as the maximum time an organ's input file takes.

Output files contain direct beam flux and mean buildup factors for each detector and can be converted into dose coefficients through the following process:

$$direct\ beam\ \left(\frac{photons}{cm^2\ s\ nt}\right) * B * K\left(\frac{rad\ \ cm^2\ s}{h}\right) * 2.778x10^{-6}\left(\frac{\frac{Gy}{s}}{\frac{rad}{h}}\right) * V(m^3) \tag{6}$$

where B is buildup factor, K is the fluence-to-dose conversion factor, and V is the volume of the water with source locations within. The H_2O dose buildup factor was used in this calculation, since the absorbing medium of interest is tissue. The fluence-to-dose conversion factor is an important factor, as it varies depending on the irradiation geometry; however, no irradiation geometry is completely applicable, as discussed in Chapter 2.3. Therefore, the fluence-to-dose conversion factors found through EASY-QAD and ICRP 116 will be compared. After these conversions to dose coefficients, the summation of inner and outer source location results was made in similar manner to the MCNP outputs. Note that the use of ICRP 116 fluence-to-dose values in this comparison disregards the difference in energy of impending photons on the body between the two cases. ICRP 116 tallies these factors for a monoenergetic source irradiating the body, but the boating scenario will see a spectrum of energy for photons incident on the body due to the self-shielding of the water source.

CHAPTER 5

OTHER MODELS

5.1 LADTAP II Boating Dose Factors

LADTAP II is a code system developed by the U.S. Nuclear Regulatory Commission to calculate the radiation exposure from routine release of nuclear reactor effluents to an individual through potable water, foods, shoreline deposits, swimming, boating, and irrigated foods. Though the LADTAP code makes effort to use multiple models to go from effluent releases to dose, the concern of this research is with the portion where contaminated water concentration is related to boating external exposure. LADTAP contains a dose factor library on external exposure that may be printed out in report number four of the output. These dose factors are used to calculate dose to an individual for recreational boating/swimming exposure through the following equation:

$$R_j = 1119\,\frac{U\,M}{G\,Q_r} q_i R_i D_{ij} \exp(-\lambda_i t) \tag{7}$$

where U is the usage factor (hours boated per unit time), M is the mixing ratio (pathway factor), Q_r is the reactor effluent discharge rate, D_{ij} is the dose factor for immersion for nuclide i in organ j, q_i is the average release rate for radionuclide i, R_i is the impoundment system reconcentration factor, t is the transit time from release point to point of exposure, and G is the geometry factor. Of important notice, the geometry factor is considered unity for swimming dose and two for boating dose – essentially demonstrating that LADTAP also assumes half of immersion dose for recreational boating dose coefficients. When considering the above equation 7, most variables are for the purpose of calculating the concentration of contamination in the water and are eventually utilized through multiplication with a dose factor. Therefore in comparison with dose coefficients with other models in this study, LADTAP II dose factors for immersion will be utilized with the geometry factor of 0.5 applied. These dose factors are found through report number four of the output, but only have immersion dose factors for total body. Conversion of the dose factors to effective boating dose coefficients was found through the following process:

$$dose\ factor \left(\frac{\frac{mrem}{h}}{\frac{pCi}{L}}\right) * \left(\frac{1\ rem}{1000\ mrem}\right) * \left(\frac{1\ Sv}{100\ rem}\right) * \left(\frac{27.03\ pCi}{1\ Bq}\right) * \left(\frac{.001\ m^3}{1\ L}\right) * \left(\frac{1\ h}{3600\ s}\right) * (0.5) \tag{8}$$

This dose factor was also attenuated through 1 cm of tissue to measure the deep-dose equivalent (DDE) – a conservative measure of the internal organ exposure from LADTAP's total body dose factor. This served as another comparison point between LADTAP and the other models studied.

5.2 MCNP Air Exposure

A very fast approach to approximating dose rates is to determine the energy imparted to air for use in approximating the energy that would be imparted to tissue. This method will result in overestimation of dose rate, as all shielding due to the body is ignored. However, the great drop in model complexity allows for a much quicker run, as will be seen in Chapter 6.3. Figure 5.1 depicts the air exposure model, where the phantom has been completely removed. All other geometry properties were kept the same between models. The point flux detector tallies (F5 and *F5) were utilized at a singular position near where the chest of the phantom would have been. The use of both F5 and *F5 tallies, which gives tally units #/cm^2 and MeV/cm^2, respectively, allowed for the determination of the average energy in MeV of impending photons on the flux detector. Dose was then calculated through the following equations; attenuation for calculation of DDE was also considered during the results discussion:

$$D_{air} = \varphi E \left(\frac{\mu_{en}}{\rho}\right)_{air} \qquad D_{tissue} = D_{air} \frac{\left(\frac{\mu_{en}}{\rho}\right)_{tissue}}{\left(\frac{\mu_{en}}{\rho}\right)_{air}} \qquad (9),(10)$$

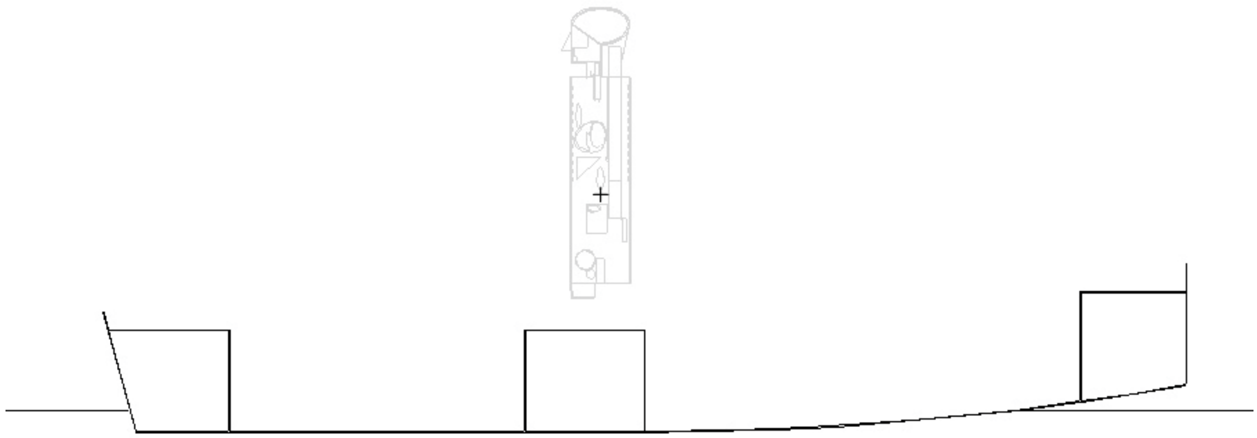

Figure 5.1: MCNP air exposure scenario with point detector location marked - PIMAL phantom indistinctly shown for reference

Conversion of simulated flux to a dose coefficient was found through the following process, utilizing both equations 9 and 10:

$$Flux\ \left(\frac{photons}{cm^2\ \ sp}\right) * E(MeV) * \left(\frac{\mu_{en}}{\rho}\right)_{tissue} \left(\frac{cm^2}{g}\right) * \left(\frac{1000\ g}{1\ kg}\right) * \left(\frac{1.602x10^{-13}\ J}{MeV}\right)\left(\frac{1\ Gy}{1\ \frac{J}{kg}}\right) * \left(\frac{\#\ sp}{nt}\right) * \left(\frac{nt}{Bq\ s}\right) * V(m^3) \tag{8}$$

where sp is source photon, nt is nuclear transformation, E is the average energy impending on the detector, and V is the volume of the contaminated body of water simulated in MCNP.

CHAPTER 6

RESULTS

Radionuclide dose coefficients for external exposure during boating activities have been found for three different radionuclide contaminants: ^{60}Co, ^{137}Cs, and ^{54}Mn. Multiple modelling techniques, MCNP with(out) realistic phantom model and QAD simplified phantom model, were employed to determine the importance of complex model geometry for a boating scenario. The results of these studies will be compared to generally accepted values for comparison purposes. For results of the QAD code, three separate dose coefficients will be compared, where the only difference is the choice in fluence-to-dose conversion factors; factors taken from the EASY-QAD code and ICRP 116 will be compared. Effective dose for the QAD simplified phantom, which did not contain every tissue-sensitive organ, was made through multiplication of organ dose by respective ICRP 103 factors and total sum normalization to unity. All organ dose coefficients presented in this study are sex-averaged between the male and female phantoms.

6.1 Comparison to 50% Immersion Dose Coefficients

Three sources of dose coefficients were used to compare and contrast dose coefficients made through each model: Federal Guidance Reports No. 12, No. 15, and LADTAP II's dose factor library. As discussed previously, it is typically assumed (such as in LADTAP II) that boating dose coefficients are approximated as half the immersion. Therefore, the dose coefficients listed in this section for FGR12/15 and LADTAP have been multiplied by the geometry factor of 0.5. LADTAP dose coefficients will also be multiplied by an attenuation factor as discussed in Chapter 5.1. This situational comparison will be made for the MCNP realistic model, QAD simplified model, and MCNP air exposure model.

6.1.1 MCNP Realistic Model

In Tables 6.1-6.3, the results of the MCNP realistic model are compared against reference values for 50% immersion. From Table 6.1 it can be seen that for the liver, lungs, thyroid, and overall effective dose, the MCNP realistic model shows these organs receiving less than 50% immersion dose from ^{60}Co, regardless of the associated error, for all reference values. The brain had a very similar dose coefficient to the FGR15 immersion value, and the gonads are significantly different; however, the associated error with the runs allows for both organs to possibly be at a similar factor below 50% immersion as the other organs.

Table 6.1: Boating dose coefficients (Gy m^3 Bq^{-1} s^{-1}) for Co-60: MCNP-derived vs. approximated value

DC Source	Brain	Liver	Lungs	Thyroid	Gonads	Effective Dose
MCNP Realistic	1.435E-16	9.611E-17	1.119E-16	6.329E-17	8.098E-17	1.125E-16
MCNP Relative Error	0.14437	0.15953	0.11348	0.52586	0.59992	0.07668
LADTAP II	----------	------------	----------	------------	----------	1.622E-16
FGR12 Immersion	----------	------------	1.340E-16	1.375E-16	1.335E-16	1.370E-16
FGR15 Immersion	1.495E-16	1.195E-16	1.315E-16	1.360E-16	1.223E-16	1.260E-16

In Table 6.2, a similar result comparison is made for ^{137}Cs contamination. It can be noted that the lower energy of the source particles allowed MCNP to achieve greater statistics with a similar run-time. This is due in part to greater attenuation, meaning less computational time per particle track. For ^{137}Cs, only the brain dose coefficient seen in Table 6.2 is below 50% immersion for FGR15 and LADTAP. The effective dose coefficient is below 50% immersion for FGR12 immersion and LADTAP; however, it is also above the coefficient for FGR15. Regardless, from the close proximity between the two FGR reported values, it can be said that a 50% immersion approximation is appropriate for determining boating effective dose coefficients for ^{137}Cs.

Table 6.2: Boating dose coefficients (Gy m^3 Bq^{-1} s^{-1}) for Cs-137: MCNP-derived vs. approximated value

DC Source	Brain	Liver	Lungs	Thyroid	Gonads	Effective Dose
MCNP Realistic	3.088E-17	2.574E-17	3.173E-17	2.702E-17	2.360E-17	2.910E-17
MCNP Relative Error	0.06730	0.05909	0.04481	0.23749	0.19518	0.02749
LADTAP II	———	———	———	———	———	3.446E-17
FGR12 Immersion	———	———	3.045E-17	3.130E-17	3.065E-17	3.130E-17
FGR15 Immersion	3.385E-17	2.605E-17	2.905E-17	3.015E-17	2.648E-17	2.770E-17

In Table 6.3, dose coefficients are reported for ^{54}Mn contamination. As visualized in Chapter 6.3, at the maximum error being realized, effective dose is almost exactly 50% FGR15 immersion. From this, it can be determined that a 50% immersion dose factor very likely overestimates boating dose coefficients for ^{54}Mn, considering its underestimating relation to FGR12 immersion as well.

Table 6.3: Boating dose coefficients (Gy m^3 Bq^{-1} s^{-1}) for Mn-54: MCNP-derived vs. approximated value

DC Source	Brain	Liver	Lungs	Thyroid	Gonads	Effective Dose
MCNP Realistic	3.999E-17	3.504E-17	3.913E-17	3.716E-17	3.539E-17	3.829E-17
MCNP Relative Error	0.09601	0.08574	0.06568	0.32121	0.44642	0.04851
LADTAP II	———	———	———	———	———	5.216E-17
FGR12 Immersion	———	———	4.330E-17	4.460E-17	4.355E-17	4.440E-17
FGR15 Immersion	4.835E-17	3.76E-17	4.185E-17	4.330E-17	3.855E-17	4.005E-17

6.1.2 QAD Simplified Model

In Tables 6.4-6.6, the results of the QAD simplistic phantom model for ^{60}Co are compared against reference values for 50% immersion. From Table 6.4, it is seen that all organ doses and the effective dose are at a reasonable factor below FGR12 and FGR15. Of all organs, the gonads were the closest in value to the reference numbers. A small part of the discrepancy for this organ may be due to the short relocation of the testes into the male torso, allowing more attenuation to occur between the source and the point detector.

Table 6.4: Boating dose coefficients (Gy m^3 Bq^{-1} s^{-1}) for Co-60: QAD-derived vs. approximated value

DC Source	Brain	Liver	Lungs	Thyroid	Gonads	Effective Dose
QAD - EASYQAD	1.030E-16	9.383E-17	9.937E-17	9.255E-17	1.058E-16	9.956E-17
QAD - ICRP ROT	1.080E-16	9.012E-17	9.971E-17	9.747E-17	1.014E-16	9.883E-17
QAD - ICRP ISO	1.015E-16	7.820E-17	8.915E-17	8.650E-17	8.995E-17	8.792E-17
LADTAP II	————	—————	————	—————	————	1.622E-16
FGR12 Immersion	————	—————	1.340E-16	1.375E-16	1.335E-16	1.370E-16
FGR15 Immersion	1.495E-16	1.195E-16	1.315E-16	1.360E-16	1.223E-16	1.260E-16

In Tables 6.5 and 6.6 above, the results of the QAD phantom model for ^{137}Cs and ^{54}Mn are reported and compared to reference values. Notable underestimation of dose can be seen for both radionuclides for all organs. This significant difference is attributable to both the geometry differences, which matter more for lower-energy photons, and the limitations of QAD modelling. As seen in Figure 4.1, the geometry of the QAD model standing on an equivalent shield of aluminum is very similar to that of a phantom standing on infinitely contaminated soil. However, it will be recognized through comparisons in Chapter 6.2 that significant discrepancies exist even between the similar geometries of contaminated soil and the QAD model.

Table 6.5: Boating dose coefficients (Gy m^3 Bq^{-1} s^{-1}) for Cs-137: QAD-derived vs. approximated value

DC Source	Brain	Liver	Lungs	Thyroid	Gonads	Effective Dose
QAD - EASYQAD	1.379E-17	1.228E-17	1.323E-17	1.225E-17	1.418E-17	1.324E-17
QAD - ICRP ROT	1.304E-17	1.060E-17	1.193E-17	1.200E-17	1.211E-17	1.184E-17
QAD - ICRP ISO	1.204E-17	8.911E-18	1.039E-17	1.005E-17	1.051E-17	1.023E-17
LADTAP II	————	—————	————	—————	————	3.446E-17
FGR12 Immersion	————	—————	3.045E-17	3.130E-17	3.065E-17	3.130E-17
FGR15 Immersion	3.385E-17	2.605E-17	2.905E-17	3.015E-17	2.648E-17	2.770E-17

Table 6.6: Boating dose coefficients (Gy m^3 Bq^{-1} s^{-1}) for Mn-54: QAD-derived vs. approximated value

DC Source	Brain	Liver	Lungs	Thyroid	Gonads	Effective Dose
QAD - EASYQAD	2.553E-17	2.289E-17	2.453E-17	2.273E-17	2.612E-17	2.453E-17
QAD - ICRP ROT	2.314E-17	1.891E-17	2.123E-17	2.109E-17	2.150E-17	2.103E-17
QAD - ICRP ISO	1.932E-17	1.610E-17	1.861E-17	1.797E-17	1.883E-17	1.826E-17
LADTAP II	———	———	———	———	———	5.216E-17
FGR12 Immersion	———	———	4.330E-17	4.460E-17	4.355E-17	4.440E-17
FGR15 Immersion	4.835E-17	3.76E-17	4.185E-17	4.330E-17	3.855E-17	4.005E-17

Limitations on source creation, organ dose tallying, and geometry specifications has seemingly played a large role in dose estimation in the QAD model. The limit of 100 source locations in any axial direction, even with source division, allowed for placement of a source location once every 0.7-0.9 meters for the inner source; whereas the realistic MCNP code uniformly positions many more source particle locations closer to the phantom.

Table 6.7: Photon flux (#/cm^2 s) experienced at point detectors in lungs and thyroid - QAD female model w/ Cs-137

Lung Detector Flux

Detector	Direct photon flux
1	4.7233E-10
2	3.9572E-10
3	4.4306E-10
4	5.5656E-10
5	5.7093E-10
6	4.6534E-10
7	3.9293E-10
8	4.4109E-10
9	5.5312E-10
10	5.6515E-10

Thyroid Detector Flux

Detector	Direct photon flux
1	3.7304E-11
2	3.7404E-11
3	4.9509E-11
4	4.9421E-11

As seen in Tables 6.7 and 6.8, detector flux experienced in organs varied greatly within themselves, even for small organs. The third and fourth detectors of the thyroid, viewable in Figure 4.3 as the detectors at the top of each cylinder, experience a greater flux than those two detectors at the bottom. Lung detector flux also varies greatly, with flux increasing as height increases (detectors 1, 2, 3 at bottom, rising to 4 and to 5). With such large variation and only a certain amount of detectors in each organ, dose underestimation is certainly possible.

Table 6.8: Photon flux (#/cm^2 s) experienced at point detectors in lungs and thyroid - QAD male model w/ Co-60

Lung Detector Flux

Detector	Direct photon flux
1	1.1582E-09
2	1.0027E-09
3	1.1964E-09
4	1.4087E-09
5	1.4505E-09
6	1.1487E-09
7	9.9760E-10
8	1.1855E-09
9	1.3960E-09
10	1.4343E-09

Thyroid Detector Flux

Detector	Direct photon flux
1	1.0263E-09
2	1.0259E-09
3	1.1586E-09
4	1.1562E-09

6.1.3 MCNP Air Exposure Model

In Table 6.9, the results of the MCNP air exposure model are compared against FGR12/15 water immersion. The dose that has been attenuated by a factor equivalent to 1 cm of tissue, the DDE, is compared as well. Error is not reported for these point detector calculations, as error was around a negligible 1 percent. It is distinguishable through Table 6.9 that the process of calculating air exposure flux and converting to dose in tissue has given a sharp overestimation of dose. This is expected, as the attenuating tissue medium has been removed from the model. The inclusion of some attenuation through the deep dose equivalent calculation shows a closer result for all radionuclides.

Table 6.9: Dose coefficient (Gy m^3 Bq^{-1} s^{-1}) comparison for MCNP air exposure model for Co-60, Cs-137, and Mn-54

Radionuclide	^{60}Co	^{137}Cs	^{54}Mn
Unadjusted MCNP	2.051E-16	5.131E-17	6.197E-17
DDE adjusted MCNP	1.849E-16	4.501E-17	5.505E-17
FGR12 immersion	1.370E-16	3.130E-17	4.440E-17
FGR15 immersion	1.260E-16	2.770E-17	4.005E-17

Table 6.10 demonstrates the importance of inclusion of attenuation due to the soft tissue of the body. For each radionuclide, the linear attenuation coefficient at the average detected energy was found[8] and used to determine the appropriate amount of attenuating tissue to include post-calculation. This determination is done through comparison to the realistic MCNP model results and multiplication by the attenuating factor, $e^{-\mu x}$. Through trial and error, a best fit was found at 4.25 cm of surrounding tissue, allowing comparable results for all three radionuclides to the complex MCNP model. These results allow the quick approximation of effective dose to an adult individual, as will be discussed in Chapter 6.3.

Table 6.10: MCNP air exposure effective dose coefficient (Gy m^3 Bq^{-1} s^{-1}) comparison – determination of attenuating factor

DC Source	^{60}Co	^{137}Cs	^{54}Mn
FGR12	1.370E-16	3.130E-17	4.440E-17
FGR15	1.260E-16	2.770E-17	4.005E-17
Unadjusted MCNP Air	2.051E-16	5.131E-17	6.197E-17
DDE adj. MCNP Air	1.849E-16	4.501E-17	5.505E-17
4.25cm adj. MCNP Air	1.318E-16	2.941E-17	3.745E-17
MCNP Realistic	1.125E-16	2.910E-17	3.829E-17
MCNP Relative Error	0.07668	0.02749	0.04851

6.2 Comparison to Infinitely Contaminated Soil

Federal Guidance Reports No. 12 and 15, as discussed in Chapter 2.1, contain dose coefficient values for an adult phantom standing on soil contaminated to an effectively infinite depth. In Tables 6.11-6.13, comparison summaries of the calculated dose coefficients can be seen for the three radionuclides of concern.

Table 6.11: Dose coefficients (Gy m^3 Bq^{-1} s^{-1}) for Co-60 - Infinite soil comparison

DC Source	Brain	Liver	Lungs	Thyroid	Gonads	Effective Dose
FGR12 Infinite Soil	———	————	8.360E-17	7.820E-17	9.080E-17	8.680E-17
FGR15 Infinite Soil	8.740E-17	7.770E-17	8.490E-17	7.940E-17	8.345E-17	8.230E-17
QAD - EASYQAD	1.030E-16	9.383E-17	9.937E-17	9.255E-17	1.058E-16	9.956E-17
QAD - ICRP ROT	1.080E-16	9.012E-17	9.971E-17	9.747E-17	1.014E-16	9.883E-17
QAD - ICRP ISO	1.015E-16	7.820E-17	8.915E-17	8.650E-17	8.995E-17	8.792E-17
MCNP Realistic	1.435E-16	9.611E-17	1.119E-16	6.329E-17	8.098E-17	1.125E-16
MCNP Relative Error	0.14437	0.15953	0.11348	0.52586	0.59992	0.07668

Table 6.12: Dose coefficients (Gy m^3 Bq^{-1} s^{-1}) for Cs-137 - Infinite soil comparison

DC Source	Brain	Liver	Lungs	Thyroid	Gonads	Effective Dose
FGR12	———	————	1.830E-17	1.700E-17	2.030E-17	1.930E-17
FGR15	1.900E-17	1.680E-17	1.840E-17	1.720E-17	1.810E-17	1.780E-17
QAD - EASYQAD	1.379E-17	1.228E-17	1.323E-17	1.225E-17	1.418E-17	1.324E-17
QAD - ICRP ROT	1.304E-17	1.060E-17	1.193E-17	1.200E-17	1.211E-17	1.184E-17
QAD - ICRP ISO	1.204E-17	8.911E-18	1.039E-17	1.005E-17	1.051E-17	1.023E-17
MCNP Realistic	3.088E-17	2.574E-17	3.173E-17	2.702E-17	2.360E-17	2.910E-17
MCNP Relative Error	0.06730	0.05909	0.04481	0.23749	0.19518	0.02749

Table 6.13: Dose coefficients (Gy m^3 Bq^{-1} s^{-1}) for Mn-54 - Infinite soil comparison

DC Source	Brain	Liver	Lungs	Thyroid	Gonads	Effective Dose
FGR12	———	————	2.640E-17	2.450E-17	2.890E-17	2.760E-17
FGR15	2.750E-17	2.430E-17	2.670E-17	2.490E-17	2.630E-17	2.590E-17
QAD - EASYQAD	2.553E-17	2.289E-17	2.453E-17	2.273E-17	2.612E-17	2.453E-17
QAD - ICRP ROT	2.314E-17	1.891E-17	2.123E-17	2.109E-17	2.150E-17	2.103E-17
QAD - ICRP ISO	1.932E-17	1.610E-17	1.861E-17	1.797E-17	1.883E-17	1.826E-17
MCNP Realistic	3.999E-17	3.504E-17	3.913E-17	3.716E-17	3.539E-17	3.829E-17
MCNP Relative Error	0.09601	0.08574	0.06568	0.32121	0.44642	0.04851

A notable trend for all three radionuclides can be seen with the QAD results. As photon energy increases from the ^{137}Cs 0.662 MeV prominent photon to the high-energy ^{60}Co 1.17 MeV and 1.33 MeV photons, the QAD dose coefficients turn from underestimating to overestimating FGR reported values for infinite soil contamination. The choice of fluence-to-dose conversion factor can also give a ranging value for boating dose coefficient. Taking the dose coefficients found using the ICRP 116 ROT conversion factor as middle ground, QAD gives a surprisingly significantly smaller dose coefficient for ^{137}Cs as compared to FGR12 and FGR15 infinite soil contamination. However, one would expect that dose coefficients for the QAD model would be greater for all three radionuclides, considering the similar geometry (phantom standing over source) and weaker-attenuating water medium. However, this is only seen for ^{60}Co. The same comparison with ^{60}Co shows that the expected dose coefficient for boating is slightly greater than that for contaminated soil and also comparable to the realistic MCNP model results. As discussed previously in Chapter 6.1.2, many limiting factors in the QAD model, as well as choice of fluence-to-dose conversion factor, likely constitute the unusual significant differences seen for ^{137}Cs and ^{54}Mn.

6.3 Results Summary and Run-time Discussion

In Figure 6.1, dose coefficients are normalized to FGR15 immersion dose in order to visualize whether a 50% immersion dose factor is appropriate for approximating dose coefficients to an individual boating on contaminated water. As seen for MCNP modelled coefficients, a 50% immersion factor is an overestimation for boating dose coefficients for either ^{54}Mn or ^{60}Co contamination; yet it is an accurate approximation for ^{137}Cs. This disagreement for certain radionuclides substantiates that a rejection of an overarching approximation factor for boating dose coefficients should typically be made, except for rough initial calculations.

Given that the 50% immersion dose factor is not always suitable, it may be desired to calculate dose coefficients to individuals boating on contaminated water for other radionuclides. Table 6.14 gives the total amount of run-time required to calculate a dose coefficient for the three radionuclides for each model. Run-times are presented below for either a male or female phantom for the QAD and MCNP realistic phantom model, as well as for the MCNP air exposure model. All calculations were made on an Intel® Core i7-4790k processor, which utilizes 4 physical cores and 4 virtual cores. In the MCNP6 calculations, all 8 cores were utilized through the built-in parallelism capabilities; whereas QAD code that was ran through the DOSBOX emulation only allowed the use of a single core. This difference in multithreading capabilities makes a significant difference in run-times. In Table 6.14, as complexity of the model increased, necessary run-time of the model also increased. QAD code took a relatively long time to run for a deterministic calculation, likely due to the large amount of source and detector points, as well as the code's single-core usage. Though accurately simulated, the complex MCNP model took the longest time to run. Therefore, the use of one of the simpler models may well be considered.

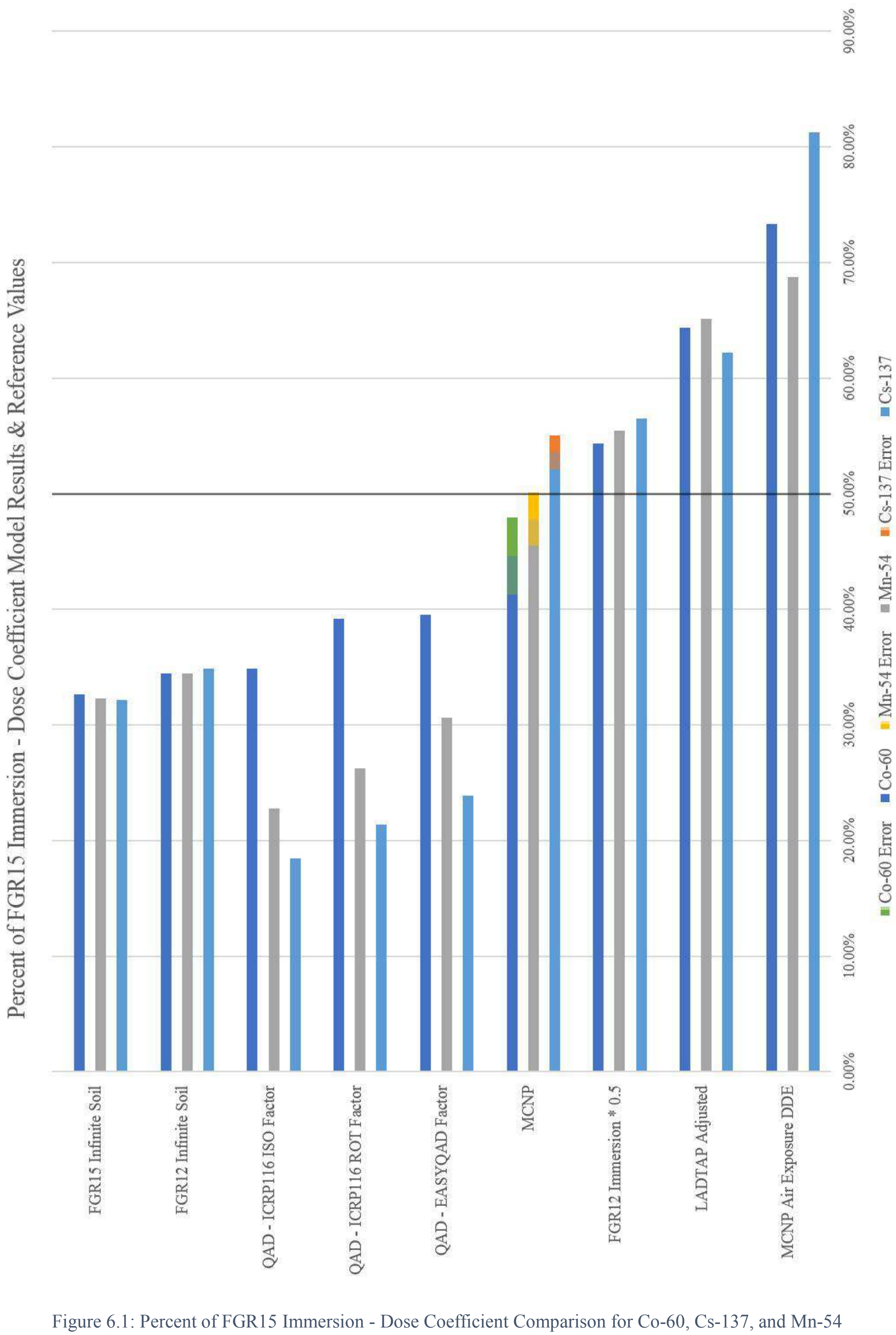

Figure 6.1: Percent of FGR15 Immersion - Dose Coefficient Comparison for Co-60, Cs-137, and Mn-54

Table 6.14: Run-time comparison between models

Radionuclide	Boating Model	Run-time (h)
^{60}Co	MCNP Realistic	40.61
^{60}Co	QAD	10.26
^{60}Co	MCNP Air Exposure	1.94
^{137}Cs	MCNP Realistic	47.10
^{137}Cs	QAD	10.24
^{137}Cs	MCNP Air Exposure	1.71
^{54}Mn	MCNP Realistic	33.61
^{54}Mn	QAD	10.20
^{54}Mn	MCNP Air Exposure	1.47

Although the QAD model kept the modelled scenario similar to MCNP, the end result showed that QAD was unable to accurately approximate dose to a boating individual. Whether due to limitations in the model or the geometric difference between a seated and standing phantom, QAD only found practical results for ^{60}Co. However, the calculation of dose through air exposure simulation in MCNP and subsequent attenuation of those results provided an accurate estimator of effective dose with a much quicker run-time.

CHAPTER 7

CONCLUSIONS

The contamination scenario of an individual boating on a contaminated body of water is a situation of plausible occurrence; this issue of external exposure provokes the question of whether certain methodologies of calculating dose coefficients to a boating individual are more accurate than others. As seen in multiple sources, these boating dose coefficients were generally taken to be half of their respective water immersion dose coefficients. To determine the appropriateness of this factor, a complex boating scenario was modelled in MCNP for three radionuclides of particular interest to water contamination through reactor liquid contamination discharge. For ^{137}Cs, it was determined that a 50% factor on immersion dose coefficients was an accurate method of obtaining these results. Despite this, the higher-energy ^{54}Mn and ^{60}Co sources had their dose coefficients slightly overestimated by a 50% factor; a factor of 46-48% on immersion dose was more appropriate for these radionuclides.

Attempts to simplify the modelled scenario in order to cut down run-time on boating simulations for future work were made through two modelling trials: the point-kernel QAD simulation of a simplified phantom standing on an equivalent boat and the MCNP simulation of air exposure above the boat with the phantom removed. After the results of both trials were compared by accuracy and run-time, the simpler method of air exposure calculation was determined to be a good approximation for effective dose coefficients for external exposure during boating activities. Through the conversion of air exposure to tissue dose, and a realistic attenuation factor of dose through 4.25 centimeters of tissue, accurate calculations for these dose coefficients were found in much shorter time. Future work should look to determine dose coefficients to individuals boating on contaminated water for other radionuclides, in order to characterize accurate factors applicable to immersion dose coefficients for any photon energy. Future work may also look toward the use of further variance reduction techniques, such as a forward-adjoint weight-window generation in MCNP.

APPENDIX A: SAMPLE MCNP INPUTS

Sample MCNP Realistic Model Input File – Male ^{60}Co Inner Source Division

```
TITLE CARD - MCNP JONBOAT TRIAL #5-1 (Male-PIMAL: Co-60)
c   CELL CARDS
c ======================================================================
c
c ============== 1.0 Head and Neck ================================
c
c ======================================================================
c
c 1.1 The Skin of Head and Neck
c ======================================================================
   1    11   -1.09 ((-7 8 ):-6 )-1 11 (2 :3 :6 :(-5 10 ))(4 :(-9 10 ):-11 )
          (-4 :6 :-3 :(-12 81 13 ):(2 -1 -13 ))#7 #8 #2
c ======================================================================
c 1.2 The Cranium
c ======================================================================
   2     2    -1.4 (14 -18 6 ):(15 -19 16 20 -6 ):(-19 -16 20 -6 )
c ======================================================================
c 1.3 The Teeth
c ======================================================================
   3     2    -1.4 -21 22 23 -24 -25
c ======================================================================
c 1.4 The Mandible
c ======================================================================
   4     2    -1.4 (-26 28 ((27 -23 -25 ):(29 -20 25 -17 )))
c ======================================================================
c 1.5 Nasal Cavity (The Upper Face Region, Facial skeleton)
c ======================================================================
   5     5   -1.22 -30 24 -20 -25 31 32 (36 37 )(38 39 )(40 41 )(42 43 )
c
c remove sphenoid Sinus
c remove ethmoid Sinus
c remove frontal Sinus
c remove maxillary Sinus
c      VOL=265.5-3.533-2.697-7.046-25.329
c ======================================================================
c 1.7 The Brain
c ======================================================================
   6     6   -1.04 (6 -33 ):(-6 -34 35 )
c ======================================================================
c 1.8 The eyes
c ======================================================================
c Left
   7     7   -1.07 -31
c
c Right
   8     7   -1.07 -32
c ======================================================================
c 1.9 Total Sinuses
c ======================================================================
c
   9     4 -0.001205 (-36 :-37 :-38 :-39 :-40 :-41 :-42 :-43 )
c ======================================================================
c 1.13 Pharynx(Skeletal Muscle)
c ======================================================================
```

```
c Residual Wall
c ======================================================================
   10    13   -1.05 -44 47 11 -46
c      VOL=22.89-8.370140424
c ======================================================================
c Contents
c ======================================================================
   11     4 -0.001205 -45 11 -46
c ======================================================================
c Mucosa Wall
c ======================================================================
   12    13   -1.05 -47 45 11 -46
c ======================================================================
c 1.14 Larynx
c ======================================================================
c Residual Wall
c ======================================================================
   13     8    -1.1 51 -49 50 -4
c       vol=6.048-2.141307850
c ======================================================================
c Content
c ======================================================================
   14     4 -0.001205 -48 50 -4
c ======================================================================
c Mucosa Wall
c ======================================================================
   15     8    -1.1 48 -51 50 -4
c ======================================================================
c 1.15 Trachea
c ======================================================================
c Residual Wall
c ======================================================================
   16    12   -1.03 55 -52 54 -50
c     vol=13.75-2.509678833
c ======================================================================
c Content
c ======================================================================
   17     4 -0.001205 -53 54 -50
c ======================================================================
c Mucosa Wall
c ======================================================================
   18    12   -1.03 53 -55 54 -50
c ======================================================================
c 1.16 Thyroid
c ======================================================================
   19    10   -1.05 (303 -4 63 -56 57 -58 -62 ):(-303 -4 63 -56 57 -59 -62 ):
           (303 64 -63 -56 57 60 -62 (50 :52 )):(-303 64 -63 -56 57 61 -62
           (50 :52 ))
c ======================================================================
c 1.17 Nose
c ======================================================================
c Contents
c ======================================================================
   20     4 -0.001205 -65 -66 69 1 -72 (-70 :71 )
c             remove Center Tissue
c ======================================================================
c  Nose Wall
c ======================================================================
   21    13   -1.05 -67 -68 69 1 -72 (-71 :66 )(70 :65 )
c ======================================================================
c 1.18 Oral Cavity (Soft tissue Behind mouth and teeth)
c ======================================================================
```

```
  22    12   -1.03 (((-29 28 -20 25 -17 ):(-25 -22 23 -24 ):(-25 -27 -23 28 ))
        ((73 74 ):-23 :46 )((75 77 ):76 :-28 )((78 80 ):-79 :25 ))
c
c Vol = (39+66+229)-(48.07692308+24.03846154+9.615384616)= 252.2692308
c ======================================================================
c 1.19 Salivery Glands
c ======================================================================
c Left & Right Parotid
c ======================================================================
c 51 1 -1.04  (-636 : -641) 531 -565
c          Vol = 48.07692308
c
c Left & Right Submandibular
c
c 53 1 -1.04  (-637 : -642) -638 536
c          Vol = 24.03846154
c
c Left & Right Sublingual
c
c 55 1 -1.04  (-639 : -643) 640 -533
c          Vol = 9.615384616
c
c Total Salivery Glands
c
  23    12   -1.03 (((-73 :-74 )23 -46 ):((-75 :-77 )-76 28 ):(
        (-78 :-80 )79 -25 ))
c ======================================================================
c 1.20 Muscle Part of head and neck
c ======================================================================
  24    13   -1.05 (-8 :-6 )-2 11 (5 :-10 :-11 )(-3 :6 :-4 :-13 )
        (-14 :18 :-6 )(-15 :19 :-16 :-20 :6 )(19 :16 :-20 :6 )
        (21 :-22 :-23 :24 :25 )(26 :-27 :-28 :23 :25 )(26 :-29 :-28 :20 :-25
         :17 )(30 :-24 :20 :25 :-31 :-32 )(81 :85 :-84 )(-6 :33 )
        (6 :34 :-35 )(31 32 )(49 :-50 :4 )(52 :-54 :50 )
        (44 :-11 :46 )#19 #22 #23
c
c    remove Cranium
c    remove teeth
c    remove mandible
c    remove nasal cavity
c    remove spine in the Head and Neck
c    remove brain
c    remove eyes
c    remove larynx
c    remove trachea
c    remove pharynx
c    remove thyroid
c    remove Oral Cavity
c    remove salivary glands
c ======================================================================
c
c =============== 2.0  Skeleton Region ==============================
c
c ======================================================================
c    2.1  Spine
c ======================================================================
c    2.1.1  Cervical Verterbra - CV(upper)
c ======================================================================
  25     2    -1.4 -81 -85 84
c ======================================================================
c    2.1.2  Thoracic Verterbra - TV (middle)
c ======================================================================
```

```
  26    2    -1.4 -81 -84 83
c ======================================================================
c     2.1.3  Lumber Verterbra - LV (lower)
c ======================================================================
  27    2    -1.4 -81 -83 82
c ======================================================================
c     2.2  Ribs
c ======================================================================
c
c     all ribs
  28    2    -1.4 87 -86 ((89 -88 ):(91 -90 ):(93 -92 ):(95 -94 ):(97 -96 ):
             (99 -98 ):(101 -100 ):(103 -102 ):(105 -104 ):(107 -106 ):
             (109 -108 ):(111 -110 ))
c ======================================================================
c     2.3  Clavicles
c ======================================================================
c     both
  29    2    -1.4 -112 ((113 -115 ):(-114 116 ))
c
c ======================================================================
c     2.4  Scapulae
c ======================================================================
c     both
  30    2    -1.4 86 -117 122 -123 ((118 -120 ):(-119 121 ))
c
c ======================================================================
c     2.5  Pelvis
c ======================================================================
  31    2    -1.4 124 -125 126 305 -128 (129 :-127 )
c
c ======================================================================
c
c ============== 3.0  Upper Chest Organs ==========================
c
c ======================================================================
c     3.1  Main Bronchi
c ======================================================================
c  Residual Wall
c ======================================================================
  32    12   -1.03 (138 -130 -132 133 140 -54 303 ):(-134 139 -136 137 141 -54
              -303 )
c ======================================================================
c  Contents
c ======================================================================
  33    4 -0.001205 (-131 -132 133 140 -54 303 ):(-135 -136 137 141 -54 -303
              )
c ======================================================================
c  Mucosa Wall
c ======================================================================
  34    12   -1.03 (131 -138 -132 133 140 -54 303 ):(-139 135 -136 137 141 -54
              -303 )
c ======================================================================
c     3.2  Lungs
c ======================================================================
c      left
  35    14   -0.26 -140 142 (149 :148 :147 )
c      right
  36    14   -0.26 -141 142 (-145 :146 :144 :-143 )
c ======================================================================
c     3.3  Thymus
c ======================================================================
  37    12   -1.03 -150
```

```
c ==================================================================
c    3.4  Heart
c ==================================================================
c
c     Wall of heart
c ==================================================================
  38    15   -1.05 (151 ((-152 154 -153 ):(156 -155 ))):(-151 (
          (-152 162 -161 ):(152 158 -157 ):(-152 -159 160 )))
c
c ==================================================================
c     Contents of heart
c ==================================================================
  39    15   -1.05 (151 ((-152 -154 155 ):(-156 ))):(-151 ((-152 -162 159 ):
          (152 -158 ):(-152 -160 )))
c
c ==================================================================
c
c ============== 4.0  Middle Chest Organs =======================
c
c ==================================================================
c    4.1  Adrenals
c ==================================================================
c    left
  40    12   -1.03 165 -163
c    right
  41    12   -1.03 165 -164
c ==================================================================
c    4.2  Kidneys
c ==================================================================
c left kidney
c
  42    16   -1.04 (-166 168 )
c right kidney
c
  43    16   -1.04 (-167 -169 )
c
c ==================================================================
c    4.3  Liver
c ==================================================================
  44    17   -1.05 -173 -174 176 -175
c
c ==================================================================
c    4.4  Gall bladder
c ==================================================================
c     wall
  45    12   -1.03 (-181 177 -178 ):(181 -182 179 -180 )
c     contents
  46    12   -1.03 (-181 -177 ):(181 -179 -182 )
c
c ==================================================================
c    4.5  Pancreas
c ==================================================================
  47    18   -1.04 -183 184 196 (185 :-186 )
c
c ==================================================================
c    4.6  Spleen
c ==================================================================
  48    19   -1.06 -187
c
c ==================================================================
c
c ============== 5.0 Gastrointestinal tract and contents =========
```

```
c
c =====================================================================
c    5.1 Male Esophagus   /*** 1996 ORNL C&E ***/
c =====================================================================
c    Mucosa Wall of the thoracic portion
c =====================================================================
  49    12   -1.03 (-188 190 175 -84 )
c =====================================================================
c    Mucosa Wall of the abdominal portion
c =====================================================================
  50    12   -1.03 (-194 192 -193 )
c =====================================================================
c    Remainder Wall of the thoracic and abdominal portion
c =====================================================================
  51    12   -1.03 (-189 188 175 -84 ):(-191 194 192 -193 81 )
c =====================================================================
c    Contents of the thoracic portion
c =====================================================================
  52     4 -0.001205 -190 175 -84
c =====================================================================
c
c =============== 5.2  Stomach =====================================
c
c =====================================================================
c     Mucosa Wall
c =====================================================================
  53    20   -1.03 -195 197
c =====================================================================
c     Remainder Wall
c =====================================================================
  54    20   -1.03 -196 195
c =====================================================================
c     Contents
c =====================================================================
  55    20   -1.03 -197
c =====================================================================
c
c ==============  5.3  S. intestine ===============================
c
c =====================================================================
  56    20   -1.03 -124 199 -200 201 -176 (204 :207 :-201 )(209 :211 :-212 )
          (214 :207 :-201 )
c           remove     a. colon
c           remove     t. colon
c           remove     d. colon
c =====================================================================
c    5.4  Right colon *
c =====================================================================
c    5.4.1 A. colon
c
c     Mucosa Wall
  57    20   -1.03 (-203 205 206 -207 )
c     Remainder Wall
  58    20   -1.03 (-204 203 206 -207 )
c     Contents
  59    20   -1.03 (-205 206 -207 )
c
c
c    5.4.2 Proximal T. colon *
c
c     Mucosa Wall
  60    20   -1.03 -208 210 -211 212 -303
```

```
c      Remainder Wall
  61    20   -1.03 -209 208 -211 212 -303
c      Contents
  62    20   -1.03 -210 -211 212 -303
c ======================================================================
c     5.5 Left colon
c     5.5.1 Distal T. colon *
c
c ======================================================================
c      Mucosa Wall
c ======================================================================
  63    20   -1.03 -208 210 -211 212 303
c ======================================================================
c      Remainder Wall
c ======================================================================
  64    20   -1.03 -209 208 -211 212 303
c ======================================================================
c      Contents
c ======================================================================
  65    20   -1.03 -210 -211 212 303
c ======================================================================
c     5.5.2  D. colon *
c ======================================================================
c      Mucosa Wall
c ======================================================================
  66    20   -1.03 (-213 215 216 -207 )
c ======================================================================
c      Remainder Wall
c ======================================================================
  67    20   -1.03 (-214 213 216 -207 )
c ======================================================================
c      Contents
c ======================================================================
  68    20   -1.03 (-215 216 -207 )
c
c ======================================================================
c     5.6  Rectosigmoid *
c ======================================================================
c
c     5.6.1 Sigmoid colon
c ======================================================================
c      Mucosa Wall
c ======================================================================
  69    20   -1.03 (-217 220 216 ):(-218 222 -216 )
c ======================================================================
c      Remainder Wall
c ======================================================================
  70    20   -1.03 (-219 217 216 ):(-221 218 -216 )
c ======================================================================
c      Total contents
c ======================================================================
  71    20   -1.03 (-220 216 ):(-222 -216 )
c ======================================================================
c
c    5.6.2  Rectum
c ======================================================================
c        Mucosa Wall
c ======================================================================
  72    20   -1.03 -224 226 -216 305
c ======================================================================
c        Remainer Wall
c ======================================================================
```

```
  73    20   -1.03 -225 224 -216 305
c ==================================================================
c       Contents
c ==================================================================
  74     4 -0.001205 -226 -216 305
c
c ==================================================================
c
c ====== 6.0   Lower Chest Organ ===================================
c
c ==================================================================
c     6.1   U. bladder
c
c      Mucosa wall
c ==================================================================
  75    21   -1.04 -230 229
c ==================================================================
c      Remainder wall
c ==================================================================
  76    21   -1.04 -228 230
c ==================================================================
c      Contents
c ==================================================================
  77    21   -1.04 -229
c
c ==================================================================
c
c ====== 8.0  Gender Specific Organs ================================
c
c ==================================================================
c     8.1    Male
c ==================================================================
c     8.1.1 Prostate
c ==================================================================
  78    12   -1.03 -227
c
c ==================================================================
c     8.1.2  Testes
c ==================================================================
c
c     Left Testes
c ==================================================================
  79    22   -1.04 -231
c ==================================================================
c     Right Testes
c ==================================================================
  80    22   -1.04 -232
c
c ==================================================================
c    8.1.3  Male Genitalia
c ==================================================================
  81    12   -1.03 -304 -305 233 -234 235 -236 300 301 (231 232 )279 291
c      remove       Testes (left / right)
c
c ==================================================================
c     8.2.3  Breasts
c ==================================================================
c      left gland
  82    25   -0.94 -237 295
c      right gland
  83    25   -0.94 -238 295
c
```

```
c ==================================================================
c  9.0  Muscle in the Trunk
c ==================================================================
   84    12   -1.03 305 -84 -295 -296 297 (81 :-82 :84 ) $========!!!CHECK THIS
          (52 :-54 :50 )(86 :-87 :88 :-89 )(86 :-87 :90 :-91 )
          (86 :-87 :92 :-93 )(86 :-87 :94 :-95 )(86 :-87 :96 :-97 )
          (86 :-87 :98 :-99 )(86 :-87 :100 :-101 )(86 :-87 :102 :-103 )
          (86 :-87 :104 :-105 )(86 :-87 :106 :-107 )(86 :-87 :108 :-109 )
          (86 :-87 :110 :-111 )(112 :-113 :115 )(112 :114 :-116 )
          (-86 :117 :-118 :120 :-122 :123 )(-86 :117 :119 :-121 :-122 :123
           )#31 (130 :132 :-133 :54 :-140 :-303 )(134 :136 :-137 :54 :-141
           :303 )(140 :-142 :(-149 -148 -147 ))(141 :-142 :
          (145 -146 -144 143 ))150 #38 #39 (163 :-165 )(164 :-165 )(167 :169 )
          (166 :-168 )(173 :174 :175 :-176 )(181 :178 )(-181 :180 :182 )
          (183 :-184 :-196 :(-185 186 ))187 (189 :-175 :84 )
          (191 :-192 :193 )196 (124 :-199 :200 :-201 :176 )(201 :204 :-206 )
          (201 :214 :-216 )(219 :-216 )(221 :216 )(225 :216 :-305 )227 228
c     remove       spine  /* vol=707 */
c     remove       trachea
c     remove       (ribs 1-9) /* vol=531 */
c     remove       clavicles (left / right) /* vol=41.6 */
c     remove       scapulae (left / right)  /* vol=154 */
c     remove       pelvis  /* 460 */
c     remove       main bronchi
c     remove       lungs (left / right)  /* vol=2200 */
c     remove        thymus  /* vol=27.3 */
c     remove        heart  /* vol=565 */
c     remove        adrenals (left / right)  /* vol=10.1 */
c     remove        kidneys (left / right)  /*vol=238.4 */
c     remove        liver /* vol=1350 */
c     remove        gall bladder  /* vol=56.02 */
c     remove        pancreas /* vol=62.4 */
c     remove        spleen /* vol=119 */
c     remove        esophagus /* vol=44.7 */
c     remove        stomach  /* vol=300 */
c     remove         s. intestine  /* vol=806 */
c     remove         a. colon  /* vol=142.9  */
c     remove         d. colon  /* vol=125.42 */
c     remove         s. colon  /* vol=74.889 */
c     remove         rectum /* vol=51.29 */
c     remove         prostate/*  vol=4.189 */
c     remove         u. bladder /* vol=188.5 */
c
c
c ==================================================================
c   10.0 Skin
c ==================================================================
c
c ==================================================================
c   10.2.2 Skin of Trunk
c ==================================================================
   85    11   -1.09 ((-245 295 -296 297 -84 305 ):(-245 9 -298 299 -302 84 ):
          (-245 -298 296 -84 305 ):(-245 -297 299 -84 305 ):(295 ((-239 237 ):
          (-240 238 ))))(9 :-84 :302 )#83 #82
c    plus         breast part /* vol=51 */
c    remove        material under neck
c    remove        material under breast area (left / right)
c                  (-10:384:371) (-10:384:373)
c ==================================================================
c    10.5 Skin of Male Genitalia
c ==================================================================
   86    11   -1.09 -304 -305 241 -242 243 -244 300 301 (304 :305 :-233 :234
```

```
          :-235 :236 :-300 :-301 )(231 232 )279 291
c      remove       genitalia & testes (left / right)
c
c =====================================================================
c =====================================================================
c      ARMS and LEGS  for PIMAL
c =====================================================================
c ======== RIGHT ARM ---- BONE
   87    2    -1.4 -246 247 251
   88    2    -1.4 -247 248
   89    2    -1.4 -248
   90    2    -1.4 -249 248 247
c ======== RIGHT ARM --- SOFT TISSUE
   91    13   -1.05 -250 246 247 251
   92    13   -1.05 -251 247 249
   93    13   -1.05 -252 247 248 249 251 253
   94    13   -1.05 -253 249 251
c ======== RIGHT ARM --- SKIN
   95    11   -1.09 -254 250 251 255
   96    11   -1.09 -255 251 253
   97    11   -1.09 -256 251 252 253 255 257
   98    11   -1.09 -257 253 255 252
c
c ======== LEFT ARM ---- BONE
   99    2    -1.4 -258 259 263
  100     2    -1.4 -259 260
  101     2    -1.4 -260
  102     2    -1.4 -261 260 259
c ======== LEFT ARM --- SOFT TISSUE
  103    13   -1.05 -262 258 259 263
  104    13   -1.05 -263 259 261
  105    13   -1.05 -264 259 260 261 263 265
  106    13   -1.05 -265 261 263
c ======== LEFT ARM --- SKIN
  107    11   -1.09 -266 262 263 267
  108    11   -1.09 -267 263 265
  109    11   -1.09 -268 263 264 265 267 269
  110    11   -1.09 -269 265 267 264
c
c
c ======= RIGHT LEG --- BONE
  111     2    -1.4 -270 -305
  112     2    -1.4 (-271 -305 272 270 ):(-271 305 245 270 272 )
  113     2    -1.4 -272
  114     2    -1.4 -273 272 271
c ======= RIGHT LEG --- TISSUE
  115    13   -1.05 -274 -305 270 271 291
  116    13   -1.05 (-275 232 -305 271 273 274 290 ):(-275 305 271 273 274 290
          -299 ):(-275 305 245 271 290 299 )
  117    13   -1.05 -276 271 272 273 275 277
  118    13   -1.05 -277 273 275
c ======= RIGHT LEG --- SKIN
  119    11   -1.09 -278 -305 279 274 291
  120    11   -1.09 (-279 232 290 275 277 274 -299 ):(-279 232 275 277 274 290
          299 -305 ):(-279 275 290 299 245 305 )
  121    11   -1.09 -280 275 276 277 279 281
  122    11   -1.09 -281 276 277 279
c
c
c ======= LEFT LEG --- BONE
  123     2    -1.4 -282 -305
  124     2    -1.4 (-283 -305 284 282 ):(-283 305 245 284 282 )
```

```
  125     2    -1.4 -284
  126     2    -1.4 -285 284 283
c ======= LEFT LEG --- TISSUE
  127    13   -1.05 -286 -305 282 283
  128    13   -1.05 (-287 231 -305 283 285 286 ):(-287 305 -298 283 285 245 ):
         (-287 305 283 285 286 298 )
  129    13   -1.05 -288 283 284 285 287 289
  130    13   -1.05 -289 285 287
c ======= LEFT LEG --- SKIN
  131    11   -1.09 -290 -305 291 286
  132    11   -1.09 (-291 231 -305 287 289 286 ):(-291 287 305 289 286 298 ):
         (-291 231 287 289 245 -298 )
  133    11   -1.09 -292 287 288 289 291 293
  134    11   -1.09 -293 288 289 291
c
c
c
c ===========================================================================
c ===========================================================================
c =============================== BOAT CELLS ================================
  135   101    -2.68 (1004 -1015 -1001 1002 1006 1007 ):(1006 -1016 1004 -1005
          -1001 1002 ):(1005 -1003 1009 -1008 -1010 -1011 1019 ):
         (-1003 1014 1009 -1008 -1011 1012 -1010 ):(1005 -1003 1009 -1008
          -1010 1012 -1020 ):(1007 -1017 1004 -1005 -1001 1002 ):
         (1002 -1013 -1005 1004 1006 1007 ):(1005 -1003 -1008 1018 -1010
          -1011 1012 ):(1015 -1030 1031 -1034 1016 1017 ):
         (1016 1017 1035 -1034 1013 -1031 ):(1033 -1032 1013 -1031 1016 1017
          ):(1031 -1030 1033 -1005 1016 1017 ):(1029 -1005 -1031 1013 1016
          1017 ):(1036 -1037 -1039 -1018 -1019 1020 ):(1039 -1038 1036 -1014
          -1019 1020 )
  136   102 -0.001225 (((-1005 1001 ):(-1005 -1002 ):-1004 :(-1005 -1006 ):
         (1005 1011 ):(-1005 -1007 ):(1005 -1012 ):(1005 1010 ):
         (1005 -1009 ):(1005 1008 ):1003 :(1030 -1001 1015 -1005 1016 1017 ):
         (-1030 1013 1034 -1033 1016 1017 ):(1015 -1035 -1031 1013 1016 1017
          ):(1032 -1029 1013 -1031 1016 1017 ):(1009 -1038 -1010 1005 -1036
          -1019 1020 -1018 ):(1009 1038 -1010 -1014 -1019 1020 ):
         (1037 -1014 -1018 -1039 -1019 1020 ))(1021 :(-1021 -1005 1015 1013
          -1001 1016 1017 ):(-1021 1005 -1018 -1010 -1014 -1019 1020 ))-1023
          -1028 -1040.1 -1040.2 )(((1 :-11 :(7 6 )):(1 :-11 :(-4 9 11 )):
         (1 :-11 :(3 -6 4 12 )))(67 :68 :-69 :-1 :72 )(-305 :245 :302 :-299
          :298 )(-245 :(239 240 ))(304 :305 :-241 :242 :-243 :244 :-300 :-301
          )254 255 256 257 266 267 268 269 278 279 280 281 290 291 292 293 )
  137   103       -1 ((-1005 1001 ):(-1005 -1002 ):-1004 :(-1005 -1006 ):
         (1005 1011 ):(-1005 -1007 ):(1005 -1012 ):(1005 1010 ):
         (1005 -1009 ):(1005 1008 ):1003 :(-1005 1015 -1001 1013 1016 1017 ):
         (1005 -1010 -1018 -1014 1009 -1019 1020 ))((-1004 :-1002 :
         (-1010 1008 1005 ):-1006 :-1007 :1011 :-1012 )-1021 )1022 -1028
          :-1041
  138     0          1028 :(-1028 1040 1021 ):(-1028 1041 -1022 )

c   SURFACE CARDS
c ====================================================================
c ====================================================================
c     1.0  Head and Neck Region
c ====================================================================
c
c     1.1  The skin of head
c
c  Skin in the Face *
c ====================================================================
    1        sq 0.015862 0.01 0 0 0 0 -1 0 0 0
    2        sq 0.01669237292 0.01041232819 0 0 0 0 -1 0 0 0
```

```
   3       py 5
   4       pz 75
   5       pz 75.2
   6       pz 88
c ==================================================================
c Skin in the TOP OF the Head *
c ==================================================================
   7       sq 0.015862 0.01 0.027778 0 0 0 -1 0 0 88
   8       sq 0.01669237292 0.01041232819 0.029727 0 0 0 -1 0 0 88
c ==================================================================
c Skin in the Neck*
c ==================================================================
   9       sq 1 1 0 0 0 0 -36.1201 0 1.2 0
  10       sq 1 1 0 0 0 0 -33.7561 0 1.2 0
  11       pz 70
c ==================================================================
c Skin in the BACK of the head*
c ==================================================================
  12       k/z 0 1.2 46.99641579 0.04605976335 0
  13       k/z 0 1.2 48.54480288 0.04751037602 0
c ==================================================================
c    1.2  The Cranium
c ==================================================================
c Cranium_Inner Surface*
  14       sq 0.01923665121 0.01163698654 0.036006 0 0 0 -1 0 0 88
  15       sq 0.01923665121 0.01163698654 0.024645 0 0 0 -1 0 0 88
  16        p 0 0.687163 1 81.63
  17       py 0
c ==================================================================
c Cranium_Outer Surface*
c ==================================================================
  18       sq 0.01669237292 0.01041232819 0.029727 0 0 0 -1 0 0 88
  19       sq 0.01669237292 0.01041232819 0.021004 0 0 0 -1 0 0 88
  20        p 0 0.704081 1 81.1
c ==================================================================
c    1.3  Teeth *
c ==================================================================
  21       sq 0.047259 0.036982 0 0 0 0 -1 0 -4.05 0
  22       sq 0.084505 0.045269 0 0 0 0 -1 0 -4.05 0
  23       pz 77.4
  24       pz 80
  25       py -4.05
c ==================================================================
c    1.4  Mandible *
c ==================================================================
  26       sq 0.024414 0.033667 0 0 0 0 -1 0 -4.05 0
  27       sq 0.086505 0.067116 0 0 0 0 -1 0 -4.05 0
  28       pz 75.5
  29       sq 0.056689 0.016437 0 0 0 0 -1 0 -4.05 0
c ==================================================================
c    1.5  Upper Face Regions *
c ==================================================================
  30       sq 0.020822 0.010851 0 0 0 0 -1 0 0 0
c ==================================================================
c    1.6  Eyes *
c ==================================================================
  31       sq 1 1 1 0 0 0 -1.4884 3.4 -7.5 84.2
  32       sq 1 1 1 0 0 0 -1.4884 -3.4 -7.5 84.2
c ==================================================================
c    1.7  Brain *
c ==================================================================
  33       sq 0.019726 0.011866 0.037268 0 0 0 -1 0 0 88
```

```
   34        sq 0.019726 0.011866 0.025356 0 0 0 -1 0 0 88
   35         p 0 0.684096 1 81.72
c ==========================================================================
c
c
c    1.9 Sphenoid Sinus * *
c ==========================================================================
   36        sq 1.929012346 0.9802960494 2.972651605 0 0 0 -1 1.2 -5.2 83.8
   37        sq 1.929012346 0.9802960494 2.972651605 0 0 0 -1 -1.2 -5.2 83.8
c ==========================================================================
c    1.10 Ethmoid Sinus  * *
c ==========================================================================
   38        sq 7.304601901 1 1.32117849 0 0 0 -1 1.166 -7.2 84.2
   39        sq 7.304601901 1 1.32117849 0 0 0 -1 -1.166 -7.2 84.2
c ==========================================================================
c    1.11 Frontal Sinus  * *
c ==========================================================================
c
   40        sq 1 2.972651605 0.4756242568 0 0 0 -1 1.5 -8.6 85.5
   41        sq 1 2.972651605 0.4756242568 0 0 0 -1 -1.5 -8.6 85.5
c
c ==========================================================================
c    1.12 Maxillary Sinus*
c ==========================================================================
   42         s 2.93 -6.8 81.5 1.446
   43         s -2.93 -6.8 81.5 1.446
c ==========================================================================
c    1.13 Pharynx *
c ==========================================================================
   44       c/z 0 1.545 1.45
   45       c/z 0 1.545 1.2
   46        pz 81
c
   47       c/z 0 1.545 1.297
c ==========================================================================
c    1.14 Larynx*
c ==========================================================================
   48       c/z 0 -1.09 0.75
   49       c/z 0 -1.09 1
   50        pz 70.6
c
   51       c/z 0 -1.09 0.847
c ==========================================================================
c    1.15 Trachea *
c ==========================================================================
   52       c/z 0 -1.09 1.17
   53       c/z 0 -1.09 0.9
   54        pz 62.77
c
   55       c/z 0 -1.09 0.955
c ==========================================================================
c    1.16 Thyroid **
c ==========================================================================
   56       c/z 0 -1.09 1.963
   57       c/z 0 -1.09 1
   58         p 0.707107 -1.797107 75 0 -2.09 71.25 0 -3.29 72.75
   59         p -0.707107 -1.797107 75 0 -2.09 71.25 0 -3.29 72.75
   60         p 0.707107 -1.797107 70 0 -2.09 71.25 0 -3.29 70.625
   61         p -0.707107 -1.797107 70 0 -2.09 71.25 0 -3.29 70.625
   62        py -1.09
   63        pz 71.25
   64        pz 70
```

```
c
c ==========================================================================
c   1.17 Nose*
c ==========================================================================
   65        p 0 -10 84.8 -1.49 -9.82 79.77 0 -11.12 82.285
   66        p 0 -10 84.8 1.49 -9.82 79.77 0 -11.12 82.285
c
   67        p 0 -10.4 84.8 -1.89 -9.712565 79.77 0 -11.52 82.285
   68        p 0 -10.4 84.8 1.89 -9.712565 79.77 0 -11.52 82.285
   69        p 0 -12.24 79.37 -1.49 -9.82 79.37 1.49 -9.82 79.37
c
   70       px -0.2
   71       px 0.2
c
   72       py -9
c
c ==========================================================================
c    1.19 Salivery Glands
c
c ==========================================================================
c    1.19.1 Parotids Glands
c ==========================================================================
c Left
c
   73       sq 0.8854238562 0.25 0 0 0 0 -1 2.5 -2.025 79.2
c
c Right
c
   74       sq 0.8854238562 0.25 0 0 0 0 -1 -2.5 -2.025 79.2
c ==========================================================================
c    1.19.2 Submandibular Glands
c ==========================================================================
c Left
c
   75      c/z 1.8 -2.2992 1.7608
   76       pz 76.734
c
c Right
c
   77      c/z -1.8 -2.2992 1.7608
c ==========================================================================
c    1.19.3 Sublingual Glands
c ==========================================================================
c Left
c
   78      c/y 0.8 76.734 0.666
   79       py -7.5
c
c Right
c
   80      c/y -0.8 76.734 0.666
c
c ==========================================================================
c
c ===============  2.0  Skeleton* ===================================
c
c ==========================================================================
c     2.1  Spine (1983 /C&E)*
c
   81       sq 4 6.25 0 0 0 0 -25 0 5 0
   82       pz 22
   83       pz 35.1
```

```
  84       pz 70
  85       pz 80.54
c =================================================================
c    2.2  Ribs (outer surface / inner surface)*
c =================================================================
  86       sq 96.04 289 0 0 0 0 -27755.56 0 0 0
  87       sq 86.49 272.25 0 0 0 0 -23546.9025 0 0 0
c
  88       pz 67.3
  89       pz 65.9
  90       pz 64.5
  91       pz 63.1
  92       pz 61.7
  93       pz 60.3
  94       pz 58.9
  95       pz 57.5
  96       pz 56.1
  97       pz 54.7
  98       pz 53.3
  99       pz 51.9
 100       pz 50.5
 101       pz 49.1
 102       pz 47.7
 103       pz 46.3
 104       pz 44.9
 105       pz 43.5
 106       pz 42.1
 107       pz 40.7
 108       pz 39.3
 109       pz 37.9
 110       pz 36.5
 111       pz 35.1
c =================================================================
c    2.3  Clavicles*
c =================================================================
 112       tz 0 11.1 68.25 20 0.7883 0.7883
 113        p 7.0342 1 0 11.1
 114        p 7.0342 -1 0 -11.1
 115        p 0.89415 1 0 11.1
 116        p 0.89415 -1 0 -11.1
c
c =================================================================
c    2.4  Scapulae  (inner surface / outer surface)*
c =================================================================
 117       sq 96.04 361 0 0 0 0 -34670.44 0 0 0
 118        p 0.25 1 0 0
 119        p 0.25 -1 0 0
 120        p 0.8 1 0 0
 121        p 0.8 -1 0 0
 122       pz 50.9
 123       pz 67.3
c =================================================================
c    2.5  Pelvis*
c =================================================================
 124       sq 127.69 127.69 0 0 0 0 -16304.7361 0 -3.8 0
 125       sq 144 144 0 0 0 0 -20736 0 -3 0
 126       py -3
 127       py 5
 128       pz 22
 129       pz 14
c =================================================================
c    3.0  Upper Chest Organs
```

```
c
c ======================================================================
c     3.1 Main Bronchi*
c ======================================================================
  130     7  cz 0.78
  131     7  cz 0.53
  132     7  pz 5.18
  133     7  pz -5.18
c
  134     8  cz 0.78
  135     8  cz 0.53
  136     8  pz 5.18
  137     8  pz -5.18
c
c
  138     7  cz 0.587
  139     8  cz 0.587
c ======================================================================
c     3.2  Lungs*
c       (left / right)
c ======================================================================
  140        sq 32.4 14.4 1.40625 0 0 0 -810 8.5 0 43.5
  141        sq 32.4 14.4 1.40625 0 0 0 -810 -8.5 0 43.5
  142        pz 43.5
  143        px -5.4
  144        py 1.5
  145        pz 46
  146        pz 54
  147        px 8
  148        py 1
  149        pz 55
c
c ======================================================================
c     3.3  Thymus*
c ======================================================================
c 195     SQ 10.24 36 1.44 0 0 0 -23.04 0 -7.3 57
  150        sq 0.390625 1.234567901 0.05948839975 0 0 0 -1 0 -7.3 57
c ======================================================================
c     3.4  Heart Model *
c ======================================================================
c    basic planes
  151     4  px 0
  152     4  pz 0
c
c    right ventricle
  153     4  sq 1225 3624.04 1849 0 0 0 -90601 0 0 0
  154     4  sq 792.9856 2621.44 1239.04 0 0 0 -50751.0784 0 0 0
c
c    left ventricle
c
  155     4  sq 0.01352082207 0.04 0.1040582727 0 0 0 -1 0 0 0
  156     4  sq 0.01876524677 0.07304601901 0.3086419754 0 0 0 -1 0 0 0
c
c    left atrium, part 1
  157     4  sq 0.03429355282 0.04 0.1040582727 0 0 0 -1 0 0 0
  158     4  sq 0.03844675126 0.04526935263 0.1275510204 0 0 0 -1 0 0 0
c
c    left atriumpart 2
  159     4  sq 0.03429355282 0.04 0.2267573696 0 0 0 -1 0 0 0
  160     4  sq 0.03844675126 0.04526935263 0.3086419754 0 0 0 -1 0 0 0
c
c    right atrium
```

```
 161     4  sq 0.03429355282 0.04 0.02040816328 0 0 0 -1 0 0 0
 162     4  sq 0.03844675126 0.04526935263 0.02227667631 0 0 0 -1 0 0 0
c
c ==================================================================
c
c ===============  4.0  Middle Chest Organs  ========================
c
c ==================================================================
c
c     4.1  Adrenals (left / right)*
c ==================================================================
c
 163     1  sq 0.4756242568 4.938271604 0.04081216202 0 0 0 -1 0 0 0
 164     2  sq 0.4756242568 4.938271604 0.04081216202 0 0 0 -1 0 0 0
 165        pz 38
c
c ==================================================================
c     4.2  Kidneys (left / right)*
c ==================================================================
 166        sq 0.049383 0.444444 0.033058 0 0 0 -1 6 6 32.5
 167        sq 0.049383 0.444444 0.033058 0 0 0 -1 -6 6 32.5
 168        px 3
 169        px -3
c
 170        pz 36.5
c
 171        py 5
c
 172        px 3
c
c ==================================================================
c     4.3  Liver *
c ==================================================================
 173        sq 64 272.24997 0 0 0 0 -17213.99808 0 0 0
 174         p 1935 1505 -1575 -67725
 175        pz 43
 176        pz 27
c
c ==================================================================
c     4.4  Gall bladder*
c ==================================================================
 177     3  so 2
 178     3  so 2.12
 179     3  gq 1 1 -0.051756 0 0 0 0 0 0.91 -4
 180     3  gq 1 1 -0.051756 0 0 0 0 0 0.9646 -4.4944
 181     3  pz 0
 182     3  pz 8
c
c ==================================================================
c     4.5  Pancreas *
c ==================================================================
c
 183        sq 0.003460207612 0.6944444444 0.06007304882 0 0 0 -1 -1 0 35.5
 184        px -1
 185        pz 35.5
 186        px 3
c
c ==================================================================
c     4.6  Spleen *
c ==================================================================
 187        sq 0.09182736454 0.3086419754 0.02972651605 0 0 0 -1 11 3 37
c
```

```
c ===================================================================
c
c ===============  5.0 Gastrointestinal tract and contents ==========
c
c ===================================================================
c     5.1  Male Esophagus*
c ===================================================================
  188        sq 1.11978948 26.29848784 0 0 0 0 -1 0 2.575 0
  189        sq 0.1764 1.3689 0 0 0 0 -0.24147 0 2.575 0
  190        sq 0.0144 0.7569 0 0 0 0 -0.0109 0 2.575 0
c
c
  191    6  cx 0.7
  192    6  px 0.1
  193    6  px 7.8
  194    6  cx 0.075
c
c ===================================================================
c     5.2  Stomach *
c ===================================================================
  195        sq 0.07631024694 0.1456791562 0.01722225667 0 0 0 -1 8 -4 35
  196        sq 576 1024 144 0 0 0 -9216 8 -4 35
  197        sq 0.0870162981 0.1750669631 0.0183109603 0 0 0 -1 8 -4 35
c
c ===================================================================
c     5.3  S. intestine *
c ===================================================================
c
  198        sq 127.69 127.69 0 0 0 0 -16304.7361 0 -3.8 0
  199        py -4.86001
  200        py 2.2
  201        pz 17
  202        pz 27
c
c ===================================================================
c     5.4  A. colon*
c ===================================================================
  203        sq 0.2526458175 0.2526458175 0 0 0 0 -1 -8.5 -2.36 0
  204        sq 6.25 6.25 0 0 0 0 -39.0625 -8.5 -2.36 0
  205        sq 3.209472 3.209472 0 0 0 0 -10.300712 -8.5 -2.36 0
  206        pz 14.45
  207        pz 24
c
c ===================================================================
c     5.5  T. colon*
c ===================================================================
  208        sq 0 0.2222893536 0.7957722213 0 0 0 -1 0 -2.36 25.5
  209        sq 0 2.247 6.25 0 0 0 -14.04375625 0 -2.36 25.5
  210        sq 0 0.946729 3.892729 0 0 0 -3.685359 0 -2.36 25.5
  211        px 10.5
  212        px -10.5
c
c ===================================================================
c     5.6  D. colon*
c ===================================================================
  213        gq 0.539863231 0.4103875659 0.01239247432 0 0.1342891249
              -0.0551169267 -8.664663532 -1.171001169 0.2507156174
              34.60172996
  214        gq 0.330295 0.265703 0.007973 0 0.086945 -0.033721 -5.301142
              -0.7581579 0.146564 20.811319
  215        gq 0.743163 0.540657 0.016409 0 0.176917 -0.075873 -11.92757
              -1.542714 0.356461 47.95909
```

```
 216        pz 8.72
c
c      use surface #303  %323     PZ 24
c
c    5.7  S. colon* (5.805->5.8051)
 217        ty 1.57 0 8.72 1.57 1.26 1.26
 218        ty 5.8051 0 8.72 2.665 1.26 1.26
 219        ty 1.57 0 8.72 1.57 1.57 1.57
 220        ty 1.57 0 8.72 1.57 1.14 1.14
 221        ty 5.8051 0 8.72 2.665 1.57 1.57
 222        ty 5.8051 0 8.72 2.665 1.14 1.14
 223        px 3
c
c      use surface #322  %335     PZ 8.72
c
c    5.8 Rectum**
 224        cz 1.396
 225        cz 1.57
 226        cz 1.33
c
c ==================================================================
c
c ==============  6.0 Lower Chest Organs  ========================
c
c ==================================================================
c
c    6.1 Prostate*
c ==================================================================
 227         s 0 -3.21 3.242 1.54
c
c ==================================================================
c    6.2  U. bladder*
c ==================================================================
 228        sq 142.98812 293.942933 293.942933 0 0 0 -3514.900218 0 -5.028 8
 229        sq 105.646247 227.630725 227.630725 0 0 0 -2339.687839 0 -5.028 8
 230        sq 0.04430267392 0.09461632183 0.09461632183 0 0 0 -1 0 -5.028 8
c ==================================================================
c
c ==================================================================
c
c ==============  8.0  Gender Specific Organs   ==================
c
c ==================================================================
c
c    8.1  Male
c ==================================================================
c    8.1.1  Testes (left / right)*
c ==================================================================
 231        sq 11.9025 8.9401 3.8025 0 0 0 -20.115225 1.3 -8 -2.3
 232        sq 11.9025 8.9401 3.8025 0 0 0 -20.115225 -1.3 -8 -2.3
c ==================================================================
c    8.1.2 Male Genitalia *
c ==================================================================
 233        pz -4.8
c         front / right / left planes
 234         p 0 -10 -1 100
 235         p -10 0 1 -100
 236         p -10 0 -1 100
c
c
c ==================================================================
c    8.2.3  Male Breasts *
```

```
c ====================================================================
c     left
c
  237        sq 0.0346777913 0.4395044149 0.04788148373 0 0 0 -1 10 -8.660254
              52
c
c      right
c
  238        sq 0.0346777913 0.4395044149 0.04788148373 0 0 0 -1 -10 -8.660254
              52
c
c ====================================================================
c
c ============== 10.0  Skin surface descriptions ================
c
c ====================================================================
c    10.2.2 Trunk *
c ====================================================================
  239        sq 0.03223217479 0.4048435484 0.04395044149 0 0 0 -1 10 -8.660254
              52
c
  240        sq 0.03223217479 0.4048435484 0.04395044149 0 0 0 -1 -10 -8.660254
              52
c ====================================================================
c    10.5 Male Genitalia *
c ====================================================================
  241        pz -5
c         front / right / left planes
  242         p 0 -10 -1 102
  243         p -10 0 1 -102
  244         p -10 0 -1 102
c ====================================================================
c
c    10.2   Trunk*
c ====================================================================
  245        sq 104.04 408.04 0 0 0 0 -42452.4816 0 0 0
c
c ====== RIGHT ARM --- BONE
  246       sph -22.75 0 66 3
  247       trc -22.75 0 66 0 0 -35 3.05 2.5
  248       sph -22.75 0 31 2.45
  249       trc -22.75 0 31 0 0 -30.7 2.5 2
c ======= RIGHT ARM --- SOFT TISSUE
  250       sph -22.75 0 66 5
  251       trc -22.75 0 66 0 0 -35 5.05 4.5
  252       sph -22.75 0 31 4.5
  253       trc -22.75 0 31 0 0 -30.7 4.5 3.8
c ====== RIGHT ARM --- SKIN
  254       sph -22.75 0 66 5.2
  255       trc -22.75 0 66 0 0 -35 5.25 4.7
  256       sph -22.75 0 31 4.7
  257       trc -22.75 0 31 0 0 -30.7 4.7 4
c
c ====== LEFT ARM --- BONE
  258       sph 22.75 0 66 3
  259       trc 22.75 0 66 0 0 -35 3.05 2.5
  260       sph 22.75 0 31 2.45
  261       trc 22.75 0 31 0 0 -30.7 2.5 2
c ======= LEFT ARM --- SOFT TISSUE
  262       sph 22.75 0 66 5
  263       trc 22.75 0 66 0 0 -35 5.05 4.5
  264       sph 22.75 0 31 4.5
```

```
 265       trc 22.75 0 31 0 0 -30.7 4.5 3.8
c ====== LEFT ARM --- SKIN
 266       sph 22.75 0 66 5.2
 267       trc 22.75 0 66 0 0 -35 5.25 4.7
 268       sph 22.75 0 31 4.7
 269       trc 22.75 0 31 0 0 -30.7 4.7 4
c
c
c ====== RIGHT LEG --- BONE
 270       sph -9 0 -3.01 4.75
 271       trc -9 0 -3.1 0 -36.54 -6.44 4.5 3
 272       sph -9 -36.54 -9.54 3
 273       trc -9 -36.54 -9.54 0 7.691e-008 -40 3.1 2
c ======= RIGHT LEG --- SOFT TISSUE
 274       sph -9 0 -3.01 8.45
 275       trc -9 0 -3.1 0 -36.54 -6.44 8.05 6.35
 276       sph -9 -36.54 -9.54 6.35
 277       trc -9 -36.54 -9.54 0 7.691e-008 -40 6.35 5.5
c ====== RIGHT LEG --- SKIN
 278       sph -9 0 -3.01 8.65
 279       trc -9 0 -3.1 0 -36.54 -6.44 8.25 6.55
 280       sph -9 -36.54 -9.54 6.55
 281       trc -9 -36.54 -9.54 0 7.691e-008 -40 6.55 5.7
c
c ====== LEFT LEG --- BONE
 282       sph 9 0 -3.01 4.75
 283       trc 9 0 -3.1 0 -36.54 -6.44 4.5 3
 284       sph 9 -36.54 -9.54 3
 285       trc 9 -36.54 -9.54 0 7.691e-008 -40 3.1 2
c ======= LEFT LEG --- SOFT TISSUE
 286       sph 9 0 -3.01 8.45
 287       trc 9 0 -3.1 0 -36.54 -6.44 8.05 6.35
 288       sph 9 -36.54 -9.54 6.35
 289       trc 9 -36.54 -9.54 0 7.691e-008 -40 6.35 5.5
c ====== LEFT LEG --- SKIN
 290       sph 9 0 -3.01 8.65
 291       trc 9 0 -3.1 0 -36.54 -6.44 8.25 6.55
 292       sph 9 -36.54 -9.54 6.55
 293       trc 9 -36.54 -9.54 0 7.691e-008 -40 6.55 5.7
c
c ==================================================================
c
 294        so 400
c
c ========  outer ellipsoid *
 295        sq 1 4 0 0 0 0 -400 0 0 0
 296        px 17.2
 297        px -17.2
 298        px 17.5
 299        px -17.5
c
c ==================================================================
c     10.4  Leg Skin
c ==================================================================
c ===========  left
 300        gq 1 1 0 0 0 -0.2 -20.04 0 -0.04 -4.008
c ===========  right
 301        gq 1 1 0 0 0 0.2 20.04 0 -0.04 -4.008
c     plane above torso
 302        pz 70.2
c
c ==================================================================
```

```
c     0.  Basic Planes*
c
 303        px 0
 304        py 0
 305        pz 0
c ===============================================================
c     Boat Surfaces
c ===============================================================
 1001     9  pz 0
 1002     9  pz -40.65
 1003     9  py 182.5
 1004     9   p 0 3.732 1 -681.1
 1005     9  py 0
 1006     9   p 2.667 0 1 -162.6
 1007     9   p -2.667 0 1 -162.6
 1008     9 c/x 0 1000 1040.65
 1009     9 c/x 0 1000 1000
 1010     9  pz 150
 1011     9   p -0.7418625 0.082621125 -0.27822125 45.2350659
 1012     9   p -0.7418625 -0.082621125 0.27822125 -45.2350659
 1013     9  pz -40.52
 1014     9  py 182.37
 1015     9   p 0 3.732 1 -680.605
 1016     9   p 2.667 0 1 -162.274
 1017     9   p -2.667 0 1 -162.274
 1018     9 c/x 0 1000 1040.52
 1019     9   p -0.73896324 0.0823569 -0.277111215 44.96223633
 1020     9   p -0.73896324 -0.0823569 0.277111215 -44.96223633
 1021     9  pz -33
 1022     9  pz -48.8
 1023     9  pz 31600
 1024     9  py -235  $unused rectangular boundings
 1025     9  py 235  $unused rectangular boundings
 1026     9  px -235  $unused rectangular boundings
 1027     9  px 235  $unused rectangular boundings
 1028     9  cz 43060  $USED cylindrical bounding
 1029     9  py -0.3175
 1030     9  pz -5.715
 1031     9  pz -6.0325
 1032     9  py -40.3225
 1033     9  py -40.64
 1034     9  py -140
 1035     9  py -140.3175
 1036     9  py 146.87
 1037     9  py 147.19
 1038     9  pz 7.24
 1039     9  pz 6.923
 1040     9 trc 0 0 -33 0 0 28700 43060 0.1
 1041     9 trc 0 0 -48.8 0 0 -86.1 43060 0.1

mode  p
c ============ MATERIAL CARDS =====================================
c
c   Composition information for materials are from ICRP-89,
c   Table 13.2 and Table 13.3
c
c
c ===============================================================
c ============== SKELETON -- Density = 1.4 g/cc ==================
c ===============================================================
m2    1001.          -0.07337
      6000.         -0.25475 7014.          -0.03057 8016.          -0.47893
```

```
     9019.         -0.00025 11023.        -0.00326 12000.        -0.00112
     14000.          -2e-005 15031.        -0.05095 16000.        -0.00173
     17000.         -0.00143 19000.        -0.00153 20000.          -0.1019
     26000.          -8e-005 30000.          -5e-005
c
c ====================================================================
c =============== AIR -- Density = 0.001205 g/cc ===================
c ====================================================================
m4    6000.         -0.000124
     7014.        -0.755267 8016.        -0.231781 18000.        -0.012827
c
c ====================================================================
c =============== UPPER FACE REGION -- Density = 1.22 g/cc =========
c ====================================================================
m5    1001.         -0.088955
     6000.         -0.24069 7014.        -0.027735 8016.         -0.55709
     9019.        -0.000125 11023.        -0.00219 12000.        -0.000625
     14000.        -0.00016 15031.        -0.026145 16000.        -0.001885
     17000.        -0.00138 19000.        -0.001805 20000.         -0.05107
     26000.        -6.5e-005 30000.          -4e-005 40000.         -1e-005
     82000.          -5e-006
c
c ====================================================================
c =============== BRAIN -- Density = 1.04 g/cc =====================
c ====================================================================
m6    1001.           -0.107
     6000.          -0.145 7014.          -0.022 8016.          -0.712
     11023.          -0.002 15031.          -0.004 16000.          -0.002
     17000.          -0.003 19000.          -0.003
c
c ====================================================================
c =============== EYES -- Density = 1.07 g/cc ======================
c ====================================================================
m7    1001.           -0.096
     6000.          -0.195 7014.          -0.057 8016.          -0.646
     11023.          -0.001 15031.          -0.001 16000.          -0.003
     17000.          -0.001
c
c ====================================================================
c =============== LARYNX -- Density = 1.10 g/cc ====================
c ====================================================================
c
m8    1001.           -0.096
     6000.          -0.099 7014.          -0.022 8016.          -0.744
     11023.          -0.005 15031.          -0.022 16000.          -0.009
     17000.          -0.003
c
c ====================================================================
c =============== TRACHEA -- Density = 1.03 g/cc ===================
c ====================================================================
c
m9    1001.           -0.105
     6000.          -0.256 7014.          -0.027 8016.          -0.602
     11023.          -0.001 15031.          -0.002 16000.          -0.003
     17000.          -0.002 19000.          -0.002
c
c ====================================================================
c ============== THYROID -- Density = 1.05 =======================
c ====================================================================
m10   1001.           -0.104
     6000.          -0.119 7014.          -0.024 8016.          -0.745
     11023.          -0.002 15031.          -0.001 16000.          -0.001
```

```
     17000.          -0.002 19000.          -0.001
c
c ===================================================================
c =============== SKIN -- Density = 1.09 g/cc =======================
c ===================================================================
c
m11   1001.            -0.1
     6000.          -0.204 7014.          -0.042 8016.          -0.645
     11023.          -0.002 15031.          -0.001 16000.          -0.002
     17000.          -0.003 19000.          -0.001
c
c ===================================================================
c =============== SOFT TISSUE -- Density = 1.03 g/cc ===============
c ===================================================================
c
m12   1001.          -0.105
     6000.          -0.256 7014.          -0.027 8016.          -0.602
     11023.          -0.001 15031.          -0.002 16000.          -0.003
     17000.          -0.002 19000.          -0.002
c
c ===================================================================
c =============== MUSCLE -- Density = 1.05 g/cc =====================
c ===================================================================
c
m13   1001.          -0.102
     6000.          -0.143 7014.          -0.034 8016.          -0.71
     11023.          -0.001 15031.          -0.002 16000.          -0.003
     17000.          -0.001 19000.          -0.004
c
c ===================================================================
c =============== LUNGS -- Density = 0.26 g/cc =====================
c ===================================================================
c
m14   1001.          -0.103
     6000.          -0.105 7014.          -0.031 8016.          -0.749
     11023.          -0.002 15031.          -0.002 16000.          -0.003
     17000.          -0.003 19000.          -0.002
c
c ===================================================================
c =============== HEART -- Density = 1.05 g/cc =====================
c ===================================================================
c
m15   1001.          -0.104
     6000.          -0.139 7014.          -0.029 8016.          -0.718
     11023.          -0.001 15031.          -0.002 16000.          -0.002
     17000.          -0.002 19000.          -0.003
c
c ===================================================================
c =============== KIDNEY -- Density = 1.05 g/cc ====================
c ===================================================================
m16   1001.          -0.103
     6000.          -0.132 7014.          -0.03 8016.          -0.724
     11023.          -0.002 15031.          -0.002 16000.          -0.002
     17000.          -0.002 19000.          -0.002 20000.          -0.001
c
c ===================================================================
c =============== LIVER -- Density = 1.05 g/cc =====================
c ===================================================================
c
m17   1001.          -0.103
     6000.          -0.186 7014.          -0.028 8016.          -0.671
     11023.          -0.002 15031.          -0.002 16000.          -0.003
```

```
     17000.          -0.002 19000.          -0.003
c
c ===================================================================
c =============== PANCREAS -- Density = 1.04 g/cc ===================
c ===================================================================
c
m18   1001.          -0.106
     6000.          -0.169 7014.          -0.022 8016.          -0.694
     11023.          -0.002 15031.          -0.002 16000.          -0.001
     17000.          -0.002 19000.          -0.002
c
c ===================================================================
c =============== SPLEEN -- Density = 1.06 g/cc ====================
c ===================================================================
m19   1001.          -0.103
     6000.          -0.113 7014.          -0.032 8016.          -0.741
     11023.          -0.001 15031.          -0.003 16000.          -0.002
     17000.          -0.002 19000.          -0.003
c
c ===================================================================
c =============== GI TRACT -- Density 1.03 g/c =====================
c ===================================================================
m20   1001.          -0.106
     6000.          -0.115 7014.          -0.022 8016.          -0.751
     11023.          -0.001 15031.          -0.001 16000.          -0.001
     17000.          -0.002 19000.          -0.001
c
c ===================================================================
c =============== URINARY BLADDER -- Density = 1.04 g/cc ============
c ===================================================================
c
m21   1001.          -0.105
     6000.          -0.096 7014.          -0.026 8016.          -0.761
     11023.          -0.002 15031.          -0.002 16000.          -0.002
     17000.          -0.003 19000.          -0.003
c
c ===================================================================
c =============== TESTES -- Density = 1.04 g/cc ====================
c ===================================================================
c
m22   1001.          -0.106
     6000.          -0.099 7014.          -0.02 8016.          -0.766
     11023.          -0.002 15031.          -0.001 16000.          -0.002
     17000.          -0.002 19000.          -0.002
c
c ===================================================================
c =============== OVARY -- Density = 1.05 g/cc =====================
c ===================================================================
c
m23   1001.          -0.105
     6000.          -0.093 7014.          -0.024 8016.          -0.768
     11023.          -0.002 15031.          -0.002 16000.          -0.002
     17000.          -0.002 19000.          -0.002
c
c ===================================================================
c =============== UTERUS -- Density = 1.02 g/cc ====================
c ===================================================================
c
m24   1001.          -0.106
     6000.          -0.315 7014.          -0.024 8016.          -0.547
     11023.          -0.001 15031.          -0.002 16000.          -0.002
     17000.          -0.001 19000.          -0.002
```

```
c
c ======================================================================
c =============== BREAST -- Density = 0.94 g/cc ====================
c   Composition information from ICRP-89, Table 13.3 on page 244
c   Note: Female Breast Values are taken from this Table
c ======================================================================
c
m25   1001.          -0.116
      6000.          -0.519 8016.          -0.365
c ========================= BOAT MATERIALS==============================
c -----------------------------------------------------------------------
c 5052 Aluminum Alloy [p=2.68 g/cm^3]
c -----------------------------------------------------------------------
m101  13000.          -0.963  $ Aluminum at 96.3 wt. %
      12000.          -0.025 26000.          -0.004 24000.          -0.0025
      14000.          -0.0025 29000.          -0.001 30000.          -0.001
      25000.          -0.001
c
c -----------------------------------------------------------------------
c Air (23.2% Oxygen, 75.5% Nitrogen, 1.3% Argon by weight) [p=0.001225 g/cm^3]
c -----------------------------------------------------------------------
m102  8000.          -0.232  $ Oxygen
      7000.          -0.755 18000.          -0.013
c
c -----------------------------------------------------------------------
c Water H_2 O [p=1.0 g/cm^3]
c -----------------------------------------------------------------------
m103  8000.              1  $ Oxygen
      1000.              2
c ======================================================================
c ==============  Axis Transformation Section * ===================
c ======================================================================
c     Adrenals (left / right)
c ======================================================================
tr1  3.5 5 38 0.6157 0.788 0 -0.788 0.6157 0 0 0 1
tr2  -3.5 5 38 0.6157 -0.788 0 0.788 0.6157 0 0 0 1
c ======================================================================
c     Gall Bladder
c ======================================================================
tr3  -4.5 -3.2 30 0.9615 0 -0.2748 -0.0574 0.9779 -0.2008 0.2687 0.209 0.9403
c ======================================================================
c     Heart
c ======================================================================
tr4  1 -1.8 50 0.6751 -0.4727 -0.5664 -0.464 0.3249 -0.8241 0.5736 0.8191 0
c ======================================================================
c     Esophagus
c ======================================================================
tr6  0 2.575 42.3 0.736084 -0.604969 -0.303634 0.634945 0.772557 0 0.234575
      -0.192791 0.952789
c ======================================================================
c Main Bronchi
c
c ======================================================================
*tr7 1.967 -1.09 59.77 33 90 57 90 0 90 123 90 33
*tr8 -1.967 -1.09 59.77 33 90 123 90 0 90 57 90 33
c ======================================================================
c Boat Transformation
c
c ======================================================================
tr9  0 15 -10
imp:p   1 136r      0           $ 1, 138
c ======================================================================
```

```
vol    280.1        364.6        31.2         170.5        226.89       $ 1, 5
       1467.6       7.6 1r       38.605       14.5199      49.763       $ 6, 11
       8.3701       3.90669      7.775        2.1413       11.2403      $ 12, 16
       19.925       2.5098       19.9         4.4879       6.904        $ 17, 21
       252.269      81.7308      1361.68      165.562      548.208      $ 22, 26
       205.774      694          54.7         202          606          $ 27, 31
       12.3468      13.53        3.01194      1560         1810         $ 32, 36
       24.7306      303          437          6.76463 1r   143.98 1r    $ 37, 43
       1830         10.1         53.6         117.264      144.312      $ 44, 48
       6.77524      0.136        37.7888      8.856        36.9664      $ 49, 53
       99.2256      265.933      1060         22.452       68.75        $ 54, 58
       96.3         14.9306      45.5694      63.5         14.9306      $ 59, 63
       45.5694      63.5         26.2342      60.0758      75.73        $ 64, 68
       12.0377      36.6692      54.32        4.9272       14.1428      $ 69, 73
       48.46        7.33303      38.367       203          15.3         $ 74, 78
       18.8 1r      158.4        81.1         81.4         31429.9      $ 79, 84
       1410         23.4         0 51r        $ 85, 138
c ====================================================================
c EXPONENTIAL TRANSFORM CARD
c ====================================================================
ext:p 0 134r 0.4V1 0.4V1 0
vect  V1 0 0 30
mt2    lwtr.01t
mt5    lwtr.01t
mt6  lwtr.01t
mt7  lwtr.01t
mt8    lwtr.01t
mt9    lwtr.01t
mt10    lwtr.01t
mt11    lwtr.01t
mt12    lwtr.01t
mt13    lwtr.01t
mt14    lwtr.01t
mt15    lwtr.01t
mt16    lwtr.01t
mt17     lwtr.01t
mt18     lwtr.01t
mt19     lwtr.01t
mt20     lwtr.01t
mt21      lwtr.01t
mt22      lwtr.01t
mt23      lwtr.01t
mt24      lwtr.01t
mt25     lwtr.01t
c ====================================================================
c     TALLY DEFINITION SECTION
c ====================================================================
c
c ENDORGAN
c ====================================================
fc216    PHOTON contribution
f216:p
c Organ: testes
     (79 80)        $ left+right
c Organ: bone marrow
        (2 3 4 5         $ Cranium and mandible
         30  29          $ Scapulae and clavicle
         28              $ ribs
         31 )            $ pelvis
c Organ: colon
       (57 58          $ right   (mucosa+wall)
         60 61          $ T colon (mucosa+wall)
```

```
        63 64          $ left    (mucosa+wall)
        66 67          $ D colon (mucosa+wall)
        69 70          $ sigmoid (mucosa+wall)
        72 73)         $ rectum  (mucosa+wall)
c Organ: lungs
       (35 36)          $ left+right
c Organ: stomach
       (53 54)        $ mucosa+wall
c Organ: urinary bladder
       (75 76)        $ mucosa+wall
c Organ: breast
       (82 83)        $ left+right
c Organ: liver
        44
c Organ: esophagus
       (49             $ thoracic  portion
        50             $ abdominal portion
        51)            $ remainder
c Organ: thyroid
       19
c Organ: skin
        (1             $ head+neck
        85             $ trunk
        86)            $ male genitalia
c Organ: bone surface
       (25 26 27        $ C,T,L-spine
        28              $ ribs
        29              $ clavicles
        30              $ scapulae
        31  )           $ pelvis
c Organ: adrenals
       (40 41)
c Organ: brain
       6
c Organ: Extrathoracic airways
       (9              $ sinuses
        12 10           $ pharynx (mucosa+wall)
        15 13)          $ larynx  (mucosa+wall)
c Organ: small intestine
       56
c Organ: kidneys
        (42 43)
c Organ: muscle
       84
c Organ: pancreas
       47
c Organ: spleen
       48
c Organ: thymus
       37
c Organ: prostate
       78
c Organ: eyes
       (7 8)
c ENDORGAN
c ==================================================================
c ENDORGAN
c ==================================================================
c ===== SOURCE DESCRIPTION
c ==================================================================
sdef POS=0 15 -10 AXS=0 0 1 EXT=D2 RAD=D1 PAR=P ERG=D3 CEL=137
si1 0 32298
```

```
sp1 -21 1
si2 -145 -30
sp2 0 1
si3 L 1.1732 1.3325
sp3 D 1.0 1.0
nps 1e9
prdmp 1e9 1e7 0 1
```

Sample MCNP Realistic Model Input File – Female ^{54}Mn Outer Source Division

```
TITLE CARD - MCNP JONBOAT TRIAL #5-1 (Female-PIMAL: Mn-54)
c   CELL CARDS
c ================================================================
c
c ============== 1.0 Head and Neck ================================
c
c ================================================================
c
c 1.1 The Skin of Head and Neck
c ================================================================
c
   1    11   -1.09 ((-8 9 ):-7 )-1 12 (2 :4 :7 :(-6 11 ))(5 :(-10 11 ):-12 )
          (-5 :7 :-4 :(-13 85 14 ):(2 -1 -14 ))#7 #8 #2
c ================================================================
c 1.2 The Cranium
c ================================================================
c
   2     2    -1.4 (15 -19 7 ):(16 -20 17 21 -7 ):(-20 -17 21 -7 )
c ================================================================
c 1.3 The Teeth
c ================================================================
c
   3     2    -1.4 -22 23 24 -25 -26
c ================================================================
c 1.4 The Mandible
c ================================================================
c
   4     2    -1.4 (-27 29 ((28 -24 -26 ):(30 -21 26 -18 )))
c ================================================================
c 1.5 Nasal Cavity (The Upper Face Region, Facial skeleton)
c ================================================================
c
   5     5   -1.22 -31 25 -21 -26 32 33 (39 40 )(41 42 )(43 44 )(45 46 )
c
c remove sphenoid Sinus
c remove ethmoid Sinus
c remove frontal Sinus
c remove maxillary Sinus
c       VOL=246.2-3.031080975-2.316809810-6.042866874-21.73095454
c ================================================================
c 1.7 The Brain
c ================================================================
c
   6     6   -1.04 (7 -34 ):(-7 -35 36 )
c ================================================================
c 1.8 The eyes
c ================================================================
c Left
   7     7   -1.07 -32
```

```
c Right
   8     7   -1.07 -33
c ==============================================================
c 1.9 Total Sinuses
c ==============================================================
c
   9     4 -0.001205 (-39 :-40 :-41 :-42 :-43 :-44 :-45 :-46 )
c ==============================================================
c 1.13 Pharynx(Skeletal Muscle)
c ==============================================================
c Residual Wall
c ==============================================================
c
  10    13   -1.05 -47 50 12 -49
c ==============================================================
c Contents
c ==============================================================
c
  11     4 -0.001205 -48 12 -49
c ==============================================================
c Mucosa Wall
c ==============================================================
c
  12    13   -1.05 -50 48 12 -49
c ==============================================================
c 1.14 Larynx
c ==============================================================
c Residual Wall
c ==============================================================
c
  13     8    -1.1 54 -52 53 -5
c ==============================================================
c Content
c ==============================================================
c
  14     4 -0.001205 -51 53 -5
c ==============================================================
c Mucosa Wall
c ==============================================================
c
  15     8    -1.1 51 -54 53 -5
c ==============================================================
c 1.15 Trachea
c ==============================================================
c Residual Wall
c ==============================================================
c
  16    12   -1.03 58 -55 57 -53
c ==============================================================
c Content
c ==============================================================
c
```

```
   17     4 -0.001205 -56 57 -53
c ===================================================================
c Mucosa Wall
c ===================================================================
c
   18    12   -1.03 56 -58 57 -53
c ===================================================================
c 1.16 Thyroid
c ===================================================================
c
   19    10   -1.05 (339 -5 66 -59 60 -61 -65 ):(-339 -5 66 -59 60 -62 -65 ):
         (339 67 -66 -59 60 63 -65 (53 :55 )):(-339 67 -66 -59 60 64 -65
         (53 :55 ))
c ===================================================================
c 1.17 Nose
c ===================================================================
c Contents
c ===================================================================
c
   20     4 -0.001205 -68 -69 73 1 -76 (-74 :75 )
c            remove Center Tissue
c ===================================================================
c  Nose Wall
c ===================================================================
c
   21    13   -1.05 -71 -72 73 1 -76 (-75 :69 )(74 :68 )
c ===================================================================
c 1.18 Oral Cavity (Soft tissue Behind mouth and teeth)
c ===================================================================
c
   22    12   -1.03 (((-30 29 -21 26 -18 ):(-26 -23 24 -25 ):(-26 -28 -24 29 ))
         ((77 78 ):-24 :49 )((79 81 ):80 :-29 )((82 84 ):-83 :26 :28 ))
c
c ===================================================================
c 1.19 Salivery Glands
c ===================================================================
c Left & Right Parotid
c ===================================================================
c
c 51 1 -1.04  (-636 : -641) 531 -565
c          Vol = 38.462
c
c Left & Right Submandibular
c
c 53 1 -1.04  (-637 : -642) -638 536
c          Vol = 19.296
c
c Left & Right Sublingual
c
c 55 1 -1.04  (-639 : -643) 640 -533 -535
c           Vol = 7.692
c
```

```
c Total Salivery Glands
c
  23    12   -1.03 (((-77 :-78 )24 -49 ):((-79 :-81 )-80 29 ):(
         (-82 :-84 )83 -26 -28 ))
c ==================================================================
c 1.20 Muscle Part of head and neck
c ==================================================================
c
  24    13   -1.05 (-9 :-7 )-2 12 (6 :-11 :-12 )(-4 :7 :-5 :-14 )
         (-15 :19 :-7 )(-16 :20 :-17 :-21 :7 )(20 :17 :-21 :7 )
         (22 :-23 :-24 :25 :26 )(27 :-28 :-29 :24 :26 )(27 :-30 :-29 :21 :-26
          :18 )(31 :-25 :21 :26 :-32 :-33 )(85 :89 :-88 )(-7 :34 )
         (7 :35 :-36 )(32 33 )(52 :-53 :5 )(55 :-57 :53 )
         (47 :-12 :49 )#19 #22 #23
c
c    remove cranium
c    remove teeth
c    remove mandible
c    remove nasal cavity
c    remove spine in the Head and Neck
c    remove brain
c    remove eyes
c    remove larynx
c    remove trachea
c    remove pharynx
c    remove thyroid
c    remove Oral Cavity
c    remove salivary glands
c ==================================================================
c
c =============== 2.0  Skeleton Region ==============================
c
c ==================================================================
c    2.1  Spine
c ==================================================================
c    2.1.1  Cervical Verterbra - CV(upper)
c ==================================================================
c
  25     2    -1.4 -85 -89 88
c ==================================================================
c    2.1.2  Thoracic Verterbra - TV (middle)
c ==================================================================
c
  26     2    -1.4 -85 -88 87
c ==================================================================
c    2.1.3  Lumber Verterbra - LV (lower)
c ==================================================================
c
  27     2    -1.4 -85 -87 86
c ==================================================================
c    2.2  Ribs
c ==================================================================
```

```
c    all ribs
  28    2    -1.4 91 -90 ((93 -92 ):(95 -94 ):(97 -96 ):(99 -98 ):
         (101 -100 ):(103 -102 ):(105 -104 ):(107 -106 ):(109 -108 ):
         (111 -110 ):(113 -112 ):(115 -114 ))
c ===================================================================
c    2.3  Clavicles
c ===================================================================
c    both
  29    2    -1.4 -116 ((117 -119 ):(-118 120 ))
c ===================================================================
c    2.4  Scapulae
c ===================================================================
c    both
  30    2    -1.4 90 -121 126 -127 ((122 -124 ):(-123 125 ))
c ===================================================================
c    2.5  Pelvis
c ===================================================================
  31    2    -1.4 128 -129 130 341 -132 (133 :-131 )
c
c ===================================================================
c
c ===================================================================
c
c =============== 3.0  Upper Chest Organs ==========================
c
c ===================================================================
c    3.1  Main Bronchi
c ===================================================================
c  Residual Wall
c ===================================================================
c
  32   12   -1.03 (152 -144 -146 147 154 -57 339 ):(-148 153 -150 151 155 -57
          -339 )
c ===================================================================
c  Contents
c ===================================================================
  33    4 -0.001205 (-145 -146 147 154 -57 339 ):(-149 -150 151 155 -57 -339
          )
c ===================================================================
c  Mucosa Wall
c ===================================================================
  34   12   -1.03 (145 -152 -146 147 154 -57 339 ):(-153 149 -150 151 155 -57
          -339 )
c ===================================================================
c    3.2  Lungs
c ===================================================================
c     left
  35   14   -0.26 -154 156 (163 :162 :161 )
c     right
  36   14   -0.26 -155 156 (-159 :160 :158 :-157 )
c ===================================================================
c    3.3  Thymus
```

```
c ==================================================================
  37    12   -1.03 -164
c ==================================================================
c     3.4  Heart
c ==================================================================
c
c      Wall of heart
c ==================================================================
  38    15   -1.05 (165 ((-166 168 -167 ):(170 -169 ))):(-165 (
         (-166 176 -175 ):(166 172 -171 ):(-166 -173 174 )))
c
c ==================================================================
c      Contents of heart
c ==================================================================
  39    15   -1.05 (165 ((-166 -168 169 ):(-170 ))):(-165 ((-166 -176 173 ):
         (166 -172 ):(-166 -174 )))
c
c ==================================================================
c
c ===============  4.0  Middle Chest Organs ========================
c
c ==================================================================
c     4.1  Adrenals
c ==================================================================
c     left
  40    12   -1.03 179 -177
c     right
  41    12   -1.03 179 -178
c ==================================================================
c     4.2  Kidneys
c ==================================================================
c left kidney
c
  42    16   -1.04 (-180 182 )
c right kidney
c
  43    16   -1.04 (-181 -183 )
c ==================================================================
c     4.3  Liver
c ==================================================================
  44    17   -1.05 -204 -205 207 -206
c
c ==================================================================
c     4.4  Gall bladder
c ==================================================================
c      wall
  45    12   -1.03 (-212 208 -209 ):(212 -213 210 -211 )
c      contents
  46    12   -1.03 (-212 -208 ):(212 -210 -213 )
c
c ==================================================================
c     4.5  Pancreas
```

```
c ======================================================================
  47    18   -1.04 -214 215 (216 :-217 )
c
c ======================================================================
c    4.6  Spleen
c ======================================================================
  48    19   -1.06 -218
c
c ======================================================================
c
c ===============  5.0 Gastrointestinal tract and contents ==========
c
c ======================================================================
c    5.1 Male Esophagus   /*** 1996 ORNL C&E ***/
c ======================================================================
c    Mucosa Wall of the thoracic portion
c ======================================================================
c
  49    12   -1.03 (-220 222 206 -88 )
c ======================================================================
c    Mucosa Wall of the abdominal portion
c ======================================================================
  50    12   -1.03 (-219 224 -225 )
c ======================================================================
c    Remainder Wall of the thoracic and abdominal portion
c ======================================================================
  51    12   -1.03 (-221 220 206 -88 ):(-223 219 224 -225 )
c ======================================================================
c    Contents of the thoracic portion
c ======================================================================
  52     4 -0.001205 -222 206 -88
c ======================================================================
c
c =============== 5.2  Stomach ========================================
c
c ======================================================================
c     Mucosa Wall
c ======================================================================
  53    20   -1.03 -226 228
c ======================================================================
c     Remainder Wall
c ======================================================================
  54    20   -1.03 -227 226
c ======================================================================
c     Contents
c ======================================================================
  55    20   -1.03 -228
c ======================================================================
c
c ===============  5.3  S. intestine =================================
c
c ======================================================================
```

```
  56    20   -1.03 -128 230 -231 232 -207 (235 :238 :-232 )(240 :242 :-243 )
         (245 :238 :-232 )
c
c          remove     a. colon
c          remove     t. colon
c          remove     d. colon
c
c ===================================================================
c     5.4  Right colon *
c ===================================================================
c     5.4.1  A. colon
c      Mucosa Wall
c
  57    20   -1.03 (-234 236 237 -238 )
c ===================================================================
c      Remainder Wall
  58    20   -1.03 (-235 234 237 -238 )
c ===================================================================
c      Contents
  59    20   -1.03 (-236 237 -238 )
c ===================================================================
c
c     5.4.2 Proximal T. colon
c
c      Mucosa Wall
c ===================================================================
  60    20   -1.03 -239 241 -242 243 -339
c ===================================================================
c      Remainder Wall
c ===================================================================
  61    20   -1.03 -240 239 -242 243 -339
c ===================================================================
c      Contents
c ===================================================================
  62    20   -1.03 -241 -242 243 -339
c ===================================================================
c
c     5.5 Left colon
c     5.5.1 Distal T. colon
c
c      Mucosa Wall
c ===================================================================
  63    20   -1.03 -239 241 -242 243 339
c ===================================================================
c      Remainder Wall
c ===================================================================
  64    20   -1.03 -240 239 -242 243 339
c ===================================================================
c      Contents
c ===================================================================
  65    20   -1.03 -241 -242 243 339
c ===================================================================
```

```
c     5.5.2  D. colon *
c ============================================================
c      Mucosa Wall
c ============================================================
  66    20   -1.03 (-244 246 247 -238 )
c ============================================================
c      Remainder Wall
c ============================================================
  67    20   -1.03 (-245 244 247 -238 )
c ============================================================
c      Contents
c ============================================================
  68    20   -1.03 (-246 247 -238 )
c
c ============================================================
c     5.6  Rectosigmoid *
c ============================================================
c
c     5.6.1 Sigmoid colon
c ============================================================
c      Mucosa Wall
c ============================================================
  69    20   -1.03 (-248 251 247 ):(-249 253 -247 )
c ============================================================
c      Remainder Wall
c ============================================================
  70    20   -1.03 (-250 248 247 ):(-252 249 -247 )
c ============================================================
c      Total contents
c ============================================================
  71    20   -1.03 (-251 247 ):(-253 -247 )
c ============================================================
c
c    5.6.2  Rectum
c ============================================================
c        Mucosa Wall
c ============================================================
  72    20   -1.03 -255 257 -247 341
c ============================================================
c        Remainer Wall
c ============================================================
  73    20   -1.03 -256 255 -247 341
c ============================================================
c        Contents
c ============================================================
  74     4 -0.001205 -257 -247 341
c
c ============================================================
c
c ====== 6.0   Lower Chest Organ ==================================
c
c ============================================================
```

```
c    6.1   U. bladder
c
c     Mucosa wall
c =====================================================================
  75    21   -1.04 -260 259
c
c =====================================================================
c     Remainder wall
c =====================================================================
  76    21   -1.04 -258 260
c =====================================================================
c     Contents
c =====================================================================
  77    21   -1.04 -259
c
c =====================================================================
c
c ====== 8.0  Gender Specific Organs ================================
c
c =====================================================================
c
c =====================================================================
c    8.2    Female
c =====================================================================
c
c
c =====================================================================
c    8.2.1  Ovaries
c =====================================================================
c     left
  78    23   -1.05 -272
c     right
  79    23   -1.05 -273
c
c =====================================================================
c    8.2.2  Uterus
c =====================================================================
  80    24   -1.02 -274 275
c
c =====================================================================
c    8.2.3  Breasts
c =====================================================================
c     left gland
  81    25   -0.94 -276 342
c     right gland
  82    25   -0.94 -277 342
c
c =====================================================================
c  9.0  Muscle in the Trunk
c =====================================================================
c
  83    12   -1.03 341 -88 -342 -343 344  $Check this, removed prostate!!
```

```
          (85 :-86 :88 )(55 :-57 :53 )(90 :-91 :92 :-93 )(90 :-91 :94 :-95 )
          (90 :-91 :96 :-97 )(90 :-91 :98 :-99 )(90 :-91 :100 :-101 )
          (90 :-91 :102 :-103 )(90 :-91 :104 :-105 )(90 :-91 :106 :-107 )
          (90 :-91 :108 :-109 )(90 :-91 :110 :-111 )(90 :-91 :112 :-113 )
          (90 :-91 :114 :-115 )(116 :-117 :119 )(116 :118 :-120 )
          (-90 :121 :-122 :124 :-126 :127 )(-90 :121 :123 :-125 :-126 :127
           )#31 (144 :146 :-147 :57 :-154 :-339 )(148 :150 :-151 :57 :-155
           :339 )(154 :92 :-156 :(-163 -162 -161 ))(155 :92 :-156 :
          (159 -160 -158 157 ))164 #38 #39 (177 :-179 )(178 :-179 )(181 :183 )
          (180 :-182 )(204 :205 :206 :-207 )(212 :209 )(-212 :211 :213 )
          (214 :-215 :(-216 217 ))218 (221 :88 :-206 )(223 :-224 :225 )227
          (128 :-230 :231 :-232 :207 )(232 :235 :-237 )(232 :245 :-247 )
          (250 :-247 )(252 :247 )(256 :247 :-341 )258 272 273 (274 :-275 )
c     remove        spine
c     remove      trachea
c     remove      (ribs 1-9)
c     remove      clavicles (left / right)
c     remove      scapulae (left / right)
c     remove      pelvis
c     remove      main bronchi
c     remove      lungs (left / right)
c     remove       thymus
c     remove       heart
c     remove       adrenals (left / right)
c     remove       kidneys (left / right)
c     remove       liver
c     remove       gall bladder
c     remove       pancreas
c     remove       spleen
c     remove      esophagus
c     remove       stomach
c     remove        s. intestine
c     remove        a. colon
c     remove        d. colon
c     remove        s. colon
c     remove        rectum
c     remove        u. bladder
c     remove        ovaries
c     remove        uterus
c
c
c ===================================================================
c   10.0 Skin
c ===================================================================
c   10.2.2 Skin of Female Trunk  (includes BREAST)
c ===================================================================
c
   84    11   -1.09 ((-278 342 -343 344 -88 341 ):(-278 10 -345 346 -283 88 ):
          (-278 -345 343 -88 341 ):(-278 -344 346 -88 341 ):(342 ((-279 276 ):
          (-280 277 ))))(10 :-88 :283 )(-342 :278 :276 )(-342 :278 :277 )
c    plus         breast part
c    remove        material under neck
```

```
c     remove        material under breast area (left / right)
c
c
c ==============================================================
c ==============================================================
c      ARMS and LEGS  for PIMAL
c ==============================================================
c ======== RIGHT ARM ---- BONE
   85     2    -1.4 -289 290 294
   86     2    -1.4 -290 291
   87     2    -1.4 -291
   88     2    -1.4 -292 291 290
c ======== RIGHT ARM --- SOFT TISSUE
   89    13   -1.05 -293 289 290 294
   90    13   -1.05 -294 290 292
   91    13   -1.05 -295 290 291 292 294 296
   92    13   -1.05 -296 292 294
c ======== RIGHT ARM --- SKIN
   93    11   -1.09 -297 293 294 298
   94    11   -1.09 -298 294 296
   95    11   -1.09 -299 294 295 296 298 300
   96    11   -1.09 -300 296 298 295
c
c ======== LEFT ARM ---- BONE
   97     2    -1.4 -301 302 306
   98     2    -1.4 -302 303
   99     2    -1.4 -303
  100     2    -1.4 -304 303 302
c ======== LEFT ARM --- SOFT TISSUE
  101    13   -1.05 -305 301 302 306
  102    13   -1.05 -306 302 304
  103    13   -1.05 -307 302 303 304 306 308
  104    13   -1.05 -308 304 306
c ======== LEFT ARM --- SKIN
  105    11   -1.09 -309 305 306 310
  106    11   -1.09 -310 306 308
  107    11   -1.09 -311 306 307 308 310 312
  108    11   -1.09 -312 308 310 307
c
c
c ======= RIGHT LEG --- BONE
  109     2    -1.4 -313 -341
  110     2    -1.4 (-314 -341 315 313 ):(341 -314 315 313 278 )
  111     2    -1.4 -315
  112     2    -1.4 -316 315 314
c ======= RIGHT LEG --- TISSUE
  113    13   -1.05 -317 -341 313 314 334
  114    13   -1.05 (-318 314 315 316 317 -346 ):(346 -341 -318 315 314 316 317
          ):(-318 314 315 316 317 341 278 )
  115    13   -1.05 -319 314 315 316 318 320
  116    13   -1.05 -320 316 318
c ======= RIGHT LEG --- SKIN
```

```
  117    11   -1.09 -321 -341 322 317 334
  118    11   -1.09 (-322 318 319 320 317 -346 ):(346 318 319 320 317 -322 -341
          ):(-322 318 319 320 317 341 278 )
  119    11   -1.09 -323 318 319 320 322 324
  120    11   -1.09 -324 319 320 322
c
c
c ======= LEFT LEG --- BONE
  121     2    -1.4 -325 -341
  122     2    -1.4 (-326 -341 327 325 ):(-326 341 278 327 325 )
  123     2    -1.4 -327
  124     2    -1.4 -328 327 326
c ======= LEFT LEG --- TISSUE
  125    13   -1.05 -329 -341 325 326 322
  126    13   -1.05 (-330 326 327 328 329 345 ):(326 -330 327 328 329 -345 -341
          ):(-330 326 327 328 329 341 278 )
  127    13   -1.05 -331 326 327 328 330 332
  128    13   -1.05 -332 328 330
c ======= LEFT LEG --- SKIN
  129    11   -1.09 -333 -341 334 329 322
  130    11   -1.09 (-334 330 331 332 329 345 ):(-334 330 331 332 329 -345 -341
          ):(-334 330 331 332 329 341 278 )
  131    11   -1.09 -335 330 331 332 334 336
  132    11   -1.09 -336 331 332 334
c
c
c
c ===========================================================================
c ===========================================================================
c ================================ BOAT CELLS ================================
  133   101    -2.68 (1004 -1015 -1001 1002 1006 1007 ):(1006 -1016 1004 -1005
          -1001 1002 ):(1005 -1003 1009 -1008 -1010 -1011 1019 ):
         (-1003 1014 1009 -1008 -1011 1012 -1010 ):(1005 -1003 1009 -1008
          -1010 1012 -1020 ):(1007 -1017 1004 -1005 -1001 1002 ):
         (1002 -1013 -1005 1004 1006 1007 ):(1005 -1003 -1008 1018 -1010
          -1011 1012 ):(1015 -1030 1031 -1034 1016 1017 ):
         (1016 1017 1035 -1034 1013 -1031 ):(1033 -1032 1013 -1031 1016 1017
          ):(1031 -1030 1033 -1005 1016 1017 ):(1029 -1005 -1031 1013 1016
          1017 ):(1036 -1037 -1039 -1018 -1019 1020 ):(1039 -1038 1036 -1014
          -1019 1020 )
  134   102 -0.001205 (((-1005 1001 ):(-1005 -1002 ):-1004 :(-1005 -1006 ):
         (1005 1011 ):(-1005 -1007 ):(1005 -1012 ):(1005 1010 ):
         (1005 -1009 ):(1005 1008 ):1003 :(1030 -1001 1015 -1005 1016 1017 ):
         (-1030 1013 1034 -1033 1016 1017 ):(1015 -1035 -1031 1013 1016 1017
          ):(1032 -1029 1013 -1031 1016 1017 ):(1009 -1038 -1010 1005 -1036
          -1019 1020 -1018 ):(1009 1038 -1010 -1014 -1019 1020 ):
         (1037 -1014 -1018 -1039 -1019 1020 ))(1021 :(-1021 -1005 1015 1013
          -1001 1016 1017 ):(-1021 1005 -1018 -1010 -1014 -1019 1020 ))-1023
          -1028 -1040.1 -1040.2 )(((1 :-12 :(8 7 )):(1 :-12 :(-5 10 12 )):
         (1 :-12 :(4 -7 5 13 )))(71 :72 :-73 :-1 :76 )(-341 :278 :283 :-346
          :345 )(-278 :(279 280 ))297 298 299 300 309 310 311 312 321 322 323
          324 333 334 335 336 )
```

```
 135   103      -1 ((-1005 1001 ):(-1005 -1002 ):-1004 :(-1005 -1006 ):
          (1005 1011 ):(-1005 -1007 ):(1005 -1012 ):(1005 1010 ):
          (1005 -1009 ):(1005 1008 ):1003 :(-1005 1015 -1001 1013 1016 1017 ):
          (1005 -1010 -1018 -1014 1009 -1019 1020 ))((-1004 :-1002 :
          (-1010 1008 1005 ):-1006 :-1007 :1011 :-1012 )-1021 )1022 -1028
           :-1041
 136    0         1028 :(-1028 1040 1021 ):(-1028 1041 -1022 )

c   SURFACE CARDS
c ===================================================================
c     1.0  Head and Neck Region
c ===================================================================
c
c     1.1  The skin of head
c
c  Skin in the Face *
c ===================================================================
c
   1        sq 0.017313 0.011317 0 0 0 0 -1 0 0 0
   2        sq 0.018114 0.011738 0 0 0 0 -1 0 0 0
   3        py 4.53
   4        py 4.7
   5        pz 67.3
   6        pz 67.47
   7        pz 80.22
c ===================================================================
c Skin in the TOP OF the Head *
c ===================================================================
   8        sq 0.017313 0.011317 0.030036 0 0 0 -1 0 0 80.22
   9        sq 0.018114 0.011738 0.031888 0 0 0 -1 0 0 80.22
c ===================================================================
c Skin in the Neck*
c ===================================================================
  10        sq 1 1 0 0 0 0 -25 0 1.78 0
  11        sq 1 1 0 0 0 0 -23.3289 0 1.78 0
  12        pz 63.1
c ===================================================================
c Skin in the BACK of the head*
c ===================================================================
  13       k/z 0 1.78 42.64351145 0.04112231498 0
  14       k/z 0 1.78 43.96522901 0.04222622069 0
c ===================================================================
c     1.2  The Cranium
c ===================================================================
c
c Cranium_Inner Surface
  15        sq 0.020525 0.012972 0.037704 0 0 0 -1 0 0 80.22
  16        sq 0.020525 0.012972 0.026612 0 0 0 -1 0 0 80.22
  17         p 0 0.698178 1 74.09
  18        py 0
c ===================================================================
c Cranium_Outer Surface*
```

```
c ===================================================================
  19        sq 0.018114 0.011738 0.031888 0 0 0 -1 0 0 80.22
  20        sq 0.018114 0.011738 0.023097 0 0 0 -1 0 0 80.22
  21         p 0 0.7128927413 1 73.64
c ===================================================================
c     1.3  Teeth *
c ===================================================================
  22        sq 0.051187 0.037998 0 0 0 0 -1 0 -3.81 0
  23        sq 0.094095 0.046448 0 0 0 0 -1 0 -3.81 0
  24        pz 69.97
  25        pz 72.22
  26        py -3.81
c ===================================================================
c     1.4  Mandible *
c ===================================================================
  27        sq 0.02652548037 0.03799839648 0 0 0 0 -1 0 -3.81 0
  28        sq 0.09409462158 0.07547397656 0 0 0 0 -1 0 -3.81 0
  29        pz 68
  30        sq 0.06157294238 0.01851080569 0 0 0 0 -1 0 -3.81 0
c ===================================================================
c     1.5  Upper Face Regions *
c ===================================================================
  31        sq 0.022613 0.012237 0 0 0 0 -1 0 0 0
c ===================================================================
c     1.6  Eyes *
c ===================================================================
  32        sq 1 1 1 0 0 0 -1.2996 3.25 -7.06 76.72
  33        sq 1 1 1 0 0 0 -1.2996 -3.25 -7.06 76.72
c ===================================================================
c     1.7  Brain *
c ===================================================================
  34        sq 0.021004 0.013212 0.038903 0 0 0 -1 0 0 80.22
  35        sq 0.021004 0.013212 0.027321 0 0 0 -1 0 0 80.22
  36         p 0 0.695402 1 74.17
  37        py 4.12
c ===================================================================
c     1.8 Spine in Head and Neck
c ===================================================================
  38        sq 0.212364 0.358564 0 0 0 0 -1 0 3.62 0
c ===================================================================
c
c
c     1.9 Sphenoid Sinus * *
c ===================================================================
  39        sq 2.137409801 1.085069445 3.293796794 0 0 0 -1 1.2 -4.8 76.12
  40        sq 2.137409801 1.085069445 3.293796794 0 0 0 -1 -1.2 -4.8 76.12
c ===================================================================
c    1.10 Ethmoid Sinus  * *
c ===================================================================
  41        sq 8.070764463 1.108033241 1.462140076 0 0 0 -1 1.166 -6.7 76.52
  42        sq 8.070764463 1.108033241 1.462140076 0 0 0 -1 -1.166 -6.7 76.52
c ===================================================================
```

```
c    1.11 Frontal Sinus  * *
c =====================================================================
c
   43        sq 1.108033241 3.293796794 0.5266251124 0 0 0 -1 1.5 -8.1 77.9
   44        sq 1.108033241 3.293796794 0.5266251124 0 0 0 -1 -1.5 -8.1 77.9
c
c =====================================================================
c    1.12 Maxillary Sinus*
c =====================================================================
   45         s 2.9 -6.2 74.02 1.374
   46         s -2.9 -6.2 74.02 1.374
c =====================================================================
c    1.13 Pharynx *
c =====================================================================
   47       c/z 0 1.96 1.08
   48       c/z 0 1.96 0.84
   49        pz 73.55
c
   50       c/z 0 1.96 0.933
c =====================================================================
c    1.14 Larynx*
c =====================================================================
   51       c/z 0 -0.13 0.59
   52       c/z 0 -0.13 0.83
   53        pz 63.67
c
   54       c/z 0 -0.13 0.683
c =====================================================================
c    1.15 Trachea *
c =====================================================================
   55       c/z 0 -0.13 1
   56       c/z 0 -0.13 0.74
   57        pz 56.23
c
   58       c/z 0 -0.13 0.793
c =====================================================================
c    1.16 Thyroid **
c =====================================================================
   59       c/z 0 -0.13 1.647
   60       c/z 0 -0.13 0.83
   61         p 0.5868986284 -0.7168986284 67.3 0 -0.96 64.15 0 -1.98 65.65
   62         p -0.5868986284 -0.7168986284 67.3 0 -0.96 64.15 0 -1.98 65.65
   63         p 0.5868986284 -0.7168986284 63.1 0 -0.96 64.15 0 -1.98 63.625
   64         p -0.5868986284 -0.7168986284 63.1 0 -0.96 64.15 0 -1.98 63.625
   65        py -0.13
   66        pz 64.15
   67        pz 63.1
c
c =====================================================================
c   1.17 Nose*
c =====================================================================
   68         p 0 -9.4 77.02 -1.416 -9.235405171 71.97 0 -10.654 74.495
```

```
  69        p 0 -9.4 77.02 1.416 -9.235405171 71.97 0 -10.654 74.495
  70        p 0 -11.528 71.97 -1.416 -9.235405171 71.97 1.416 -9.235405171
             71.97
c
  71        p 0 -9.78 77.02 -1.796 -9.133757296 71.97 0 -11.034 74.495
  72        p 0 -9.78 77.02 1.796 -9.133757296 71.97 0 -11.034 74.495
  73        p 0 -11.528 71.59 -1.416 -9.235405171 71.59 1.416 -9.235405171
             71.59
c
  74       px -0.19
  75       px 0.19
c
  76       py -8.4
c ==================================================================
c    1.19 Salivery Glands
c
c ==================================================================
c    1.19.1 Parotids Glands
c ==================================================================
c Left
c
  77       sq 1.200449511 0.2770083103 0 0 0 0 -1 1.875 -1.905 71.735
c
c Right
c
  78       sq 1.200449511 0.2770083103 0 0 0 0 -1 -1.875 -1.905 71.735
c ==================================================================
c    1.19.2 Submandibular Glands
c ==================================================================
c Left
c
  79      c/z 1.75 -2.305 1.495
  80       pz 69.369
c
c Right
c
  81      c/z -1.75 -2.305 1.495
c ==================================================================
c    1.19.3 Sublingual Glands
c ==================================================================
c Left
c
  82      c/y 0.7 69.369 0.601
  83       py -7.2
c
c Right
c
  84      c/y -0.7 69.369 0.601
c
c ==================================================================
c
c ==============  2.0  Skeleton* ==================================
```

```
c
c ==================================================================
c     2.1  Spine (1983 /C&E)*
c
   85        sq 0.1665972511 0.3341240937 0 0 0 0 -1 0 4.775 0
   86        pz 19.83
   87        pz 31.64
   88        pz 63.1
   89        pz 72.91
c
c ==================================================================
c     2.2  Ribs (outer surface / inner surface)*
c ==================================================================
   90        sq 92.26 214.92 0 0 0 0 -19806.62 0 0 0
   91        sq 83.36 201.36 0 0 0 0 -16784.42 0 0 0
c
   92        pz 60.65
   93        pz 59.39
   94        pz 58.13
   95        pz 56.87
   96        pz 55.61
   97        pz 54.35
   98        pz 53.09
   99        pz 51.83
  100        pz 50.57
  101        pz 49.31
  102        pz 48.05
  103        pz 46.79
  104        pz 45.53
  105        pz 44.27
  106        pz 43.01
  107        pz 41.75
  108        pz 40.49
  109        pz 39.23
  110        pz 37.97
  111        pz 36.71
  112        pz 35.45
  113        pz 34.19
  114        pz 32.93
  115        pz 31.67
c ==================================================================
c     2.3  Clavicles*
c ==================================================================
  116        tz 0 7.22 61.52 15.93 0.7274 0.7274
  117         p 6.4852 1 0 7.22
  118         p 6.4852 -1 0 -7.22
  119         p 0.73137 1 0 7.22
  120         p 0.73137 -1 0 -7.22
c
c ==================================================================
c     2.4  Scapulae  (inner surface / outer surface)*
c ==================================================================
```

```
 121        sq 92.16 267.65 0 0 0 0 -24666.59 0 0 0
 122         p 0.28 1 0 0
 123         p 0.28 -1 0 0
 124         p 0.91 1 0 0
 125         p 0.91 -1 0 0
 126        pz 45.88
 127        pz 60.67
c ==================================================================
c     2.5  Pelvis*
c ==================================================================
 128        sq 122.54 95.06 0 0 0 0 -11649.4246 0 -3.72 0
 129        sq 138.3 107.12 0 0 0 0 -14814.78 0 -2.94 0
 130        py -2.94
 131        py 4.9
 132        pz 19.83
 133        pz 12.62
c
c ==================================================================
c     3.0  Upper Chest Organs
c
c ==================================================================
c     3.1 Main Bronchi*
c ==================================================================
 144     7  cz 0.741
 145     7  cz 0.504
 146     7  pz 4.92
 147     7  pz -4.92
c
 148     8  cz 0.741
 149     8  cz 0.504
 150     8  pz 4.92
 151     8  pz -4.92
c
 152     7  cz 0.558
 153     8  cz 0.558
c ==================================================================
c     3.2  Lungs*
c       (left / right)
c ==================================================================
 154        sq 0.0597796522 0.02052528303 0.002367970827 0 0 0 -1 7.33 0 39.21
 155        sq 0.0597796522 0.02052528303 0.002367970827 0 0 0 -1 -7.33 0
             39.21
 156        pz 39.21
 157        px -5
 158        py 1.2
 159        pz 41.6
 160        pz 48.5
 161        px 7
 162        py 0.7
 163        pz 49
c ==================================================================
c     3.3  Thymus*
```

```
c ====================================================================
  164        sq 0.2921840759 0.9425959091 0.05948839975 0 0 0 -1 0 -7.15 52
c
c ====================================================================
c     3.4  Heart Model *
c ====================================================================
c    basic planes
  165     4  px 0
  166     4  pz 0
c
c    right ventricle
  167     4  sq 0.01618657291 0.04788148373 0.0244140625 0 0 0 -1 0 0 0
  168     4  sq 0.01871394057 0.06187965644 0.02922054203 0 0 0 -1 0 0 0
c
c    left ventricle
  169     4  sq 0.01618657291 0.04788148373 0.1248610921 0 0 0 -1 0 0 0
  170     4  sq 0.02247751687 0.08753194918 0.3718024986 0 0 0 -1 0 0 0
c
c    left atrium, part 1
  171     4  sq 0.04097756069 0.04788148373 0.1248610921 0 0 0 -1 0 0 0
  172     4  sq 0.04585283989 0.05408328825 0.1525878906 0 0 0 -1 0 0 0
c
c    left atrium, part 2
  173     4  sq 0.04097756069 0.04788148373 0.2741152929 0 0 0 -1 0 0 0
  174     4  sq 0.04585283989 0.05408328825 0.3718024986 0 0 0 -1 0 0 0
c
c    right atrium
  175     4  sq 0.04097756069 0.04788148373 0.0244140625 0 0 0 -1 0 0 0
  176     4  sq 0.04585283989 0.05408328825 0.02661209412 0 0 0 -1 0 0 0
c
c ====================================================================
c
c ============== 4.0  Middle Chest Organs  ======================
c
c ====================================================================
c
c     4.1  Adrenals (left / right)*
c ====================================================================
  177     1  sq 0.5917159763 5.408328825 0.05408328825 0 0 0 -1 0 0 0
  178     2  sq 0.5917159763 5.408328825 0.05408328825 0 0 0 -1 0 0 0
  179        pz 34.26
c
c ====================================================================
c     4.2  Kidneys (left / right)*
c ====================================================================
c
  180        sq 0.06096631609 0.4271861249 0.04064776274 0 0 0 -1 5.18 5.88
              29.3
  181        sq 0.06096631609 0.4271861249 0.04064776274 0 0 0 -1 -5.18 5.88
              29.3
  182        px 2.48
  183        px -2.48
```

```
c
 202        px 2.48
 203        px -2.48
c
c ===================================================================
c    4.3  Liver *
c ===================================================================
 204        sq 61.47 201.36 0 0 0 0 -12376.4735 0 0 0
 205         p 0.03173595684 0.02234636872 -0.0257997936 -1
 206        pz 38.76
 207        pz 24.34
c
c ===================================================================
c    4.4  Gall bladder*
c ===================================================================
 208     3  so 1.916
 209     3  so 2.015
 210     3  gq 1 1 -0.05175625 0 0 0 0 0 0.87178 -3.671056
 211     3  gq 1 1 -0.05175625 0 0 0 0 0 0.916825 -4.060225
 212     3  pz 0
 213     3  pz 7.66
c
c ===================================================================
c    4.5  Pancreas *
c ===================================================================
c
 214        sq 0.004271861249 0.7694675285 0.05948839975 0 0 0 -1 -1.22 0
             31.85
 215        px -1.22
 216        pz 31.85
 217        px 2.11
c
c ===================================================================
c    4.6  Spleen *
c ===================================================================
 218        sq 95.2 226.53 29.72 0 0 0 -800.6568 9.49 2.94 33.35
c
c ===================================================================
c
c ===============  5.0 Gastrointestinal tract and contents ==========
c
c ===================================================================
c    5.1  Male Esophagus*
c ===================================================================
 219     6  cx 0.07
 220        sq 1.41723356 27.70083102 0 0 0 0 -1 0 2.29 0
 221        sq 0.16 1.1025 0 0 0 0 -0.1764 0 2.29 0
 222        sq 0.0144 0.5929 0 0 0 0 -0.00854 0 2.29 0
c
c 409 0.64 cm -> 0.5504 cm
 223     6  cx 0.5504
 224     6  px 0
```

```
 225     6  px 7.07
c
c ==================================================================
c    5.2  Stomach *
c ==================================================================
c
 226       sq 0.105209014 0.151049895 0.02154384531 0 0 0 -1 6.9 -3.92 31.55
 227       sq 437.11 603.135 100.312 0 0 0 -5142.57 6.9 -3.92 31.55
 228       sq 242.612 358.799 45.876 0 0 0 -1998.369 6.9 -3.92 31.55
c
c ==================================================================
c    5.3  S. intestine *
c ==================================================================
c
 229       sq 122.54 95.06 0 0 0 0 -11649.4246 0 -3.72 0
 230       py -4.76
 231       py 2.16
 232       pz 15.32
 233       pz 24.34
c
c ==================================================================
c    5.4  A. colon*
c ==================================================================
 234       sq 0.3505425171 0.2553338605 0 0 0 0 -1 -7.33 -2.31 0
 235       sq 0.2143545522 0.1666108517 0 0 0 0 -1 -7.33 -2.31 0
 236       sq 3.24 2.2801 0 0 0 0 -7.3875 -7.33 -2.31 0
 237       pz 13.03
 238       pz 21.63
c
c ==================================================================
c    5.5  T. colon*
c ==================================================================
 239       sq 0 0.2278410353 1.010075503 0 0 0 -1 0 -2.31 22.99
 240       sq 0 0.1666108517 0.5487781425 0 0 0 -1 0 -2.31 22.99
 241       sq 0 0.7396 3.8416 0 0 0 -2.8412 0 -2.31 22.99
 242       px 9.06
 243       px -9.06
c
c ==================================================================
c    5.6  D. colon*
c ==================================================================
 244       gq 0.7790048836 0.4200182372 0.01515605581 0 0 0.1494618274
            -0.0761241083 -10.78635348 -1.174769963 0.3180008868
            37.15927759
 245       gq 0.4385772553 0.2712673611 0.009634411191 0 0.09652941682
            -0.04285762924 -6.072682475 -0.7587212163 0.1617163245
            20.55160754
 246       gq 1.02030405 0.5102040817 0.01858708278 0 0.1815541031
            -0.09970378577 -14.12745976 -1.427015251 0.436366562
            48.90116638
 247       pz 7.86
c
```

```
c ===================================================================
c     5.7  S. colon
c ===================================================================
  248        ty 1.18 0 7.86 1.18 1.463 0.883
  249        ty 4.8336 0 7.86 2.4736 1.463 0.883
c
  250        ty 1.18 0 7.86 1.18 1.76 1.18
  251        ty 1.18 0 7.86 1.18 1.35 0.77
  252        ty 4.8336 0 7.86 2.4736 1.76 1.18
  253        ty 4.8336 0 7.86 2.4736 1.35 0.77
  254        px 3
c
c ===================================================================
c     5.8 Rectum
c ===================================================================
  255        sq 0.9592869045 0.3901371761 0 0 0 0 -1 0 0 0
  256        sq 3.0976 1.3924 0 0 0 0 -4.3131 0 0 0
  257        sq 2.3716 0.9216 0 0 0 0 -2.1857 0 0 0
c
c ===================================================================
c
c ==============  6.0 Lower Chest Organs  ========================
c
c ===================================================================
c     6.1  U. bladder
c ===================================================================
  258        sq 110.4979 176.3504 208.2999 0 0 0 -2014.6979 0 -5.15 7.21
  259        sq 82.3012 135.3779 161.9511 0 0 0 -1343.297 0 -5.15 7.21
  260        sq 0.06004361208 0.09820789256 0.1172025028 0 0 0 -1 0 -5.15 7.21
c ===================================================================
c
c ===================================================================
c     8.2  Female
c ===================================================================
c     8.2.1  Ovaries (left / right)*
c ===================================================================
c     Ovaries (left / right)(Shifted -0.1cm x-direction w/ lower abs)
c ===================================================================
  272        sq 0.730513551 2.972651605 0.3086419754 0 0 0 -1 5.08 0 13.52
  273        sq 0.730513551 2.972651605 0.3086419754 0 0 0 -1 -5.08 0 13.52
c ===================================================================
c     8.2.2  Uterus *
c ===================================================================
  274        sq 75.6117 14.6574 192.0071 0 0 0 -461.2995 0 -1.96 12.62
  275        py -4.77
c
c ===================================================================
c     8.2.3  Breasts *
c ===================================================================
c      left
  276        sq 0.03648939207 0.04654794612 0.05084084402 0 0 0 -1 8.63
              -8.485408314 46.87
```

```
c
c     right
 277       sq 0.03648939207 0.04654794612 0.05084084402 0 0 0 -1 -8.63
            -8.485408314 46.87
c
c ===================================================================
c
c ===============  10.0  Skin surface descriptions  =================
c
c ===================================================================
c
c    10.2   Trunk*
c ===================================================================
 278       sq 99.4 303.4564 0 0 0 0 -30163.8393 0 0 0
c
c    10.2.2 Female Trunk
c
 279       sq 0.03423013431 0.04331249643 0.04715640955 0 0 0 -1 8.63
            -8.485408314 46.87
c
 280       sq 0.03423013431 0.04331249643 0.04715640955 0 0 0 -1 -8.63
            -8.485408314 46.87
c     plane above torso
 283       pz 63.27
c
c ===================================================================
c ===== START CHANGES FOR ARMS AND LEGS HERE ========================
c ===================================================================
c
c ====== RIGHT ARM --- BONE
 289      sph -20.25 0 58.6 2.75
 290      trc -20.25 0 58.6 0 0 -31 2.8 2.05
 291      sph -20.25 0 27.6 1.95
 292      trc -20.25 0 27.6 0 0 -27.3 2.05 1.5
c ======= RIGHT ARM --- SOFT TISSUE
 293      sph -20.25 0 58.6 4.5
 294      trc -20.25 0 58.6 0 0 -31 4.55 4
 295      sph -20.25 0 27.6 4
 296      trc -20.25 0 27.6 0 0 -27.3 4 3
c ======= RIGHT ARM --- SKIN
 297      sph -20.25 0 58.6 4.7
 298      trc -20.25 0 58.6 0 0 -31 4.75 4.2
 299      sph -20.25 0 27.6 4.2
 300      trc -20.25 0 27.6 0 0 -27.3 4.2 3.2
c ====== LEFT ARM --- BONE
 301      sph 20.25 0 58.6 2.75
 302      trc 20.25 0 58.6 0 0 -31 2.8 2.05
 303      sph 20.25 0 27.6 1.95
 304      trc 20.25 0 27.6 0 0 -27.3 2.05 1.5
c ======= LEFT ARM --- SOFT TISSUE
 305      sph 20.25 0 58.6 4.5
 306      trc 20.25 0 58.6 0 0 -31 4.55 4
```

```
 307       sph 20.25 0 27.6 4
 308       trc 20.25 0 27.6 0 0 -27.3 4 3
c ======= LEFT ARM --- SKIN
 309       sph 20.25 0 58.6 4.7
 310       trc 20.25 0 58.6 0 0 -31 4.75 4.2
 311       sph 20.25 0 27.6 4.2
 312       trc 20.25 0 27.6 0 0 -27.3 4.2 3.2
c
c
c ====== RIGHT LEG  --- BONE
 313       sph -7.7 0 -3.01 4.75
 314       trc -7.7 -0.09 -3.03 0 -35.95 -6.34 4.5 2.75
 315       sph -7.7 -35.95 -9.35 2.75
 316       trc -7.7 -35.95 -9.35 0 0 -38.7 2.85 1.85
c =======RIGHT LEG -- SOFT TISSUE
 317       sph -7.7 0 -3.01 7.45
 318       trc -7.7 -0.09 -3.03 0 -35.95 -6.34 7.05 6.05
 319       sph -7.7 -35.95 -9.35 6.05
 320       trc -7.7 -35.95 -9.35 0 0 -38.7 6.05 5.05
c =======RIGHT LEG -- SKIN
 321       sph -7.7 0 -3.01 7.65
 322       trc -7.7 -0.09 -3.03 0 -35.95 -6.34 7.25 6.25
 323       sph -7.7 -35.95 -9.35 6.25
 324       trc -7.7 -35.95 -9.35 0 0 -38.7 6.25 5.25
c ====== LEFT LEG  -- BONE
 325       sph 7.7 0 -3.01 4.75
 326       trc 7.7 -0.09 -3.03 0 -35.83 -6.96 4.5 2.75
 327       sph 7.7 -35.83 -9.97 2.75
 328       trc 7.7 -35.83 -9.97 0 0.68 -38.69 2.85 1.85
c =======  LEFT LEG -- SOFT TISSUE
 329       sph 7.7 0 -3.01 7.45
 330       trc 7.7 -0.09 -3.03 0 -35.83 -6.96 7.05 6.05
 331       sph 7.7 -35.83 -9.97 6.05
 332       trc 7.7 -35.83 -9.97 0 0.68 -38.69 6.05 5.05
c =======  LEFT LEG -- SKIN
 333       sph 7.7 0 -3.01 7.65
 334       trc 7.7 -0.09 -3.03 0 -35.83 -6.96 7.25 6.25
 335       sph 7.7 -35.83 -9.97 6.25
 336       trc 7.7 -35.83 -9.97 0 0.68 -38.69 6.25 5.25
c ===== STOP CHANGES FOR ARMS AND LEGS HERE ========================
c
c ===============================================================
 339        px 0
 340        py 0
 341        pz 0
c      outer ellipsoid
 342        sq 0.003360638521 0.01041232819 0 0 0 0 -1 0 0 0
 343        px 15.2
 344        px -15.2
 345        px 15.5
 346        px -15.5
c ===============================================================
```

```
c     Boat Surfaces
c ==============================================================
 1001     9  pz 0
 1002     9  pz -40.65
 1003     9  py 182.5
 1004     9   p 0 3.732 1 -681.1
 1005     9  py 0
 1006     9   p 2.667 0 1 -162.6
 1007     9   p -2.667 0 1 -162.6
 1008     9 c/x 0 1000 1040.65
 1009     9 c/x 0 1000 1000
 1010     9  pz 150
 1011     9   p -0.7418625 0.082621125 -0.27822125 45.2350659
 1012     9   p -0.7418625 -0.082621125 0.27822125 -45.2350659
 1013     9  pz -40.52
 1014     9  py 182.37
 1015     9   p 0 3.732 1 -680.605
 1016     9   p 2.667 0 1 -162.274
 1017     9   p -2.667 0 1 -162.274
 1018     9 c/x 0 1000 1040.52
 1019     9   p -0.73896324 0.0823569 -0.277111215 44.96223633
 1020     9   p -0.73896324 -0.0823569 0.277111215 -44.96223633
 1021     9  pz -33
 1022     9  pz -45.9
 1023     9  pz 31600
 1024     9  py -290  $unused rectangular boundings
 1025     9  py 290  $unused rectangular boundings
 1026     9  px -170  $unused rectangular boundings
 1027     9  px 170  $unused rectangular boundings
 1028     9  cz 35250  $USED cylindrical bounding
 1029     9  py -0.3175
 1030     9  pz -5.715
 1031     9  pz -6.0325
 1032     9  py -40.3225
 1033     9  py -40.64
 1034     9  py -140
 1035     9  py -140.3175
 1036     9  py 146.87
 1037     9  py 147.19
 1038     9  pz 7.24
 1039     9  pz 6.923
 1040     9 trc 0 0 -33 0 0 23500 35250 0.1
 1041     9 trc 0 0 -45.9 0 0 -70.3 35250 0.1

mode  p
c   MISC. CARDS
c ==============================================================
c
c ============ MATERIAL CARDS ======================================
c
c ==============================================================
c ============== SKELETON -- Density = 1.4 g/cc ===================
```

```
c =================================================================
m2    1001.         -0.07337
      6000.         -0.25475 7014.         -0.03057 8016.         -0.47893
      9019.         -0.00025 11023.        -0.00326 12000.        -0.00112
      14000.        -2e-005 15031.         -0.05095 16000.        -0.00173
      17000.        -0.00143 19000.        -0.00153 20000.        -0.1019
      26000.        -8e-005 30000.         -5e-005
c
c =================================================================
c =============== AIR -- Density = 0.001205 g/cc ===================
c =================================================================
m4    6000.         -0.000124
      7014.        -0.755267 8016.         -0.231781 18000.       -0.012827
c
c =================================================================
c =============== UPPER FACE REGION -- Density = 1.22 g/cc ==========
c =================================================================
m5    1001.         -0.088955
      6000.         -0.24069 7014.         -0.027735 8016.        -0.55709
      9019.        -0.000125 11023.        -0.00219 12000.        -0.000625
      14000.        -0.00016 15031.        -0.026145 16000.       -0.001885
      17000.        -0.00138 19000.        -0.001805 20000.       -0.05107
      26000.       -6.5e-005 30000.        -4e-005 40000.         -1e-005
      82000.        -5e-006
c
c =================================================================
c =============== BRAIN -- Density = 1.04 g/cc =====================
c =================================================================
m6    1001.          -0.107
      6000.          -0.145 7014.          -0.022 8016.          -0.712
      11023.         -0.002 15031.         -0.004 16000.         -0.002
      17000.         -0.003 19000.         -0.003
c
c =================================================================
c =============== EYES -- Density = 1.07 g/cc ======================
c =================================================================
m7    1001.          -0.096
      6000.          -0.195 7014.          -0.057 8016.          -0.646
      11023.         -0.001 15031.         -0.001 16000.         -0.003
      17000.         -0.001
c
c =================================================================
c =============== LARYNX -- Density = 1.10 g/cc ====================
c =================================================================
c
m8    1001.          -0.096
      6000.          -0.099 7014.          -0.022 8016.          -0.744
      11023.         -0.005 15031.         -0.022 16000.         -0.009
      17000.         -0.003
c
c =================================================================
c =============== TRACHEA -- Density = 1.03 g/cc ===================
```

```
c ====================================================================
c
m9   1001.         -0.105
     6000.         -0.256 7014.         -0.027 8016.         -0.602
     11023.        -0.001 15031.        -0.002 16000.        -0.003
     17000.        -0.002 19000.        -0.002
c
c ====================================================================
c =============== THYROID -- Density = 1.05 =========================
c ====================================================================
m10  1001.         -0.104
     6000.         -0.119 7014.         -0.024 8016.         -0.745
     11023.        -0.002 15031.        -0.001 16000.        -0.001
     17000.        -0.002 19000.        -0.001
c
c ====================================================================
c =============== SKIN -- Density = 1.09 g/cc =======================
c ====================================================================
c
m11  1001.         -0.1
     6000.         -0.204 7014.         -0.042 8016.         -0.645
     11023.        -0.002 15031.        -0.001 16000.        -0.002
     17000.        -0.003 19000.        -0.001
c
c ====================================================================
c =============== SOFT TISSUE -- Density = 1.03 g/cc ================
c ====================================================================
c
m12  1001.         -0.105
     6000.         -0.256 7014.         -0.027 8016.         -0.602
     11023.        -0.001 15031.        -0.002 16000.        -0.003
     17000.        -0.002 19000.        -0.002
c
c ====================================================================
c =============== MUSCLE -- Density = 1.05 g/cc =====================
c ====================================================================
c
m13  1001.         -0.102
     6000.         -0.143 7014.         -0.034 8016.         -0.71
     11023.        -0.001 15031.        -0.002 16000.        -0.003
     17000.        -0.001 19000.        -0.004
c
c ====================================================================
c =============== LUNGS -- Density = 0.26 g/cc ======================
c ====================================================================
c
m14  1001.         -0.103
     6000.         -0.105 7014.         -0.031 8016.         -0.749
     11023.        -0.002 15031.        -0.002 16000.        -0.003
     17000.        -0.003 19000.        -0.002
c
c ====================================================================
```

```
c ============== HEART -- Density = 1.05 g/cc =====================
c ==================================================================
c
m15   1001.          -0.104
      6000.          -0.139 7014.          -0.029 8016.          -0.718
      11023.         -0.001 15031.         -0.002 16000.         -0.002
      17000.         -0.002 19000.         -0.003
c
c ==================================================================
c ============== KIDNEY -- Density = 1.05 g/cc ====================
c ==================================================================
m16   1001.          -0.103
      6000.          -0.132 7014.          -0.03 8016.           -0.724
      11023.         -0.002 15031.         -0.002 16000.         -0.002
      17000.         -0.002 19000.         -0.002 20000.         -0.001
c
c ==================================================================
c ============== LIVER -- Density = 1.05 g/cc =====================
c ==================================================================
c
m17   1001.          -0.103
      6000.          -0.186 7014.          -0.028 8016.          -0.671
      11023.         -0.002 15031.         -0.002 16000.         -0.003
      17000.         -0.002 19000.         -0.003
c
c ==================================================================
c ============== PANCREAS -- Density = 1.04 g/cc ==================
c ==================================================================
c
m18   1001.          -0.106
      6000.          -0.169 7014.          -0.022 8016.          -0.694
      11023.         -0.002 15031.         -0.002 16000.         -0.001
      17000.         -0.002 19000.         -0.002
c
c ==================================================================
c ============== SPLEEN -- Density = 1.06 g/cc ====================
c ==================================================================
m19   1001.          -0.103
      6000.          -0.113 7014.          -0.032 8016.          -0.741
      11023.         -0.001 15031.         -0.003 16000.         -0.002
      17000.         -0.002 19000.         -0.003
c
c ==================================================================
c ============== GI TRACT -- Density 1.03 g/c =====================
c ==================================================================
m20   1001.          -0.106
      6000.          -0.115 7014.          -0.022 8016.          -0.751
      11023.         -0.001 15031.         -0.001 16000.         -0.001
      17000.         -0.002 19000.         -0.001
c
c ==================================================================
c ============== URINARY BLADDER -- Density = 1.04 g/cc ===========
```

```
c ======================================================================
c
m21   1001.           -0.105
      6000.           -0.096 7014.           -0.026 8016.           -0.761
      11023.          -0.002 15031.          -0.002 16000.          -0.002
      17000.          -0.003 19000.          -0.003
c
c ======================================================================
c =============== TESTES -- Density = 1.04 g/cc =====================
c ======================================================================
c
m22   1001.           -0.106
      6000.           -0.099 7014.           -0.02 8016.           -0.766
      11023.          -0.002 15031.          -0.001 16000.          -0.002
      17000.          -0.002 19000.          -0.002
c
c ======================================================================
c =============== OVARY -- Density = 1.05 g/cc ======================
c ======================================================================
c
m23   1001.           -0.105
      6000.           -0.093 7014.           -0.024 8016.           -0.768
      11023.          -0.002 15031.          -0.002 16000.          -0.002
      17000.          -0.002 19000.          -0.002
c
c ======================================================================
c =============== UTERUS -- Density = 1.02 g/cc =====================
c ======================================================================
c
m24   1001.           -0.106
      6000.           -0.315 7014.           -0.024 8016.           -0.547
      11023.          -0.001 15031.          -0.002 16000.          -0.002
      17000.          -0.001 19000.          -0.002
c
c ======================================================================
c =============== BREAST -- Density = 0.94 g/cc =====================
c   Composition information from ICRP-89, Table 13.3 on page 244
c   Note: Female Breast Values are taken from this Table
c ======================================================================
c
m25   1001.           -0.116
      6000.           -0.519 8016.           -0.365
c ===========================================================================
c ========================== BOAT MATERIALS =============================
c ---------------------------------------------------------------------
c 5052 Aluminum Alloy [p=2.68 g/cm^3]
c ---------------------------------------------------------------------
m101  13000.          -0.963  $ Aluminum at 96.3 wt. %
      12000.          -0.025 26000.          -0.004 24000.          -0.0025
      14000.          -0.0025 29000.          -0.001 30000.          -0.001
      25000.          -0.001
c
```

```
c -----------------------------------------------------------------------
c Air (23.2% Oxygen, 75.5% Nitrogen, 1.3% Argon by weight) [p=0.001205 g/cm^3]
c -----------------------------------------------------------------------
m102  8000.          -0.232  $ Oxygen
     7000.         -0.755 18000.         -0.013
c
c -----------------------------------------------------------------------
c Water H_2 O [p=1.0 g/cm^3]
c -----------------------------------------------------------------------
m103  8000.               1  $ Oxygen
     1000.                2
c ======================================================================
c ===============  Axis Transformation Section * ====================
c ======================================================================
c     Adrenals (left / right)
c ======================================================================
tr1  3.22 4.9 34.26 0.565 0.8251 0 -0.8251 0.565 0 0 0 1
tr2  -3.22 4.9 34.26 0.565 -0.8251 0 0.8251 0.565 0 0 0 1
c ======================================================================
c     Gall Bladder
c ======================================================================
tr3  -3.98 -3.14 27.04 0.955 0 -0.2964 -0.0606 0.9789 -0.1952 0.2903 0.2044
      0.9349
c ======================================================================
c     Heart
c ======================================================================
tr4  0.86 -2.1 45.1 0.6453 -0.5134 -0.5658 -0.4428 0.3523 -0.8245 0.6226 0.7825
      0
c ======================================================================
c     Esophagus
c ======================================================================
tr6  0 2.29 38.08 0.708385 -0.637547 -0.30286 0.668965 0.743294 0 0.225114
      -0.202603 0.953035
c ======================================================================
c Main Bronchi
c
c ======================================================================
*tr7 1.6 -0.13 54 33 90 57 90 0 90 123 90 33
*tr8 -1.6 -0.13 54 33 90 123 90 0 90 57 90 33
c ======================================================================
c Boat Transformation
c ======================================================================
tr9  0 15 -10
imp:p   1 134r      0           $ 1, 136
vol   214.8       284.5       30.2        144.8       213.078      $ 1, 5
      1310.2      6.2 1r      33.1217     9.71475     23.165       $ 6, 11
      5.41325     2.53589     3.97        1.35011     8.67493      $ 12, 16
      12.799      1.89907     11.9        4.7773      6.865        $ 17, 21
      231.616     65.385      1119.94     130.626     418.9        $ 22, 26
      157.258     531         41.6        154         460          $ 27, 31
      9.827       10.8258     2.403       1020        1180         $ 32, 36
      32.725      231         334         5.05 1r     119.2 1r     $ 37, 43
```

```
      1350       7.61609     47.1        98.929      119          $ 44, 48
      5.13854     0.108834    26.4836     7.06549     39.3811      $ 49, 53
      73.6189     187         806         16.9075     52.5925      $ 54, 58
      73.4        11.3315     34.8185     48          11.3315      $ 59, 63
      34.8185     48          16.6975     49.7925     58.93        $ 64, 68
      9.09886     28.3061     37.484      3.85355     10.9264      $ 69, 73
      36.51       5.33584     29.1642     154         5.05 1r      $ 74, 79
      76          235.921 1r  24297.3     958         0 51r        $ 80, 136
c ======================================================================
c EXPONENTIAL TRANSFORM CARD
c ======================================================================
ext:p 0 132r 0.4V1 0.4V1 0
vect  V1 0 0 30
mt2    lwtr.01t
mt5    lwtr.01t
mt6  lwtr.01t
mt7  lwtr.01t
mt8    lwtr.01t
mt9    lwtr.01t
mt10    lwtr.01t
mt11    lwtr.01t
mt12    lwtr.01t
mt13    lwtr.01t
mt14    lwtr.01t
mt15    lwtr.01t
mt16    lwtr.01t
mt17     lwtr.01t
mt18     lwtr.01t
mt19     lwtr.01t
mt20     lwtr.01t
mt21      lwtr.01t
mt22      lwtr.01t
mt23      lwtr.01t
mt24      lwtr.01t
mt25     lwtr.01t
c ======================================================================
c      TALLY DEFINITION SECTION
c ======================================================================
c
c ENDORGAN
c ==================================================
fc216    PHOTON contribution
f216:p
c Organ: ovaries
       (78 79)
c Organ: bone marrow
       (2 3 4 5          $ Cranium and mandible
        30  29           $ Scapulae and clavicle
        28               $ ribs
        31  )            $ pelvis
c Organ: colon
      (57 58           $ right   (mucosa+wall)
```

```
      60 61         $ T colon (mucosa+wall)
      63 64         $ left    (mucosa+wall)
      66 67         $ D colon (mucosa+wall)
      69 70         $ sigmoid (mucosa+wall)
      72 73)        $ rectum  (mucosa+wall)
c Organ: lungs
     (35 36)          $ left+right
c Organ: stomach
     (53 54)        $ mucosa+wall
c Organ: urinary bladder
     (75 76)        $ mucosa+wall
c Organ: breast
     (81 82)        $ left+right
c Organ: liver
      44
c Organ: esophagus
     (49            $ thoracic  portion
      50            $ abdominal portion
      51)           $ remainder
c Organ: thyroid
     19
c Organ: skin
      (1            $ head+neck
      84)           $ trunk
c Organ: bone surface
     (25 26 27        $ C,T,L-spine
      28            $ ribs
      29            $ clavicles
      30            $ scapulae
      31   )         $ pelvis
c Organ: adrenals
     (40 41)
c Organ: brain
     6
c Organ: Extrathoracic airways
     (9             $ sinuses
      12 10           $ pharynx (mucosa+wall)
      15 13)          $ larynx  (mucosa+wall)
c Organ: small intestine
     56
c Organ: kidneys
      (42 43)
c Organ: muscle
     83
c Organ: pancreas
     47
c Organ: spleen
     48
c Organ: thymus
     37
c Organ: uterus
    80
```

```
c Organ: eyes
       (7 8)
c ENDORGAN
c ===================================================================
c ENDORGAN
c ===================================================================
c ===== SOURCE DESCRIPTION
c ===================================================================
sdef POS=0 15 -10 AXS=0 0 1 EXT=D2 RAD=D1 PAR=P ERG=0.83486 CEL=135
si1 26441 35255
sp1 -21 1
si2 -127 -30
sp2 0 1
nps 1.8e9
prdmp 1.8e9 9e7 0 1
```

APPENDIX B: SAMPLE QAD INPUTS

Sample QAD Model Input File - Male ^{60}Co Inner Source Division – Lung Dose

```
Project : QAD Male (Co-60) Lung - Inner Sources
50 50 50 18 9 1 2 0 0 12 1 3 0 0 0 0
1 6*0
0 51i4306
-167.8 51i-80.8
0 51i6.2832
0 0 MALEMODEL
rpp 1 -17.5 17.5 -20 20 0 70
rec 2 0 0 0 0 0 70 20 0 0 0 10 0
rcc 3 0 0 70 0 0 5 6
rec 4 0 -1 75 0 0 19 0 9.5 0 8 0 0
trc 5 9 0 0 0 0 -80.2 8.3 5.5
trc 6 -9 0 0 0 0 -80.2 8.3 5.5
trc 7 -22.75 0 68 0 0 -66 5.2 4
trc 8 22.75 0 68 0 0 -66 5.2 4
rcc 9 -1.25 -2 70.025 0 0 4.95 0.8
rcc 10 1.25 -2 70.025 0 0 4.95 0.8
ell 11 0 -3.853 87 0 1.853 87 17.2
ell 12 8.5 0 42.809 8.5 0 44.191 48.66
ell 13 -8.5 0 42.809 -8.5 0 44.191 48.66
rcc 14 -8.5 0 43.5 0 0 27 6.5
rcc 15 8.5 0 43.5 0 0 27 6.5
rcc 16 -10 -1 29 0 0 13.79 6.5
rec 17 0 0 -80.6 0 0 -0.2 0 160 0 67.5 0 0
rcc 18 0 0 -80.8 0 0 -87 43060
rcc 19 0 0 -80.8 0 0 43060 43060
ell 20 -1.3 -8 2.305 -1.3 -8 3.095 4.6
ell 21 1.3 -8 2.305 1.3 -8 3.095 4.6
end
TRK 0 +2 +1 -16 -12 -13 -20 -21 or +2 +1 -16 -14 -15 -20 -21
NCK 0 +3 -9 -10
HED 0 +4 -11
LEG 0 +5 or +6
ARM 0 +7 or +8
THY 0 +9 or +10
BRA 0 +11
LUN 0 +12 +15 or +13 +14
LIV 0 +16
BAL 0 +20 or +21
ALM 0 +17
H2O 0 +18
AIR 0 +19 -1 -3 -4 -5 -6 -7 -8 -17 or +19 -2 -3 -4 -5 -6 -7 -8 -17
VOD 0 -18 -19
end
21*1
1 1 1 1 1 4 5 2 3 9 6 8 7 0
```

1 1 6 7 8 11 12 13 14 15 16 17 18 19 24 25 26 29 30
.10815 .26368 .0278 .62006 .00103 0 0 0 .00206 .00309 .00206 0 .00206 0 0 0 0 0
.02678 .0273 .00806 .19474 .00052 0 0 0 .00052 .00078 .00078 0 .00052 0 0 0 0 0
.10815 .19530 .0294 .70455 .00210 0 0 0 .0021 .00315 .0021 0 .00315 0 0 0 0 0
.10920 .12495 .02520 .78225 .00210 0 0 0 .00105 .00105 .0021 0 .00105 0 0 0 0 0
.11128 .1508 .02288 .74048 .00208 0 0 0 .00416 .00208 .00312 0 .00312 0 0 0 0 0
0 0 0 0 0 .067 2.5808 .0067 0 0 0 0 0 .0067 .00268 .01072 .00268 .00268
0 0 9.101e-4 2.793e-4 0 0 0 0 0 0 0 1.5456e-5 0 0 0 0 0 0
.11167 .0 .0 .88833 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.11024 .10296 .0208 .79664 .00208 0 0 0 .00104 .00208 .00208 0 .00208 0 0 0 0 0
1.173 1.333
1.173 1.333
1.609e-006 1.609e-006
4.645e-012 5.040e-012
1.333-1.173
1.173-1.173 1.333-1.333
PHOT/CM2_S rad/hr J/kg
-8.5 44.15 4.5 1 0 0 0
-4.75 44.15 -3 1 0 0 0
-12 44.15 -3 1 0 0 0
-8.5 54 0 1 0 0 0
-8.5 65.5 0 1 0 0 0
8.5 44.15 4.5 1 0 0 0
4.75 44.15 -3 1 0 0 0
12 44.15 -3 1 0 0 0
8.5 54 0 1 0 0 0
8.5 65.5 0 1 0 0 0
3*0 -1 3*0

Sample QAD Model Input File - Female ^{54}Mn Outer Source Division – Brain Dose

```
Project : QAD Female (Mn-54) Brain - Outer Sources
49 50 50 18 9 1 1 0 0 12 1 3 0 0 0 0
1 6*0
3595.5 50i35250
-151.8 51i-80.8
0 51i6.2832
0 0 FEMALEMODEL
rpp 1 -15.5 15.5 -20 20 0 63
rec 2 0 0 0 0 0 63 19 0 0 0 10 0
rcc 3 0 2 63 0 0 4 5
rec 4 0 -0.75 67 0 0 19 0 9 0 7.5 0 0
trc 5 7.75 0 0 0 0 -78.2 7.1 5.2
trc 6 -7.75 0 0 0 0 -78.2 7.1 5.2
trc 7 -20.25 0 60.5 0 0 -58 4.7 3.1
trc 8 20.25 0 60.5 0 0 -58 4.7 3.1
rcc 9 -1 -1 63.025 0 0 3.95 0.692
rcc 10 1 -1 63.025 0 0 3.95 0.692
ell 11 0 -4.048 79 0 2.048 79 15.9
ell 12 7.5 0 38.8 7.5 0 40.1 40
ell 13 -7.5 0 38.8 -7.5 0 40.1 40
rcc 14 -7.5 0 39.5 0 0 22 6
rcc 15 7.5 0 39.5 0 0 22 6
rcc 16 -8.5 -1 25 0 0 13.79 6.5
rec 17 0 0 -80.6 0 0 -0.2 0 160 0 67.5 0 0
rcc 18 0 0 -80.8 0 0 -71 35250
rcc 19 0 0 -80.8 0 0 35300 35250
ell 20 -5.05 0 13.2 -5.05 0 13.6 1.8
ell 21 5.05 0 13.2 5.05 0 13.6 1.8
end
TRK 0 +2 +1 -16 -12 -13 -20 -21 or +2 +1 -16 -14 -15 -20 -21
NCK 0 +3 -9 -10
HED 0 +4 -11
LEG 0 +5 or +6
ARM 0 +7 or +8
THY 0 +9 or +10
BRA 0 +11
LUN 0 +12 +15 or +13 +14
LIV 0 +16
OVA 0 +20 or +21
ALM 0 +17
H2O 0 +18
AIR 0 +19 -1 -3 -4 -5 -6 -7 -8 -17 or +19 -2 -3 -4 -5 -6 -7 -8 -17
VOD 0 -18 -19
end
21*1
1 1 1 1 1 4 5 2 3 9 6 8 7 0
1 1 6 7 8 11 12 13 14 15 16 17 18 19 24 25 26 29 30
.10815 .26368 .0278 .62006 .00103 0 0 0 .00206 .00309 .00206 0 .00206 0 0 0 0 0
.02678 .0273 .00806 .19474 .00052 0 0 0 .00052 .00078 .00078 0 .00052 0 0 0 0 0
```

```
.10815 .19530 .0294 .70455 .00210 0 0 0 .0021 .00315 .0021 0 .00315 0 0 0 0 0
.10920 .12495 .02520 .78225 .00210 0 0 0 .00105 .00105 .0021 0 .00105 0 0 0 0 0
.11128 .1508 .02288 .74048 .00208 0 0 0 .00416 .00208 .00312 0 .00312 0 0 0 0 0
0 0 0 0 0 .067 2.5808 .0067 0 0 0 0 0 .0067 .00268 .01072 .00268 .00268
0 0 9.101e-4 2.793e-4 0 0 0 0 0 0 0 1.5456e-5 0 0 0 0 0 0
.11167 .0 .0 .88833 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0 .0
.11025 .09765 .0252 .8064 .0021 0 0 0 .0021 .0021 .0021 0 .0021 0 0 0 0 0
0.8348
0.8348
1.328e-6
3.478e-12
0.8348-0.8348
0.8348-0.8348
PHOT/CM2_S rad/hr J/kg
0 83 -5.5 1 0 0 0
0 83 -1 1 0 0 0
0 83 3.5 1 0 0 0
4.5 79 -1 1 0 0 0
-4.5 79 -1 1 0 0 0
0 79 -7 1 0 0 0
0 79 5 1 0 0 0
0 79 -1 1 0 0 0
0 75 -5.5 1 0 0 0
0 75 -1 1 0 0 0
0 75 3.5 1 0 0 0
3*0 -1 3*0
```

APPENDIX C: PYTHON SCRIPT

MCNP Output Parser and Dose Coefficient Calculator

```
import re #Good for splitting strings
import linecache #used for reading individual lines of a file
import os
import glob  #used for listing all of the files in a directory

pimalDatabase = {}
pimalDatabase["Female"] = []
pimalDatabase["Male"] = []

pimalFemale = open("pimalFemaleOrgans.txt","r")
for line in pimalFemale:
    [indicator,organ] = line.split()
    pimalDatabase["Female"].append(organ)
pimalFemale.close()
pimalMale = open("pimalMaleOrgans.txt","r")
for line in pimalMale:
    [indicator,organ] = line.split()
    pimalDatabase["Male"].append(organ)
pimalMale.close()

log = open("dataDump.txt","w")

for filename in glob.glob("*.o"):
    inputfile = open(filename, "r")
    pos = False
    if len(filename.split("_")) == 3:
        newfilename = filename[0:-2] + "_Inn.o"
    else:
        newfilename = filename
    for num,line in enumerate(inputfile):
        if filename.split("_")[1] == "Female":
            if "cell (" in line and pos == False:
                pos = True
                startPos = num + 2
                for number in range(23):
                    newPos = startPos + number*3
                    print>>log, "\n" , newfilename[0:-2].ljust(20), pimalDatabase["Female"][number],
linecache.getline(filename,newPos).strip().ljust(40)
        if filename.split("_")[1] == "Male":
            if "cell (" in line and pos == False:
                pos = True
                startPos = num + 2
                for number in range(23):
                    newPos = startPos + number*3
                    print>>log, "\n" , newfilename[0:-2].ljust(20), pimalDatabase["Male"][number],
linecache.getline(filename,newPos).strip().ljust(40)
```

```
    inputfile.close()

log.close()

data = {}
organs = []
log = open("dataDump.txt","r")
for line in log:
    if len(line) > 1:
        [filename, organ, tally, error] = line.split()
        [gender, src, position] = filename.split("_")[1:]
        if organ not in organs:
            organs.append(organ)
        if gender not in data:
            data[gender] = {}
        if src not in data[gender]:
            data[gender][src] = {}
        if position not in data[gender][src]:
            data[gender][src][position] = {}

        #Volume determination (m^3) and gammas per decay (for conversion of per source particle to per Bq)
        if position == "Inn":
            if src == "Cs137":
                volume = 92082.7
                ppd = 0.8499
            if src == "Mn54":
                volume = 105513.6
                ppd = 1
            if src == "Co60":
                volume = 192807.8
                ppd = 1.9984
        else:
            if src == "Cs137":
                volume = 10070.8
                ppd = 0.8499
            if src == "Mn54":
                volume = 36318.1
                ppd = 1
            if src == "Co60":
                volume = 66405.9
                ppd = 1.9984
        #Tally conversion (MeV/gram*srcparticle)
        #Converting to (MeV/kg*sp)
        tally = float(tally) * 1e3
        #Converting to (J/kg*sp) = (Gy/sp)
        tally = float(tally) * 1.602e-13
        #Converting (Gy/sp)(#sp/decay)(1 decay/s / 1 Bq) => (Gy/Bq*s)
        tally = float(tally) * ppd
        #Converting to (Gy*m^3/Bq*s)
        tally = float(tally) * volume

        data[gender][src][position][organ] = (tally,float(error))
```

```
log.close()

newData = {}
genders = ["Male","Female"]
srcs = ["Cs137","Mn54","Co60"]

#Source addition (inner and outer)
for gender in genders:
  if gender not in newData:
    newData[gender] = {}
  for src in srcs:
    if src not in newData[gender]:
      newData[gender][src] = {}
    for organ in organs:
      if src in data[gender]:
        if organ in data[gender][src]["Inn"]:
          [innerTally, innerError] = data[gender][src]["Inn"][organ][0:]
          [outerTally, outerError] = data[gender][src]["Out"][organ][0:]
          tally = innerTally + outerTally
          if outerError == 0:
            error = innerError
          else:
            error = (((innerTally*innerError)**2 + (outerTally*outerError)**2)**0.5)/tally
          newData[gender][src][organ] = (tally,error)
############
#  ICRP 103    -  Calculation of Effective dose for the three sources
############
print "ICRP 103 Values"
for src in srcs:
  effective = 0
  effective = effective + (0.06 * newData["Female"][src]["COLON"][0]) + (0.06 *
newData["Male"][src]["COLON"][0])
  effective = effective + (0.06 * newData["Female"][src]["LUNGS"][0]) + (0.06 *
newData["Male"][src]["LUNGS"][0])
  effective = effective + (0.06 * newData["Female"][src]["STWALL"][0]) + (0.06 *
newData["Male"][src]["STOMACH"][0])
  effective = effective + (0.06 * newData["Female"][src]["BONEMARROW"][0]) + (0.06 *
newData["Male"][src]["BONEMARROW"][0])
  effective = effective + (0.06 * newData["Female"][src]["BREASTS"][0]) + (0.06 *
newData["Male"][src]["BREASTS"][0])
  effective = effective + (0.04 * newData["Male"][src]["TESTES"][0])
  effective = effective + (0.04 * newData["Female"][src]["OVARIES"][0])
  effective = effective + (0.02 * newData["Female"][src]["UBLADDER"][0]) + (0.02 *
newData["Male"][src]["UBLADDER"][0])
  effective = effective + (0.02 * newData["Female"][src]["ESOPHAGUS"][0]) + (0.02 *
newData["Male"][src]["ESOPHAGUS"][0])
  effective = effective + (0.02 * newData["Female"][src]["LIVER"][0]) + (0.02 *
newData["Male"][src]["LIVER"][0])
  effective = effective + (0.02 * newData["Female"][src]["THYROID"][0]) + (0.02 *
newData["Male"][src]["THYROID"][0])
```

```
    effective = effective + (0.005 * newData["Female"][src]["BONESURFACE"][0]) + (0.005 *
newData["Male"][src]["BONESURFACE"][0])
    effective = effective + (0.005 * newData["Female"][src]["BRAIN"][0]) + (0.005 *
newData["Male"][src]["BRAIN"][0])
    #removal of salivary glands - normalization of effective dose gives rise to multiplying factor of 1/0.99
    #effective = effective + (0.005 * newData["Female"][src]["SGLANDS"][0]) + (0.005 *
newData["Male"][src]["SGLANDS"][0])
    effective = effective + (0.005 * newData["Female"][src]["SKIN"][0]) + (0.005 *
newData["Female"][src]["SKIN"][0])
    # Remainders
    effective = effective + (0.006667 * newData["Female"][src]["ADRENALS"][0]) + (0.006667 *
newData["Male"][src]["ADRENALS"][0])
    effective = effective + (0.006667 * newData["Female"][src]["KIDNEYS"][0]) + (0.006667 *
newData["Male"][src]["KIDNEYS"][0])
    effective = effective + (0.006667 * newData["Female"][src]["MUSCLE"][0]) + (0.006667 *
newData["Male"][src]["MUSCLE"][0])
    effective = effective + (0.006667 * newData["Female"][src]["PANCREAS"][0]) + (0.006667 *
newData["Male"][src]["PANCREAS"][0])
    effective = effective + (0.013334 * newData["Male"][src]["PROSTATE"][0])
    effective = effective + (0.013334 * newData["Female"][src]["UTERUS"][0])
    effective = effective + (0.006667 * newData["Female"][src]["SIWALL"][0]) + (0.006667 *
newData["Male"][src]["SIWALL"][0])
    effective = effective + (0.006667 * newData["Female"][src]["SPLEEN"][0]) + (0.006667 *
newData["Male"][src]["SPLEEN"][0])
    effective = effective + (0.006667 * newData["Female"][src]["THYMUS"][0]) + (0.006667 *
newData["Male"][src]["THYMUS"][0])
    #normalization (see above comment)
    nf = 1/0.99
    effective = effective * nf
    #Calculation of propagated relative error
    if effective == 0:
        prop_error = 0
    else:
        del_prop_error = ((0.06 * nf * newData["Female"][src]["COLON"][0] *
newData["Female"][src]["COLON"][1])**2 + \
        (0.06 * nf * newData["Male"][src]["COLON"][0] * newData["Male"][src]["COLON"][1])**2 + \
        (0.06 * nf * newData["Female"][src]["LUNGS"][0] * newData["Female"][src]["LUNGS"][1])**2 + \
        (0.06 * nf * newData["Male"][src]["LUNGS"][0] * newData["Male"][src]["LUNGS"][1])**2 + \
        (0.06 * nf * newData["Female"][src]["STWALL"][0] * newData["Female"][src]["STWALL"][1])**2 + \
        (0.06 * nf * newData["Male"][src]["STOMACH"][0] * newData["Male"][src]["STOMACH"][1])**2 + \
        (0.06 * nf * newData["Female"][src]["BONEMARROW"][0] *
newData["Female"][src]["BONEMARROW"][1])**2 + \
        (0.06 * nf * newData["Male"][src]["BONEMARROW"][0] *
newData["Male"][src]["BONEMARROW"][1])**2 + \
        (0.06 * nf * newData["Female"][src]["BREASTS"][0] * newData["Female"][src]["BREASTS"][1])**2 + \
        (0.06 * nf * newData["Male"][src]["BREASTS"][0] * newData["Male"][src]["BREASTS"][1])**2 + \
        (0.04 * nf * newData["Male"][src]["TESTES"][0] * newData["Male"][src]["TESTES"][1])**2 + \
        (0.04 * nf * newData["Female"][src]["OVARIES"][0] * newData["Female"][src]["OVARIES"][1])**2 + \
        (0.02 * nf * newData["Female"][src]["UBLADDER"][0] * newData["Female"][src]["UBLADDER"][1])**2 +
\
        (0.02 * nf * newData["Male"][src]["UBLADDER"][0] * newData["Male"][src]["UBLADDER"][1])**2 + \
```

```
        (0.02 * nf * newData["Female"][src]["ESOPHAGUS"][0] * newData["Female"][src]["ESOPHAGUS"][1])**2 + \
        (0.02 * nf * newData["Male"][src]["ESOPHAGUS"][0] * newData["Male"][src]["ESOPHAGUS"][1])**2 + \
        (0.02 * nf * newData["Female"][src]["LIVER"][0] * newData["Female"][src]["LIVER"][1])**2 + \
        (0.02 * nf * newData["Male"][src]["LIVER"][0] * newData["Male"][src]["LIVER"][1])**2 + \
        (0.02 * nf * newData["Female"][src]["THYROID"][0] * newData["Female"][src]["THYROID"][1])**2 + \
        (0.02 * nf * newData["Male"][src]["THYROID"][0] * newData["Male"][src]["THYROID"][1])**2 + \
        (0.005 * nf * newData["Female"][src]["BONESURFACE"][0] * newData["Female"][src]["BONESURFACE"][1])**2 + \
        (0.005 * nf * newData["Male"][src]["BONESURFACE"][0] * newData["Male"][src]["BONESURFACE"][1])**2 + \
        (0.005 * nf * newData["Female"][src]["BRAIN"][0] * newData["Female"][src]["BRAIN"][1])**2 + \
        (0.005 * nf * newData["Male"][src]["BRAIN"][0] * newData["Male"][src]["BRAIN"][1])**2 + \
        # (0.005 * nf * newData["Female"][src]["SGLANDS"][0] * newData["Female"][src]["SGLANDS"][1])**2 + \
        # (0.005 * newData["Male"][src]["SGLANDS"][0] * newData["Male"][src]["SGLANDS"][1])**2 + \
        (0.005 * nf * newData["Female"][src]["SKIN"][0] * newData["Female"][src]["SKIN"][1])**2 + \
        (0.005 * nf * newData["Male"][src]["SKIN"][0] * newData["Male"][src]["SKIN"][1])**2 + \
        (0.006667 * nf * newData["Female"][src]["ADRENALS"][0] * newData["Female"][src]["ADRENALS"][1])**2 + \
        (0.006667 * nf * newData["Male"][src]["ADRENALS"][0] * newData["Male"][src]["ADRENALS"][1])**2 + \
        (0.006667 * nf * newData["Female"][src]["KIDNEYS"][0] * newData["Female"][src]["KIDNEYS"][1])**2 + \
        (0.006667 * nf * newData["Male"][src]["KIDNEYS"][0] * newData["Male"][src]["KIDNEYS"][1])**2 + \
        (0.006667 * nf * newData["Female"][src]["MUSCLE"][0] * newData["Female"][src]["MUSCLE"][1])**2 + \
        (0.006667 * nf * newData["Male"][src]["MUSCLE"][0] * newData["Male"][src]["MUSCLE"][1])**2 + \
        (0.006667 * nf * newData["Female"][src]["PANCREAS"][0] * newData["Female"][src]["PANCREAS"][1])**2 + \
        (0.006667 * nf * newData["Male"][src]["PANCREAS"][0] * newData["Male"][src]["PANCREAS"][1])**2 + \
        (0.013334 * nf * newData["Female"][src]["UTERUS"][0] * newData["Female"][src]["UTERUS"][1])**2 + \
        (0.013334 * nf * newData["Male"][src]["PROSTATE"][0] * newData["Male"][src]["PROSTATE"][1])**2 + \
        (0.006667 * nf * newData["Female"][src]["SIWALL"][0] * newData["Female"][src]["SIWALL"][1])**2 + \
        (0.006667 * nf * newData["Male"][src]["SIWALL"][0] * newData["Male"][src]["SIWALL"][1])**2 + \
        (0.006667 * nf * newData["Female"][src]["SPLEEN"][0] * newData["Female"][src]["SPLEEN"][1])**2 + \
        (0.006667 * nf * newData["Male"][src]["SPLEEN"][0] * newData["Male"][src]["SPLEEN"][1])**2 + \
        (0.006667 * nf * newData["Female"][src]["THYMUS"][0] * newData["Female"][src]["THYMUS"][1])**2 + \
        (0.006667 * nf * newData["Male"][src]["THYMUS"][0] * newData["Male"][src]["THYMUS"][1])**2)**0.5
        prop_error = del_prop_error / effective
    print src
    print "Effective dose %s %s" % (effective, prop_error)
```

APPENDIX D: FLUENCE-TO-DOSE CONVERSION FACTORS

Table D.1: Fluence-to-dose conversion factors for the female phantom

Co-60 Fluence-to-Dose Conversion Factors (rad cm^2 s h^{-1})					
Factor Source	Brain	Liver	Lungs	Thyroid	Ovary
EASY-QAD	1.609E-06	1.609E-06	1.609E-06	1.609E-06	1.609E-06
ICRP 116 ROT	1.701E-06	1.598E-06	1.658E-06	1.703E-06	1.490E-06
ICRP 116 ISO	1.598E-06	1.375E-06	1.474E-06	1.544E-06	1.310E-06
Mn-54 Fluence-to-Dose Conversion Factors (rad cm^2 s h^{-1})					
Factor Source	Brain	Liver	Lungs	Thyroid	Ovary
EASY-QAD	1.328E-06	1.328E-06	1.328E-06	1.328E-06	1.328E-06
ICRP 116 ROT	1.216E-06	1.138E-06	1.182E-06	1.239E-06	1.049E-06
ICRP 116 ISO	1.128E-06	9.600E-07	1.032E-06	1.079E-06	9.060E-07
Cs-137 Fluence-to-Dose Conversion Factors (rad cm^2 s h^{-1})					
Factor Source	Brain	Liver	Lungs	Thyroid	Ovary
EASY-QAD	1.022E-06	1.022E-06	1.022E-06	1.022E-06	1.022E-06
ICRP 116 ROT	9.792E-07	9.180E-07	9.504E-07	1.004E-06	8.352E-07
ICRP 116 ISO	9.036E-07	7.632E-07	8.208E-07	8.604E-07	7.056E-07

Table D.2: Fluence-to-dose conversion factors for the male phantom

Co-60 Fluence-to-Dose Conversion Factors (rad cm^2 s h^{-1})					
Factor Source	Brain	Liver	Lungs	Thyroid	Testes
EASY-QAD	1.609E-06	1.609E-06	1.609E-06	1.609E-06	1.609E-06
ICRP 116 ROT	1.674E-06	1.492E-06	1.571E-06	1.687E-06	1.593E-06
ICRP 116 ISO	1.573E-06	1.307E-06	1.413E-06	1.463E-06	1.426E-06
Mn-54 Fluence-to-Dose Conversion Factors (rad cm^2 s h^{-1})					
Factor Source	Brain	Liver	Lungs	Thyroid	Testes
EASY-QAD	1.328E-06	1.328E-06	1.328E-06	1.328E-06	1.328E-06
ICRP 116 ROT	1.191E-06	1.056E-06	1.116E-06	1.225E-06	1.137E-06
ICRP 116 ISO	1.106E-06	9.084E-07	9.835E-07	1.021E-06	1.008E-06
Cs-137 Fluence-to-Dose Conversion Factors (rad cm^2 s h^{-1})					
Factor Source	Brain	Liver	Lungs	Thyroid	Testes
EASY-QAD	1.022E-06	1.022E-06	1.022E-06	1.022E-06	1.022E-06
ICRP 116 ROT	9.540E-07	8.460E-07	8.928E-07	9.972E-07	9.108E-07
ICRP 116 ISO	8.820E-07	7.200E-07	7.848E-07	8.172E-07	8.100E-07

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